

Reef Rescue Marine Monitoring Program

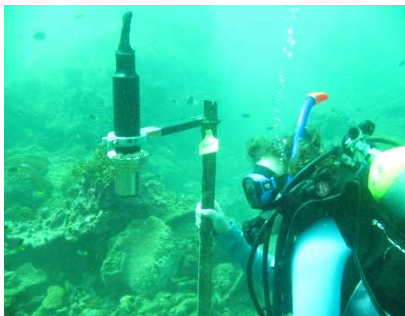
Final Report of AIMS Activities 2009/10 Project 3.7.1b Inshore Coral Reef Monitoring

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Executive Summary

The coral reef monitoring component of the Reef Rescue Marine Monitoring Program (MMP) undertaken in 2009/10 was largely an extension of activities established under previous arrangements from 2004 to 2008.

The coral monitoring program continued to survey the cover of benthic organisms, the numbers of genera, the number of juvenile-sized coral colonies and sediment quality at 23 inshore reef locations in four NRM regions, the Wet Tropics, Burdekin, Mackay Whitsunday and Fitzroy regions. Coral recruitment monitoring also continued at three core sites in each of the four NRM regions.

- The completion of the fifth inshore coral reef survey under MMP allows for updated assessments of the overall status of the inshore coral reef communities monitored over the four year period. In summary, the regional estimates of status were as follow:
 - The assessment of the coral community status returned an overall positive score for the monitored reefs in the Daintree and Johnstone-Russell/Mulgrave sub-regions of the Wet Tropics NRM Region. These coral communities had generally high coral cover that increased rapidly during periods free from acute disturbance, low cover of macroalgae, and moderate to high densities of juvenile colonies relative to other regions. The Johnstone-Russell/Mulgrave sub-region also had high settlement of coral larvae to deployed settlement tiles. Levels of chlorophyll a and turbidity at 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", in contrast to Snapper Island, Daintree Sub-region, where turbidity was highly variable and on average exceeded the Guidelines.
 - Overall coral community status in the Whitsunday Mackay NRM region was marginally positive. Here, average coral cover was high but did not increase despite a lack of acute disturbance. The cover of macroalgae was low and the relative density of juvenile colonies was high, but has declined over recent years. The settlement of coral larvae to tiles was also low relative to other regions. The sediment at these reefs has a high proportion of fine (silt and clay) particles, which increased after repeated flood events in recent years. Water quality monitoring showed relatively high chlorophyll and turbidity levels with averages at two of the three core reefs near or above the Guidelines in 2007/08 and 2008/09.
 - Coral community status in the Fitzroy region was assessed as neutral. The positive attributes were high average coral cover and high settlement of coral

larvae. These were offset by high macroalgal cover and low densities of juvenile colonies. The water quality at Pelican Island did not comply with the Guidelines and this reef along with Peak Island, which is situated in similarly turbid waters, had a clearly different benthic reef community composition at depth compared to the other monitoring locations in Keppel Bay. The other two core reefs had water quality variables generally below the Guidelines and were dominated by *Acropora*, a coral genus common in relatively clear waters. Recovery from disturbance in this region was usually by re-growth from fragments and not recruitment. It is currently unclear how resilient these reefs would be to a disturbance that would cause widespread mortality.

- o Negative scores of coral reef status were returned for reefs in the Herbert Tully sub-region of the Wet Tropics NRM region and the Burdekin NRM region. On average, reefs in these areas had relatively high cover of macroalgae and low coral cover. The lack of observed recovery in the Herbert Tully sub-region is inconclusive as insufficient time has elapsed since reefs were severely impacted by Cyclone Larry (2006). Water quality in this region was only assessed at one site, Dunk Island, where mean levels of turbidity exceeded the Guidelines. In the Burdekin region the lack of recovery is of real concern as there have been no obvious disturbances since coral bleaching impacted reefs in this region in 2002. Settlement of spat to tiles and numbers of juvenile colonies were both low. The regionally low coral cover may be limiting the availability of coral larvae which may explain the regionally low density of juvenile colonies. Water quality in this region is characterised by high chlorophyll values and sporadic high turbidity due to wind-driven resuspension.
- The now recognised differences in coral reef communities provide a useful starting point for the detection of long-term trends in coral reef benthos. The present assessment of coral communities is beginning to focus on areas of the GBR where certain aspects of coral communities appear to be underperforming and highlights the likely environmental correlations to these assessments. Our results also suggest that particulate components of marine water quality (suspended sediment and particulate nutrients and carbon) are the most important drivers of coral reef communities. Should changes in land management practices in the GBR catchments under the Reef Plan lead to decreased loads of sediments and nutrients to GBR coastal and inshore waters, we expect to be able to detect consequential improvements in coral reef communities. High frequency water quality monitoring by instruments will improve the assessment of changes in the medium term.

Introduction to the Program

The Reef Rescue Marine Monitoring Program (MMP), formerly known as 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, Modelling and Reporting Program, which is a key action of Reef Plan 2009 and is designed to evaluate the efficiency and effectiveness of implementation and report on progress towards the Reef Plan (and Reef Rescue) goals and targets. The Paddock to Reef Program involves the development of an annual report card on Reef water quality, to be preceded by a Baseline Report Card published in late 2010. 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 May 2010 to provide monitoring activities under the MMP for the period 2009/10.

The AIMS monitoring activities in the current contract period of the MMP are largely an extension of activities established under a previous arrangements from 2004 to 2009 and are grouped into two components:

- Project 3.7.8: Inshore Marine Water Quality Monitoring
- Project 3.7.1 ext b: Inshore coral reef monitoring

The latter component, the Inshore Coral Reef Monitoring, is reported in this Report, presenting the results of AIMS coral reef monitoring activities during the period 01 May 2009 to 30 April 2010, with inclusion of data from the previous MMP monitoring since 2005.

Outcomes from the Inshore Marine Water Quality Monitoring are reported in a separate report (Schaffelke *et al.* 2010).

Inshore Coral Reef Monitoring

1. Introduction

Coral reef communities occur in a wide range of environmental settings and vary in their composition varies 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; 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 these 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 Commonwealth and Queensland governments in 2003 (Anon. 2003). Reef Plan activities 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 should, with time, also translate into 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.* 2010), it is logical to expect that coral reef communities will change in response to improved land management practices. Reef Plan actions also include the establishment of monitoring programs to assess the effectiveness of the Reef Plan's implementation. The MMP is an integral part of this monitoring to provide reliable physicochemical and biological data to investigate the effects of changes in inputs from the GBR catchments on marine water quality and inshore ecosystems.

The MMP coral monitoring task firstly provides a baseline of the condition at the start of Reef Plan and the subsequent documentation of the changes in environmental and biological parameters arising from 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.

To meet these two monitoring objectives, the collected 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 one 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. For corals, energy is derived in two ways either by feeding on ingested particles and organisms or as a product of the photosynthesis undertaken by their symbiotic algae (zooxanthellae). The ability to compensate for a reduction in energy derived from photosynthesis, as a result of light attenuation in turbid waters, by feeding, varies between species (Anthony 1999, Anthony & 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 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). The result being 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 recruiting would reflect the current conditions. In recognition of this, monitoring of benthic foraminifera communities was added to the suite of biological indicators monitored at the individual survey reefs 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). After discussions at the 2008 MMP Synthesis Workshop it was decided by the GBRMPA for cost efficiency to collect foraminifera samples every year but to analyse the community composition only every other year, with the option to analyse samples of the intervening years if a significant change was observed. However, to find a solution for budget constraints it was mutually agreed (AIMS, GBRMPA, RRRC) not to carry out the analysis of the foraminifera indicators in the collected sediment samples in 2009/10 and so no foraminifera data are presented here. It is expected, however, that this component will again become a regular, i.e. annual component of the MMP in 2010/11.

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 status 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 the 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 to describe accumulation of fine sediments, presumably derived from land run off. The MMP water quality monitoring sites (see separate report, Schaffelke *et al.* 2010) are matched to the core coral reef monitoring locations and to obtain water quality information for the non-core reef sites, we are currently exploring the use of MMP remote sensing data.

In order to quantify inshore coral reef community status in relation to variations in local reef water quality, this project has several key objectives (as identified in the contract):

- I. Provide 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 status 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 fifth annual survey of coral reef sites under MMP (undertaken in the period from May 2009 to January 2010; hereafter called “2009”) and provides summaries of the monitored suite of community variables over the period 2005 to 2009. The improved assessment of the status of reef communities presented in this report provides an overview of the relative status of the benthic communities monitored. The assessment protocol used here builds on that presented previously, however, designations of status may vary slightly from those presented in the previous annual report (Schaffelke *et al.* 2009). We emphasise that this assessment is a work in progress. As our understanding of the dynamics and drivers of coral communities in inshore waters develops 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, was provided to the RRRC in a separate report in May 2009, 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 runoff, 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. Observations on a number of inshore reefs undertaken by AIMS in 2004 during the pilot study to the current monitoring (Sweatman *et al.* 2007) highlighted marked differences in community structure and exposure to perturbations with depth and so 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, at cycle reefs sampling is undertaken every other year and coral recruitment estimates are not included.

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 substrate) that a coral reef community had been viable in the past.

Where well-developed reefs existed on more than one aspect of an island, two reefs were included in the design. Coral reef communities can be quite different on windward compared to leeward reefs even though the surrounding water quality is relatively similar. Differences in wave and current regimes determine whether materials, e.g. sediments, fresh water, nutrients or toxins imported by flood events, accumulate or disperse and hence determine the exposure of benthic communities to environmental stresses. A list of 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 substrates typical of reef flats.

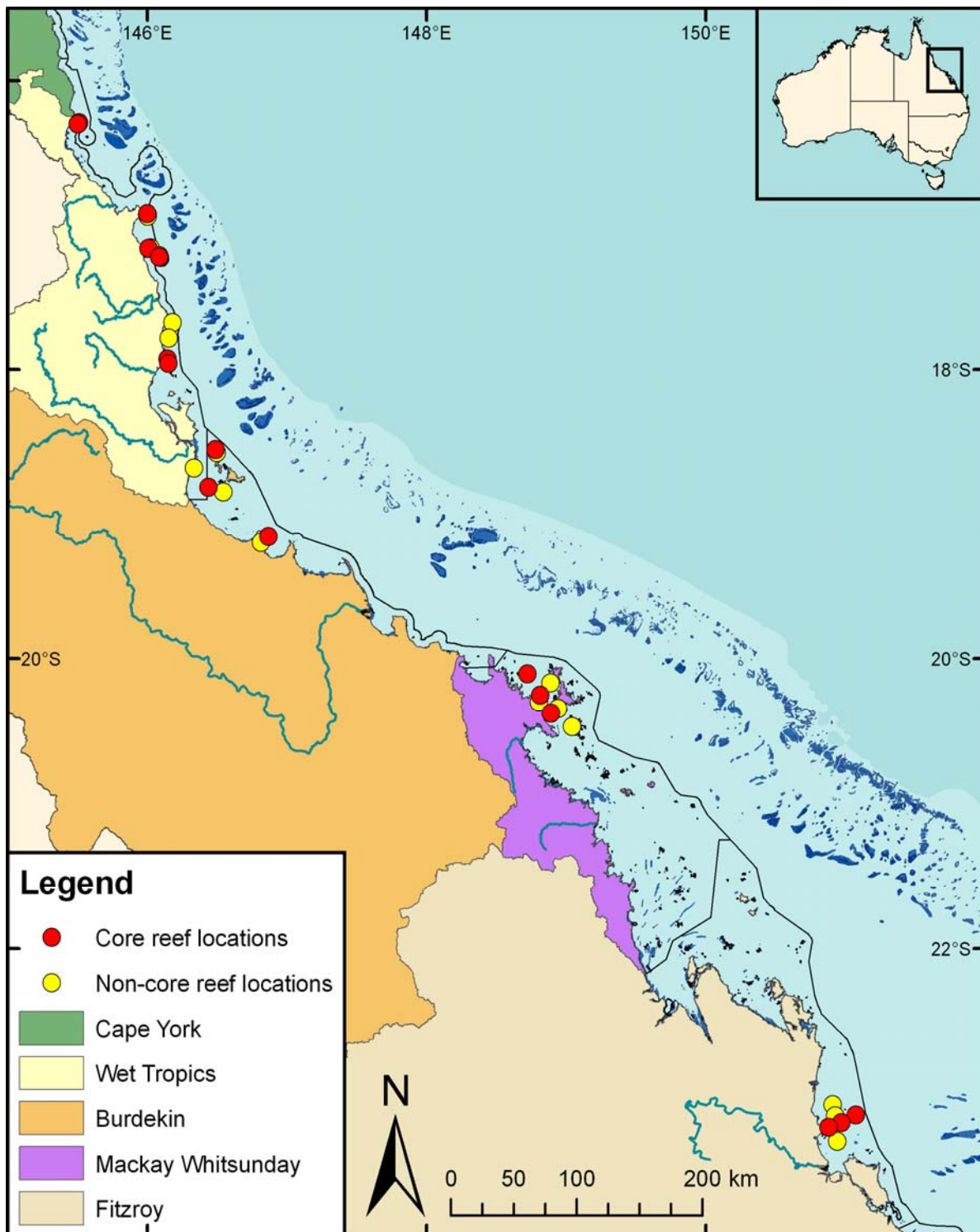


Figure 1 Sampling locations of the Reef Rescue MMP inshore coral monitoring. Core reef locations have annual coral reef benthos surveys, coral settlement assessments and regular water quality monitoring. Non-core reef locations have benthos surveys every two years and no water quality monitoring. Exceptions are Snapper Is and Dunk Is North (water quality monitoring, annual coral surveys, but no coral settlement). See Table 2.1 for the list of surveys completed in 2009. NRM region boundaries are represented by coloured catchment areas and the black line for marine boundaries.

Table 1 Inshore coral reef monitoring completed (✓), coral settlement tiles also deployed (✓^T)

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

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 transect 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. There were 5m gaps between consecutive 20m transects. 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 identified in the sampling design, however, there were subtle differences in width or length of transect or spatial extent of the data sets as listed in Table 2 and detailed 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 substrate of major benthic habitat components.	Approximately 25cm belt along upslope side of transect from which 160 points were sampled.	Full sampling design
Demography	Size structure and density of juvenile (<10cm) coral communities.	34cm belt along the upslope side of 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 1 st , 3 rd and 5 th transects of 5m deep sites.	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

Photo point intercept transects (PPIT)

This method was used to gain estimates of the percent cover of benthic community components. 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 points overlaid onto these images. For the majority of hard and soft corals identification to at least genus level was achieved.

Juvenile coral surveys

This survey aims to provide an estimate of the number of coral colonies that were successfully recruiting and surviving early post settlement pressures. In the first year of sampling under this programme these juvenile coral colonies were counted as part of a demographic survey that counted the number of individuals falling into a broad range of size classes. As the focus narrowed to just juvenile colonies, the number of size classes was reduced allowing an increase in the spatial coverage of sampling.

Coral colonies less than 10cm in diameter were counted within a belt 34cm wide (data slate length) along the upslope side of each 20m transect. 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 agents causing coral mortality or disease. 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). A search was conducted of a 2m wide belt (1m either side of the transect midline) 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 section of the study aims to provide standardised estimates of availability and relative abundance of coral larvae competent to settlement at individual locations. 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 2009 tiles were deployed to all reefs prior to the full moon in early November 2009. This allowed a period of 2 to 3 weeks for tiles to condition before any settlement was expected. The tiles were left in place until the first week in January 2010, i.e. for a period of four weeks after the final main spawning event that was expected to occur following the full moon in December 2009. Deployment details for 2009/10 are shown in Table 3.

Tiles were fixed to small stainless steel base plates attached to the substrate with plastic masonry plugs, or cable ties (when no solid substrate was available). Each base plate holds one tile at a nominal distance of 10-20mm above the substrate. Tiles were distributed in clusters of six at around the star pickets marking the start of the 1st, 3rd and 5th transect at each 5m depth site on core reefs. 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.

NRM Region	Catchment	Coral monitoring locations	Coral settlement tile deployment
Wet Tropics	Russell-Mulgrave Johnstone	Fitzroy Island West	22-Oct-09 to 06-Jan-10
		High Island West	23-Oct-09 to 06-Jan-10
		Frankland Group West	23-Oct-09 to 06-Jan-10
Burdekin	Burdekin	Geoffrey Bay	26-Oct-09 to 08-Jan-10
		Pandora Reef	14-Oct-09 to 07-Jan-10
		Orpheus Is & Pelorus Is West	14-Oct-09 to 07-Jan-10
Mackay Whitsunday	Proserpine	Double Cone Island	15-Oct-09 to 03-Jan-10
		Daydream Island	17-Oct-09 to 05-Jan-10
		Pine Island	17-Oct-09 to 05-Jan-10
Fitzroy	Fitzroy	Pelican Island	16-Oct-09 to 04-Jan-10
		Humpy Island & Halfway Island	16-Oct-09 to 04-Jan-10
		Barren Island	16-Oct-09 to 04-Jan-10

2.3 Sediment quality monitoring

Sediment samples were collected from all reefs visited during 2009 (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. The sample jars were stored in an esky with ice packs to minimise bacterial decomposition and volatilisation of the organic compounds until transferred to a freezer at AIMS.

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 larger fractions (>1.4mm) and MALVERN laser analysis of smaller fractions (<1.4mm). Sieving and laser analysis was carried out 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 12% of the sample, values lower than this can be interpreted as including higher proportions of non-reefal (terrestrially derived) components.

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 are used for the sea surface temperature logger program. The first type is an Odyssey temperature logger (<http://www.odysseydatarecording.com/>). These are currently being phased out. The second type is a Sensus Ultra Temperature logger (<http://reefnet.ca/products/sensus/>). The Odyssey Temperature loggers are set to take readings every 30 minutes. The Sensus Temperature loggers are set to take readings every 10 minutes. Loggers are double- or triple- calibrated against a certified reference thermometer after each deployment and are generally accurate to $\pm 0.2^\circ\text{C}$.

As a reference, long-term means for each week of the year were estimated for each region for the period from July 1999 to July 2008. The long-term estimate for temperature in a given week of the year is the average of all reefs and all years sampled in that particular week, i.e. data for each year at each reef is first aggregated into 52 weekly estimates. 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; 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 Island.

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 *a* fluorescence emission, using blue LEDs (centred at 455 nm and modulated at 1 kHz) as the excitation source. A blue interference filter is used to reject the small amount of red light emitted by the LEDs. The blue light from the sources enters the water at an angle of approximately 55–60 degrees with respect to the end face of the unit. The red fluorescence emitted (683 nm) is detected by a silicon photodiode positioned where the acceptance angle forms a 140-degree intersection with the source beam. A red interference filter discriminates against the scattered blue excitation light. 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.

Pre- and post-deployment checks of each instrument included measurements of the maximum fluorescence response, the dark count (instrument response with no external fluorescence, essentially the 'zero' point) and of a dilution series of a pure plankton culture (for chlorophyll fluorescence) and of a 4000 NTU Formazin turbidity standard in a custom-made calibration chamber (see Schaffelke *et al.* 2007 for details on the calibration procedure). After retrieval from the field locations, the instruments were cleaned and data downloaded and converted from raw instrumental records into actual measurement units ($\mu\text{g L}^{-1}$ for chlorophyll fluorescence, NTU for turbidity, $^{\circ}\text{C}$ for temperature) according to standard procedures by the manufacturer. Deployment information and all raw and converted instrumental records were stored in an Oracle-based data management system developed by AIMS. Records are quality-checked using a time-series data editing software (WISKI[®]-TV, Kisters). Instrumental data are also validated by comparison with chlorophyll and suspended solid concentration obtained by analyses of water samples collected close to the instruments, which was carried out at each change-over.

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.* 2010). In this report results are presented to reveal temporal and spatial differences, however, statistical analyses of the spatial patterns were not repeated.

We are working toward the development of appropriate statistical tools to more fully interrogate the temporal components of the data as the time series of observations lengthen. As yet meaningful trends can not be statistically evaluated given the relatively short (five observations over four years) duration of the data set. Temporal models will become more meaningful as the temporal span of the data set increases. Five years of annual survey data are relatively short compared to the dynamics of coral reef communities and a formal analysis of trends is unlikely to reveal more than a visual assessment of data plots.

2.6.1 Assessment of coral community status

As expected, coral communities show clear relationships to local environmental conditions, however, these relationships do not easily translate into an assessment of the resilience of these communities as gradients in both environmental condition and community composition may naturally occur. The

assessment of coral community status presented here considers the values 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 status presented previously (Schaffelke *et al.* 2009).

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 is usually interpreted as an indication of resilience as the corals are clearly coping with the ambient environmental conditions and high cover also equates to high broodstock, a necessary link to recruitment. However, high coral cover may simply indicate the absence of disturbance events in the recent past, as these events can drastically reduce coral cover in an otherwise resilient community. 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 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 estimation of expected increases in cover for communities of varying composition and levels of cover. As the model was parameterized with some 300 existing observations of change in cover from Great Barrier Reef inshore reefs estimates of expected change implicitly include considerations such as the interplay between background mortality and growth of colonies that manifest as observed change in cover. Further, the inclusion of terms for the cover of macroalgae and the differentiation of the coral communities into; soft corals, hard corals of the family Acroporidae, and hard corals of all other families, provide realistic limitations to expected change in each coral group that account for the cover of 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.

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.

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 demonstrating the survival of larvae (implicit in coral settling to tiles) and settled colonies (as demonstrated by the presence of juvenile colonies). At present, the data are too sparse and too variable between years to allow for a confident interpretation to determine whether observed levels 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 substrates on to which corals are unlikely to settle. To create a comparative estimate of juvenile colonies between reefs, the numbers of recruits per m² were converted to standardised recruit densities per m² of available substratum by correcting the fixed area of transect by subtracting the estimated % cover of hard coral, soft coral, sand and silt. 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 status of the reef was determined by aggregation across these categories. To aggregate the status assessment to a sub-regional or regional assessment, the assessments for each attribute are 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 “fair” and coloured yellow
- >60%-80% equates to “good”, and coloured light green
- >80% is assessed as “very good” and coloured dark green.

Table 4 Summary of decision rules for the assessment of coral reef status 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	+	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 substrate (2m) > 13 juvenile colonies per m ² of available substrate (5m)
	neutral	- between 7 and 10.5 juvenile colonies per m ² of available substrate (2m) - between 7 and 13 juvenile colonies per m ² of available substrate (5m)
	-	< 7 juvenile colonies per m ² of available substrate
Settlement of coral spat	+	> 70 recruits per tile
	neutral	between 30 and 70 recruits per tile
	-	< 30 recruits per tile

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 spatial scale of NRM regions. This is to highlight any major changes in the benthic communities and reef-level environmental parameters, and to provide a summary of status of communities at this scale. Spatial differences among regions are also evident in the figures presented; however, the discussion of results deliberately focuses on the comparison of trajectories of the various variables between regions rather than on consistent inter-regional differences in magnitude. For a full analysis of the differences in community attributes between regions, and reefs within regions, and associations between these spatial patterns and environmental conditions, see Schaffelke *et al.* (2008) and Thompson *et al.* (2010).

The second section provides detailed reef-level data for each NRM region, or in the case of the Wet Tropics region, sub-regions based on major catchments. It is these reef-level estimates that were aggregated to form the regional and sub regional assessments presented in Section I of the results.

3.1 Summary of changes in environmental variables and benthic communities between 2008 and 2009 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 AI-I). The grain size and nutrient content 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 allowing the settlement rather than re-suspension and transport of fine sediments away from the site. In combination with measures of turbidity, which can be considered a measure of sediment resuspension, an indication of exposure to sedimentation can be gained. 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), 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 algae 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 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 2009 (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. The lack of accumulation of fine sediments, however, is likely

due to the frequent re-suspension of sediments by wind waves and subsequent advection away 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. However, this is not unexpected considering that 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 adsorbed to sediment particles (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 sediments in 2008 following a major flood 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. 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 than reefs in other regions to pressures associated with high sedimentation and nutrient levels. 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 substrates on these reefs. There is also a relationship between changes in sediment composition and annual fluctuations in river flow. In the Mackay Whitsunday region flows in the period 2001/02 to 2005/06 were substantially lower than flows from 2006/07 on (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, all increased (Figure 2). Data from the Wet Tropics are more variable with moderate proportions of clay and silt 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 over which our annual sampling is haphazardly applied.

In summary, while the sediment composition in future monitoring will vary among sites from year to year, the last four years of monitoring has established a range of regional values to support a baseline against which future changes in the catchment can be assessed.

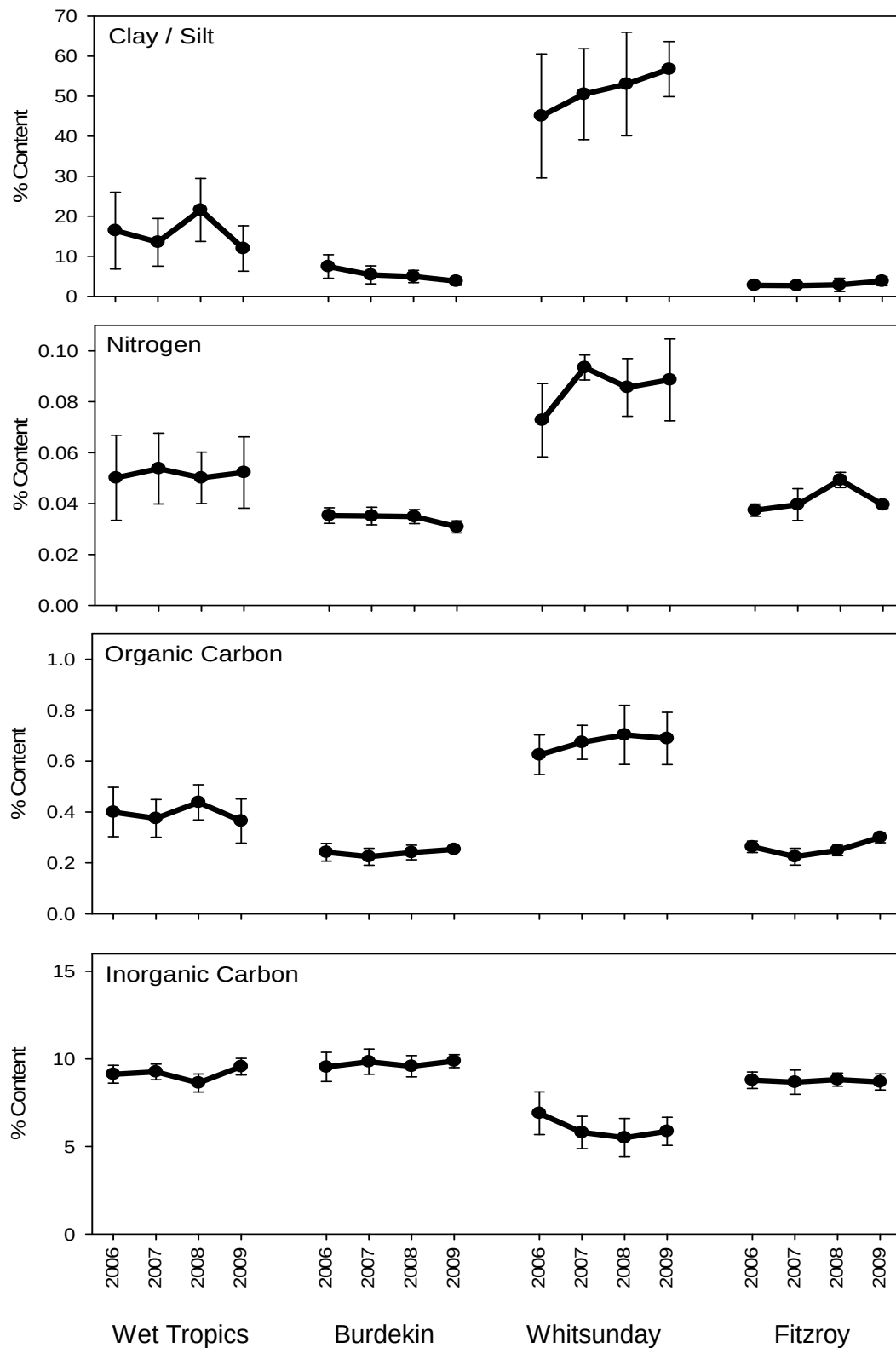


Figure 2 Average proportions of sediment consisting of clay and silt size grains, nitrogen, organic carbon, and inorganic carbon for each NRM region (+/- standard error). For each region only reefs sampled in all years are included to ensure consistency among means.

Table 5 Annual freshwater discharge (ML) for the major GBR Catchment rivers.

Shaded cells highlight years for which river flow exceeded the median annual flow as estimated from available long-term time series for each river. Discharge data supplied by the Queensland Department of The Environment and Natural Resource Management. Long-term medians were estimated from annual totals available on www.nrw.qld.gov.au/watershed/precomp; accessed 23/06/2009.

Region	River	1999/00	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09
Wet Tropics	Barron	1,643,548	852,458	165,895	113,644	950,206	392,223	745,779	471,359	1,582,470	779,456
	Mulgrave			183,890	333,262	1,132,754		1,014,701	757,914	938,122	688,515
	Russell		1,176,637	433,935	615,927	1,345,243	990,734	1,299,019	1,276,654	1,075,370	1,212,230
	North Johnstone	3,215,647	2,073,998	657,433	819,665	2,316,733	1,483,325	2,170,982	2,083,947	1,886,425	1,986,776
	South Johnstone			345,066	311,763		542,835	1,014,726	955,321	811,656	1,043,893
	Tully	5,286,940	3,556,981	1,208,801	1,442,043	3,283,940	2,200,706	3,624,129	4,149,772	3,232,667	3,759,051
	Herbert	9,370,780	4,661,616	929,933	688,775	3,303,782	1,481,771	3,874,894	4,089,009	3,312,563	9,606,409
Burdekin	Burdekin	13,849,188	8,765,755	4,485,312	2,092,834	1,516,194	4,328,246	2,191,850	9,170,162	27,970,750	30,110,062
Mackay Whitsunday	Proserpine	59,605	14,486	19,973	18,676	10,344	23,770	20,395	44,750	76,490	63,263
	O'Connell	259,726	147,717	85,202	23,236	23,973	75,989	84,072	256,362	596,356	167,586
	Pioneer	1,503,064	731,538	218,405	111,677	44,931	196,180	72,849	716,325	1,300,639	931,808
Fitzroy	Fitzroy	1,640,007	3,120,928	579,616	2,734,901	1,310,320	920,295	677,845	886,272	12,051,412	2,193,040

3.1.2 Sea temperature monitoring

Sea temperature data are reported for the period of January 2005 to June 2009 (Figure 3). For each region data are represented as the deviation from long-term (9 year) weekly averages. Weeks above the long-term average are represented as red bars and the magnitude of their deviation from the mean represented by the length of the bars, bars are blue for weeks with temperatures lower than the average and are plotted as negative deviations. Prolonged exposures to temperatures above the local mean temperatures have been shown to cause stress to corals resulting in bleaching and in severe cases, mortality (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 cover 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 Whitsunday / Mackay 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 Island were visited frequently over this period of high temperature with no bleaching observed (Ray Berkelmans pers. comm.). Fluctuations around the long-term averages in the period April 2006 to June 2009 have been relatively minor and or short lived and have not caused marked mortality of corals in any regions. Temperatures in November and December 2008 in the Burdekin and Whitsunday / Mackay regions were elevated, however this was alleviated by heavy rainfall in the following months. Coral bleaching did occur in early 2009 but was most likely due to exposure to low salinity 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.

