Reef Rescue Marine Monitoring Program

Final Report of AIMS Activities 2008/09
Project 3.7.1b Inshore Coral Reef Monitoring
Project 3.7.8 Inshore Water Quality Monitoring

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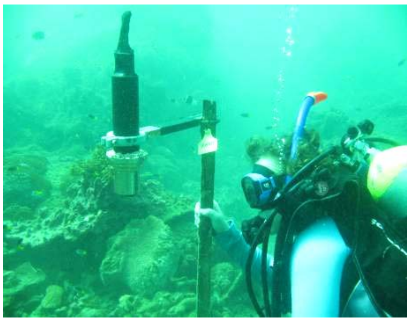

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Executive Summary

The AIMS Reef Rescue monitoring activities in the current contract period are largely an extension of activities established under previous arrangements from 2004 to 2008 and are grouped into two components, Inshore Marine Water Quality Monitoring and Inshore Coral Reef Monitoring, which are reported together in this joint Final Report.

- Water quality monitoring in the inshore lagoon was carried out at three occasions during 2008-09 at 14 fixed locations in four NRM regions, the Wet Tropics, Burdekin, Mackay Whitsunday and Fitzroy regions. Sampling of the longest available time series of water quality data for the Great Barrier Reef (GBR) in coastal waters between Cape Tribulation and Cairns from 1989 to the present was also continued under Reef Rescue MMP.

- Direct water sampling indicated that most water quality variables at Dunk Island (Wet Tropic Region), Magnetic Island (Burdekin Region) and Pelican Island (Fitzroy Region) did not comply with GBRMPA Water Quality Guidelines trigger values. Instrumental monitoring indicated that additionally Daydream and Pine Islands in the Mackay Whitsunday Region had chlorophyll *a* and turbidity levels exceeding trigger values.

- Water quality in the inshore GBR showed clear gradients away from river mouths and was clearly driven by flood events and resuspension at the time of sampling. Analyses of the data from the direct water sampling showed significant high-level interactions between the four sampling years, seasons and regions. This means that no single factor can be considered in isolation. Especially river discharge was different in each year, and resuspension affected locations differently in the four regions.

- Instrument-derived water quality data delivered continuous records for 1.5 years of two water quality variables, chlorophyll *a* and turbidity. This information will allow improved characterisation of the environmental conditions corals are exposed to as well as improved identification of driving factors (e.g., floods, tide and/or wind-driven resuspension). Longer-term time series of these high-frequent measurements of water quality are essential to detect change due to changes in land management, which needs to be distinguished from the recognised large natural year-to-year fluctuations.

- Surface chlorophyll concentrations in GBR waters have been measured since 1992 as part of a long-term monitoring program and continued under Reef Rescue MPP, with the GBRMPA assuming responsibility for liaison and maintenance of the sampler network in 2007. In 2008/09 this component of Reef Rescue MMP was very unsuccessful. Of the three identified major nodes of the network, Cape York, Mackay Whitsunday and Burnett Coast, only the Mackay Whitsunday node was functional and was regularly sampled.

- 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 24 inshore reef locations in four NRM regions, the Wet Tropics, Burdekin, Mackay Whitsunday and Fitzroy regions. Coral recruitment monitoring also continued at 3 core sites in each of the four NRM regions.

- The completion of the fourth inshore coral reef survey under Reef Rescue MMP allows a first assessment 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:

    - A positive score of coral community status was indicated for the Daintree and Johnstone-Russell/Mulgrave sub-regions of the Wet Tropics NRM region. Coral communities on average showed generally high coral cover that increased during periods without acute disturbance, and the reefs had low cover of macroalgae and relatively high densities of juvenile colonies. These reefs had water quality variables generally below guideline trigger values, apart from Snapper Island which had high turbidity levels.

    - Coral community status in the Whitsunday Mackay NRM region was also scored highly. 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 and settlement of spat to tiles was moderate relative to other regions. While these reefs have relatively high chlorophyll and turbidity levels, the concentrations of particulate nutrients are within guidelines.

    - The assessment of coral community status in the Fitzroy region was marginally positive. The positive attributes of high average coral cover with a clear capacity to recover following disturbance events and high, albeit variable, settlement of spat were offset by high macroalgal cover and low densities of juvenile colonies. The water quality at Pelican Island did not comply with water quality guidelines trigger values and had a clearly different benthic reef community composition at depth. The other two reefs had water quality variables generally below guideline trigger values and were dominated by *Acropora*, which is generally only found 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.

    - Negative scores of 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 moderate to low coral cover that did not show clear evidence of increase.

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) for any trend to be significant. Water quality in this region is only assessed at one site, Dunk Island. At this site most water quality trigger values are exceeded and the water is generally turbid.
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. Our results indicate that the 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 associated changes in coral reef communities. High frequency water quality monitoring by instruments will improve this assessment.

1. Introduction to the Program

The Reef Rescue Marine Monitoring Program, formerly known as Reef Water Quality Protection Plan Marine Monitoring Programme (Reef Plan MMP), was designed and developed by the Great Barrier Reef Marine Park Authority (GBRMPA) and is now funded under the Australian Government's Reef Rescue initiative. In the current year, 2008/09 which is the fourth full year of monitoring, the Program has been integrated into the Marine Tropical Sciences Research Facility (MTSRF) and is managed by the Reef and Rainforest Research Centre (RRRC).

The Australian Institute of Marine Science (AIMS) and the RRRC entered into a co-investment contract on 23 March 2009 to provide monitoring activities under the Reef Rescue MMP.