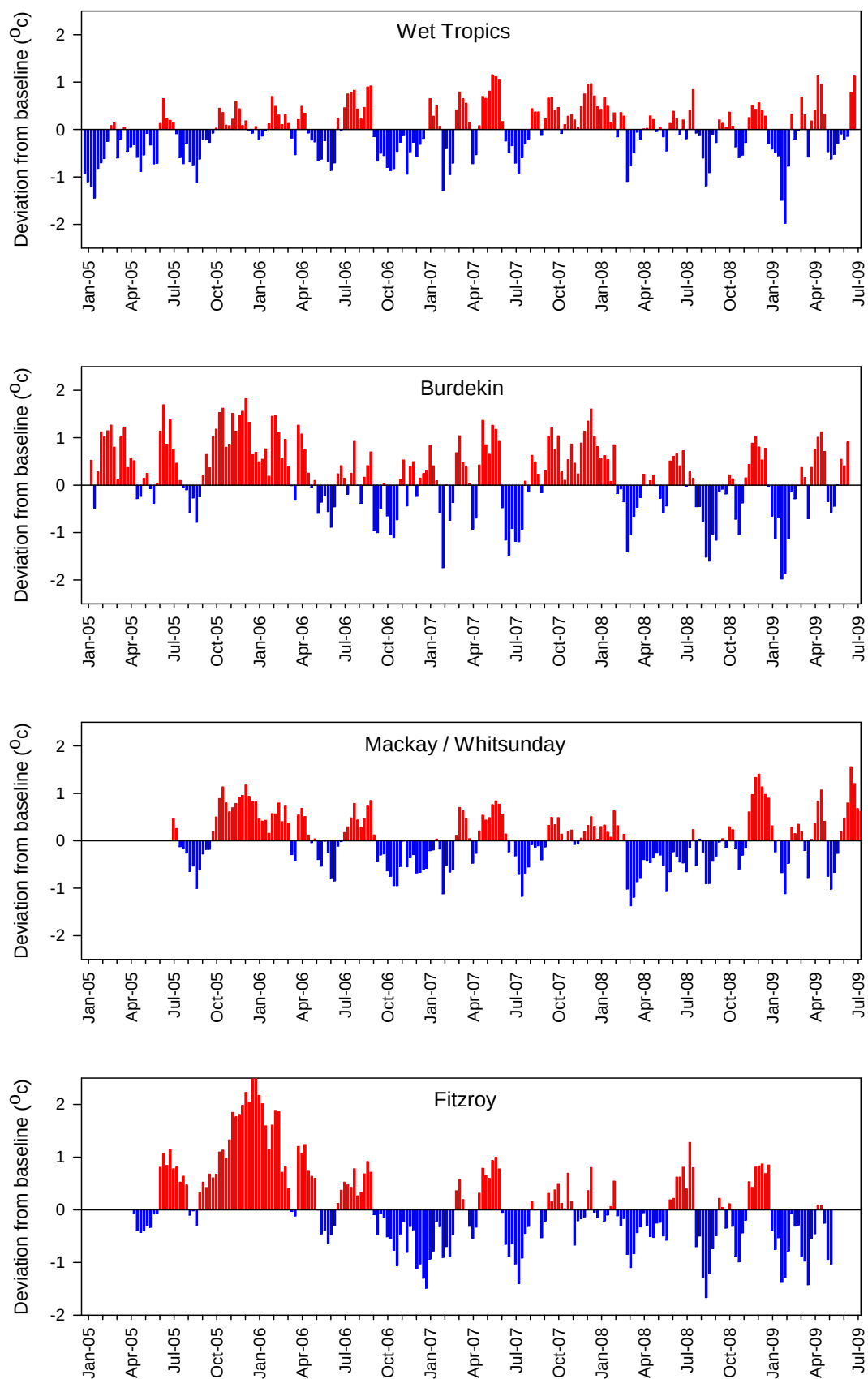


Figure 3 Sea temperature monitoring 2005 to 2009. Data presented a deviations from 9-year mean weekly temperature records (based on records from July 1999 to June 2008).

3.1.3 Inshore coral reef community status

The assessment of coral reef community status presented here scores coral reef communities based on a combination of their current status (cover of corals and macroalgae) 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..

Regional estimates of status were derived based on the observed dynamics of benthic communities over the period 2005-2009 (Table 6) by aggregating reef level status scores within each region and sub-region (see section 3.2). In summary, the regional estimates of status were as follows:

- The assessment of the coral community status returned an overall positive score for the monitored reefs in the Daintree and Johnstone-Russell/Mulgrave sub-regions of the Wet Tropics NRM region. On average the reefs in these sub-regions had high cover of corals, with this cover increasing rapidly during periods free from acute disturbances and relatively low cover of macroalgae. For the Johnstone – Russell/ Mulgrave sub-region the density of juvenile hard coral colonies and numbers of coral larvae settling to tiles were also relatively high.
- Coral communities in the Whitsunday Mackay NRM region returned a marginally positive status score. Here, average coral cover was high but typically did not show a strong propensity for growth despite relatively high density of juvenile colonies and low cover of macroalgae. The settlement of coral larvae was also relatively low.
- Negative scores of status were returned for reefs in the Herbert Tully sub-region of the Wet Tropics NRM region and also the Burdekin NRM region. On average, reefs in these areas had relatively high cover of macroalgae and moderate to low coral cover that did not show clear evidence of increase. The lack of recovery observed in the Herbert Tully sub-region is inconclusive as insufficient time has elapsed since reefs were severely impacted by Cyclone Larry (2006) for any clear trend to emerge. However, the negative attributes were partly offset by moderate densities of juvenile colonies. In the Burdekin region the lack of recovery is of real concern as there have been no obvious disturbances since coral bleaching impacted reefs in this region in 2002. Settlement of coral larvae to settlement tiles and numbers of juvenile colonies were both low. The regionally low adult coral cover may be limiting the availability of coral larvae which may in turn explain the regionally low density of juvenile colonies and slow recovery of coral communities.
- Coral communities in the Fitzroy region returned a neutral status score. The positive attributes of high coral cover and settlement of larvae were offset by high macroalgal cover and low densities of juvenile colonies. In this region corals have been repeatedly affected by coral bleaching with substantial declines in coral cover observed in 1998, 2002 and 2007. Rapid recovery has been well documented (Sweatman *et al.* 2007, Diaz-Pulido *et al.* 2009), however, this is to be expected given the high proportion of branching corals of the fast-growing genus *Acropora*. Recovery was mostly due to re-growth/regeneration of colonies that suffered only partial mortality. It is not clear how corals would recover should whole colony mortality occur in the future, given the low density of juvenile colonies. The discrepancy between high rates of coral larvae settling to tiles and the low density of juveniles indicates high mortality of coral recruits on the reefs in this region.

Table 6 Regional and sub regional estimates of coral community status The overall status aggregates over assessments given to the five indicators, coral cover, change in hard coral cover, 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 colour scheme used is consistent with Paddock to Reef Reporting and fits the three category assessments taken at reef level to a five point scale as described in Section 2.6.1. In brief, colours reflect relative condition of reef communities with assessments of condition ranging sequentially from Red (Poor) through Orange to Yellow (Fair) then through Light Green to Dark Green (Good)

Region	Sub region	Overall Status	Coral Cover	Coral Cover Change	Macroalgae Cover	Coral Juveniles	Coral Settlement
Wet Tropics	Daintree*						N/A
	Johnstone						
	Tully*						N/A
Wet Tropic (Regional)							
Burdekin							0%
Mackay Whitsunday							
Fitzroy							

*Settlement data was not collected from the Daintree or Tully sub-regions.

It is well documented that both susceptibility to disturbance and environmental condition, and also growth and mortality rates, vary among coral taxa. For GBR inshore reefs this variable susceptibility to disturbance has been reported in Sweatman *et al.* (2007). Thompson and Dolman (2010) use GBR inshore reef community data to model expected growth rates (increases in cover) based on gross differences in community composition. This analysis forms the basis of the status estimates for the 'Change in coral cover' assessment presented here (Table 6). As the time series extends it is expected that the estimation of status will evolve to incorporate consideration of community composition into more of the status indicators.

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. For example, lower numbers of juvenile colonies in a community dominated by large colonies of relatively resilient taxa (*Porites* for example) may provide adequate to replace colonies lost to mortality, whereas if more susceptible taxa (*Acropora* for example) suffered higher rates of mortality far greater levels of recruitment may be required to maintain a status quo. 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

Of the reefs surveyed in both 2008 and 2009 there was a slight increase in overall cover of hard corals (34% to 35 %). The magnitude of decreases in cover at Burdekin and Mackay Whitsunday region reefs was similar to that of increases at Wet Tropics region reefs and exceeded by rapid increase at Fitzroy region reefs (Figure 4).

In the Wet Tropics region the observed increase in cover at the core reefs largely reflects an increase in cover of the family Acroporidae at 2m depth on Snapper Island South and Fitzroy Island West and, to a lesser extent, Dunk Is North and Frankland Group West as communities continued to recover from past disturbance events. The 2m depth at High Island West was the only site where cover decreased between 2008 and 2009. It is likely that this decline was due to exposure to low salinity waters during early 2009. At the remaining locations cover remained relatively stable. Cover also increased at non-core reefs in this region.

Core reefs in the Fitzroy region were impacted by bleaching in 2006 and then storms and flooding of the Fitzroy River in 2008. Following these set-backs hard coral cover has increased rapidly, primarily through the growth of *Acropora* colonies surviving the disturbances. This is not the case for the 5m site at Pelican reef where the coral community is not dominated by the genus *Acropora*. Here, changes in coral cover were far less pronounced as both the susceptibility to disturbance, and rate of subsequent recovery, were lower than on the *Acropora*-dominated reefs. An exception to the rapid recovery of the *Acropora* communities in this region is the non-core location at North Keppel Island where cover remained low following bleaching in 2006.

In both the Burdekin and Mackay Whitsunday regions average coral cover on the core reefs declined slightly to 2009. In the Burdekin region cover has been consistently low over the period 2005-2009 with no widespread acute disturbances recorded. From past monitoring studies (Sweatman *et al.* 2007, Done *et al.* 2007) it is clear that reefs in this region had minimal recovery since being severely impacted by bleaching in 1998. The most recent decline on core reefs was mostly due to declines at Pandora Reef where storm damage was obvious in early 2009. Flooding in early 2009 caused a reduction in salinity in Cleveland Bay resulting in localised bleaching and mortality, especially in shallow waters. This event is likely to have suppressed recovery of cover at Geoffrey Bay and resulted in a decline in cover at the non-core Middle Reef. The average hard coral cover on core reefs in the Whitsunday region remained high in 2009 though did decline slightly at both Double Cone Is and Pine Is. No acute disturbances were observed, however, it was noticed that there was a more pronounced sediment layer on these reefs during surveys in 2009 compared with previous years. It is possible that flooding in early 2009 had increased the flux of fine sediments in the system and contributed to the observed declines. Increased sediment loads impact corals by either smothering or indirectly by reducing light intensity and hence energy derived through photosynthesis (Fabricius 2005).

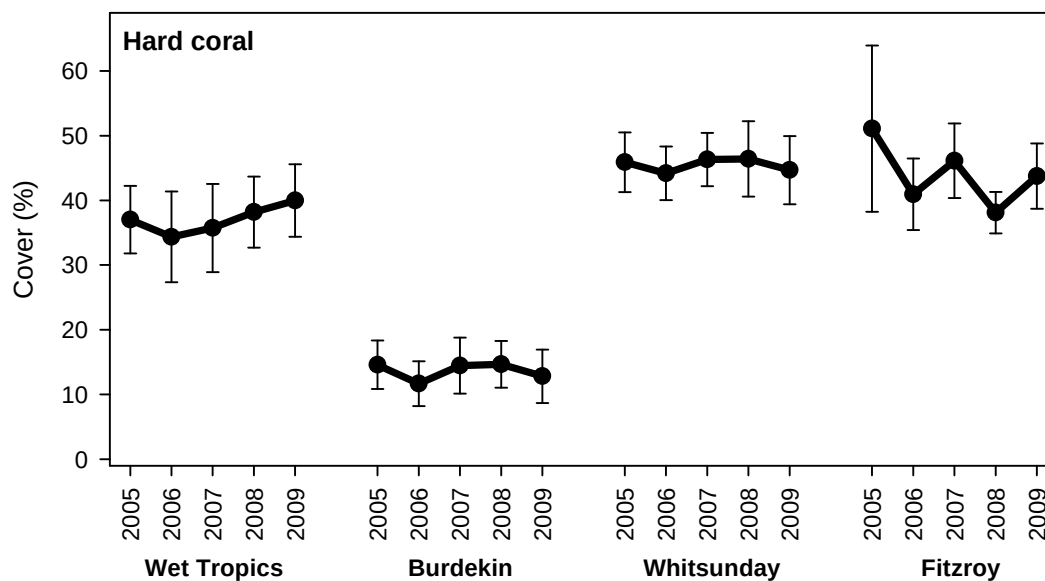


Figure 4 Average cover of hard coral on reefs for each NRM region (+/- standard error). For each region only reefs sampled in all years are included to ensure consistency among annual averages.

Cover of soft corals

The average cover of soft corals has been stable on core reefs between 2005 and 2009 in both the Wet Tropics and Mackay Whitsunday regions (Figure 5). In the Fitzroy region a slight decline observed in 2008 was the result of storm damage at Barren Is. By 2009, this soft coral cover had largely recovered. In the Burdekin region the decrease in the regional average reflects the soft coral cover at just one location, Pelorus Island & Orpheus Island 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.

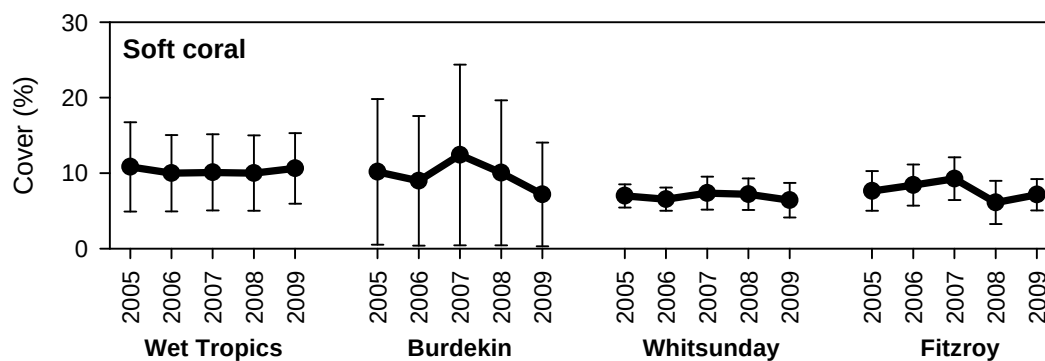


Figure 5 Average cover of soft coral on reefs for each NRM region (+/- standard error). For each region only reefs sampled in all years are included to ensure consistency among annual averages.

Cover of macroalgae

The cover of macroalgae can be 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. This variability limits the interpretation of minor fluctuations. The overall average cover of macroalgae on core reefs declined from 10.5% in 2008 to 8.5% in 2009, continuing the decline from the maximum overall mean of 13.6% in 2007. This overall average masks the variable profiles of algae cover at the regional level (Figure 6) and also at reefs within each region.

In the Wet Tropics region macroalgae cover was typically low on reefs in the Daintree and Johnstone/Russell–Mulgrave sub-regions and was mostly comprised of red algae that colonised coral rubble and spaces between coral branches. In 2009 the cover of these algae was within the range observed in previous years. In the Tully/Herbert sub-region brown algae were more common and followed the general trajectory of moderate cover in 2005, a reduction in 2006 following the passage of Cyclone Larry followed by a subsequent rapid increase to the relatively high cover maintained through to 2009.

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 Rf. was reduced following storm damage with this reduction largely responsible for the marked reduction in the core reef mean (Figure 6). A similar reduction was also observed at Havannah Island though evidence of storm damage was not obvious at this reef.

On the Mackay Whitsunday region core reefs macroalgae were only common at Pine Island. The regional average cover largely reflects the variability in the cover of brown algae at this reef. In 2009, cover of macroalgae was the lowest observed over the period since 2005. Similarly, cover at the non-core reef at Seaforth Island was also lower than previously observed.

In the Fitzroy region, macroalgal communities differed markedly between Peak and Pelican Islands and the Islands further away from the coast. The regional-level increase between 2005 and 2007 was due to the rapid colonisation by *Lobophora* of coral skeletons after coral bleaching mortality on the more offshore reefs in early 2006 (Diaz-Pulido *et al.* 2009). Declines in average macroalgal cover to 2008 reflect both a decline of *Lobophora* on these reefs along with slight declines in the cover of a more mixed community at Pelican Island. This decrease in cover coincided with flooding of the Fitzroy River. In 2009 macroalgal cover at each surveyed reef had returned to levels similar to those reached in 2007.

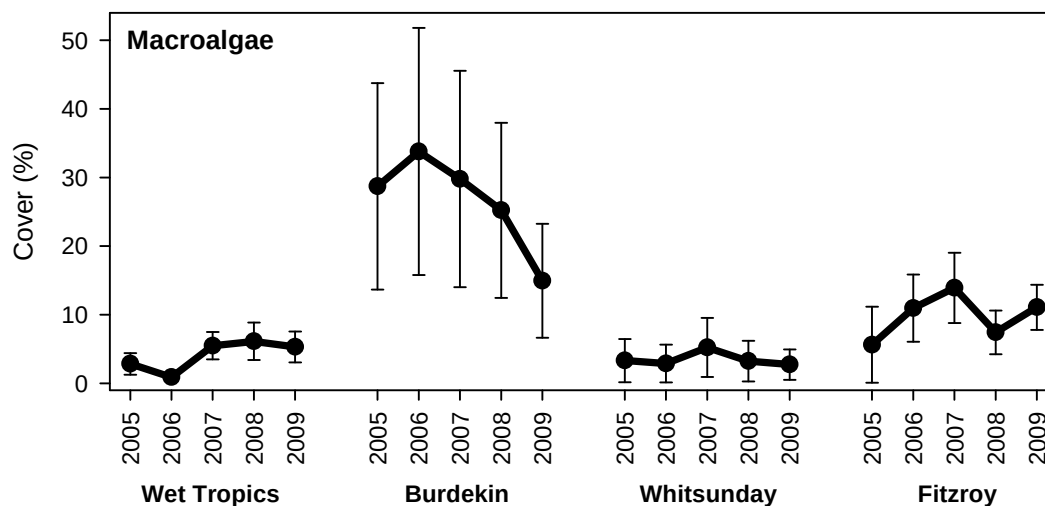


Figure 6 Average cover of macroalgae on reefs for each NRM region (+/- standard error). For each region only reefs sampled in all years are included to ensure consistency among annual averages.

Density and count of juvenile hard coral colonies

On the core reefs the average density of juvenile hard coral colonies per m² has declined annually from 4.9 in 2005 to 3.3 in 2009. This decline was marked in the Wet Tropics, Burdekin and Mackay Whitsunday regions (Figure 7). The decline in the Fitzroy region was less pronounced though here the density of recruits has been consistently low. It is possible that such variation occurs naturally however, as there are no previous studies of this nature, it is only future data from this project that will provide estimates of the scales and magnitudes of variation in juvenile abundances. That coral cover has remained relatively stable over the same period excludes pre-emption of space as an explanation for the observed declines.

While speculative, possible explanations for these declines 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. Considering impacts of Cyclone Larry and associated flooding in 2006, and bleaching of corals in the Keppel region in 2006, it is plausible to infer a downstream effect of these events from the lower density of juvenile colonies recorded in the following years. Disturbances directly reduce broodstock as well as cause sublethal stress to corals that may influence reproductive success in following seasons. The decline in 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 the 2005 sampling, with flows in 2003/04 not greatly exceeding the median. The Burdekin River had below median flows for the six years preceding sampling in 2006. Rivers influencing the Mackay Whitsunday reefs had below median flows in both the O'Connell River and Pioneer River for 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 2008, with near median flow in 2002/03.

Flooding of the Burdekin, Pioneer and Fitzroy Rivers in 2007/08 and Burdekin again in 2008/09 greatly exceeded median flow. It is plausible that increased flux of fine sediments associated with these wetter years contributed to the decline in juvenile density as the repeated re-suspension of fine material would repeatedly reduce light availability at the reef surface and when settling require energetic input from the corals for sediment removal.

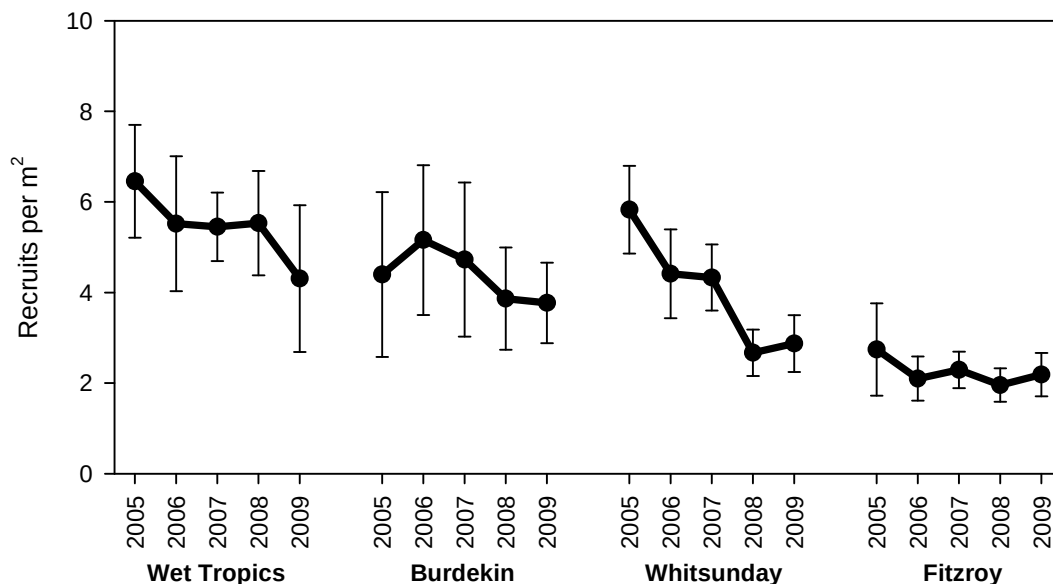


Figure 7 Average number of hard coral colonies < 10cm in diameter per m² on reefs within each NRM region (+/- standard error). For each region only reefs sampled in all years are included to ensure consistency among annual averages.

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 2005-2009, the average number of hard coral genera recorded on photo transects on the core reefs remained relatively stable or showed slight increases (Figure 8). At the level of genus there is no evidence for a loss of diversity. However this result cannot be used to infer a pattern of 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.

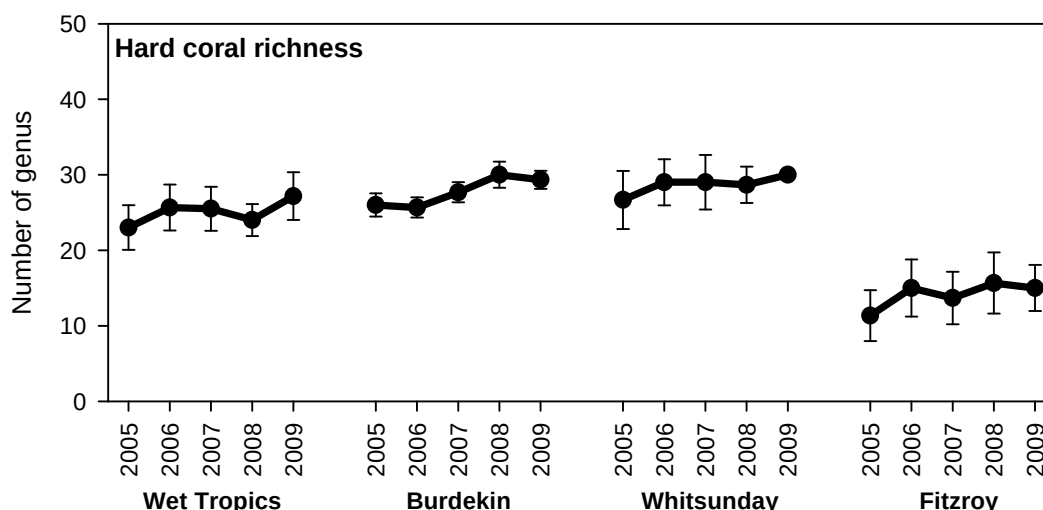


Figure 8 Average number of hard coral genera per reef observed on photo transects for each NRM region (+/- standard error). For each region only reefs sampled in all years are included to ensure consistency among annual averages.

Richness of juvenile (<10cm) hard coral colonies

Estimates of the richness of juvenile hard corals from 2007 to 2009 are not directly comparable to those from 2005 and 2006 due to a doubling of the transect area in the latter surveys after a review of the program. 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 at this stage interpreted as a sampling artefact (Figure 9).

In the Burdekin and Fitzroy regions the richness of hard coral recruits remained relatively stable with slight overall increase between 2007 and 2009. There was a substantial decline in the number of genera represented by juvenile sized hard coral colonies in the Mackay Whitsunday region in 2008, corresponding to occurrence of a substantial 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. The dropping out of rare genera is consistent with the reduced overall density of juvenile colonies observed in this region (Figure 9). In 2009 richness had begun to increase, as had the density of juvenile colonies.

In the Wet Tropics region, differences in richness between 2007 and 2009 varied more strongly between reefs. Richness declined each year at High Is West and Snapper Is North with an overall decrease of 9 and 8 genera, respectively. Richness also declined from 2007 to 2008 at Snapper Is South, Dunk Is North and Frankland Group West but increased slightly to 2009. For the most part these fluctuations are consistent with fluctuations in overall abundance of juveniles at most reefs and represent the inclusion or not of relatively rare taxa. It is unknown whether these declines represent natural fluctuations as individuals from strong recruitment years pass through the juvenile size classes or are responses to unfavourable environmental conditions. Again, longer monitoring of juvenile

communities will provide a better basis for identification of key factors influencing the dynamics of this life-history stage.

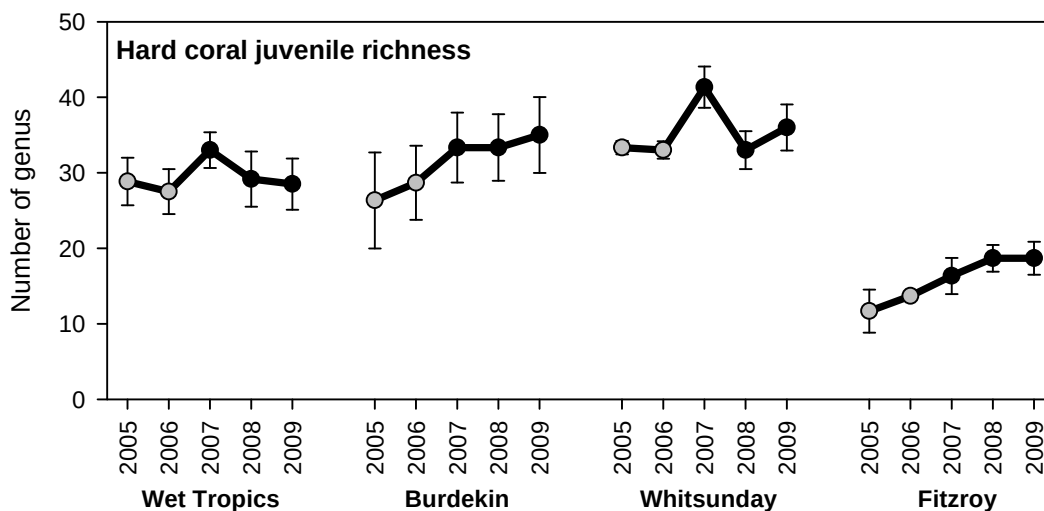


Figure 9 Average number of hard coral genera per reef represented by colonies < 10cm in diameter observed during transect searches for juvenile colonies (+/- standard error). Note that data from 2005 and 2006 (grey dots) are not directly comparable to later years (black dots) due to a doubling in transect area searched. For each region only reefs sampled in all years are 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 followed a similar pattern in three of the four regions (Wet Tropics, Burdekin, Mackay Whitsunday), with a distinctly high pulse of settlement 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, Australian Institute of Marine Science (electronic resource) and a marked reduction in coral cover (Figures 30, 31). Bleaching of corals can reduce per capita fecundity in the following season (Ward *et al.* 2002, Baird and Marshall 2002), so the increase in the Fitzroy region in 2006 may reflect the absence of this effect, and/or a compensatory high survival during the larvae's dispersive and settlement stages.

In 2009, recruitment in the Wet Tropics and Burdekin regions was the lowest recorded in the MMP surveys, and within the bounds of 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. These large pulses and inter-annual changes in Acroporidae recruitment occurred in regions with high cover of adult Acroporidae that act as broodstock. Variability in the relationship between regional broodstock and settlement at any given reef suggests the relationship between larval availability and settlement is controlled by stochastic events such as current patterns

and weather at critical times during dispersal. 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 17) and Daydream Is in the Mackay Whitsunday region (Figure 28) in 2007.

Conversely, when regional broodstock is low, as in the Burdekin region, and/or currents or weather unfavourable, a particularly low settlement can result (e.g. Geoffrey Bay in 2009 (Figure 24).

In the fifth year of this study the settlement of coral larvae to tiles is recognised as highly variable within and among reefs within each region. However, the range within which settlement fluctuates in each region is emerging (Figure 10). Notable is the consistently lower settlement in the Burdekin region, compared to the other three regions.

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) is 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 again, which is linked to the combination of locally variable turbidity and wind driven re-suspension over the settlement period.

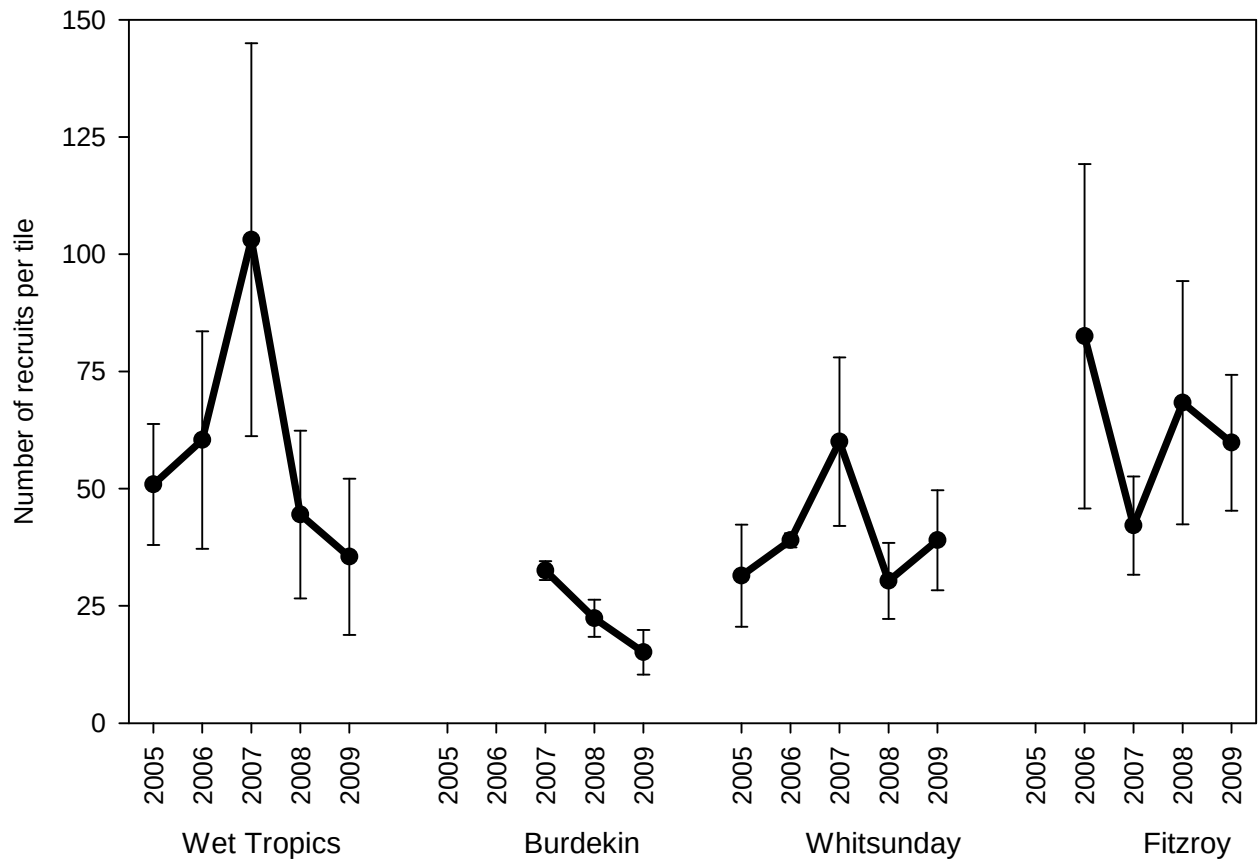


Figure 10 Average number of hard coral recruits per tile on core reefs in each NRM region. Settlement tiles were deployed only at 5m depth.

3.2 Description of coral communities on survey reefs in each NRM region

3.2.1 Wet Tropics NRM region: Barron Daintree sub-region

Two reefs, Snapper Island North and Snapper Island South are sampled annually in this sub-region (Figure 11). These reefs have been monitored by Sea Research since 1995. This historical data show that while the benthic communities have experienced several disturbances (Table A1-2) they showed 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.

The reefs in this area are subject to outflows from the Daintree River and, to a lesser extent, the Mossman and Barron rivers. Snapper Island is 4km from the mouth of the Daintree River. Prior to surveys in 2005, corals at 2m sites of Snapper Island 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 a substantial reduction in cover in 1999 as a result of Cyclone Rona (Ayling and Ayling 2005).

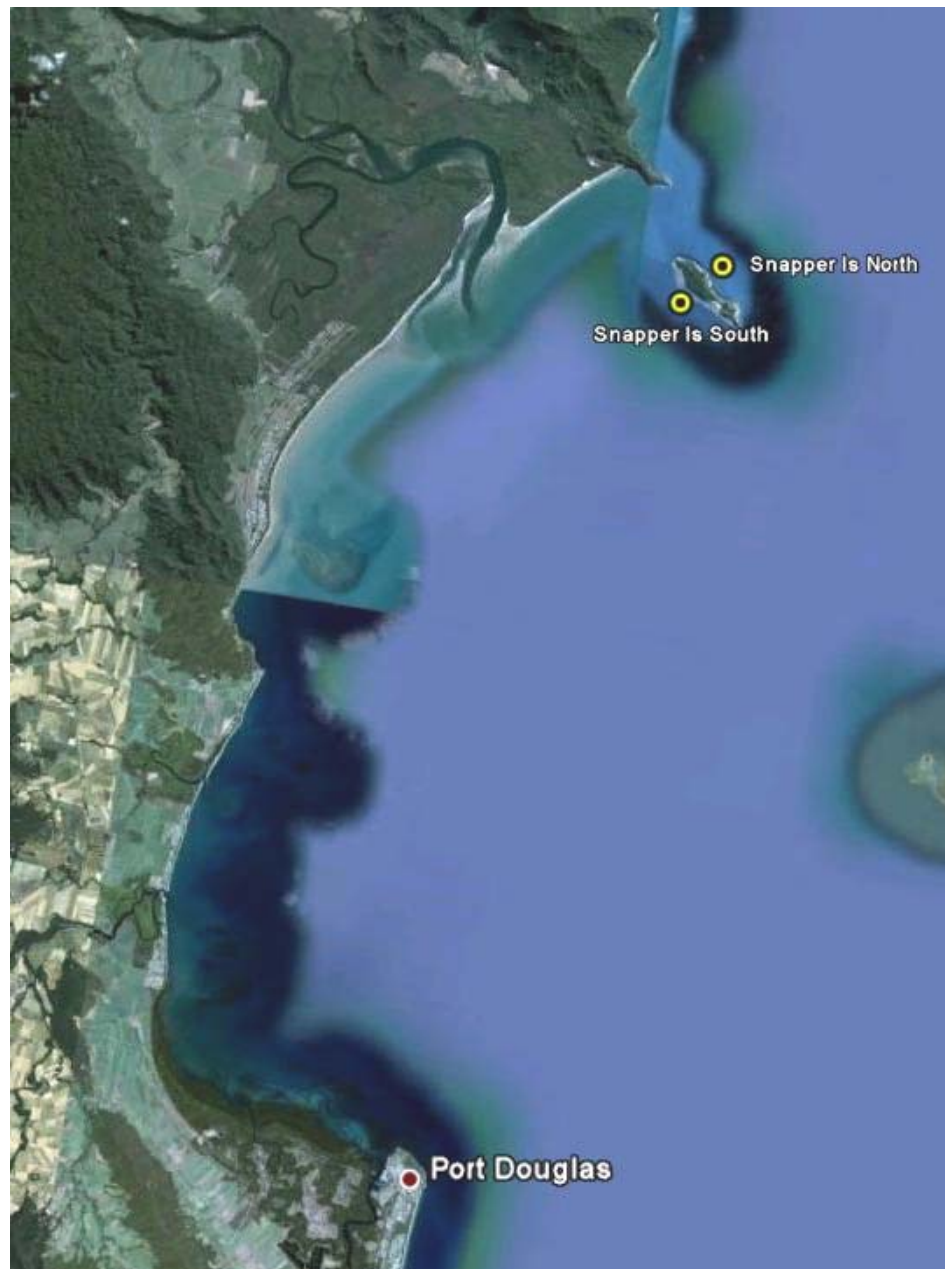
Over the period 2005 to November 2009 the only disturbance that impacted these reefs was an unidentified storm event (possibly associated with Cyclone Hamish in March 2009) and caused physical damage to corals at Snapper Is North. It is likely that this disturbance caused the slight reduction in cover of hard coral, soft coral and macroalgae observed in early 2009. By late 2009 the cover of soft corals (largely *Clavularia*) had recovered and the cover of macroalgae increased (Figure 12).

In the absence of disturbance the cover of hard coral, and to a lesser extent soft coral, has increased annually at Snapper Is South. Prior to the impact of flooding the 2m sites were dominated by *Acropora* (Ayling and Ayling 2005) with this taxa disproportionately killed leaving a community dominated by *Porites* following the flood. By late 2009 the cover of *Acropora* was rapidly increasing (Figure 13). This increase in *Acropora* cover at Snapper Is South 2m reflects the rapid growth of juvenile colonies. Many of the strong cohort of 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 13). At 5m the density of juvenile colonies was much lower (Figure 13) and increases in cover (Figure 12) more likely representing growth of existing adult colonies.

Sediments at Snapper Is North had above average levels of clay and silt sized particles, organic carbon (Figure 12) and nitrogen (Table A1-1a-c). Conversely, inorganic carbon was low (Table A1-1d) in combination these results suggest 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.

The mean turbidity at Snapper Is North (Figure 12) exceeded the Guidelines (GBRMPA 2009) in both years for which instrumental data were available, 2007/08 and 2008/09 (GBRMPA 2009). High turbidity causes rapid attenuation of light in the water column, which results in a steep environmental gradient with increasing water depth. This is reflected in the marked compositional difference

between hard coral communities at 2m and 5m depth (Figure 13). Mean chlorophyll *a* concentrations in 2007/08 and 2008/09 were below the Guidelines (Figure 12). A significant positive correlation was identified between water column chlorophyll *a* and cover of reef macroalgae (De'ath and Fabricius 2010) and the low chlorophyll *a* concentrations at this site may in part explain the low cover of macroalgae (i.e. both may be limited by low ambient nutrient availability).



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Figure 11 Reef Rescue MMP inshore coral reef monitoring sites (yellow symbols): Barron Daintree sub-region, Wet Tropics region.

The overall status rating for both Snapper Is North and South was positive (Table 7), based on:

- high coral cover with demonstrated potential for increase during non-disturbance periods;
- low cover of macroalgae; and
- moderate to high densities of juvenile colonies at 2m.

Table 7 Benthic community status: Barron Daintree sub-region, Wet Tropics region. Overall status aggregates over the indicators coral cover, change in hard coral cover, macroalgal cover and juvenile hard coral density. Sub regional scores convert the three point categorical assessments aggregated across each indicator into an evenly spaced five point scale for consistency of reporting through to Paddock to Reef (see section 2.6.1) Colours reflect this five point scale with assessments of condition ranging sequentially from Red (Poor) through Orange to Yellow (Fair) then through Light Green to Dark Green (Good)

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

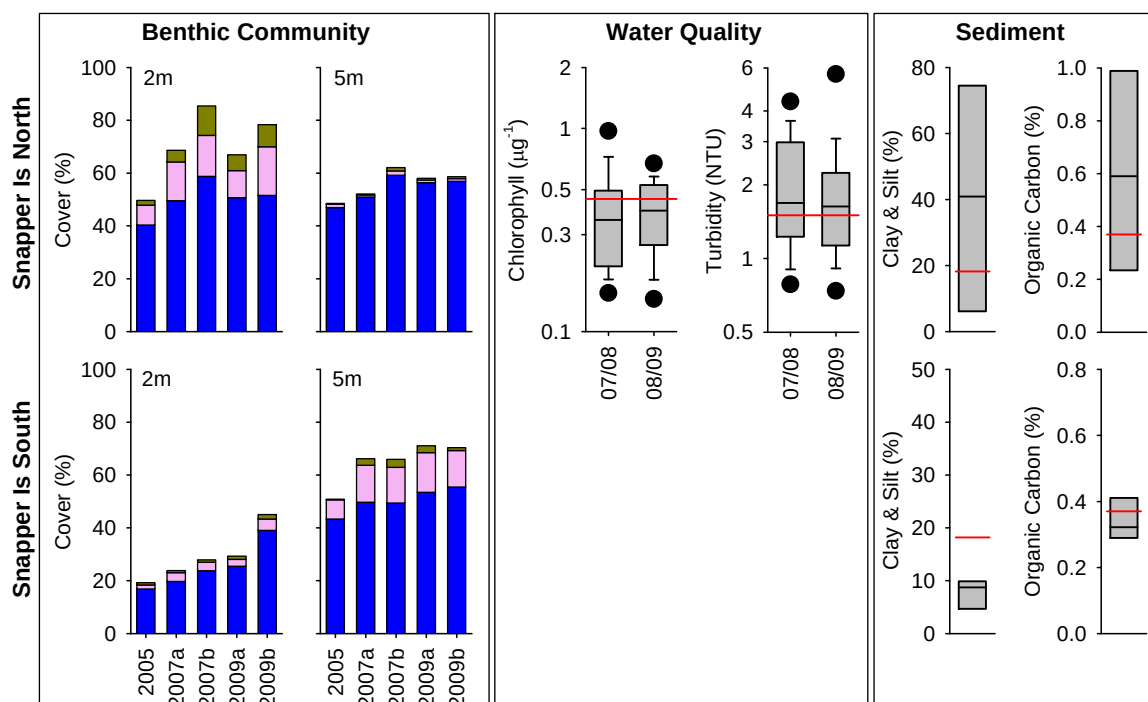


Figure 12 Percent cover estimates of major benthic groups and levels of key environmental parameters: Barron Daintree sub-region, Wet Tropics region. Bar colours represent cumulative cover of hard coral (blue), soft coral (pink) and macroalgae (green). Data for water quality condition are derived from Eco FLNTUSB instruments, for sediment quality from sediment sampling from 2006-09. The box plots for water quality represent the distribution of observations in each year: the box spans the range of the central 50% of observations, the whiskers range of the central 80%, and the dots the range of the central 90% of observations. Red reference lines indicate the Guidelines for water quality parameters (GBRMPA 2009), and the overall mean across all reefs for sediment parameters.

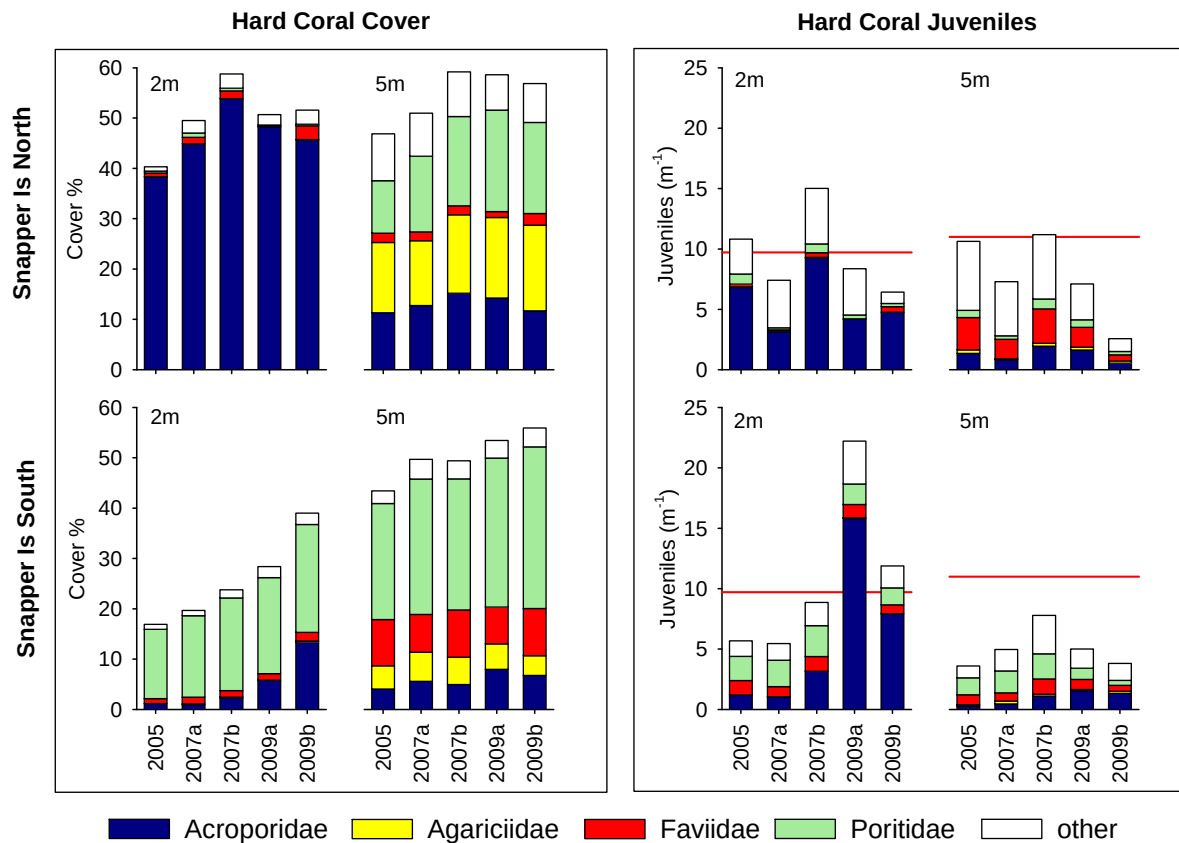


Figure 13 Composition of hard coral communities: Barron Daintree sub-region, Wet Tropics region. Bars are the cumulative cover, or density of juvenile colonies per m^2 of available substrate, of dominant families within the region. Families are indicated by colour of bar section. Only families for which cover exceeded 4% cover on at least one reef at one depth in one year are differentiated; all other families are aggregated into the 'other' group (white bars). Red reference lines are the overall mean density of juvenile colonies across all reefs and years.

3.2.2 Wet Tropics NRM region: Johnstone and Russell/Mulgrave sub-region

Of the reefs surveyed in this sub-region (Figure 14) those at the Frankland Group and Fitzroy Island 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 responsible for substantial reductions in coral cover on reefs in this region; coral bleaching in 1998 and in 2002, crown-of-thorns starfish (COTS) outbreaks 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 NRM region. Of reefs for which 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%. Fitzroy Island 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 Island lost 78% of their hard coral and the eastern reef communities of the Frankland Group lost 68%. Bleaching in 2002 was less severe than in 1998 but still affected most coral communities in some way. 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, there were no marked impacts on coral cover directly attributable to these events at the depth of monitoring sites. It is possible that coral communities in shallower water than those monitored may have suffered some mortality during these flood events. Observations from these reefs in February 2009 immediately following flooding of the Russell-Mulgrave strongly suggested that freshwater had impacted shallow reef flat communities at some locations (AIMS unpublished data). At this time physical damage to corals at Fitzroy Island West was also noticed and attributed to Cyclone Hamish. Longer-term trajectories of coral cover at Fitzroy Island and the Frankland Group are presented in Sweatman *et al.* (2007), and show periods of recovery to 2005 following these multiple disturbances.

The reefs in this area are regularly subjected to outflows from the Johnstone and the Russell-Mulgrave rivers. The majority of reefs surveyed have sediments with moderately low proportion of clay and silt, organic carbon (Figure 15) and nitrogen (Table A1-1a-c) indicating low residence or accumulation of sediment components derived from these rivers. The exception is the site Frankland Group West with 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. The complex topography and sheltered nature of the site likely 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.

Within this sub-region turbidity levels and chlorophyll *a* concentrations rarely reach the Guidelines (GBRMPA 2009, Figure 15). The regionally low cover of macroalgae (Figure 15) is consistent with the observed low levels of these key water quality variables. The low cover of macroalgae adds to the positive assessment of resilience at most reefs (Table 8). In addition, broad similarities in community composition between 2m and 5m depths (Figure 16) is consistent with low turbidity; light climate is generally acknowledged as a strong determinant of coral community and the rate of change in light climate with depth is inversely proportional to turbidity.

Despite the above described disturbance history for reefs in this region the cover of corals is high on most reefs. 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 16). The family Acroporidae is typically susceptible to disturbance events but has the capacity to recover quickly given high growth rate relative to most other corals. While the family Poritidae is typically less susceptible to disturbance, it has a slower growth rate. The combination of moderate to high cover and rates of increase consistent with, or above, modelled expectation, given the composition of the coral communities, added to the positive assessment of resilience most reefs. The exceptions were the *Porites*-dominated communities at 5m on the western Frankland Group reef and 2m on the western High Is reef where cover of the family Poritidae, although high, has declined (Figure 16). These declines contributed to the negative assessments of resilience at these reefs. At Frankland Group West this decline is due largely to the colonisation of spaces between branches of *Porites cylindrica* and *Porites rus* by red algae, which may indicate environmental conditions that favour these particular macroalgae, rather than any acute disturbance event.

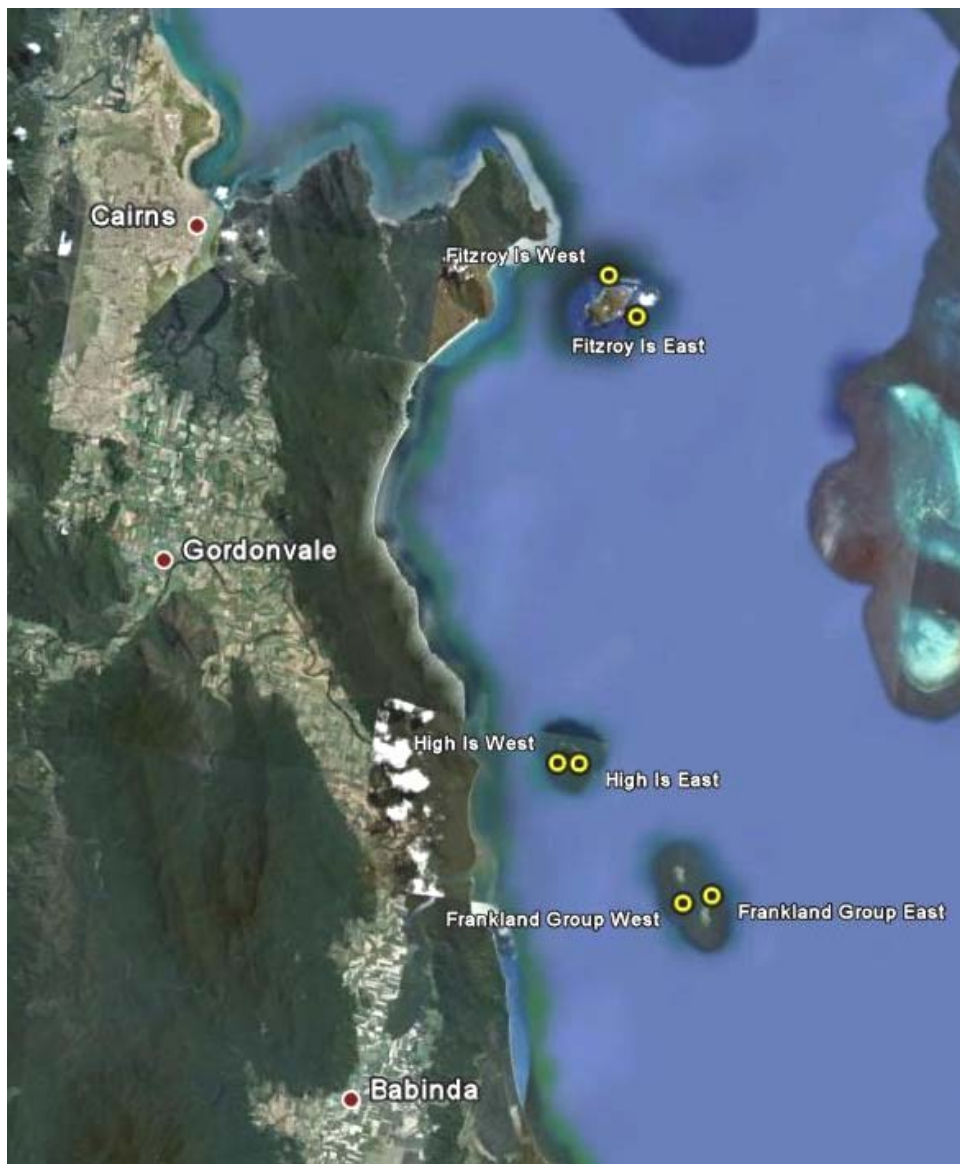


Figure 14 Reef Rescue MMP inshore coral reef monitoring sites (yellow symbols): Johnstone and Russell/Mulgrave sub-region, Wet Tropics region.

The resilience in coral cover within this sub-region seems to be underpinned by the generally high level of coral recruitment to settlement tiles (Figure 17) and high density of juvenile colonies. The only reef at which the observed levels of these early life stages do 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 16, 17).

At Frankland Group West 2m previous monitoring data indicate that 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). Despite a lack of subsequent disturbance this component of the community has failed to recover. The very low settlement of Acroporidae larvae (Figure 17) may explain this lack of recovery, but the reasons for the low settlement is 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 conspecifics than larvae of other taxa.

Table 8 Benthic community status: Johnstone and Russell / Mulgrave sub-region, Wet Tropics region. Overall status aggregates over the indicators coral cover, change in hard coral cover, macroalgal cover, juvenile hard coral density and settlement (where sampled). Sub regional scores convert the three point categorical assessments aggregated across each indicator into an evenly spaced five point scale for consistency of reporting through to Paddock to Reef (see section 2.6.1) Colours reflect this five point scale with assessments of condition ranging sequentially from Red (Poor) through Orange to Yellow (Fair) then through Light Green to Dark Green (Good)

Reef	Depth (m)	Overall Status	Coral cover	Change in hard coral cover	Macroalgae cover	Juvenile density	Settlement
Fitzroy Is East	2	+++	neutral	neutral	+	+	+
	5	+++++	+	+	+	+	+
Frankland Group East	2	+	neutral	neutral	+	neutral	neutral
	5	++++	neutral	+	+	+	+
Frankland Group West	2	-	neutral	neutral	+	-	-
	5	--	+	-	neutral	neutral	-
Fitzroy Is West	2	+++++	+	+	+	+	+
	5	+++++	+	+	+	+	+
High Is East	2	++	+	neutral	+	neutral	neutral
	5	+++	+	neutral	+	neutral	+
High Is West	2	+	+	-	+	neutral	neutral
	5	+	neutral	neutral	+	neutral	neutral
Sub-regional assessment							

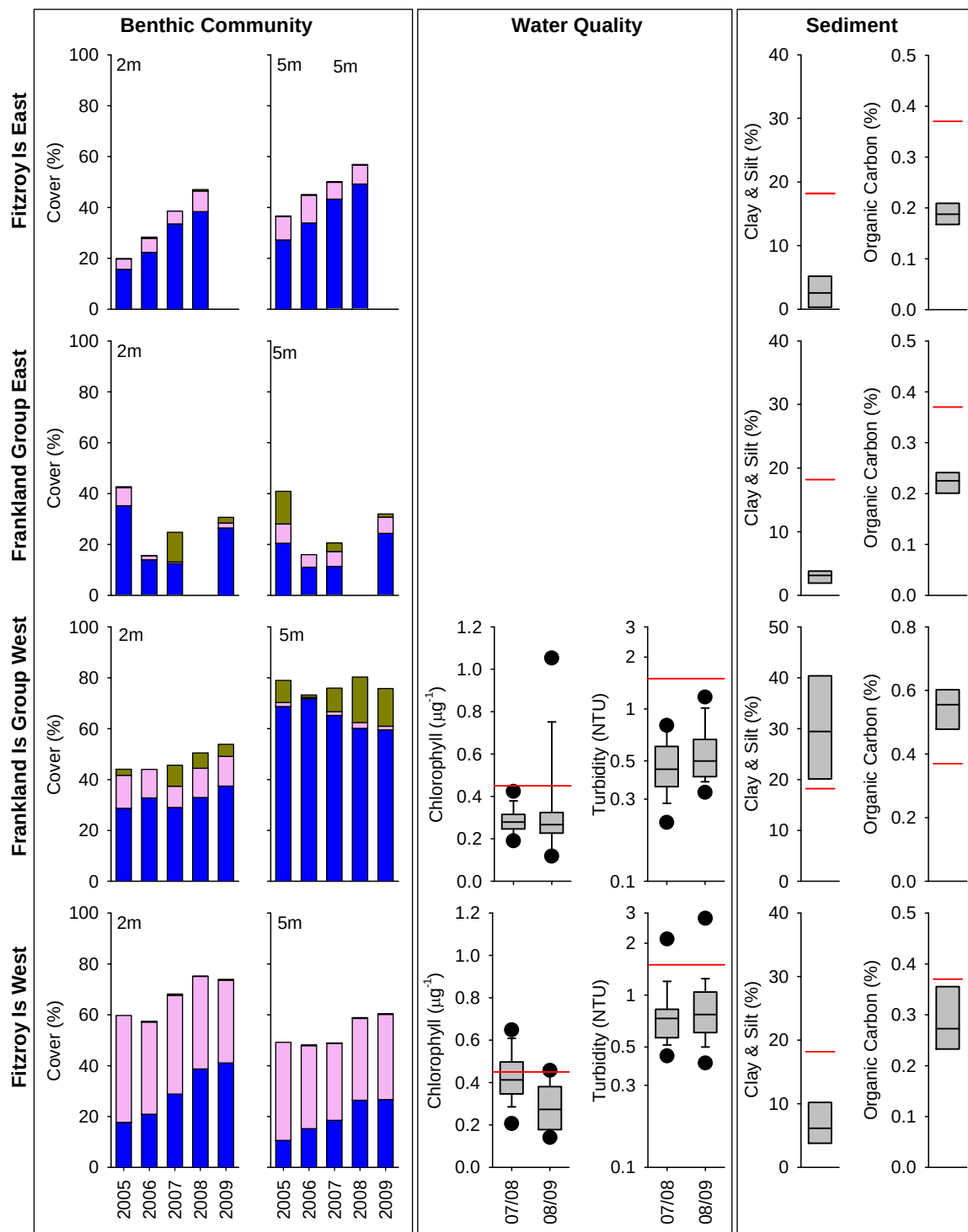


Figure 15 Percent cover estimates of major benthic groups and levels of key environmental parameters: Johnstone and Russell / Mulgrave sub-region, Wet Tropics region. Bar colours represent cover of hard coral (blue), soft coral (pink) and macroalgae (green). Data for water quality condition are derived from Eco FLNTUSB instruments, for sediment quality from sediment sampling from 2006-09 (see Figure 12 for details about the box plot presentation). Red reference lines indicate the Guidelines for water quality parameters (GBRMPA 2009), and the overall mean across all reefs for sediment parameters

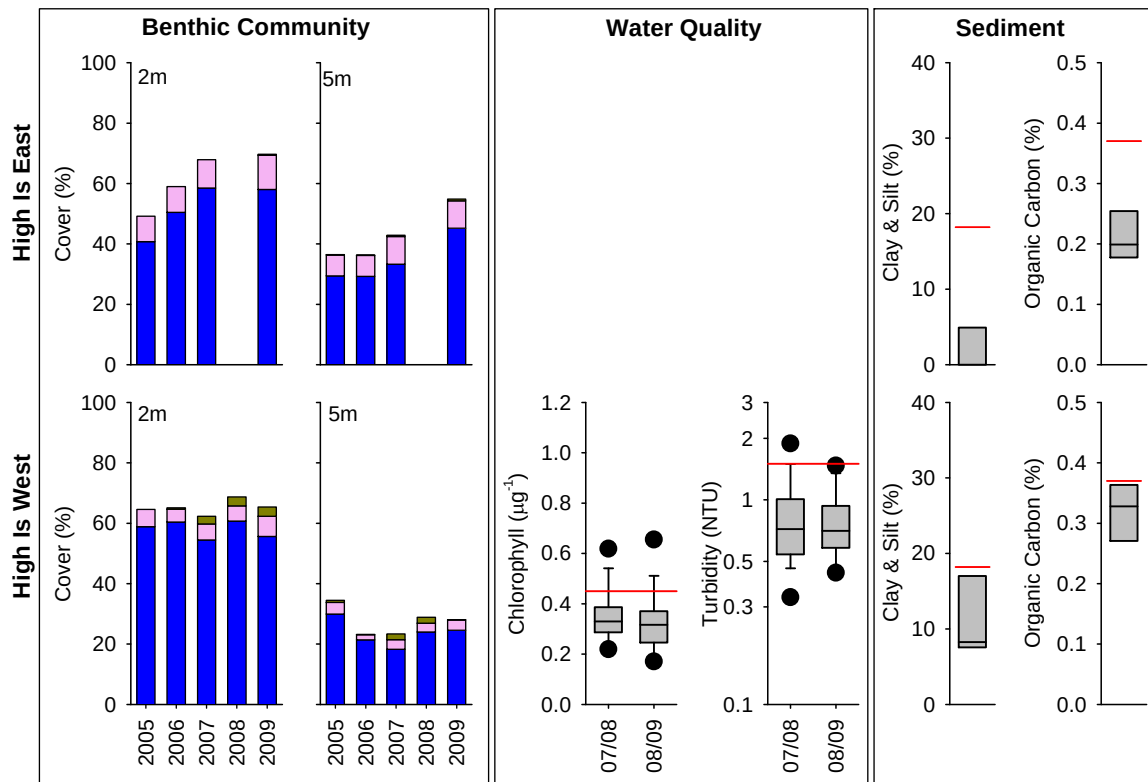


Figure 15 continued.

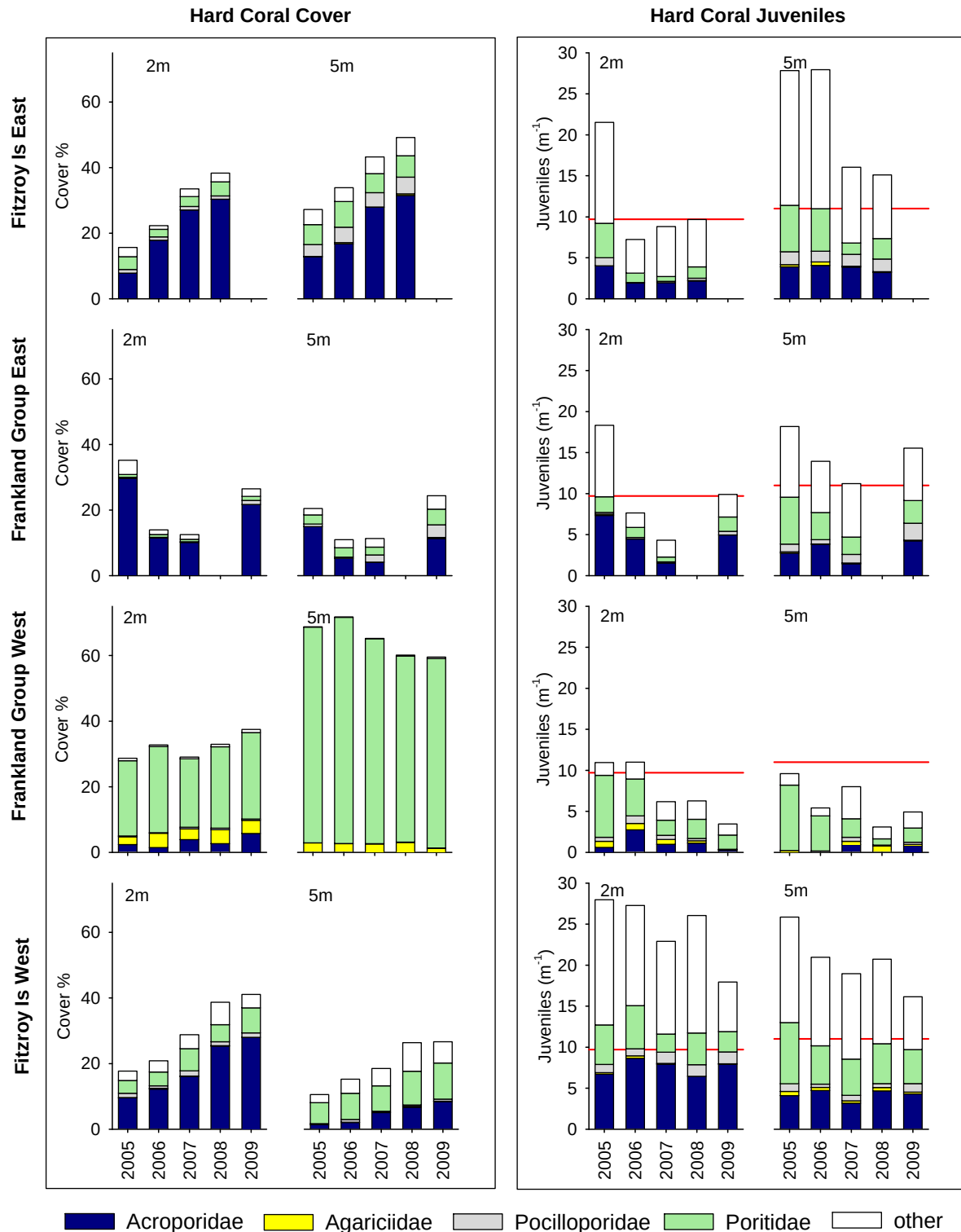


Figure 16 Composition of hard coral communities: Johnstone and Russell / Mulgrave sub-region, Wet Tropics region. Bars are the cumulative cover, or density of juvenile colonies per m^2 of available substrate, of dominant families within the region. Families are indicated by colour of bar section. Only families for which cover exceeded 4% cover on at least one reef at one depth in one year are differentiated; all other families are aggregated into the 'other' group (white bars). Red reference lines are the mean density of juvenile colonies over all reefs and years.

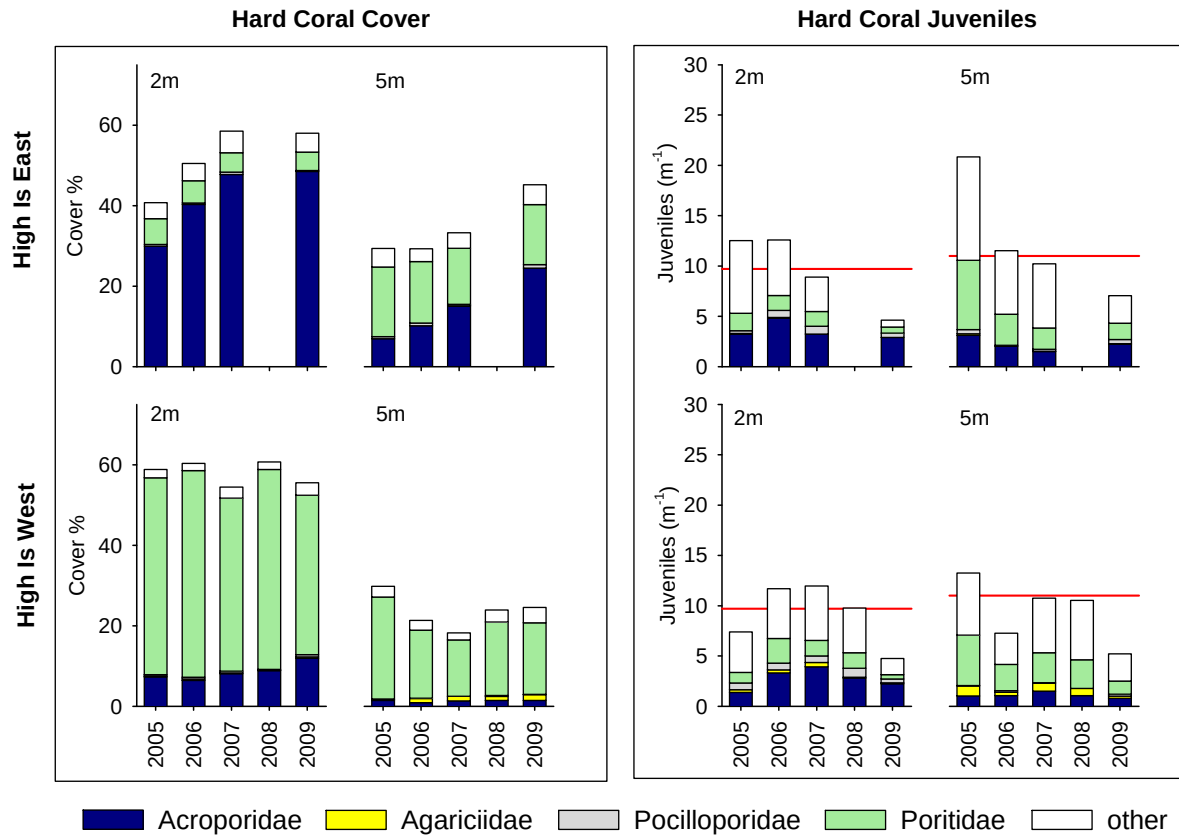


Figure 16 continued.

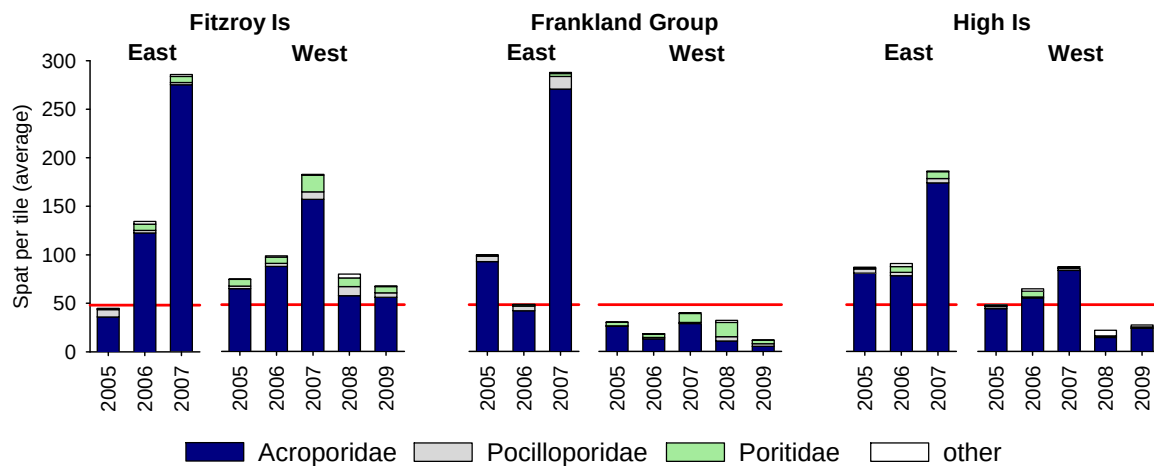


Figure 17 Coral settlement to tiles: Johnstone and Russell / Mulgrave sub-region, Wet Tropics region. Data are from 5m tile deployments. Average values from all reefs and NRM regions over all years are indicated by red reference lines.

3.2.3 Wet Tropics NRM region: Herbert Tully sub-region

The past dynamics of the reefs in this region are largely unknown as no quantitative monitoring was been undertaken prior to Reef Rescue MMP. Flood plume observations by Devlin *et al.* (2001) show reefs were subject to flood events on three or more occasions between 1991 and 2001 (Table A1-2) though the impacts on the benthic communities are unknown.

Recent modelling work (Wooldridge and Done 2004) indicates hard coral communities in this sub-region were likely to have been impacted by coral bleaching in 1998 and 2002 (Table A1-2). Similar reductions in hard coral cover (43%) to those observed by Ayling and Ayling (2005) at the Frankland Island Group in 1998 are plausible.

The reefs in this group are subject to the outflow from the Herbert and Tully Rivers, with Dunk Island only 10km from the Tully river mouth (Figure 18). The levels of fine sediment and organic carbon in the reefal sediments are low compared to the average from all regions (Figure 19). Turbidity levels at Dunk Is North are high with mean turbidity in both 2007/08 and 2008/09 exceeding the Guidelines (GBRMPA 2009), above which coral reef communities undergo substantial changes (De'ath and Fabricius 2008, 2010) (Figure 19). In combination, the sediment and turbidity data suggest a process of frequent re-suspension rather than accumulation of sediments at the sites sampled. Mean chlorophyll *a* concentrations were above the Guidelines in 2007/08 and below it in 2008/09 (Figure 19).

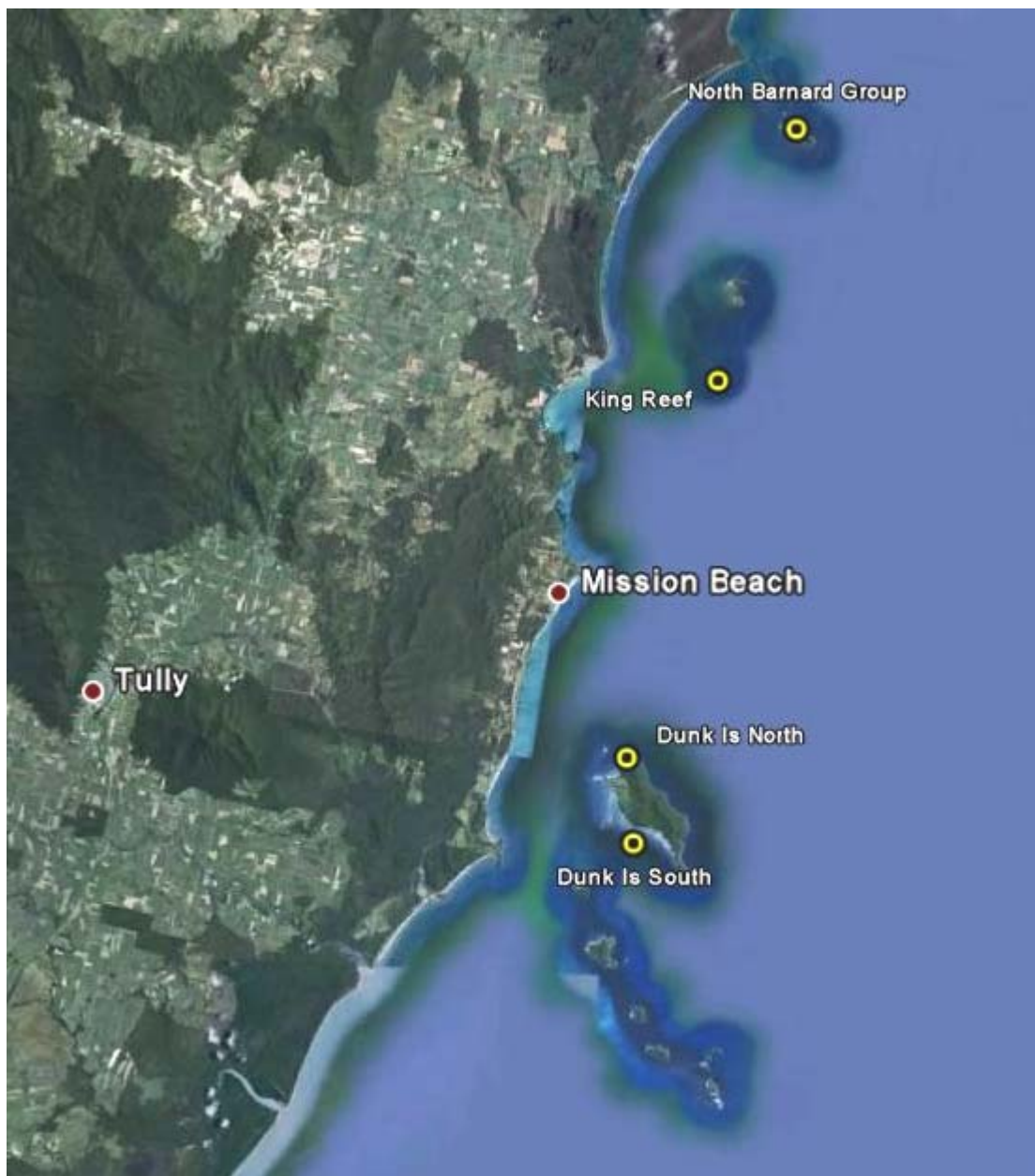
In March 2006 Cyclone Larry severely impacted the coral communities at North Barnard Group and Dunk Island North resulting in a substantial reduction in the cover of hard and soft corals and also macroalgae (Figure 19). King Reef was also influenced at this time; however, as coral cover was already very low, the disturbance was most evident in the removal of macroalgae (Figure 19). 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 sites open to the north and east.

The reduction of macroalgae observed directly following Cyclone Larry was short-lived with cover rapidly rebounding to similar or higher levels than observed prior to the cyclone in subsequent surveys (Figure 19). The high cover at most reefs in 2008-2009 result in predominantly negative assessment of coral community resilience for this indicator.

In 2008-2009 recovery of the coral communities had begun with observed increases in cover in line with model-based expectations at all locations except for King Reef (Figure 19, and neutral score for assessment of change in coral cover, Table 9). Despite some recovery the level of coral cover was still below 25% on most reefs leading to a negative assessment of resilience based on the level of cover present for all reefs other than the 5m depth at Dunk Island South (Table 9).

At two of the four reefs within this sub-region, North Barnard Group and Dunk Is North, density of juvenile colonies was the only indicator of resilience that was positive (Table 9). King Reef at 2m returned a negative assessment with the density of juvenile colonies consistently low (Figure 20). At both North Barnard Group and Dunk Is North reefs, juvenile communities have high proportions of

the families Dendrophylliidae, Faviidae and Poritidae while the adult communities, as estimated by cover, were dominated by Acroporidae (Figure 20). Within the families Faviidae and Poritidae 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 adult cover of these families in the future. Juveniles of the family Dendrophylliidae are almost entirely of the genus *Turbinaria*. *Turbinaria* can form high cover stands especially on turbid water reefs though it often suffers high mortality as larvae tend to settle on unconsolidated substrates and topple prior to gaining sufficient size to survive such an event. Should there be a moderate survivorship of *Turbinaria* it is possible that the adult community composition may shift on these reefs. Such a shift in community composition would be consistent with that expected for communities exposed to increasing exposure to chronic stressors such as turbidity and sedimentation.



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Figure 18 Reef Rescue MMP inshore coral reef monitoring sites (yellow symbols): Herbert Tully sub-region, Wet Tropics region.

The overall status rating for reefs in this sub-region was low primarily due to low cover of corals and high cover of macroalgae (Table 9). The present low cover of corals at Dunk Island North and the North Barnard Group are clearly the result of Cyclone Larry and these reefs are likely to reach higher adult coral cover soon, given the relatively high densities of juvenile colonies. This is not the case for King Reef or the shallow sites at Dunk Island South where coral cover prior to the cyclone was low, macroalgal cover very high and juvenile densities also relatively low. It is difficult to see these reefs improving markedly without a substantial reduction in the cover of macroalgae.

Unfortunately we have current water quality data only for Dunk Island North and are unable to draw any conclusions about the environmental conditions at the other three sites and their suitability for sustained hard coral growth. Water sampling at King Reef during the first two years of the MMP (2005-06) showed high suspended solid and chlorophyll a concentrations at that site, indicating that development of hard coral communities may be limited by environmental conditions (see Thompson *et al*, 2010).

Table 9 Benthic community status: Herbert / Tully sub-region, Wet Tropics region. Overall status aggregates over the indicators coral cover, change in hard coral cover, macroalgal cover and juvenile hard coral density. Sub regional scores convert the three point categorical assessments aggregated across each indicator into an evenly spaced five point scale for consistency of reporting through to Paddock to Reef (see section 2.6.1) Colours reflect this five point scale with assessments of condition ranging sequentially from Red (Poor) through Orange to Yellow (Fair) then through Light Green to Dark Green (Good)

Reef	Depth (m)	Overall Status	Coral cover	Change in hard coral cover	Macroalgae cover	Juvenile density	Settlement
North Barnard Group	2	-	-	neutral	-	+	N/A
	5	-	-	neutral	-	+	N/A
Dunk Is North	2	-	-	neutral	-	+	N/A
	5	neutral	-	neutral	neutral	+	N/A
King Reef	2	----	-	-	-	-	N/A
	5	--	-	-	-	+	N/A
Dunk Is South	2	--	-	neutral	-	neutral	N/A
	5	neutral	neutral	neutral	neutral	neutral	N/A
Sub-regional assessment							N/A

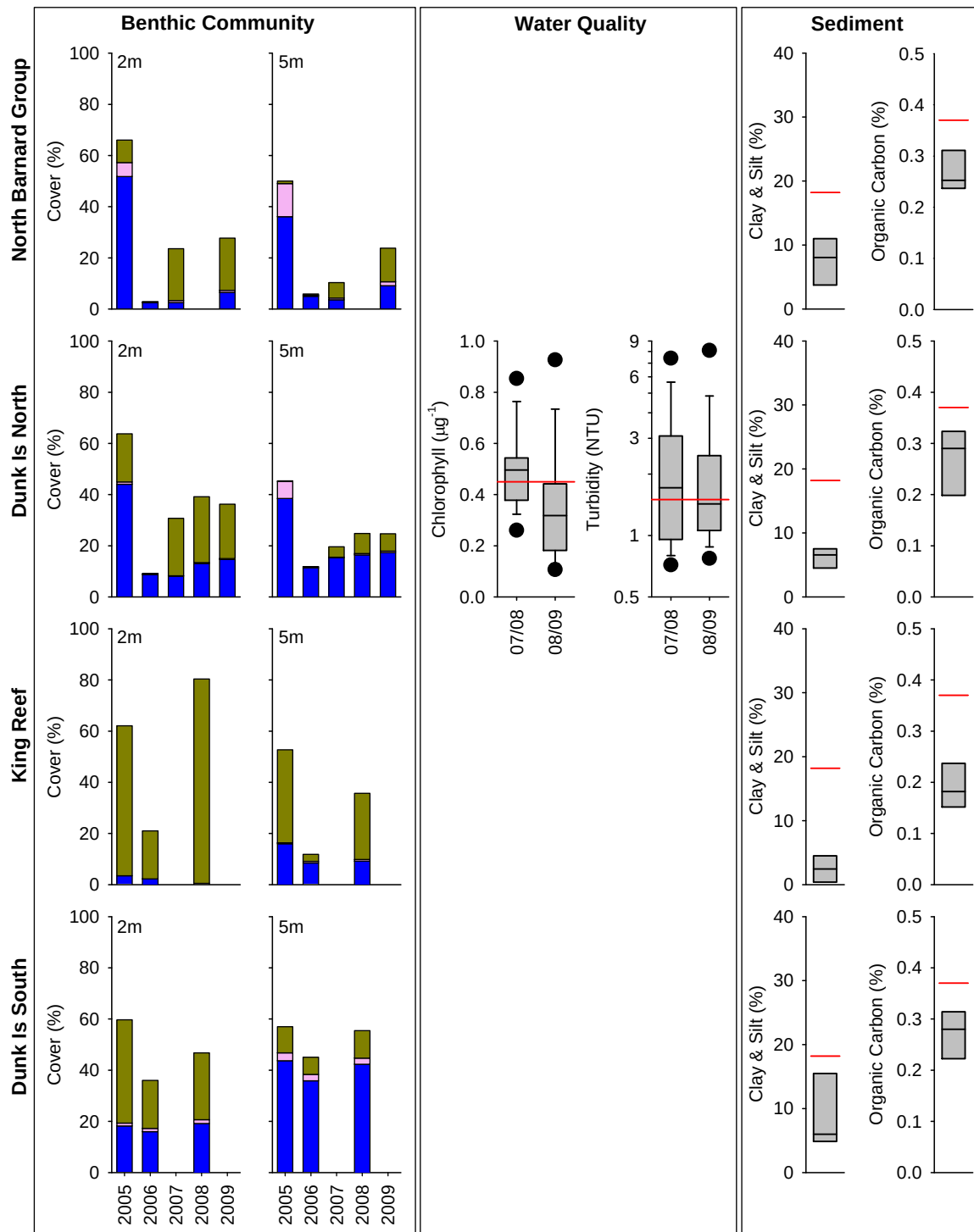


Figure 19 Percent cover estimates of major benthic groups and levels of key environmental parameters: Herbert Tully sub-region, Wet Tropics region. Bar colours represent cover of hard coral (blue), soft coral (pink) and macroalgae (green). Data for water quality condition are derived from Eco FLNTUSB instruments, for sediment quality from sediment sampling from 2006-09 (see Figure 12 for details about the box plot presentation). Red reference lines indicate the Guidelines for water quality parameters (GBRMPA 2009), and the mean across all reefs for sediment parameters.

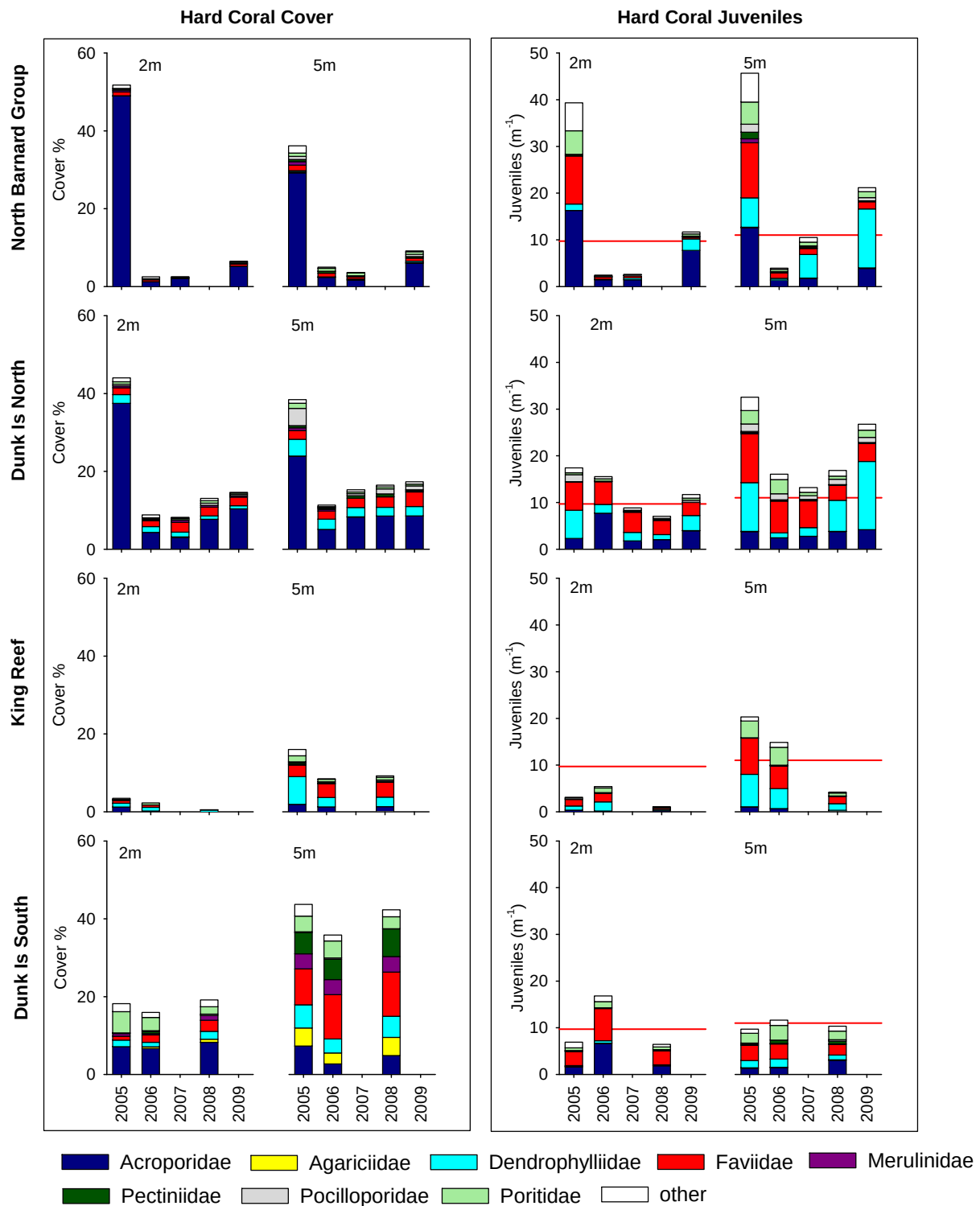


Figure 20 Composition of hard coral communities: Herbert Tully sub-region, Wet Tropics region. Bars are the cumulative cover, or density of juvenile colonies per m^2 of available substrate, of dominant families within the region. Families are indicated by colour of bar section. Only families for which cover exceeded 4% cover on at least one reef at one depth in one year are differentiated; all other families are aggregated into the 'other' group (white bars). Red reference lines are the mean density of juvenile colonies over all reefs and years.

3.2.4 Burdekin NRM region

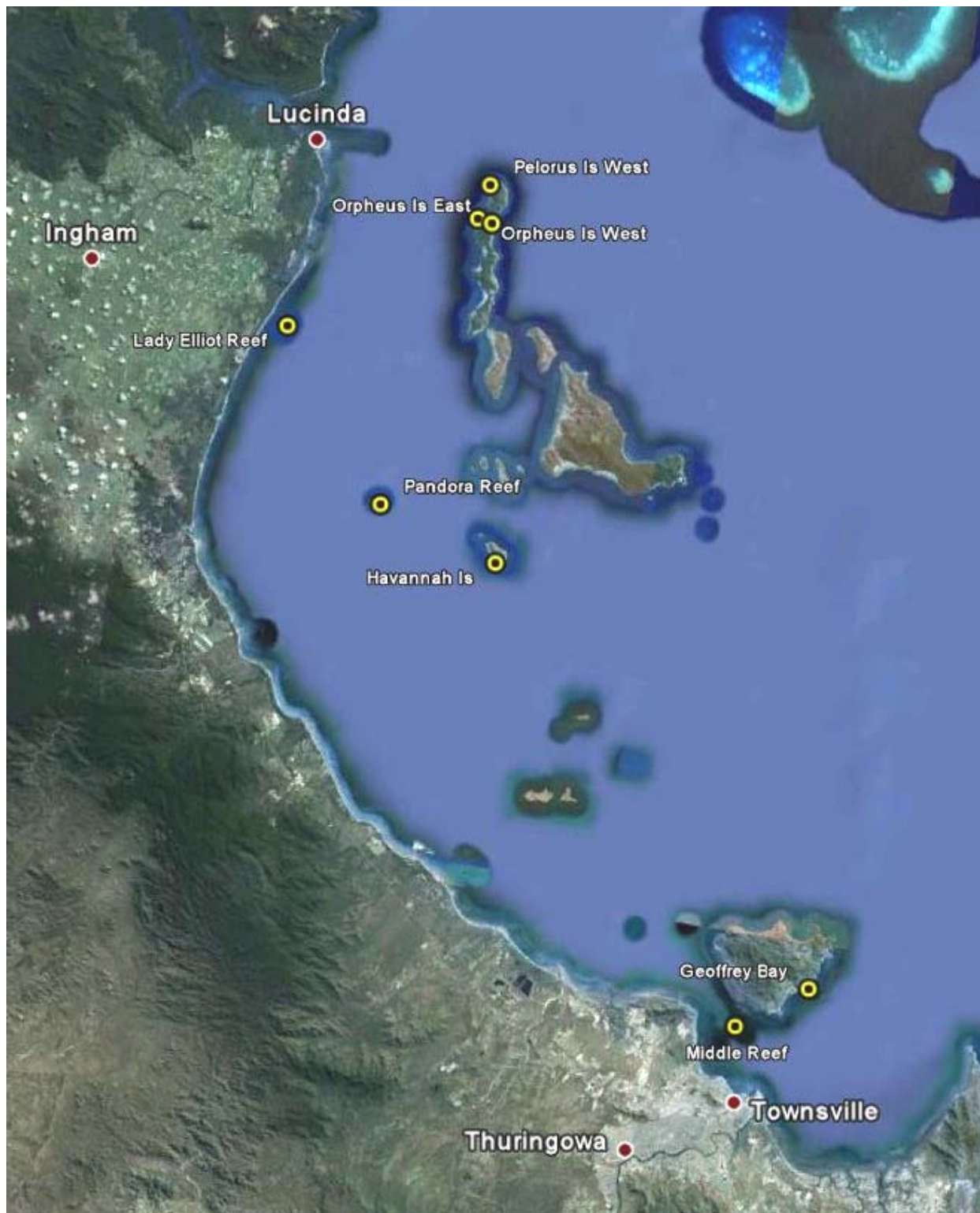
Reefs in the Burdekin Region have been monitored since 1989 under a variety of projects. The long period of monitoring reveals the intense and frequent nature of disturbance to some reefs (Ayling and Ayling 2005, Sweatman *et al.*, 2007, Table A1-2). The largest disturbance since monitoring began in 1989 was coral bleaching in 1998. This event affected all coral communities on the target reefs in this NRM region (Table A1-2). In 2002 bleaching was less severe than in 1998 but still affected the majority of coral communities (Table A1-2). Cyclonic disturbances in 1990 (TC Joy), 1996 (TC Justin) and 2000 (TC Tessi) impacted some reefs, and a large decrease in coral cover attributed to cyclone Tessi at Havannah Island 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). Monitoring studies (Ayling and Ayling 2005, Sweatman *et al.*, 2005) found no discernable direct effects of these flood plumes on the coral communities at the depths monitored. Where there has been evidence of increasing coral cover between disturbances the recovery has 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 (Sweatman *et al.*, 2007).

The loss of well-established coral communities following the bleaching events in 1998 and 2002, particularly of corals in the family Acroporidae, has resulted in low settlement rates of coral larvae and relatively low juvenile counts compared with reefs in other regions (Figures 23, 24). While local diversity has been retained, the recovery rate of coral cover has been limited here, and assessment of the combined hard coral and soft coral cover at reefs in this region continued to be neutral or negative (Table 10).

There were only slight changes in coral cover among some sites between 2008 and 2009; increases in Poritidae at Havannah 2m, decreases in Agariciidae and soft coral at Middle Reef, decreases in soft coral at Pelorus Is & Orpheus Is West 2m and 5m, and slight drop across all coral groups at Geoffrey Bay 5m. These slight decreases in cover may be the result of the Burdekin River floods during early 2009. At most reefs in this region, the rate of increase in hard coral cover remained at or below expectations (Table 10) based on modelled predicted change (Thompson and Dolman 2010). Pandora Reef 5m had a positive projection based on rates of growth from 2006 to 2008 despite storm damage in 2009 that resulted in a decrease of most of the Acroporidae cover that was gained from 2006-2008. Orpheus Is East has positive projections based on an increase in coral cover between 2006 and 2008. The N/A noted for Lady Elliot Reef 5m arises due to a probable error in transect placement in 2006 resulting in a low estimate of cover in that year. We were not confident then that the increase in cover from 2006 to 2008 was not a sampling artefact and so no estimate of growth rate could confidently be made.

The regional average for macroalgae in the Burdekin is the highest among all regions (see Figure 6), driven by the very high cover of brown macroalgae (comprising the genera *Sargassum*, *Dictyota*, *Padina* and *Lobophora*) at Pandora Reef, Havannah Is, and Geoffrey Bay (Magnetic Is) (Figure 22). Cover of macroalgae at other locations was low (Appendix Table A1-5). The distribution of these macroalgae varied considerably, with *Sargassum*, *Dictyota*, and *Padina* more prevalent at Pandora and Geoffrey Bay, and *Lobophora* dominant in the shallow sites at Havannah Is. *Lobophora* had been dominant in the shallow areas of Pandora Reef in 2008, but was removed by storms in early 2009. By contrast, Lady

Elliot Reef maintains an abundance of red macroalgae, mostly of the genus *Hypnea*, the highest of any reef surveyed in the MMP.



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Figure 21 Reef Rescue MMP inshore coral reef monitoring sites (yellow symbols): Burdekin region.

Macroalgae are rare at Orpheus Is East and Pelorus Is & Orpheus Is West. 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 status assessment at these sites. The presence of abundant macroalgae on reefs can influence the local coral community across various life-cycle stages, by chemical and/or physical interference (Kuffner *et al.* 2006, Birrell *et al.* 2008, Diaz-Pulido *et al.* 2009, 2010). High macroalgal cover is most often observed on degraded reefs following disturbances. However, macroalgal cover is also positively correlated with water column chlorophyll *a* concentrations (De'ath and Fabricius 2010), a parameter which show high values at all three core sites in this region, especially after the 2008 and 2009 floods of the Burdekin River (Schaffelke *et al.* 2009). Mean chlorophyll *a* concentrations at the three core reefs in 2007/08 and 2008/09 exceeded the Guidelines (GBRMPA 2009, Figure 22). The sustained high macroalgal cover at Havannah was recently interpreted as a persistent coral-algal phase shift and attributed to a different assemblage of herbivorous fish at this site (Cheal *et al.* 2010). This herbivore assemblage has been unable to control the abundant macroalgae, which in turn has prevented the recovery of hard coral cover.

The abundance and diversity of hard coral juveniles at many reefs in this region reflects the adult community (Figure 23). In general where cover of adult corals is low juvenile colonies are sparse. With the exceptions of Middle Reef and Lady Elliot Reef at 2m, juvenile densities in 2009 were below the combined regional average. 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. A general decline in juvenile density is apparent from 2006 or 2007 onwards on most sites (Orpheus Is East, Pelorus Is & Orpheus Is West, Lady Elliot Reef, Middle Reef, Geoffrey Bay), with only a slight increase at Pandora Reef and Havannah Is. A similar decline was observed at several reefs in the other regions.

Recruitment of coral larvae to settlement tiles in the Burdekin region is well below the overall average among regions (Figure 24) and results in a negative assessment score (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 23). 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 underlines 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. The discharge from the Burdekin has increased every year since the start of the MMP in 2005, with major flood events in 2008 and 2009 (Table 5). Despite the large input, the reefs in the Burdekin region have sediments with below average clay and silt, organic carbon and nitrogen components (Table AI-Ia-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 22, Table AI-Ia-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 for the five survey sites further away from the river mouths of the Burdekin and Ross rivers where 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.* in press). Sediment accumulation was apparent at Middle Reef (see above) but not at Geoffrey Bay. The latter site, however, had regular high turbidity events, with the average levels in 2007/08 and 2008/09 exceeding the Guidelines. 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 status: Burdekin region. Overall status aggregates over the indicators coral cover, change in hard coral cover, macroalgal cover, juvenile hard coral density and settlement (where sampled). Regional scores convert the three point categorical assessments aggregated across each indicator into an evenly spaced five point scale for consistency of reporting through to Paddock to Reef (see section 2.6.1). Colours reflect this five point scale with assessments of condition ranging sequentially from Red (Poor) through Orange to Yellow (Fair) then through Light Green to Dark Green (Good)

Reef	Depth (m)	Overall Status	Coral cover	Change in hard coral cover	Macroalgae cover	Juvenile density	Settlement
Orpheus Is East	2	neutral	neutral	neutral	+	-	N/A
	5	+	neutral	+	+	-	N/A
Pelorus Is & Orpheus Is West	2	++	neutral	neutral	+	+	N/A
	5	-	neutral	-	+	neutral	-
Havannah Is	2	-	-	neutral	+	-	N/A
	5	----	-	-	-	-	N/A
Pandora Reef	2	--	-	+	-	-	N/A
	5	---	-	+	-	-	-
Lady Elliot Reef	2	neutral	neutral	neutral	-	+	N/A
	5	+	neutral	N/A	neutral	+	N/A
Middle Reef		++	neutral	neutral	+	+	N/A
Geoffrey Bay	2	---	-	neutral	-	-	N/A
	5	----	-	-	-	neutral	-
Regional assessment							

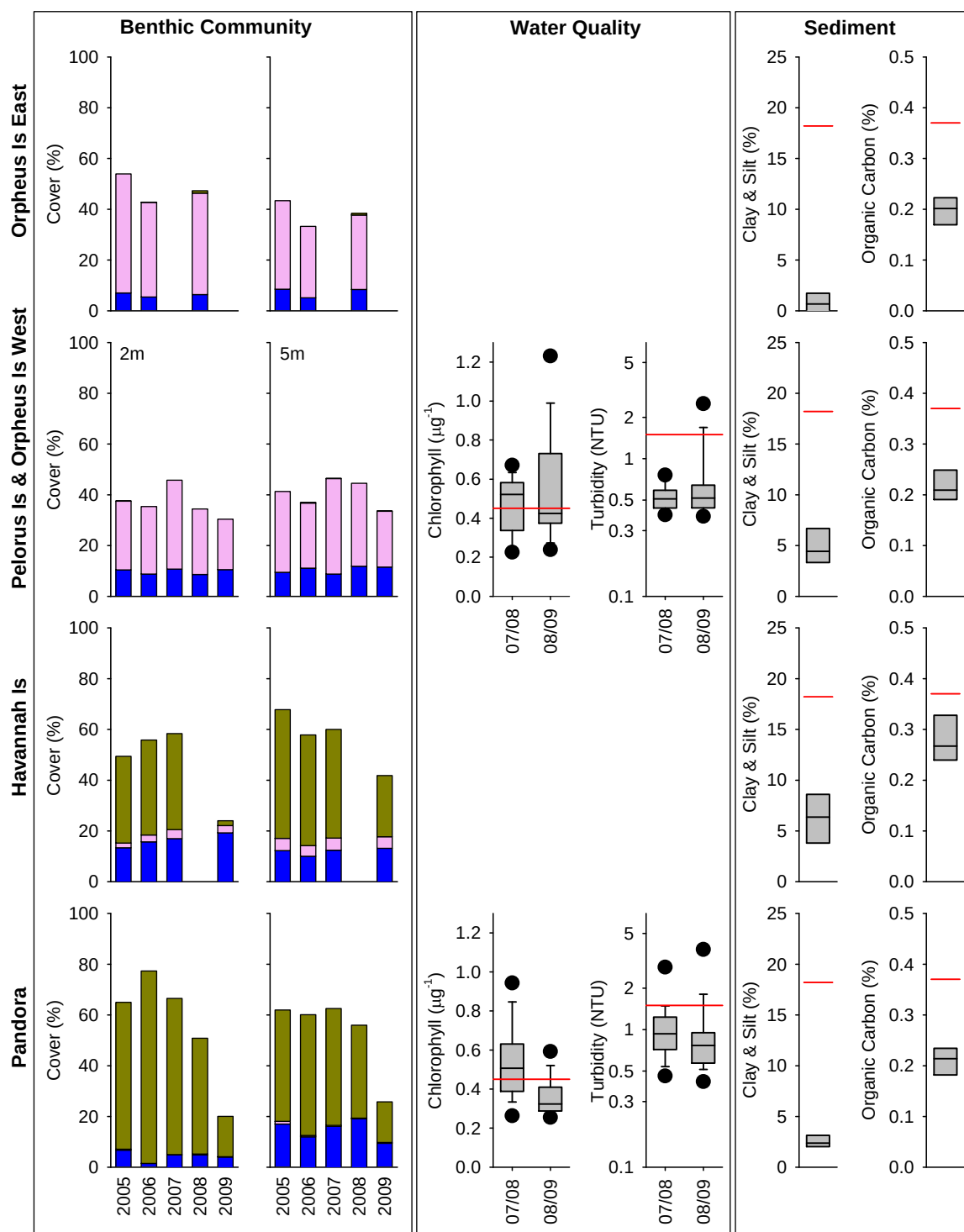


Figure 22 Percent cover estimates of major benthic groups and levels of key environmental parameters: Burdekin region. Bar colours represent cover of hard coral (blue), soft coral (pink) and macroalgae (green). Data for water quality condition are derived from Eco FLNTUSB instruments, for sediment quality from sediment sampling from 2006-09 (see Figure 12 for details about the box plot presentation). Red reference lines indicate the Guidelines for water quality parameters (GBRMPA 2009), and the mean across all reefs for sediment parameters.

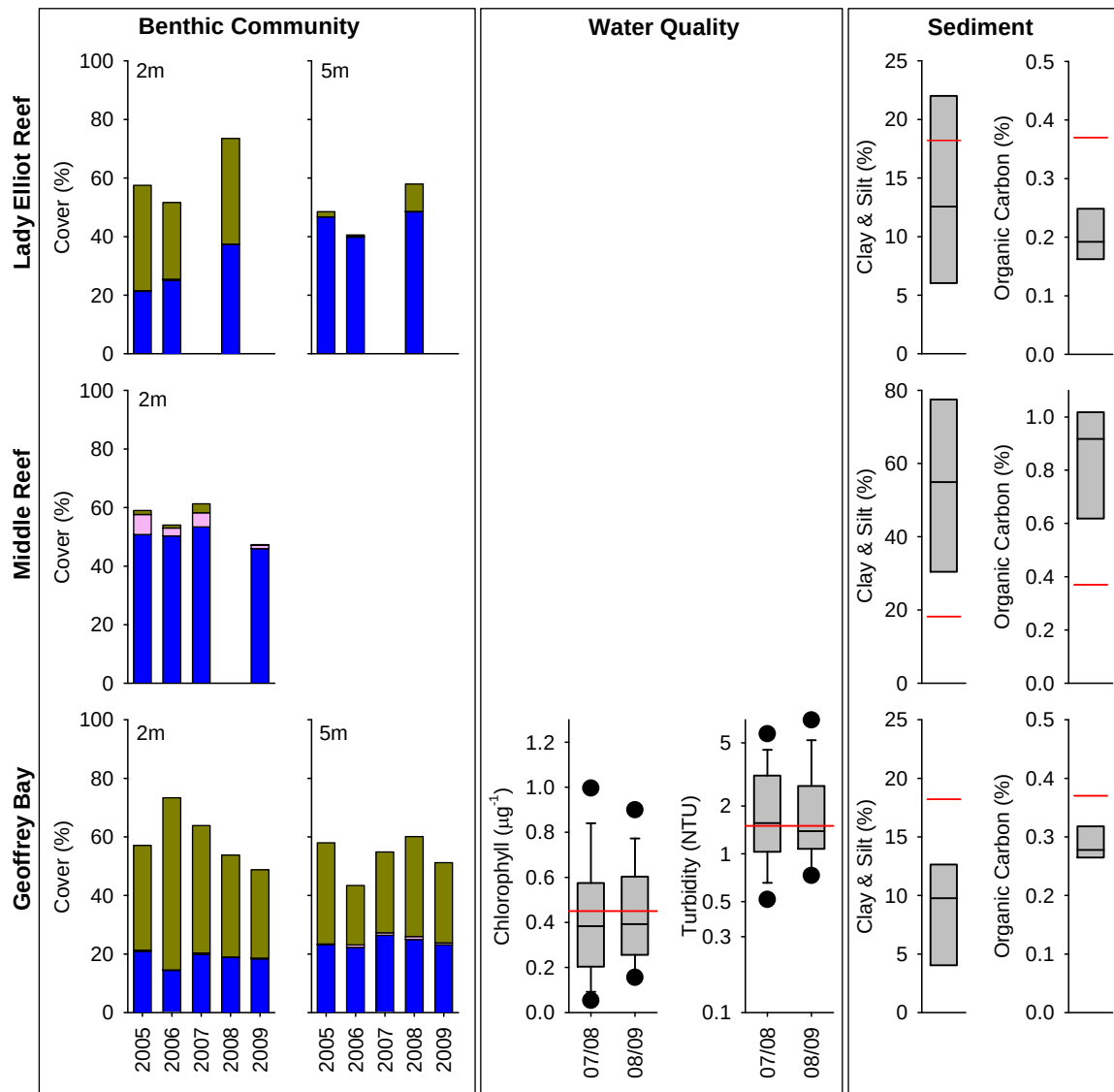


Figure 22 continued. Note different scales for sediment quality parameters at different reefs.

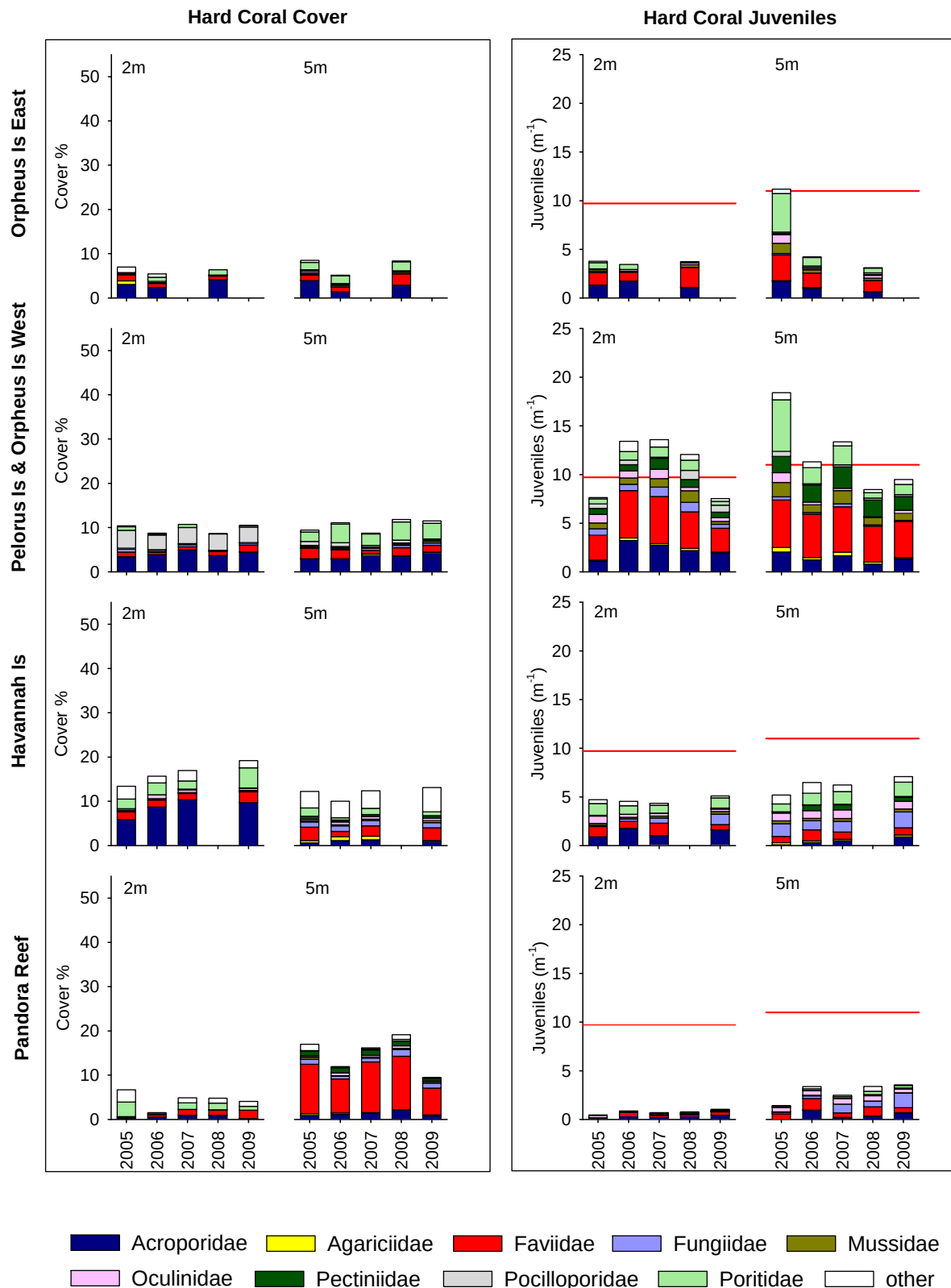


Figure 23 Composition of hard coral communities: Burdekin region. Bars are the cumulative cover, or density of juvenile colonies per m^2 of available substrate, of dominant families within the region. Families are indicated by colour of bar section. Only families for which cover exceeded 4% cover on at least one reef at one depth in one year are differentiated; all other families are aggregated into the 'other' group (white bars). Red reference lines are the mean density of juvenile colonies over all reefs and years.

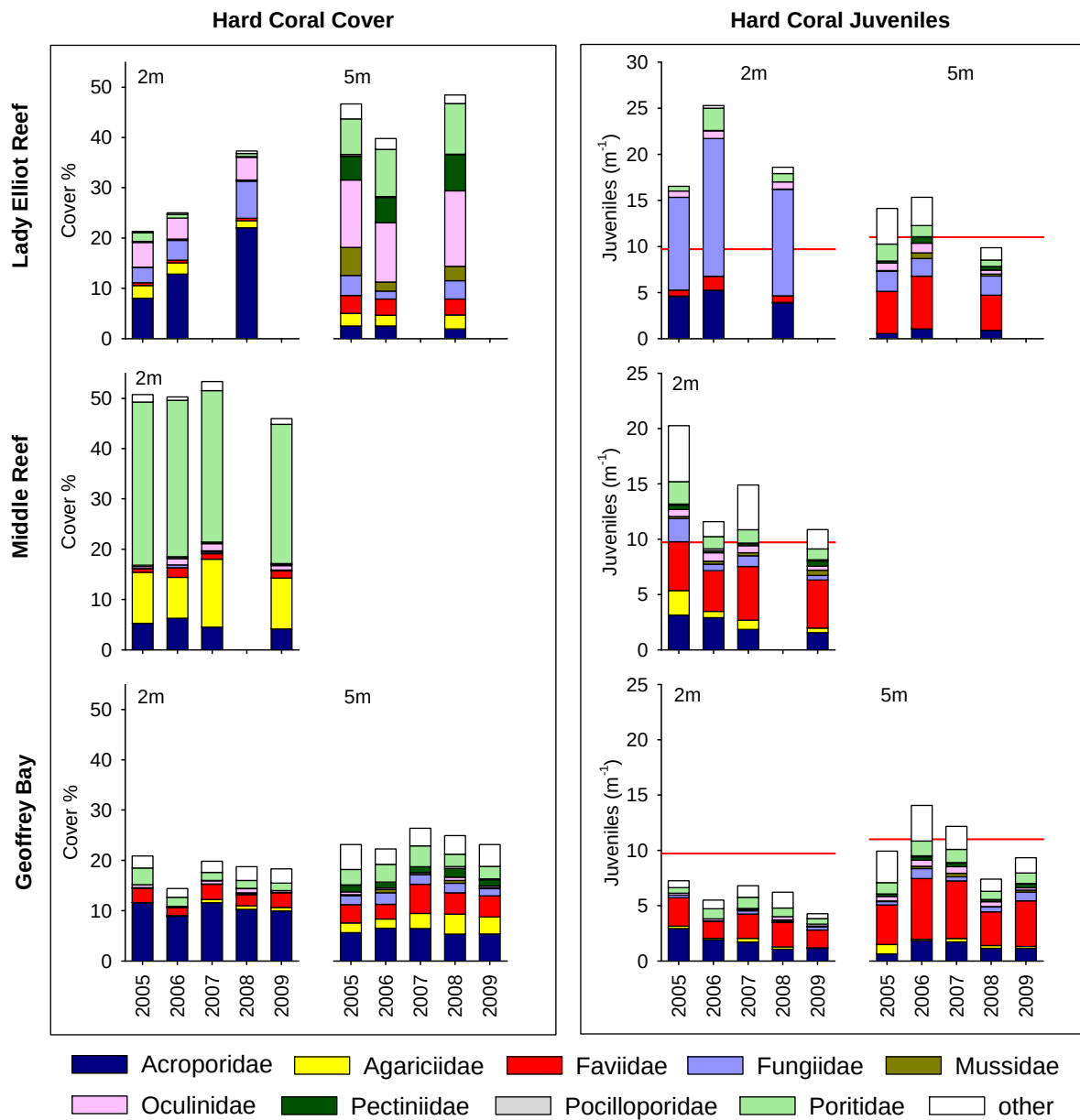


Figure 23 continued.

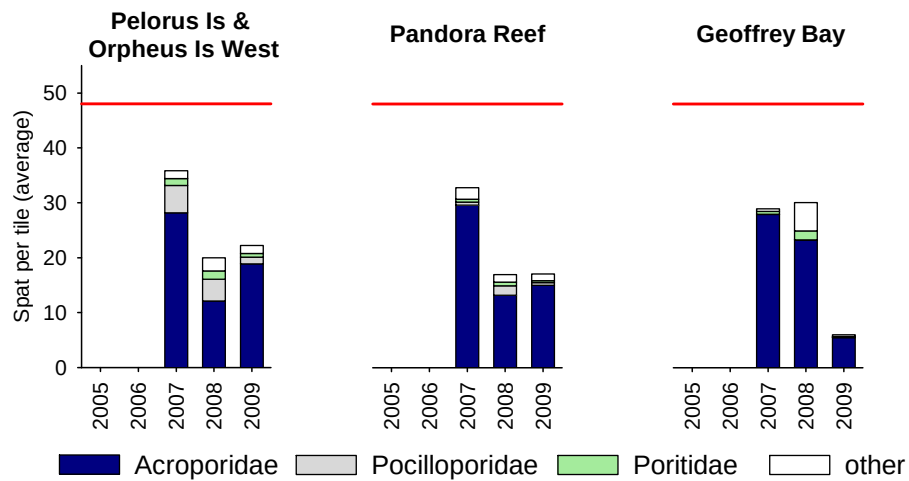


Figure 24 Coral settlement to tiles: Burdekin region. Data are from 5m tile deployments. Average values from all reefs and NRM regions sampled in each year are indicated by red reference lines.

3.2.5 Mackay Whitsunday NRM region

The main sources of sediments 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). The environmental data collected under Reef Rescue MMP all point to high exposure to terrestrially derived sediments. Collectively the sediments on the reefs monitored in this region have the highest proportion of fine grained particles and nutrients and the lowest levels of inorganic carbon, which is a measure of the reef-derived component of marine sediments (Figures 2, 26). The surrounding waters are nutrient-rich and highly turbid with mean chlorophyll concentrations at or above the Guidelines (GBRMPA 2009) at the three core reefs and mean turbidity levels above the Guidelines at both Daydream Is and Pine Island (Figure 26). This combination of fine grained sediments and high turbidity along with observations of high sediment loads to substrates and coral settlement tiles indicates that coral communities in this region are exposed to sediments both directly through sedimentation and smothering and indirectly through turbidity reducing the light 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 subsequent transport of sediments away from the reefs leading to the accumulation of fine sediments on the fringing reefs. The selection for sediment tolerant corals is clear 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 high sedimentation and turbidity with many species favouring high light environments (Thompson *et al.* 2010). 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 with branching growth forms. The families Oculinidae, Pectiniidae and Agariciidae and Poritidae (genus *Goniopora*) are all found in relatively high abundance on some reefs (Figure 26) and are collectively considered sediment-tolerant taxa (Thompson *et al.* 2010). 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 2009, sediment loads to living corals were high especially at 5m depths. The proportion of substrate classified as 'silt' in 2009 was higher than in any prior survey at the 5m depths at 4 the 5 reefs visited in 2009; a result corresponding to higher than median flows in adjacent catchments over recent years (Table 5).

There is 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 disturbances in recent history were coral bleaching events in 1998 and 2002 that 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 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). Between 2005 and 2009 there were no major acute disturbances to the reefs in this region, and it will be informative to assess the damage caused by Cyclone Ului in early 2010 and the subsequent recovery.



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Figure 25 Reef Rescue MMP inshore coral reef monitoring sites (yellow symbols): Mackay Whitsunday region.

The lack of any substantial disturbance to these reefs since at least 1998 explains the moderate to high cover of corals in 2009 (Figure 26). Of concern, however, is that, with the exception of 2m depths at Shute Is & Tancred Is and Hook Is, cover of hard corals has not increased at the rate expected for the types of coral communities at these sites (Table 11, Figure 27). Observations from scuba search surveys indicated coral disease as a probable cause of declines in cover of Acroporidae at Daydream Is and Dent Is.

The cover of macroalgae has remained consistently low on all reefs with the exception of the 2m depths at Pine Is and Seaforth Is. These are the reefs closest to the rivers influencing this region and water quality data from Pine Island shows that mean chlorophyll *a* concentrations and levels of turbidity exceeded the Guidelines in both 2007/08 and 2008/09 (Figure 26). Mean chlorophyll *a* concentration and turbidity at Daydream Is also exceeded the Guidelines, potentially making this reef susceptible to increases in macroalgal cover should coral cover decline in the future.

The average density of juvenile hard coral colonies was moderate to high on all reefs (Table 11, Figure 27). There were, however, general declines at Double Cone Is, Dent Is, Hook Is and at the 5m depth of Daydream Is. Juvenile density also declined from 2005 to 2008 at Pine Is but recovered again in 2009 (Figure 27). This recent increase in the density of juveniles per area of available substrate was, however, primarily due to a large increase in proportion of substrate covered by silt, thus reducing the area of substrate considered available to settlement, rather than an increase in actual juvenile numbers. Juvenile and adult coral community composition are 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 Island, the lack 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 cope well with high sedimentation and turbidity; the presence of this family in the juvenile community at Daydream Is corresponds to the environmental conditions observed. More unusual here is the moderate density of juvenile *Acropora* and the high adult cover attained by that genus. Relatively high proportions of Faviidae in the juvenile communities compared with their representation in terms of cover are not uncommon and reflect; relatively slow growth of some species, a tendency toward small size in others, along with the tendency for colonies to exist in the understory 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 was close to or slightly below the overall average settlement for all regions (Figure 28). 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 the occasional high or low estimate 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 28). [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 27). In general, the high variability of settlement between reefs and years remains unexplained however 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 positive assessments of status due to the generally high cover of corals, the low cover of macroalgae and the moderate to high density of juvenile colonies. This outweighed the mostly low rates of cover increase and the moderate to low settlement of larvae (Table 11). Only the 2m depth communities at Pine Is and Daydream Is returned negative assessments. At both reefs low rates of coral cover increase and low settlement (Figures 27, 28) influenced this result while at Pine Is high cover of macroalgae was also a negative consideration (Figure 26).

Table 11 Benthic community status: Mackay Whitsunday region. Overall status aggregates over the indicators coral cover, change in hard coral cover, macroalgal cover, juvenile hard coral density and settlement (where sampled). Regional scores convert the three point categorical assessments aggregated across each indicator into an evenly spaced five point scale for consistency of reporting through to Paddock to Reef (see section 2.6.1) Colours reflect this five point scale with assessments of condition ranging sequentially from Red (Poor) through Orange to Yellow (Fair) then through Light Green to Dark Green (Good)

Reef	Depth (m)	Overall Status	Coral cover	Change in hard coral cover	Macroalgae cover	Juvenile density	Settlement
Double Cone Is	2	neutral	+	-	+	neutral	-
	5	+	+	-	+	neutral	neutral
Daydream Is	2	-	neutral	-	+	neutral	-
	5	+	neutral	-	+	+	neutral
Hook Is	2	++	+	neutral	+	neutral	N/A
	5	+	+	-	+	neutral	N/A
Dent Is	2	++	+	-	+	+	N/A
	5	neutral	neutral	-	+	neutral	N/A
Shute Is & Tancred Is	2	+++	+	neutral	+	+	N/A
	5	+	neutral	-	+	+	N/A
Pine Is	2	--	neutral	-	neutral	neutral	-
	5	+	neutral	-	+	+	neutral
Seaforth Is	2	neutral	neutral	-	neutral	+	N/A
	5	neutral	-	-	+	+	N/A
Regional assessment							

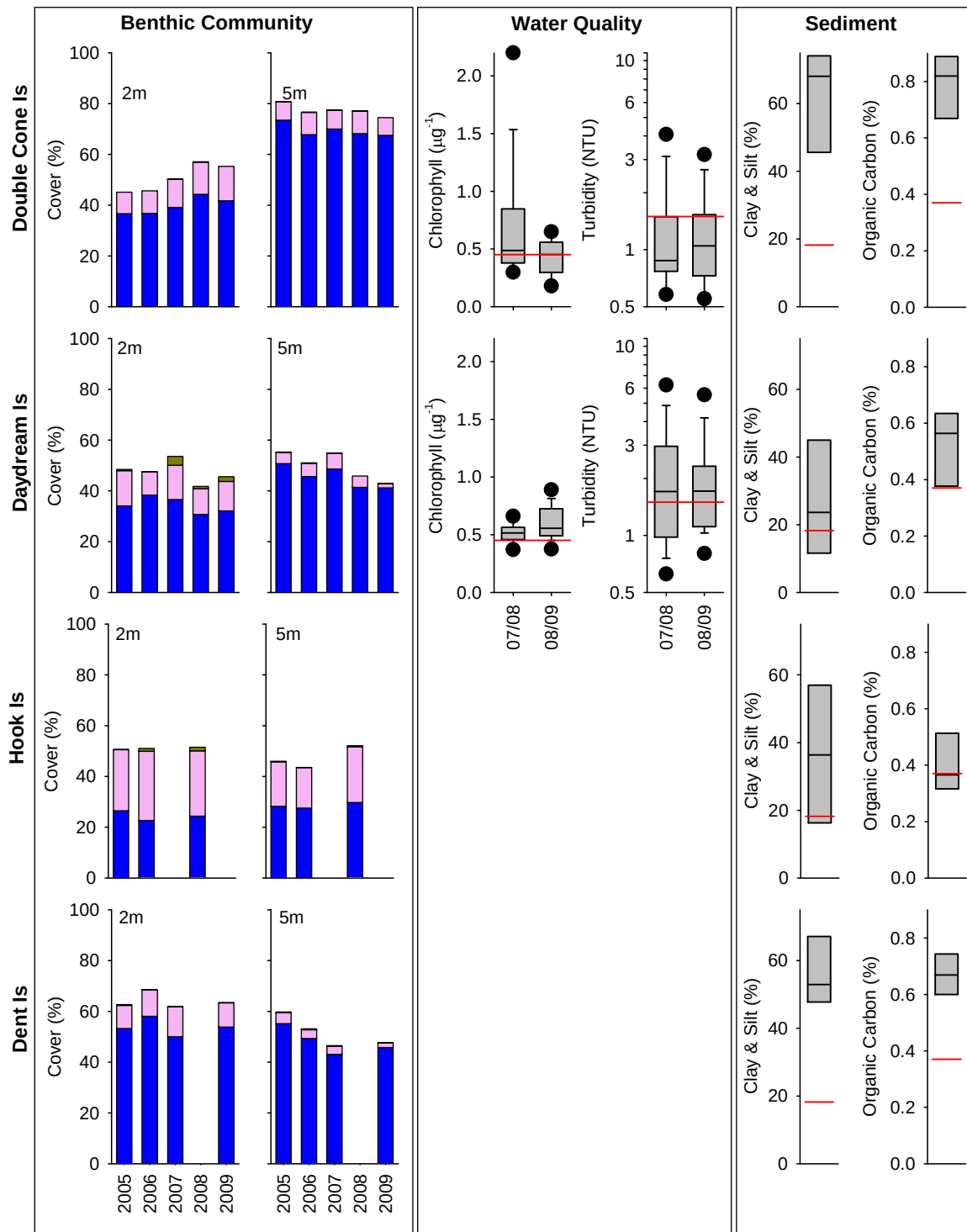


Figure 26 Percent cover estimates of major benthic groups and levels of key environmental parameters: Mackay Whitsunday region. Bar colours represent cover of hard coral (blue), soft coral (pink) and macroalgae (green). Data for water quality condition are derived from Eco FLNTUSB instruments, for sediment quality from sediment sampling from 2006-09 (see Figure 12 for details about the box plot presentation). Red reference lines indicate the Guidelines for water quality parameters (GBRMPa 2009), and the mean across all reefs for sediment parameters.

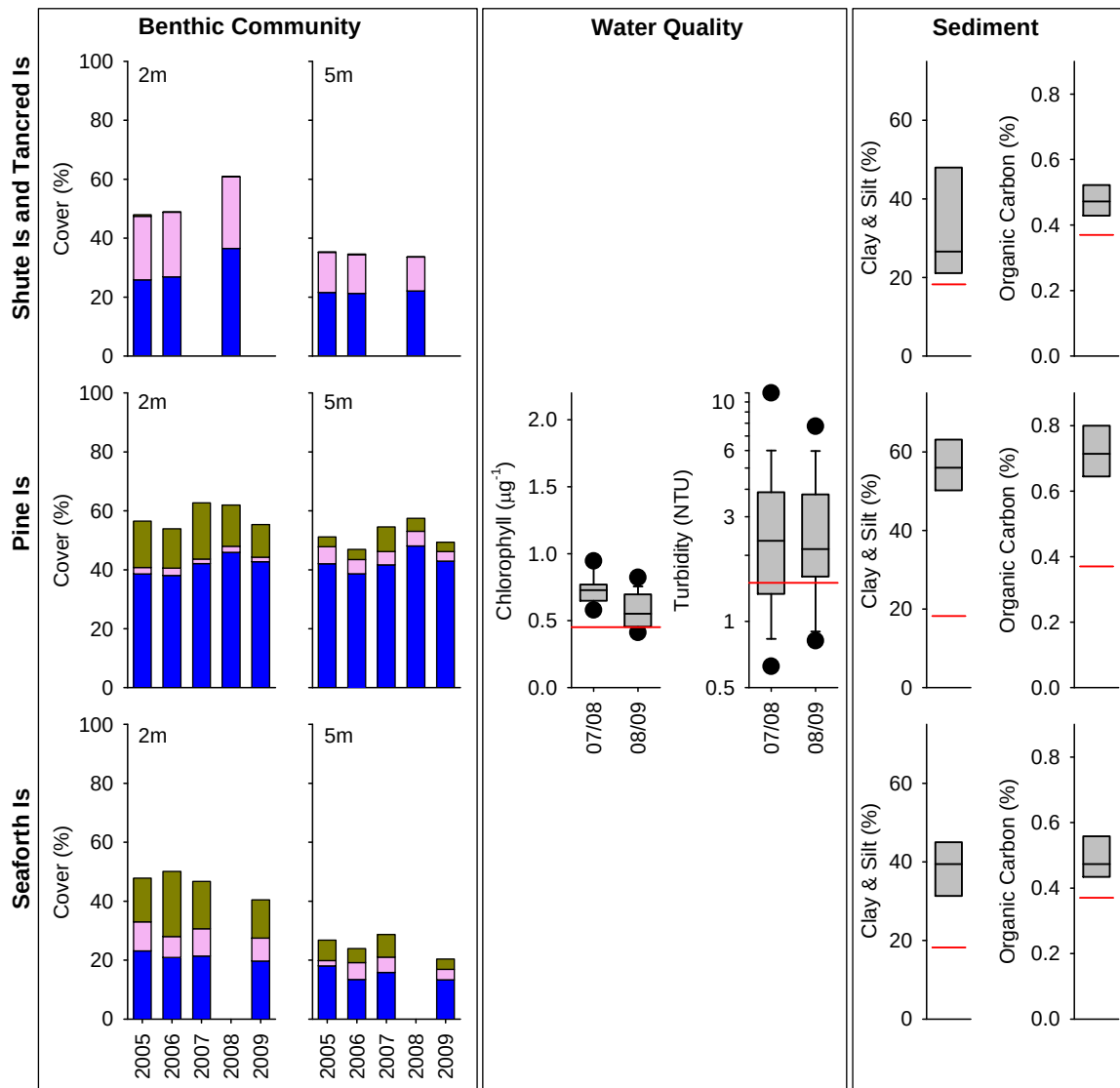


Figure 26 continued.

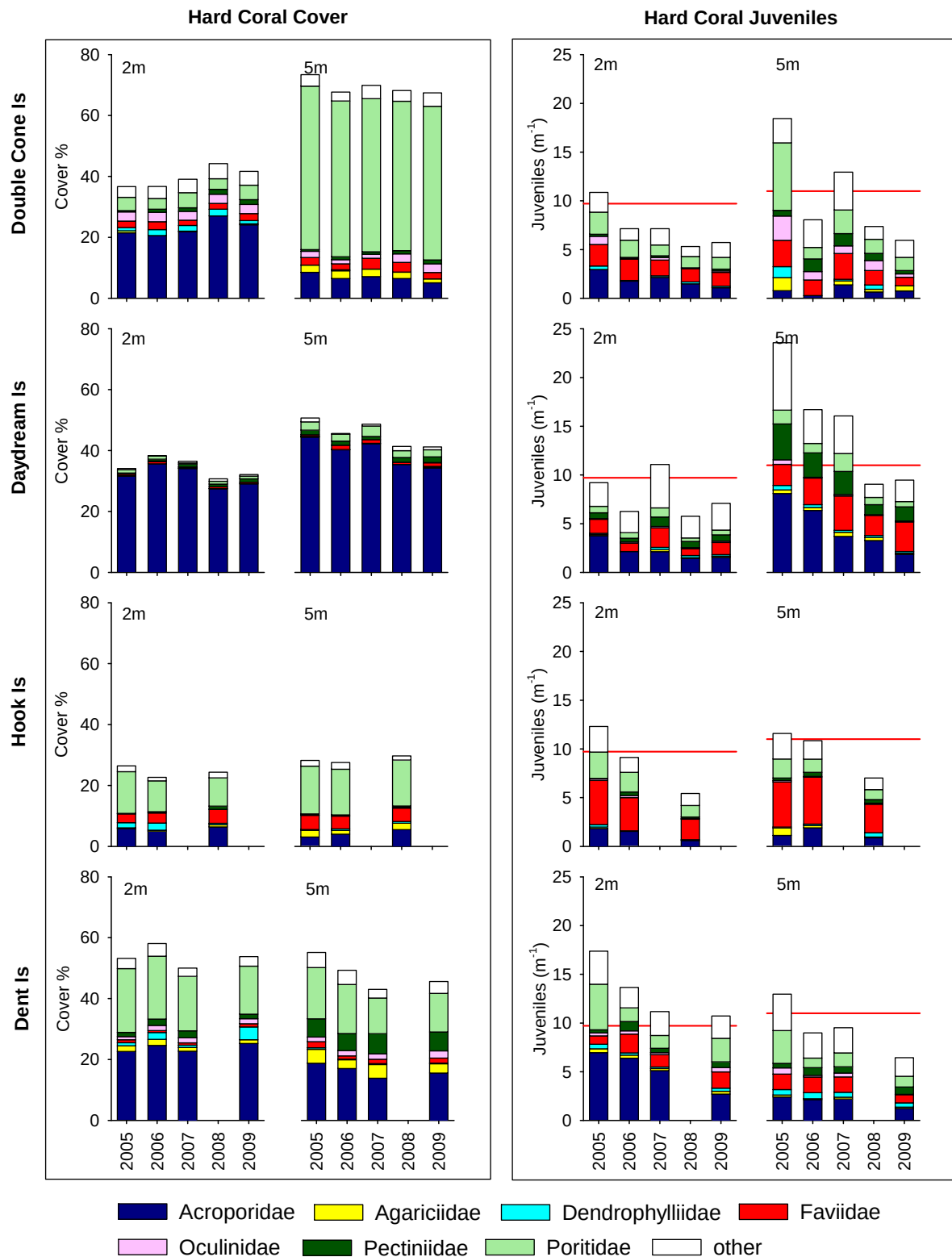


Figure 27 Composition of hard coral communities: Mackay Whitsunday region. Bars are the cumulative cover, or density of juvenile colonies per m^2 of available substrate, of dominant families within the region. Families are indicated by colour of bar section. Only families for which cover exceeded 4% cover on at least one reef at one depth in one year are differentiated; all other families are aggregated into the 'other' group (white bars). Red reference lines are the mean density of juvenile colonies over all reefs and years.

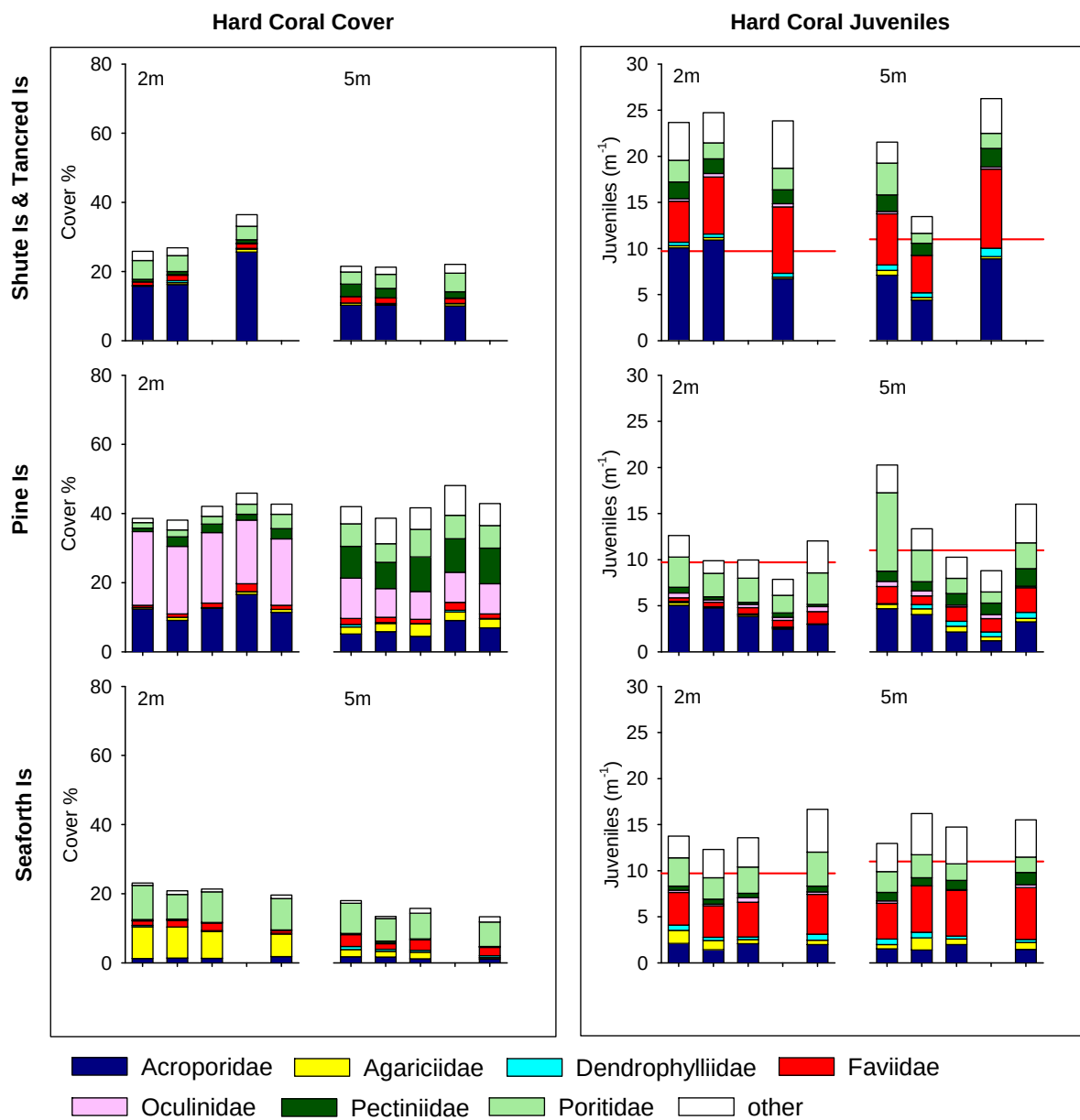


Figure 27 continued

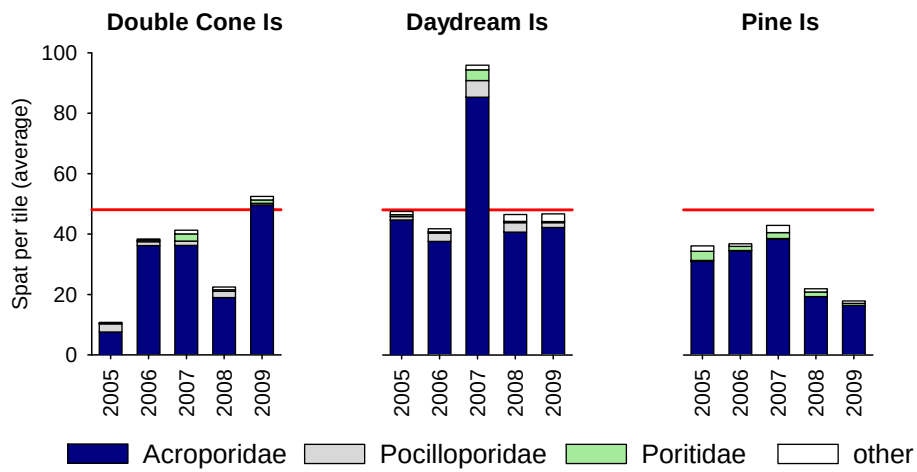


Figure 28 Coral settlement to tiles: Mackay Whitsunday region. Data are from 5m tile deployments. Average values from all reefs and NRM regions sampled in each year are indicated by red reference lines.

3.2.6 Fitzroy NRM region

The Fitzroy region is one of the two large dry tropical catchment regions in the GBR Region with cattle grazing as the primary land use, the other being the Burdekin (Brodie *et al.* 2003). The main river system influencing reefs in this region is the Fitzroy River. The reef communities at six locations in Keppel Bay were monitored under the MMP in 2009 (Figure 29). The sediments at the reefs in this group have the lowest clay and silt levels of all catchments (Table AI-Ia), suggesting fine grained sediments entering the area from the Fitzroy River are not accumulating at the locations sampled. The proportion of inorganic carbon (a measure the marine derived component of sediments), however, is low at both Peak Is and Pelican Is (Table AI-I d) implying that larger grained sediments of terrestrial origin are present at these sites closer to the Fitzroy River. Levels of organic carbon are low, while nitrogen levels remain average with a modest increase in 2008 (Table AI-I b & c), perhaps as a result of flooding in February 2008. A strong gradient in water quality exists between the reefs in this region with increasing distance from both the coast and Fitzroy river mouth. This is clearly evident in the differences in water column turbidity and chlorophyll *a* (Figure 30). The discrepancy between sediment composition and turbidity is taken to indicate that while fine sediments are not accumulating at the locations visited, tidal and wind driven re-suspension repeatedly expose corals to locally accumulated deposits. The clear distinction between coral communities at Peak Is and Pelican Is and those on the reefs further from shore reflect the sharp difference in environmental setting between these, otherwise nearby, reefs (Figure 31). Turbidity at Pelican Is was extremely high in 2007/08 with median level of almost 5 NTU, a level suggested as the upper threshold beyond which corals may be severely light-limited (Cooper *et al.* 2007, 2008). This is clearly demonstrated in the marked difference in community composition between 2m and 5m sites (Figure 31). In 2008/09; in absence of a substantial Fitzroy River flood, turbidity across the region was lower than in the previous year demonstrating the important influence of the Fitzroy River for the water quality in Keppel Bay.

There is a clear separation of hard coral community composition types. Reefs of the outer Keppel islands were dominated by Acroporidae, predominantly *Acropora intermedia* and *A. muricata*, whereas reef of the inner Keppel islands, Pelican Is and Peak Is had a more mixed composition (Figure 31). Historical monitoring data collected by Queensland Parks and Wildlife Service (QPWS) show that coral cover at reefs with *Acropora*-dominated communities was reduced in 1998 and 2002 by coral bleaching events, with cover increasing in the intervening period (Sweatman *et al.* 2007). In addition, the repeat sampling of sites following a large flood of the Fitzroy River in 1991 documented up to 85% mortality of corals in depths down to 1.5m at Humpy Is, Halfway Is and Middle Is (van Woesik 1991).

When this current monitoring program began in 2005 the cover of Acroporidae at the outer Keppel reefs was high, ranging from 46% at Barren Is (2m) to 92% at Barren Is (5m). Bleaching in the summer of 2006 caused a marked reduction in coral cover at these reefs coupled by a marked increase in the cover of macroalgae, predominantly the brown algal genus *Lobophora* (Figure 30). In 2008 coral cover was reduced at Barren Island as a result of physical damage incurred during a strong northerly wind event. Assessments of status for these reefs largely reflect the degree of damage incurred during these disturbances, the persistence of the subsequent *Lobophora* bloom, and the subsequent rate of coral cover recovery (Table 12). At both depths at North Keppel Is, 5m depth at Humpy Is & Halfway Is and 2m depth at Middle Island the impact of bleaching in 2006 was severe, the recovery of

coral cover has been slower than expected given the predominance of the typically fast growing *Acropora*, and the algae *Lobophora* has persisted (Figure 30), all leading to negative assessments of status.



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Figure 29 Reef Rescue MMP inshore coral reef monitoring sites (yellow symbols): Fitzroy region.

At Humpy Is & Halfway Is (2m) and Middle Is (5m) coral cover was not as severely impacted by bleaching in 2006 and the cover of *Lobophora* has declined. The increasing coral cover at Humpy Is & Halfway Is was also consistent with the expected growth rate of *Acropora* (Figure 30). At Barren Is (2m) the level of cover in 2009 was moderate, cover of macroalgae low and rate of increase in cover normal, the negative assessment for this reef stemming from very low levels of coral recruitment to settlement tiles in most years (Figure 32). The dynamics of the coral communities observed in this program are similar to, although not as extreme as, those reported by Diaz-Pulido *et al.* (2009) for

the same suite of reefs covering the decline and subsequent rapid recovery from the 2006 bleaching event.

There are no historical data available for the coral communities found on the more turbid water reefs of inner Keppel Bay, i.e. Pelican Is and Peak Is. Unlike the communities further offshore there was little evidence of a bleaching impact in 2006. The coral community at Pelican Is (2m) had a reasonable component of the family Acroporidae that is generally susceptible to bleaching, however, here cover increased markedly during the period of recorded declines in cover at the outer Keppel reefs (Figure 31). In 2008 coral cover declined at the 2m depths of both Pelican Is and Peak Is (Figure 30), likely as a result of the major flooding of the Fitzroy River. 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 obviously tolerant of the low light and high nutrient conditions found at these reefs. The persistent low cover at Peak Is, 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 bounds that can support a true coral reef community.

Associated with the mortality of corals at Middle Is, Humpy Is & Halfway Is and to a lesser degree Barren Is, following bleaching in 2006 was an increase in the cover of macroalgae of the genus *Lobophora*. While still present the cover of *Lobophora* had declined by 2009 (see macroalgae cover, Figure 30). The macroalgae communities at Pelican Is and Peak Is were more diverse and were well-established when these reefs were first visited in 2004 (Sweatman *et al.* 2007). Cover of macroalgae on these inshore reefs had also declined in 2008 following the Fitzroy River flood. Similar to the other regions, the pattern is confirmed here that persistent macroalgal communities occur on reefs with water column chlorophyll *a* levels above the Guidelines (GBRMPA 2009).

The density of juvenile hard corals was again low in the Fitzroy region (Figure 31). This along with the rapid increase in cover following disturbances to the branching *Acropora* communities indicates that recovery was largely due to the growth of surviving colonies rather than the recruitment and subsequent growth of new colonies. A possible exception is Pelican Island (2m) where surveys in 2004 (Sweatman *et al.* 2007) recorded high numbers of small *Acropora* colonies and subsequent observations indicated that the growth of this cohort resulted in the increase in cover to 2007. High densities of juvenile colonies in 2005 at Middle Is (5m) and Barren Is (5m) should be viewed with caution because the adult coral cover was so high that the correction for available space disproportionately weighted the relatively few juveniles actually observed, compared to other reefs with a higher proportion of available space.

Settlement of coral larvae to tiles varied substantially among the core reefs in this region. At Barren Island the numbers of recruits was the lowest of any reef in any region (Figure 32), which might explain the low numbers of juvenile colonies at this reef. The consistently low settlement of larvae observed at Barren Is relative to the above average levels at the other reefs in the region could represent limited connectivity or larval retention at this reef. Conversely, the low density of juvenile corals at both Humpy Is & Halfway Is and Pelican Is suggest limited recruitment success given the evident ample availability of competent larvae (Figure 32). Similarly, the particularly high settlement at Humpy Is & Halfway Is in 2006 did not result in substantial numbers of juvenile corals in later years (Figure 31).

The assessment of coral community status indicated lower than expected values for reefs in this region (Table 12) especially considering the documented rapid recovery from previous disturbances (Sweatman *et al.* 2007, Diaz-Pulido *et al.* 2009). In part this discrepancy arises because the rapid recovery of corals does not ensure a positive indication for change; the family Acroporidae, which accounts for a high proportion of the cover on many of the Fitzroy region reefs, is expected to recover rapidly due to its fast growth rate. It is of concern that this did not occur at North Keppel Island. Low scores were also influenced by high cover of macroalgae and low densities of juvenile colonies. The high cover of a taxonomically diverse macroalgal community at both Pelican Is and Peak Is most likely represents a typical benthic community of rocky reefs in a turbid water situation in the tropical-temperate transition zone. However, the high and persistent cover of macroalgae, and in particular the genus *Lobophora* amongst the branching *Acropora* stands at reefs of the outer Keppel islands, is of concern and is likely influencing the rate of recovery at some reefs. The branching *Acropora*-dominated communities have proven resilient to disturbance despite low numbers of juveniles because recovery was largely resulting from the growth of surviving fragments (Diaz-Pulido *et al.* 2009) rather than settlement and growth of new colonies. This raises the question as to whether these communities would recover from future disturbances causing total mortality of colonies. There is a strong mismatch between the life history stages of corals in this region with little relationship between the availability of coral larvae, observed juvenile density and cover of adult colonies.

Table 12 Benthic community status: Fitzroy region. Overall status aggregates over the indicators coral cover, change in hard coral cover, macroalgal cover, juvenile hard coral density and settlement (where sampled). Regional scores convert the three point categorical assessments aggregated across each indicator into an evenly spaced five point scale for consistency of reporting through to Paddock to Reef (see section 2.6.1) Colours reflect this five point scale with assessments of condition ranging sequentially from Red (Poor) through Orange to Yellow (Fair) then through Light Green to Dark Green (Good)

Reef	Depth (m)	Overall Status	Coral cover	Change in hard coral cover	Macroalgae cover	Juvenile density	Settlement
Barren Is	2	-	neutral	neutral	+	-	-
	5	+	+	+	neutral	neutral	-
North Keppel Is	2	----	-	-	-	-	N/A
	5	----	-	-	-	-	N/A
Humpy Is & Halfway Is	2	+	+	neutral	neutral	-	+
	5	--	neutral	-	-	-	+
Middle Is	2	--	neutral	N/A	-	-	N/A
	5	+	+	N/A	neutral	neutral	N/A
Pelican Is	2	+++	+	+	neutral	neutral	+
	5	+	neutral	+	neutral	-	+
Peak Is	2	--	-	+	-	-	N/A
	5	---	neutral	-	-	-	N/A
Regional assessment							

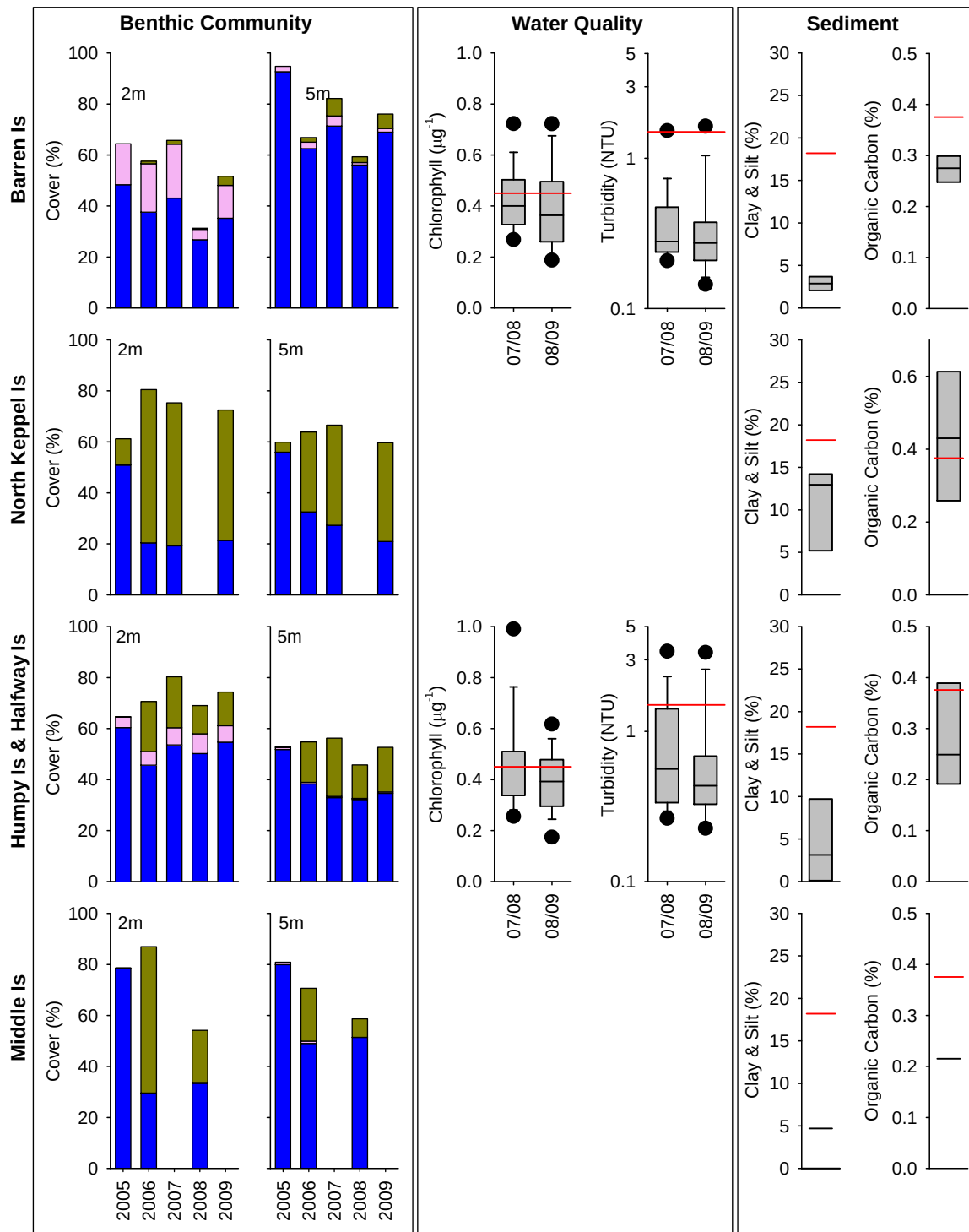


Figure 30 Percent cover estimates of major benthic groups and levels of key environmental parameters: Fitzroy region. Bar colours represent cover of hard coral (blue), soft coral (pink) and macroalgae (green). Data for water quality condition are derived from Eco FLNTUSB instruments, for sediment quality from sediment sampling from 2006-09 (see Figure 12 for details about the box plot presentation). Red reference lines indicate the Guidelines for water quality parameters (GBRMPA 2009), and the mean across all reefs for sediment parameters.

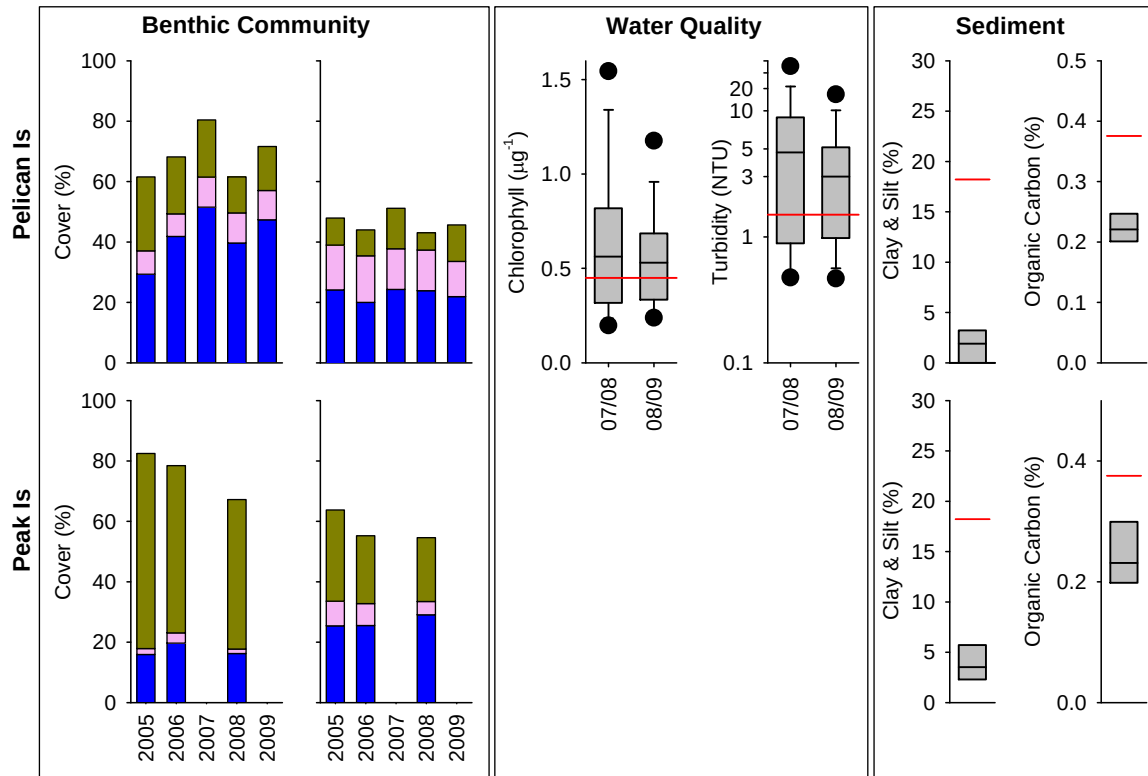


Figure 30 continued

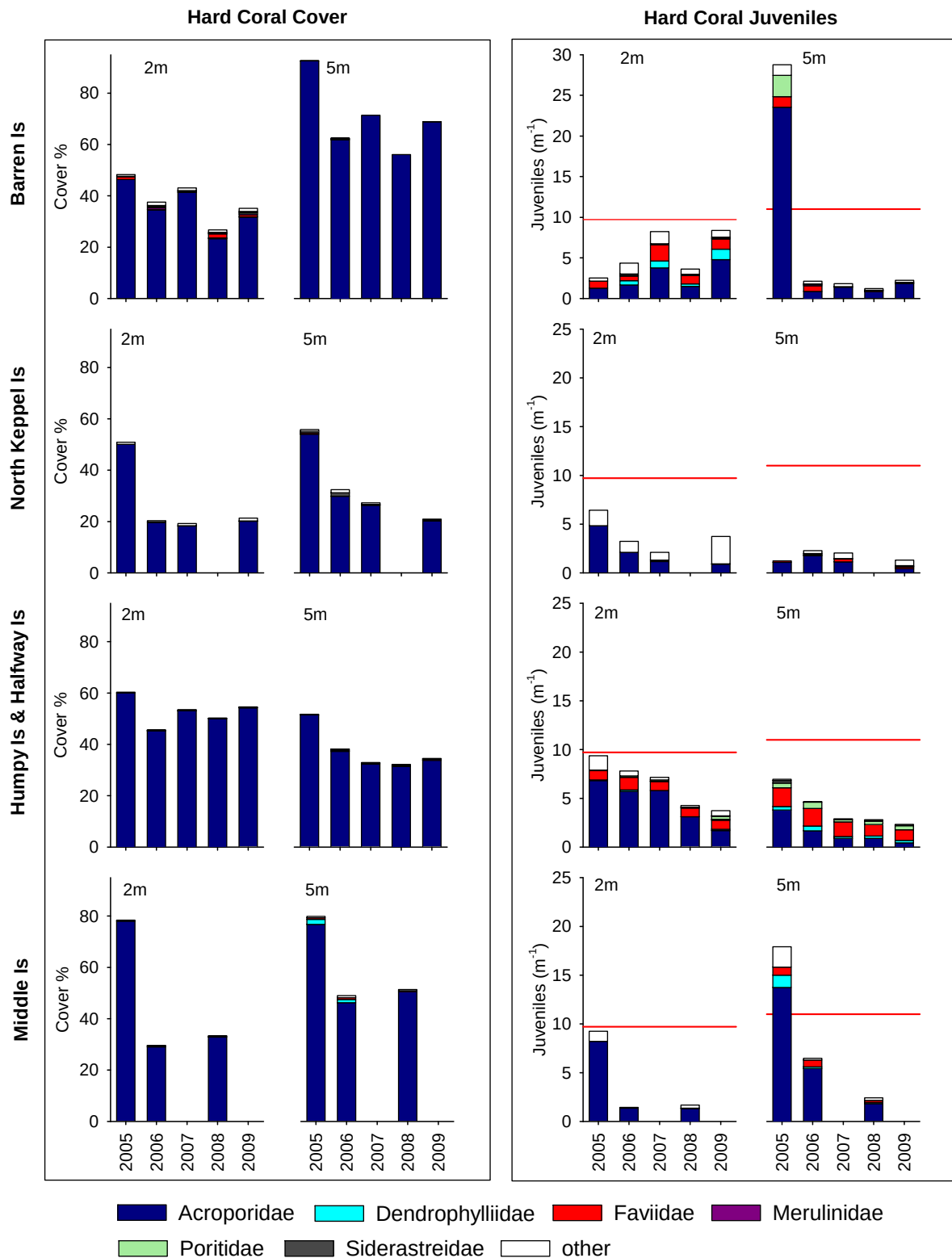


Figure 31 Composition of hard coral communities: Fitzroy region. Bars are the cumulative cover, or density of juvenile colonies per m^2 of available substrate, of dominant families within the region. Families are indicated by colour of bar section. Only families for which cover exceeded 4% cover on at least one reef at one depth in one year are differentiated; all other families are aggregated into the 'other' group (white bars). Red reference lines are the mean density of juvenile colonies over all reefs and years.

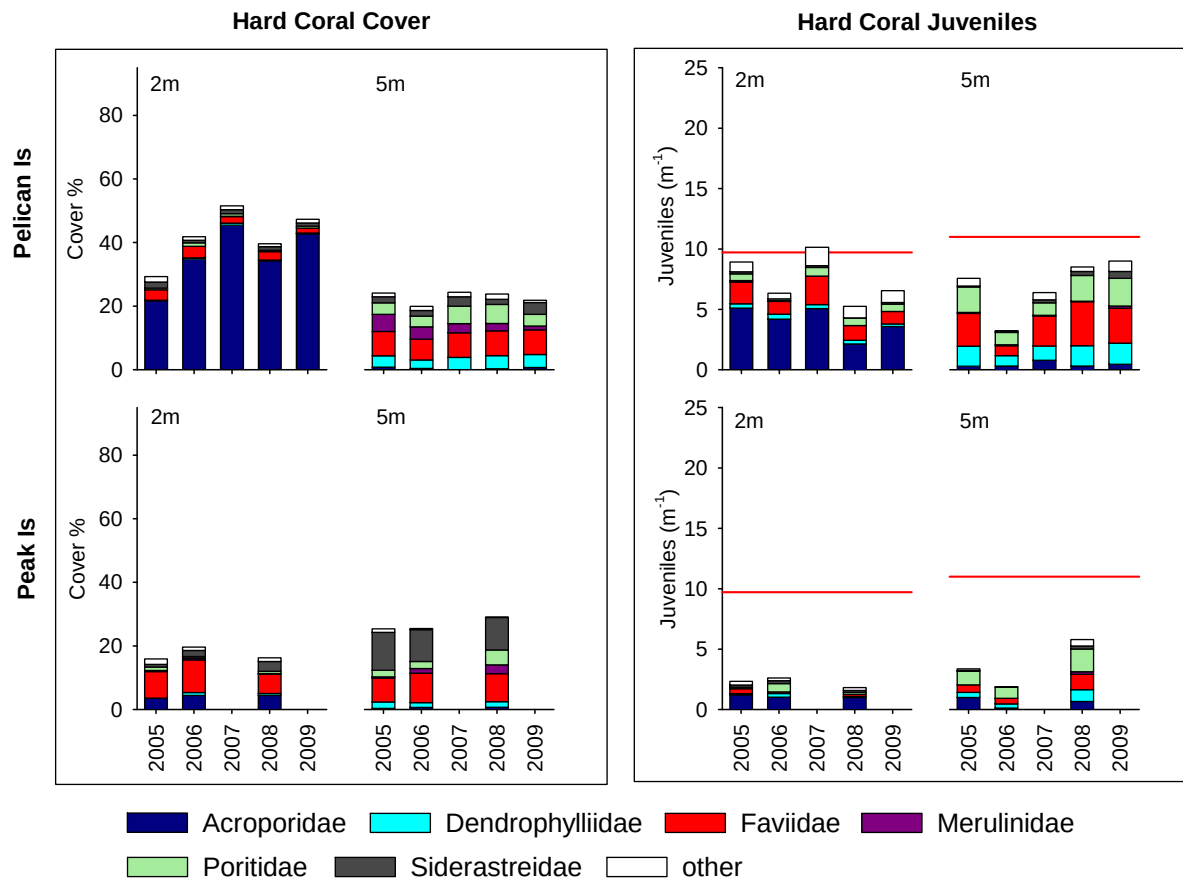


Figure 31 continued.

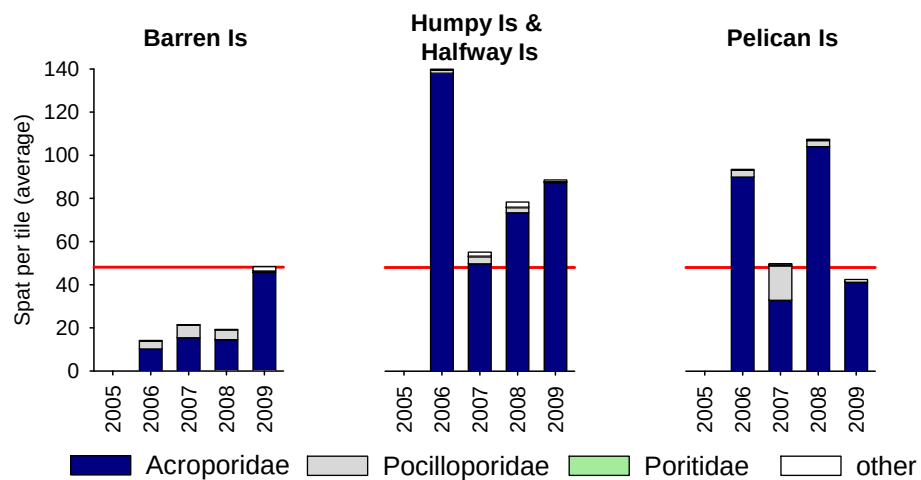


Figure 32 Coral settlement to tiles Fitzroy region. Data are from 5m tile deployments. Average values from all reefs and NRM regions sampled in each year are indicated by red reference lines.

4. Conclusions

Scientists and managers have realised that the continued management of regional and local disturbances 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 is an essential component to the effective management of water quality in the inshore GBR but was also established to help assess the long-term status and health of GBR inshore ecosystems. The monitoring of changes in the inshore marine environment 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.

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.* 2010). As a consequence, communities will be susceptible to any deterioration in environmental conditions such as increases in the rates of sedimentation, levels of turbidity, nutrient concentrations or novel pressures associated with anthropogenic activities in the connected catchments or coastal zones. Conversely, if improvements under Reef Plan led to better water quality in the inshore GBR, coral communities are expected to change over time to reflect the changed 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.* 2010, Uthicke *et al.* 2010). Simplistically, species that are tolerant to environmental stresses of a location are advantaged, and hence more likely to be 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 then persist in conditions unlike those into which they recruited, forming relic communities. In combination, the above considerations add variability to the relationship between community composition and environmental conditions. This variability makes it difficult to assess status and resilience of GBR inshore coral reef communities based on their composition.

We propose a new conceptual approach to estimating and ranking status and resilience of reef communities which considers their potential to recover from disturbance events. This assessment uses the observed levels of community attributes against estimates of expected change derived from a coral growth model (Thompson and Dolman 2010), which is based on our understanding of

community dynamics. 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 status based on composition. Importantly, it allows communities across naturally occurring environmental gradients to be considered within a uniform framework. This then allows the identification of those reefs that are underperforming irrespective of the underlying environmental envelope in which those communities have developed.

Application of our assessment protocol indicates that reefs in the Burdekin region are showing the least capacity to recover from disturbance events. In this region, coral cover is low and increasing at a slow rate, some reefs have very high cover of macroalgae and the density of juvenile colonies and the settlement of coral larvae are both low. The poor status of coral reef communities in this NRM region almost certainly reflects the consequences of coral mortality during the mass bleaching event in the summer of 1998 (Berkelmans *et al.* 2004, Sweatman *et al.* 2007). One GBR inshore reef (Pandora Rf.) 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. The mortality of a high proportion of adult corals in the Burdekin region during the 1998 bleaching event implies a substantial reduction in larval supply, leading to low juvenile densities and limited rate of recovery, as observed in the MMP surveys. The reduced availability of larvae results in low recovery even without considering post-settlement stress to coral recruits due environmental conditions at some of the reefs, such as high turbidity and chlorophyll *a* concentrations.

The status of coral communities in the Burdekin region also illustrates some key issues facing inshore coral reefs in general. Particularly worrying is the proposed synergy between nutrient loads and susceptibility of corals to bleaching (Wooldridge 2009). Increased sea temperatures have globally increased the frequency of broad-scale, severe mortality, events of coral reefs (Hoegh-Guldberg 1999, Wilkinson 2004). That the Burdekin reefs show little evidence of recovery potential after 10 years illustrates the long-term susceptibility of some inshore coral reef communities to such regional scale disturbance. A similar lack of resilience was shown in a long-term study of a GBR offshore reef at Lizard Island and was attributed to an increased frequency of disturbance (Wakeford *et al.* 2008). 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 anthropogenic nutrient loads will be catastrophic for GBR inshore communities. Interactions between water quality and climate change are poorly understood and require urgent experimental investigation.

While the overall assessment of coral communities in the Mackay Whitsunday region is positive there are three aspects of the community dynamics that are a cause for concern. Despite 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 this trajectory as a response to regional environmental stress. 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.* 2010), which has noticeably increased on reefs in the Mackay Whitsunday region since 2005. 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 sediment loads from the catchment have led to observed changes in sediment composition at the reef sites is that during surveys in 2009 the proportion of the substrate categorised as "silt" was the highest recorded over the 5 years of observation at 4 of the 5 reefs visited. As turbidity is largely a function of wave and tidal resuspension (Larcombe *et al.* 1995) changes in sediment composition toward finer grained particles would logically lead to increased levels of 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 increases in this region. Juvenile corals are generally more susceptible to turbidity and sedimentation than adult colonies (Fabricius *et al.* 2003, Fabricius 2005). Declines in juvenile density over the period of increased river flows is further evidence of the direct influence of increased sediment supply on the coral communities of the Mackay Whitsunday Region. Declining densities of juvenile colonies may reflect reduced survivorship or declines in the number of larvae settling to the reef. Settlement of coral larvae to tiles is low in the Mackay Whitsunday Region. Although not quantified, it is readily 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 substrate (e.g. Negri *et al.* 2002). A thick layer of sediments will limit settlement both chemically, by precluding the development of appealing bio-films, and physically by not providing a suitably stable substrate for attachment (Birrell *et al.* 2005). Accumulation of sediments on tiles almost certainly influences the low settlement recorded but, importantly, also mirrors the accumulation of sediments to the reefal substrate.

Such clear changes in sediment composition have not been observed in other regions, however, similar correspondence between higher river flows in recent years and lower juvenile coral densities are consistent across regions. 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. A current MTRSF research project also focuses on the questions of how water quality in the inshore region of the GBR is linked to sediment discharges by the rivers and aims at answering the questions of how long discharged fine particles remain in the system and undergo re-suspension and how water clarity changes throughout the year, especially after flood events. Results to date indicate that fine sediment imported by flood events remains in the coastal zone for long after the event leading to recurring high turbidity by resuspension (Wolanski *et al.* 2008, Lambrechts *et al.* in press).

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 position along a multidimensional environmental gradient, and exposure to past disturbance events. With these

factors in mind our approach has been to develop an assessment protocol focusing on the recovery potential shown by 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 density of juvenile colonies that would be sufficient to sustain a coral community, or cover of macroalgae that represents a resilience threshold beyond which coral recovery is impeded. At present our assessment defaults to considering relative levels of these key variables. It is intended that we continue to improve our protocol of coral community assessment. 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 a, Secchi depth and turbidity from satellite remote sensing).

The present assessment of coral communities is beginning to focus on areas of the GBR where certain aspects of coral communities appear to be underperforming and highlights the likely environmental correlations to these assessments. Our results indicate 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* 2010, Uthicke *et al* 2010). In the Mackay Whitsunday Region high levels of fine grained sediments disproportionately exposed coral communities to turbidity and sedimentation with indications that this is affecting coral growth and recruitment. In the Burdekin region coral communities are struggling to recover from severe disturbance in 1998 associated with high temperatures. If hypothesised links between elevated nutrient loads and susceptibility to thermal bleaching events prove true then this will have dire consequences for inshore reefs into the future. Should changes in land management practices in the GBR catchments under the Reef Plan lead to decreased loads of sediments and nutrients to GBR coastal and inshore waters, we expect to be able to detect associated changes in coral reef communities in the longer term.

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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
- 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. *Oecologia* 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, R.C., 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
- 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
- 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
- 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.pone.0005239
- 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 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, Coastal 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, Coastal and Shelf Science* 57:613-621
- Fabricius KE, De'ath 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
- 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
- Hoegh-Guldberg O (1999) Climate change coral bleaching and the future of the world's coral reefs. *Marine and Freshwater Research* 50:839-866
- 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, Mortschaniwsky 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, Mortschaniwskyj 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
- 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
- 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, Gourage O, Fabricius KE, Mehta AJ, Lewis S, Wolanski E (in press) Importance of wave-induced liquefaction in the fine sediment budget of Cleveland Bay, Great Barrier Reef. *Estuarine, Coastal and Shelf Science*
- 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
- 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
- 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) 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
- Todd PA (2008) Morphological plasticity in Scleractinian corals. *Biological Reviews* 83:315-337
- Uthicke S, Nobes K (2008) Benthic foraminifera as ecological indicators for water quality on the Great Barrier Reef. *Estuarine, Coastal 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, 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
- 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
- Wilkinson C (2004) Status of coral reefs of the world:2004 volume 2. Australian Institute of Marine Science, Townsville
- 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 AI-1a-d Sediment analysis results for reefs sampled between 2006 and 2008.

Table AI-1(a) Clay & silt. Values are the average proportion of the sediment samples, by weight, with grain sizes <0.063mm for each reef and year sampled..

NRM Region	Catchment	Reef	2006	2007	2008	2009
Wet Tropics	Daintree	Cape Tribulation North	3.73			
		Cape Tribulation Middle	7.42			
		Cape Tribulation South	8.22			
		Snapper Island North	42.86		38.96	39.70
		Snapper Island South	8.73		7.25	7.28
	Johnstone	Fitzroy Island West	4.07	9.04	9.56	4.60
		Fitzroy Island East	4.77		0.57	
		High Island West	9.95	6.20	18.74	8.14
		High Island East	8.69	0.58		0
		Frankland Islands West	35.27	25.30	36.41	23.11
		Frankland Islands East	17.85	3.12		3.26
	Tully	North Barnard Islands	12.27	5.93		5.81
		King	3.27		1.64	
		Dunk Island North	5.03	6.65	14.86	5.85
		Dunk Island South	12.27		5.28	
Burdekin	Burdekin	Pelorus and Orpheus Islands West	5.76	3.97	3.89	5.35
		Orpheus Island East	1.60		0	
		Lady Elliot	14.50		12.57	
		Pandora	3.43	2.36	2.98	1.85
		Havannah Island	7.62	7.45		2.99
		Geoffrey Bay	13.16	9.76	7.97	4.12
		Middle Reef	80.48	54.92		30.0
Mackay Whitsunday	Proserpine	Double Cone Island	14.12	34.59	28.52	33.33
		Hook Island	36.66		36.36	
		Daydream Island	61.56	72.46	72.39	38.64
		Shute and Tancred Islands	38.07		25.60	
		Dent Island	58.15	52.93		56.19
		Pine Island	59.53	44.47	58.21	40.57
		Seaforth Island	36.43	41.37		37.39
Fitzroy	Fitzroy	North Keppel Island	14.38	8.94		9.15
		Barren Island	2.62	2.37	2.82	4.24
		Middle Island			4.69	
		Humpy and Halfway Islands	3.26	3.14	5.74	5.45
		Pelican Island	2.42	2.55	0	1.69
		Peak Island	2.51		5.16	

Table AI-1(b) Average organic carbon content expressed as a proportion of the total sediment sample for each reef in each year sampled.

NRM Region	Catchment	Reef	2006	2007	2008	2009
Wet Tropics	Daintree	Cape Tribulation North	0.27			
		Cape Tribulation Middle	0.30			
		Cape Tribulation South	0.39			
		Snapper Island North	0.60		0.62	0.59
		Snapper Island South	0.28		0.30	0.36
	Johnstone	Fitzroy Island West	0.25	0.35	0.38	0.24
		Fitzroy Island East	0.20		0.18	
		High Island West	0.37	0.26	0.35	0.32
		High Island East	0.26	0.19		0.19
		Frankland Islands West	0.58	0.51	0.57	0.53
		Frankland Islands East	0.23	0.23		0.22
	Tully	North Barnard Islands	0.28	0.27		0.25
		King	0.18		0.20	
		Dunk Island North	0.28	0.24	0.26	0.31
		Dunk Island South	0.31		0.23	
Burdekin	Burdekin	Pelorus and Orpheus Islands West	0.23	0.19	0.20	0.26
		Orpheus Island East	0.22		0.17	
		Lady Elliot	0.21		0.19	
		Pandora	0.19	0.19	0.23	0.24
		Havannah Island	0.26	0.25		0.33
		Geoffrey Bay	0.31	0.29	0.30	0.25
		Middle Reef	0.98	0.77		0.79
Mackay Whitsunday	Proserpine	Double Cone Island	0.49	0.56	0.48	0.53
		Hook Island	0.37		0.43	
		Daydream Island	0.62	0.79	0.88	0.88
		Shute and Tancred Islands	0.48		0.46	
		Dent Island	0.65	0.67		0.70
		Pine Island	0.76	0.66	0.75	0.66
		Seaforth Island	0.47	0.49		0.54
Fitzroy	Fitzroy	North Keppel Island	0.21	0.48		0.56
		Barren Island	0.26	0.28	0.25	0.33
		Middle Island			0.22	
		Humpy and Halfway Islands	0.30	0.22	0.28	0.30
		Pelican Island	0.23	0.17	0.21	0.26
		Peak Island	0.23		0.25	

Table AI-1(c) Average total nitrogen content expressed as a proportion of the total sediment sample for each reef in each year sampled

NRM Region	Catchment	Reef	2006	2007	2008	2009
Wet Tropics	Daintree	Cape Tribulation North	0.0388			
		Cape Tribulation Middle	0.0392			
		Cape Tribulation South	0.0416			
		Snapper Island North	0.0679		0.0508	0.0791
		Snapper Island South	0.0146		0.0306	0.0457
	Johnstone	Fitzroy Island West	0.0256	0.0416	0.0367	0.0310
		Fitzroy Island East	0.0211		0.0240	
		High Island West	0.0429	0.0381	0.0436	0.0468
		High Island East	0.0180	0.0303		0.0256
		Frankland Islands West	0.0820	0.0814	0.0700	0.0787
		Frankland Islands East	0.0203	0.0335		0.0336
	Tully	North Barnard Islands	0.0374	0.0323		0.0377
		King	0.0281		0.0225	
		Dunk Island North	0.0288	0.0316	0.0293	0.0416
		Dunk Island South	0.0334		0.0331	
Burdekin	Burdekin	Pelorus and Orpheus Islands West	0.0345	0.0309	0.0312	0.0346
		Orpheus Island East	0.0184		0.0282	
		Lady Elliot	0.0318		0.0209	
		Pandora	0.0304	0.0325	0.0332	0.0265
		Havannah Island	0.0234	0.0370		0.0364
		Geoffrey Bay	0.0409	0.0419	0.0403	0.0314
		Middle Reef	0.1157	0.0756		0.1086
Mackay Whitsunday	Proserpine	Double Cone Island	0.0439	0.0920	0.0640	0.0677
		Hook Island	0.0466		0.0574	
		Daydream Island	0.0860	0.1025	0.1020	0.1201
		Shute and Tancred Islands	0.0663		0.0720	
		Dent Island	0.0792	0.0886		0.0872
		Pine Island	0.0883	0.0856	0.0906	0.0778
		Seaforth Island	0.0575	0.0750		0.0657
Fitzroy	Fitzroy	North Keppel Island	0.0300	0.0528		0.0764
		Barren Island	0.0383	0.0520	0.0512	0.0414
		Middle Island			0.0365	
		Humpy and Halfway Islands	0.0410	0.0352	0.0532	0.0369
		Pelican Island	0.0329	0.0316	0.0433	0.0401
		Peak Island	0.0346		0.0519	

Table AI-1 (d) Average inorganic carbon content expressed as a proportion of the total sediment sample for each reef in each year sampled

NRM Region	Catchment	Reef	2006	2007	2008	2009
Wet Tropics	Daintree	Cape Tribulation North	7.87			
		Cape Tribulation Middle	8.53			
		Cape Tribulation South	8.21			
		Snapper Island North	6.99		5.98	6.98
		Snapper Island South	9.57		7.87	9.60
	Johnstone	Fitzroy Island West	9.80	9.47	9.35	10.26
		Fitzroy Island East	9.76		9.58	
		High Island West	9.45	9.91	8.90	9.77
		High Island East	10.09	10.58		10.76
		Frankland Islands West	8.12	8.39	7.63	8.64
		Frankland Islands East	10.62	10.37		10.33
	Tully	North Barnard Islands	8.95	9.43		9.47
		King	9.30		9.12	
		Dunk Island North	8.47	8.65	7.15	8.64
		Dunk Island South	9.60		9.71	
Burdekin	Burdekin	Pelorus and Orpheus Islands West	10.17	10.57	10.10	10.06
		Orpheus Island East	10.48		10.58	
		Lady Elliot	3.82		5.08	
		Pandora	10.56	10.55	10.27	10.41
		Havannah Island	10.19	10.11		10.22
		Geoffrey Bay	7.88	8.40	8.36	9.17
		Middle Reef	2.00	4.70		4.75
Mackay Whitsunday	Proserpine	Double Cone Island	9.31	7.49	7.61	7.25
		Hook Island	8.73		8.27	
		Daydream Island	6.01	4.29	3.93	4.47
		Shute and Tancred Islands	7.58		7.59	
		Dent Island	6.69	6.42		6.27
		Pine Island	5.37	5.62	4.97	5.86
		Seaforth Island	8.40	7.79		7.82
Fitzroy	Fitzroy	North Keppel Island	5.68	8.70		9.05
		Barren Island	9.64	9.81	9.49	9.39
		Middle Island			3.74	
		Humpy and Halfway Islands	8.68	8.76	8.73	8.86
		Pelican Island	8.03	7.42	8.21	7.80
		Peak Island	6.76		8.38	

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.

NRM region	Catchment	Reef	Bleaching		Other recorded disturbances
			1998	2002	
Wet Tropics	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%)
	Russell-Mulgrave and Johnstone	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)
		North Barnard Group	0.93	0.80	Cyclone Larry 2006 (95% at 2m , 86% at 5m)
	Tully	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.

NRM region	Catchment	Reef	Bleaching			Other recorded disturbances
			1998	2002	2006	
Burdekin	Burdekin	Orpheus Is (East)	0.93	0.80		Cyclone Larry 2006 (22% at 2m, 40% at 5m)
		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	1.00		Coral Bleaching Jan 2006, probable though not observed we did not visit region at time of event. Same for other reefs in region.
		Dent Is	0.57 (crest 32%)	0.95		
		Seaforth Is	0.57	0.95		
		Double Cone Is	0.57	1.00		
		Daydream Is	0.31 (crest 44%)	1.00		
		Shute Is & Tancred Is	0.57	1.00		
		Pine Is	0.31	1.00		
Fitzroy	Fitzroy	Barren Is	1.00	1.00	(22%, 2m) (33%, 5m)	Storm Feb 2008 (38% at 2m, 21% at 5m)
		North Keppel Is	1 (15%)	0.89 (36%)	(60%, 2m) (42% , 5m)	
		Middle Is	1 (56%)	1 (Nil)	(62%, 2m) (39%, 5m)	
		Humpy & Halfway Is	1 (6%)	1 (26%)	(24%, 2m) (26%, 5m)	Flood 2008 (6% at 2m, 2% at 5m)
		Pelican Is	1.00	1.00	17%, 5m	Flood 2008 (23% at 2m, 2% at 5m)
		Peak Is	1.00	1.00		Flood 2008 (17% at 2m)

Table A1-3 Composition of coral reef communities represented by common hard coral families (% cover) 2009

Region	Catchment	Reef	Depth	Acroporidae	Agariciidae	Astrocoeniidae	Dendrophylliidae	Euphylliidae	Favidae	Fungiidae	Merulinidae	Mussidae	Oculinidae	Pectinidae	Pocilloporidae	Poritidae	Siderastreidae	Unknown
Wet Tropics	Daintree	Snapper Is North	2	45.69	0.04	0	0	0	2.71	0.37	0.12	0.04	0.87	0	0.67	0.33	0.70	0
			5	11.67	17.03	0	0	0	2.34	0.79	1.47	0.12	0.62	1.79	2.94	18.08	0	0
		Snapper Is South	2	13.34	0.25	0	0.08	0	1.70	0.08	0	0.04	0.92	0	0.71	21.44	0.42	0
			5	6.78	3.86	0	0.23	0	9.40	1.07	0.28	0.28	0.40	0.06	0.23	32.14	1.19	0
	Johnstone	Fitzroy Is West	2	28.00	0	0	0	0	2.06	0.19	0.25	0.50	1.06	0	1.38	7.63	0	0
			5	8.44	0.06	0	0	0.44	2.00	0.50	0.19	1.56	1.38	0.38	0.69	11.00	0	0
		High Is West	2	11.94	0.31	0	0	0	1.31	0.75	0.44	0.25	0.31	0	0.56	39.63	0	0.06
			5	1.44	1.44	0	0	0	1.63	0.81	0.13	0.25	0.50	0.31	0.13	17.75	0.06	0.13
		High Is East	2	48.48	0	0	0.13	0	3.13	0	0.13	1.00	0.25	0	0.25	4.56	0.06	0
			5	24.44	0	0	0.13	0	3.44	0.19	0.50	0	0.44	0	0.94	14.88	0.19	0.06
		Frankland Group West	2	5.75	4.00	0	0	0	0.19	0.13	0.06	0.19	0.38	0	0.44	26.31	0	0
			5	0.13	1.06	0	0	0	0.13	0.13	0	0	0.19	0	0.13	57.75	0	0
		Frankland Group East	2	21.69	0	0	0	0	1.69	0.13	0.19	0.06	0.13	0	1.25	1.25	0.06	0
			5	11.31	0.31	0	0.13	0.06	2.06	0.38	0.63	0.06	0.69	0.13	3.88	4.75	0	0
	Tully	North Barnard Group	2	5.19	0	0	0	0	0.56	0	0.06	0	0.19	0	0.19	0.31	0	0
			5	6.00	0.06	0	0.44	0	0.81	0	0	0.13	0.06	0.38	0.56	0.63	0.06	0
		Dunk Is North	2	10.38	0	0	0.75	0	2.25	0.06	0.31	0	0.06	0	0.38	0.38	0.06	0
			5	8.56	0	0	2.38	0	3.75	0	0.31	0.06	0.38	0.25	1.00	0.44	0.19	0
Burdekin	Burdekin	Pelorus Is and Orpheus Is West	2	4.44	0.06	0	0	0	1.56	0.44	0.06	0.06	0	0.06	3.50	0.31	0	0
			5	4.25	0.19	0	0.44	0.06	1.56	0.50	0	0.44	0	0.31	0.19	3.56	0	0
		Pandora	2	0.19	0	0	0	0	1.88	0	0.19	0	0	0	0	0.88	0.94	0
			5	0.88	0.13	0	0	0	6.06	1.13	0.06	0.38	0.13	0.50	0	0.19	0	0
		Havannah Is	2	9.69	0	0	1.38	0	2.44	0.06	0.25	0.25	0.50	0.06	0	4.56	0	0
			5	0.88	0.25	0	3.56	0	2.88	1.19	1.44	0.44	0.56	0.50	0.06	0.88	0.50	0
		Geoffrey Bay	2	9.94	0.69	0	2.38	0	2.94	0.06	0.31	0	0.38	0	0	1.50	0.13	0
			5	5.38	3.38	0	2.31	0.06	4.19	1.44	1.88	0.25	0.31	1.19	0.19	2.50	0	0.06
		Middle Reef	2	4.13	10.13	0	1.06	0	1.44	0.13	0.06	0.06	0.88	0.19	0.19	27.71	0	0

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	24.13	0.31	0	1.06	0.06	2.31	0.38	2.44	1.56	3.00	1.56	0.13	4.75	0	0
			5	5.06	1.25	0	0	0.06	2.13	0.38	0.75	3.06	2.88	1.25	0.19	50.44	0	0
		Daydream Is	2	29.06	0	0	0	0.13	0.50	0.13	0	0.19	0	1.13	0.06	0.94	0	0
			5	34.25	0.31	0	0.19	0	1.25	0.06	0.19	0.31	0.06	1.88	0.19	2.31	0.19	0
		Dent Is	2	25.25	1.25	0	4.19	0	1.06	0.63	0.75	1.13	1.63	1.50	0.31	15.81	0	0.31
			5	15.57	3.06	0	0.19	0	1.69	0.75	1.81	0.88	2.31	6.19	0.25	12.69	0	0.25
		Pine Is	2	11.41	0.88	0	0	0.19	1.13	1.44	0.50	0.69	19.20	3.01	0	4.19	0	0.06
			5	6.94	2.56	0	0.13	0.50	1.31	2.69	0.25	2.88	8.75	10.32	0	6.50	0	0.06
		Seaforth Is	2	1.81	6.56	0	0.19	0.13	0.81	0.13	0	0.69	0.06	0.06	0.06	9.14	0	0
			5	1.13	0.38	0	0.56	0.38	2.44	0.44	0.25	0.31	0.19	0.06	0.13	7.06	0	0
Fitzroy	Fitzroy	North Keppel Is	2	20.13	0	0	0.06	0	0.06	1.00	0	0	0	0	0.06	0	0	0
			5	20.25	0	0	0	0	0.06	0.06	0	0.25	0	0	0	0	0.31	0
		Barren Is	2	31.75	0.06	0.06	0.06	0	0.81	0	0.56	0.19	0	0	0.88	0.38	0.38	0
			5	68.88	0	0	0	0	0	0	0	0	0	0	0.06	0	0	0
		Humpy Is and Halfway Is	2	54.25	0	0	0	0	0.06	0	0	0	0	0	0.19	0.13	0	0
			5	33.81	0	0	0.13	0	0.38	0	0.06	0	0	0	0	0.19	0	0
		Pelican Is	2	42.75	0	0	0.25	0	1.56	0	0	0.13	0	0	1.00	0.56	1.06	0
			5	0.69	0	0	4.13	0	7.69	0	1.25	0.13	0	0.19	0.44	3.63	3.75	0

Table A1-4 Composition of coral reef communities represented by common soft coral families (% cover) 2009

Region	Catchment	Reef	Depth	Alcyoniidae	Anthothelidae	Briareidae	Clavulariinae	Ellisellidae	Unknown Gorgonians	Helioporidae	Nephtheidae	Tubiporidae	Xeniidae
Wet Tropics	Daintree	Snapper Is North	2	0.87	0	1.96	15.47	0	0	0	0	0	0.04
			5	0.31	0	0.55	0.06	0	0	0	0.06	0	0.06
		Snapper Is South	2	2.07	0	0.04	0	0	0	2.21	0	0.04	0
			5	0.28	0	8.33	0	0.06	0	5.38	0	0	0
	Johnstone	Fitzroy Is West	2	32.06	0	0.44	0	0	0	0	0	0	0
			5	33.50	0	0	0	0	0	0	0.06	0	0
		High Is West	2	3.31	0	0	0	0	0	3.25	0.13	0	0
			5	1.19	0	0.94	0	0	0	1.25	0	0	0
		High Is East	2	6.00	0	5.38	0	0	0	0	0	0	0
			5	0.63	0	8.19	0.25	0	0	0	0	0	0
		Frankland Group West	2	5.00	0	0	6.13	0	0	0.38	0.06	0	0.06
			5	1.19	0	0	0.25	0	0	0	0	0	0
		Frankland Group East	2	1.19	0	0	0.50	0	0	0	0	0	0.31
			5	5.94	0	0	0.25	0	0	0	0	0.06	0.06
	Tully	North Barnard Group	2	0.13	0	0.63	0	0	0	0	0	0	0
			5	0.50	0	0.81	0	0	0	0	0	0	0.19
		Dunk Is North	2	0.19	0	0.13	0	0	0	0	0	0	0
			5	0.06	0	0	0	0	0.50	0	0	0	0
Burdekin	Burdekin	Pelorus Is and Orpheus Is West	2	16.88	0	0.25	1.13	0	0.13	0	1.31	0	0.19
			5	18.25	0	1.81	0.69	0	0.63	0	0.63	0	0
		Pandora	2	0	0	0	0	0	0	0	0	0	0.06
			5	0.25	0	0	0.06	0	0	0	0	0	0
		Havannah Is	2	1.19	0	1.69	0	0	0	0	0	0	0
			5	0.19	0	4.38	0	0	0	0	0	0	0
		Geoffrey Bay	2	0.06	0	0.13	0.06	0	0	0	0	0	0
			5	0.31	0	0.31	0	0	0	0	0	0	0
		Middle Reef	2	1.13	0	0	0	0	0	0	0	0	0

Table A1-4 Continued

Region	Catchment	Reef	Depth	Alcyoniidae	Anthothelidae	Briareidae	Clavulariinae	Ellisellidae	Unknown Gorgonians	Helioporidae	Nephtheidae	Tubiporidae	Xenidae
Mackay Whitsunday	Proserpine	Double Cone Is	2	7.81	0	5.69	0	0	0	0	0	0.06	0
			5	4.81	0	2.19	0	0	0	0	0	0	0
		Daydream Is	2	11.56	0	0	0	0	0	0	0	0	0
			5	1.56	0	0	0	0	0	0	0	0	0
		Dent Is	2	5.06	0	4.44	0	0	0	0	0	0	0
			5	2.00	0	0	0	0	0	0	0	0	0
		Pine Is	2	1.19	0	0.31	0	0	0	0	0	0	0
			5	3.26	0	0	0	0	0	0	0	0	0
		Seaforth Is	2	5.63	0.19	2.00	0	0	0	0	0	0	0
			5	0.88	2.38	0	0	0.06	0	0	0.06	0.06	0.13
Fitzroy	Fitzroy	North Keppel Is	2	0	0	0	0	0	0	0	0	0	0
			5	0	0	0	0	0	0	0	0	0	0
		Barren Is	2	0.75	0	0.19	0	0	0.06	0	0	0	11.94
			5	0	0	0	0	0	0	0	0	0	1.44
		Humpy Is and Halfway Is	2	0.06	0	0	0	0	0	0	0	0	6.44
			5	0.56	0	0	0	0	0	0	0	0	0
		Pelican Is	2	8.94	0	0	0	0	0	0	0.13	0.25	0.44
			5	8.94	0	0.06	0	0	1.75	0	0.38	0.31	0.25

Table A1-5 Composition of coral reef communities represented by common macro algal genera and families (% cover). 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) 2009.

Region	Catchment	Reef	Depth	<i>Asparagopsis</i>	<i>Peyssonnelia</i>	<i>Hypnea</i>	Calcareous Rhodophyta	Other Rhodophyta	<i>Caulerpa</i>	<i>Halimeda</i>	Other Chlorophyta	<i>Dictyota</i>	<i>Lobophora</i>	<i>Padina</i>	<i>Sargassum</i>	Other Phaeophyta	Unknown Family
Wet Tropics	Daintree	Snapper Is North	2	1.54	0.12	0.75	3.41	3.03	0	0	0	0.13	0	0	0	0	0
			5	0.06	0	0	0.06	0.24	0	0.13	0	0.18	0	0	0	0	0
		Snapper Is South	2	0	0	0	1.16	1.21	0	0	0	0	0	0	0	0	0
			5	0	0.11	0.40	0.57	0.34	0	0	0	0	0	0	0	0.06	0
	Johnstone	Fitzroy Is West	2	0	0.06	0	0.50	0.31	0	0	0	0	0	0	0	0	0
			5	0	0.06	0.06	0.63	0	0	0	0	0	0.06	0	0	0	0
		High Is West	2	0	0	0.13	1.19	0.94	0	0	0.06	0	0	0	0	0	1.94
			5	0	0.06	0	1.06	0.06	0	0	0	0	0	0	0	0	0
		High Is East	2	0	0	0.25	0.69	0.06	0	0	0	0	0	0	0	0	0
			5	0	0	0.25	1.81	0.25	0	0	0.06	0	0	0	0	0	0
		Frankland Group West	2	0	0.31	0.44	2.75	2.31	0	0	0.19	0	0	0	0	0	1.50
			5	0	0.19	0	3.25	10.56	0	0.19	0.19	0	0	0	0	0	3.13
		Frankland Group East		0	0.06	0.06	2.69	0.38	0.88	0	0.13	0	0	0	0	0.06	0.13
				0	0.06	0	1.13	0.19	0.19	0.19	0.06	0	0	0	0	0	0.06
	Tully	North Barnard	2	4.25	0.06	0.06	0.13	0.31	0.31	0.19	0.56	2.25	0	0.06	0.19	0.81	11.3
			5	0.75	0	0	2.25	0.69	0.13	0.38	0	2.38	0	0.06	0.19	0.13	6.38
		Dunk Is North	2	0	0	0.06	0.56	3.69	0	0	0.13	3.75	2.25	0.88	9.00	0.56	0.88
			5	0	0.06	0.06	0.31	1.00	0	0	0.06	3.75	0.19	0.19	1.06	0.31	0.06
Burdekin	Burdekin	Pelorus Is and Orpheus Is West	2	0	0	0	0.25	0	0	0	0	0	0	0	0	0	0
			5	0	0.06	0	0.31	0	0	0	0	0	0	0	0	0	0
		Pandora	2	0	0	0	0.88	0.13	0	0	0	1.38	1.19	2.75	8.63	0.81	1.00
			5	0	0.13	0	0.69	0.25	0	0	0	8.31	2.50	3.44	0.25	0.25	0.88
		Havannah Is	2	0	0	0	1.00	0.25	0.19	0	0	0	1.38	0	0	0	0
			5	0	0.19	0	1.94	0.06	0.06	0	0	0.06	20.0	0.19	3.31	0	0.25
		Geoffrey Bay	2	0	0.44	0.06	1.81	0.69	0	0	0.13	3.88	7.75	0.19	13.38	3.56	0.06
			5	0	0.50	0	1.31	0.75	0.38	0	0.06	2.94	1.88	0.06	9.00	11.3	0.44
		Middle Reef	2	0	0	0	0.13	0	0	0	0	0.06	0.13	0	0.06	0	0

Table A1-5 Continued

Region	Catchment	Reef	Depth	<i>Asparagopsis</i>	<i>Peyssonnelia</i>	<i>Hypnea</i>	Calcareous Rhodophyta	Other Rhodophyta	<i>Caulerpa</i>	<i>Halimeda</i>	Other Chlorophyta	<i>Dictyota</i>	<i>Lobophora</i>	<i>Padina</i>	<i>Sargassum</i>	Other Phaeophyta	Unknown Family
Mackay Whitsunday	Proserpine	Double Cone Is	2	0	0	0	0.06	0	0	0	0	0	0	0	0	0	0
			5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Daydream Is	2	0	0	0	0	0	0	0	0	0	1.88	0	0	0	0
			5	0	0	0	0	0	0.19	0	0	0	0	0	0	0	0
		Dent Is	2	0	0	0	0.19	0	0	0	0	0	0	0	0.06	0	0
			5	0	0	0	0.19	0.06	0	0	0	0	0	0	0	0	0
		Pine Is	2	0	0.31	0	0.44	0.56	0	0	0	0	2.63	0	6.39	0.13	0.88
			5	0	0.19	0	0	0	0	0.13	0	0	2.63	0	0.13	0.06	0
		Seaforth Is	2	0	0	1.88	1.25	0.25	0	0	0	0.13	1.69	0.25	6.63	0.31	1.00
			5	0	0	0	0.56	0	0	0.06	0	0	1.69	0	0.81	0.06	0.31
Fitzroy	Fitzroy	North Keppel Is	2	0	1.13	0	7.81	0.38	0	0	0	0	49.69	0	0	0	0
			5	0	0.88	0	3.75	0.19	0	0	0	0	37.63	0	0	0	0
		Barren Is	2	0	0.19	0	4.56	0.94	0	0	0	0	2.44	0	0	0	0
			5	0	0.56	0	5.38	0.25	0	0	0	0	4.81	0	0	0	0
		Humpy Is and Halfway Is	2	0	0.63	0.06	1.38	0	0	0	0.06	0.13	11.38	0	0.50	0.44	0
			5	0	1.69	0	1.94	0.06	0	0	0	0.06	15.52	0	0	0.06	0
		Pelican Is	2	0	0.13	0	1.81	3.38	0	0	0	0	4.13	0.38	5.19	0.38	0.44
			5	0	0.25	0	1.44	6.75	0	0	0.13	0.25	3.00	0.25	0.94	0.44	0

Table A1-6 Composition of juvenile hard coral communities represented by common families (count per 34m²) 2009

Region	Catchment	Reef	Depth	Acroporidae	Agariciidae	Astrocoeniidae	Dendrophylliidae	Euphyllidae	Faviidae	Fungiidae	Merulinidae	Mussidae	Oculinidae	Pectiniidae	Pocilloporidae	Poritidae	Siderastreidae
Wet Tropics	Daintree	Snapper Is North	2	21.7	0	0	0	0	1.3	6.3	0	0	0.3	0	0	1	0.7
			5	6	2	0	1.5	0	6	2	0	1	2.5	1	4	3	0
		Snapper Is South	2	143.7	0	0	0.7	0.3	14	5.3	0	0.3	7.3	0	14.7	24	4.3
			5	11	1.5	0	0	0	3.5	2	1	0	2.5	0	0.5	2.5	3.5
	Johnstone	Fitzroy Is West	2	67.5	0.5	0	0	1.5	23	12	2	4.5	6.5	0.5	12	20	0
			5	46.5	2.5	0.5	0.5	3	18.5	13.5	3	13	16	5	12	47	0.5
		High Is West	2	26	1	0	3	0	4	4	1.5	3	2	0.5	4.5	5	0.5
			5	14	4	0	7	1	19.5	7.5	1.5	2.5	7	2.5	3.5	23.5	0.5
		High Is East	2	24.5	0	0	0	0.5	5.5	0	0	0	0.5	0	3.5	5.5	0
			5	30	0.5	0	5.5	1	17	0	1.5	1	4.5	0.5	6	21	2.5
		Frankland Group West	2	5	1.5	0	0	1	4	10	0	2	10	0.5	0.5	33	0
			5	10.5	2	0	0	0	2.5	13	0.5	0.5	6	0.5	3.5	22.5	2.5
		Frankland Group East	2	114.5	0	0	0.5	0	26	12.5	5	1.5	11.5	1	10	41	4.5
			5	92.5	1.5	0.5	5	3	50	16.5	3.5	6.5	21.5	1	35	56.5	9.5
	Tully	North Barnard Group	2	194.5	0	0	65	0	10.5	2	0.5	0.5	3.5	0	5	12.5	4.5
			5	69	2	0	230.5	0	27.5	3	1	2	1	2	12	22	9.5
		Dunk Is North	2	102.5	0.5	0	85	0	75	5.5	0.5	2	4	0.5	11	12	8
			5	71	0	0	284	1	67	1.5	1	2	2.5	2.5	19	29	17
Burdekin	Burdekin	Pelorus Is and Orpheus Is West	2	40	1	1	1.5	0.5	49.5	8.5	2.5	6	8	11.5	15	8	0
			5	24.5	2.5	0	7	1.5	69.5	1.5	1	13.5	6	26.5	3.5	19.5	0
		Pandora	2	14	0.5	0	1.5	0.5	10	1.5	0.5	0.5	1.5	0	0.5	2.5	0
			5	18	2	0	0	1	15	45	0.5	0.5	10	3.5	0	7	0.5
		Havannah Is	2	37.5	0	0.5	2.5	0	12.5	25	1	6	6	1	1.5	24.5	0.5
			5	24.5	5	0	7	3	20	44.5	3	8	21.5	12	2	40	2
		Geoffrey Bay	2	28.5	1.5	0	7	0	38.5	7	0.5	1.5	4.5	0.5	0	13	3
			5	24.5	3.5	0	22	1.5	89	15.5	4.5	4	4	6.5	1	21	1
		Middle Reef	2	17	3.5	0	13.5	0	43.5	4.5	2.5	5	3.5	5.5	1	10.5	2

Table A1-6 Continued

Region	Catchment	Reef	Depth	Acroporidae	Agariciidae	Astrocoeniidae	Dendrophylliidae	Euphyllidae	Favidae	Fungiidae	Merulinidae	Mussidae	Oculinidae	Pectiniidae	Pocilloporidae	Poritidae	Siderastreidae
Mackay Whitsunday	Proserpine	Double Cone Is	2	15.5	0	0	2	1.5	20	4.5	3	6.5	2	2.5	5	15.5	0
			5	5	2.5	0	0	3	5.5	3.5	2	1.5	2	2.5	0.5	9.5	0
		Daydream Is	2	24	1.5	0	2.5	0.5	19.5	12.5	6	21.5	2	10	2	7.5	0
			5	19.5	1.5	0	2	1	31	7.5	2.5	10	1	15.5	2.5	5.5	0
		Dent Is	2	27.5	3	0	3.5	1.5	19	8.5	5	6	5	6	2.5	23.5	0
			5	18	2	0	6.5	1	12	8.5	3	11.5	0.5	11	3.5	16	0.5
		Pine Is	2	35.5	1	1.5	0	1.5	12.5	17.5	1.5	12.5	5.5	3.5	1	42	0.5
			5	26.5	3	0.5	4.5	6.5	21	8	4.5	10.5	1.5	14.5	0.5	23.5	0.5
		Seaforth Is	2	38.5	9	1.5	12.5	8	84	12.5	5.5	56.5	4.5	12.5	4	70.5	2.5
			5	19	10	0	4	4.5	73	6	5	35	4	17.5	2	22	0
Fitzroy	Fitzroy	North Keppel Is	2	23	0	0	0	0	0.5	71.5	0	1	0	0	0	0	0.5
			5	10	0	0	0	0	3.5	13.5	1	0	0	0	0	1	1
		Barren Is	2	78	0.5	0	19	0	20	0	0	0.5	0	0	12.5	1.5	2
			5	18.5	0	0	0	0	0	0.5	0.5	0	0	0	2	0.5	0.5
		Humpy Is and Halfway Is	2	19	0	0	1.5	0	10.5	2.5	1	0.5	0	0	3	3.5	0.5
			5	9	0	0	5	0	22	1	0	1	0	0	0	8.5	0.5
		Pelican Is	2	45.5	0	0	2.5	0	13	0	0	6.5	0	0	5.5	7.5	1.5
			5	6	0	0	23	0	38	0	2.5	6.5	0	0	5	30	7.5

Table A1-7 Composition of juvenile soft coral communities represented by common families (count per 34m²) 2009

Region	Catchment	Reef	Depth	Alcyoniidae	Briareidae	Clavulariidae	Nephtheidae	Xeniidae
Wet Tropics	Daintree	Snapper Is North	2	0	0	0	0	0
			5	0	0	0	0	0
		Snapper Is South	2	0	0	0	0	0
			5	0.5	0	0	0	0
	Johnstone	Fitzroy Is West	2	78.5	0	0	1.5	3
			5	69.5	1	0	0	0
		High Is West	2	10	1	0	0	0
			5	11	2.5	0	0	0.5
		High Is East	2	27.5	2	1	0	0
			5	15	4	0.5	0	0
		Frankland Group West	2	10	0	5	0.5	0
			5	4.5	0	4	2	7.5
		Frankland Group East	2	23	1.5	9	3	25.5
			5	36	4.5	2.5	0.5	8
	Tully	North Barnard	2	22	0.5	0	0	0
			5	25.5	0.5	0	0.5	1
		Dunk Is North	2	9.5	0.5	0	0	0
			5	13.5	0	0	0.5	0
Burdekin	Burdekin	Pelorus Is and Orpheus Is West	2	101.5	5	19.5	15.5	19
			5	120.5	5.5	3	310	0
		Pandora	2	1	0	4.5	0	0
			5	1.5	0	5	0	0
		Havannah Is	2	8.5	3.5	0	0	0
			5	12.5	12.5	0	0	0.5
		Geoffrey Bay	2	2.5	2.5	0	0	0
			5	17.5	0	0	0	0
		Middle Reef	2	22.5	0	0	0	0

Table A1-7 Continued

Region	Catchment	Reef	Depth	Alcyoniidae	Briareidae	Clavulariidae	Nephtheidae	Xeniidae
Mackay Whitsunday	Proserpine	Double Cone Is	2	42	1	0	0.5	0
			5	59	2.5	0	1	0
		Daydream Is	2	91.5	0	0	0.5	0
			5	79	0	0	0.5	0
		Dent Is	2	60.5	1	0	0	0
			5	61.5	0	0	0	0
		Pine Is	2	10	2	0	0	3
			5	17.5	1	0	0	0
		Seaforth Is	2	51.5	1	0	5	18
			5	27.5	0	0	1.5	2
Fitzroy	Fitzroy	North Keppel Is	2	0.5	0	0	0.5	0
			5	1.5	0	0	0	0
		Barren Is	2	1	0	0	0	1500
			5	0	0	0	0	283.5
		Humpty Is and Halfway Is	2	2.5	0	0	0	81
			5	3.5	0	0	0	4
		Pelican Is	2	14	0	0	9	49.5
			5	37	0	0	29.5	27

Appendix 2: QAQC Information

Validation of benthic community assessments

Photo point intercept transects.

The QA/QC for the estimation of percent cover of benthic community components has two components. The sampling strategy that uses permanently marked transects ensures estimates are derived from the same area of substrate 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 check 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 2009. Data from Snapper Island is 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. We are confident that no bias was introduced as a result of his participation. 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. All other reefs were surveyed by experienced AIMS staff that have previously undergone training in the technique sufficient to ensure its standardised application. To ensure no drift occurs between observers informal comparative counts were undertaken along short sections of transect and count and size class information compared and discrepancies discussed with direct reference to the colony in question. As most dives included two of the experienced aims staff uncertainties in identification were typically discussed in situ or that evening with reference to photographs taken of problem individuals. It must be acknowledged however that for some of the smallest size class <2cm identification to genus is impossible in the field, though for the most part this is the case for relatively rare taxa for which reference to nearby larger individuals cannot be made.

Settlement plate spat counts

It is the stated QA/QC aim that hard coral recruits (spat) on retrieved settlement tiles were to be counted and identified using a stereo dissecting microscope with identification to the highest practicable taxonomic resolution and between observer errors (spat overlooked) should not exceed 10%. 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 2009/10

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.

QAQC documentation for MMP:

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.