The AIMS monitoring activities in the current contract period of the Reef Rescue MMP are largely an extension of activities established under a previous arrangements from 2004 to 2008 and are grouped into two components, which are reported together in this joint draft Final Report:

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

This report presents the results of AIMS monitoring activities during the period 01 May 2008 to 30 April 2009, with inclusion of data from the previous MMP monitoring since 2005.

2. Inshore Marine Water Quality Monitoring

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2.1 Introduction

The biological productivity of the Great Barrier Reef (GBR) is supported by nutrients (e.g. nitrogen, phosphorus, silicate, iron), which are supplied by a number of processes and sources (Furnas *et al.* 1997; Furnas 2003). These include upwelling of nutrient-enriched subsurface water from the Coral Sea, rainwater, fixation of gaseous nitrogen by cyanobacteria and freshwater runoff from the adjacent catchment. Land runoff is the largest source of new nutrients to the GBR (Furnas 2003). However, most of the inorganic nutrients used by marine plants and bacteria on a day-to-day basis come from recycling of nutrients already within the GBR ecosystem (Furnas *et al.* 2005).

Extensive water sampling throughout the GBR over the last 25 years has established the typical concentration range of nutrients, chlorophyll *a* and other water quality parameters and the occurrence of persistent latitudinal, cross-shelf and seasonal variations in these concentrations (summarised in Furnas 2005, De'ath and Fabricius 2008). While concentrations of most nutrients, suspended particles and chlorophyll *a* are normally low, water quality conditions can change abruptly and nutrient levels increase dramatically for short periods following disturbance events (wind-driven re-suspension, cyclonic mixing, river flood plumes). However, nutrients introduced, released or mineralised into GBR lagoon waters during these events are generally rapidly taken up by pelagic and benthic algae and microbial communities (Alongi and McKinnon 2005), sometimes fuelling short-lived phytoplankton blooms and high levels of organic production (Furnas *et al.* 2005).

The longest and most detailed time series of a suite of water quality parameters has been measured by AIMS at 11 coastal stations in the GBR lagoon between Cape Tribulation and Cairns since 1989; and has been continued under Reef Plan MMP and Reef Rescue MMP. Concentrations of nutrients and suspended solids, but not chlorophyll a, show significant long-term patterns, generally decreasing since the early 2000s (Schaffelke *et al.*, 2008). However, the understanding of the causes of the observed fluctuations is incomplete.

Regional-scale monitoring of surface chlorophyll *a* concentrations in GBR waters since 1992 shows consistent regional (latitudinal), cross-shelf and seasonal patterns in phytoplankton biomass, which is regarded as a proxy for nutrient availability (Brodie *et al.* 2007). In the mid- and southern GBR, higher chlorophyll *a* concentrations are usually found in shallow waters (within 20m depth) close to the coast (less than 25km offshore). Overall, however, no long-term *net* trends in chlorophyll *a* concentrations were found (Brodie *et al.* 2007; CRC Consortium 2006).

This component of the Reef Rescue MMP– 'Inshore Marine Water Quality Monitoring' aims to describe spatial and temporal patterns in concentrations of GBR marine water quality indicators in inshore areas.

This project has several key objectives:

a) To describe spatial patterns and temporal trends in marine water quality (suspended sediments, nutrients,) in high risk (inshore) areas of the GBR lagoon;
b) To describe spatial and temporal patterns in concentrations of GBR inshore marine water parameters using remote sensing (to be carried out by CSIRO and reported separately)
c) Determine time integrated baseline concentrations of specific organic chemicals in water with the aim to evaluate long term trends in pesticide concentrations along inshore waters of the GBR (to be carried out by Entox-UQ and reported separately).

2.2 Methods

In the following an overview is given of the sample collection, preparation and analyses methods. Detailed documentation of the AIMS methods used under Reef rescue MMP was provided to RRRC in a separate report in May 2009 (Schaffelke, 2009: Reef Rescue Marine Monitoring Program-Methods and Quality Assurance/Quality Control Procedures).

Marine Water Quality Sampling

Sample locations

The 14 fixed sampling locations, spanning four NRM regions, are congruent with the 14 'core' sites of the inshore coral reef monitoring. At these sites detailed manual and instrumental water sampling is undertaken (see below) as well as annual surveys of reef status, including assessments of coral recruitment (see Chapter 3 in this report). Sampling of the six open water stations of the 'Cairns Coastal Transect' was also continued (Table 2.1, Figure 2.1).

Table 2.1 Locations selected for inshore water quality monitoring (water sampling during research cruises in July 2008, October 2008 and February 2009 and continuous deployment of autonomous water quality instruments). The six locations of the "Cairns coastal transect" (open water sampling) are in italics.

NRM Region	Primary Catchment	Water quality monitoring locations
Wet Tropics	Daintree, Barron	*Cape Tribulation*
		Snapper Island North
		Port Douglas
		Double Island
		Green Island
		Yorkey's Knob
		Fairlead Buoy
		Fitzroy Island West
	Russell-Mulgrave, Johnstone	High Island West
		Frankland Group West
	Tully	Dunk Island North
Burdekin	Herbert, Burdekin	Pelorus & Orpheus Is West
		Pandora Reef
	Burdekin	Geoffrey Bay, Magnetic Island
Mackay Whitsunday	Proserpine,	Double Cone Island
	Pioneer,	Daydream Island
	O'Connell	Pine Island
Fitzroy	Fitzroy	Barren Island
		Pelican Island
		Humpy & Halfway Island

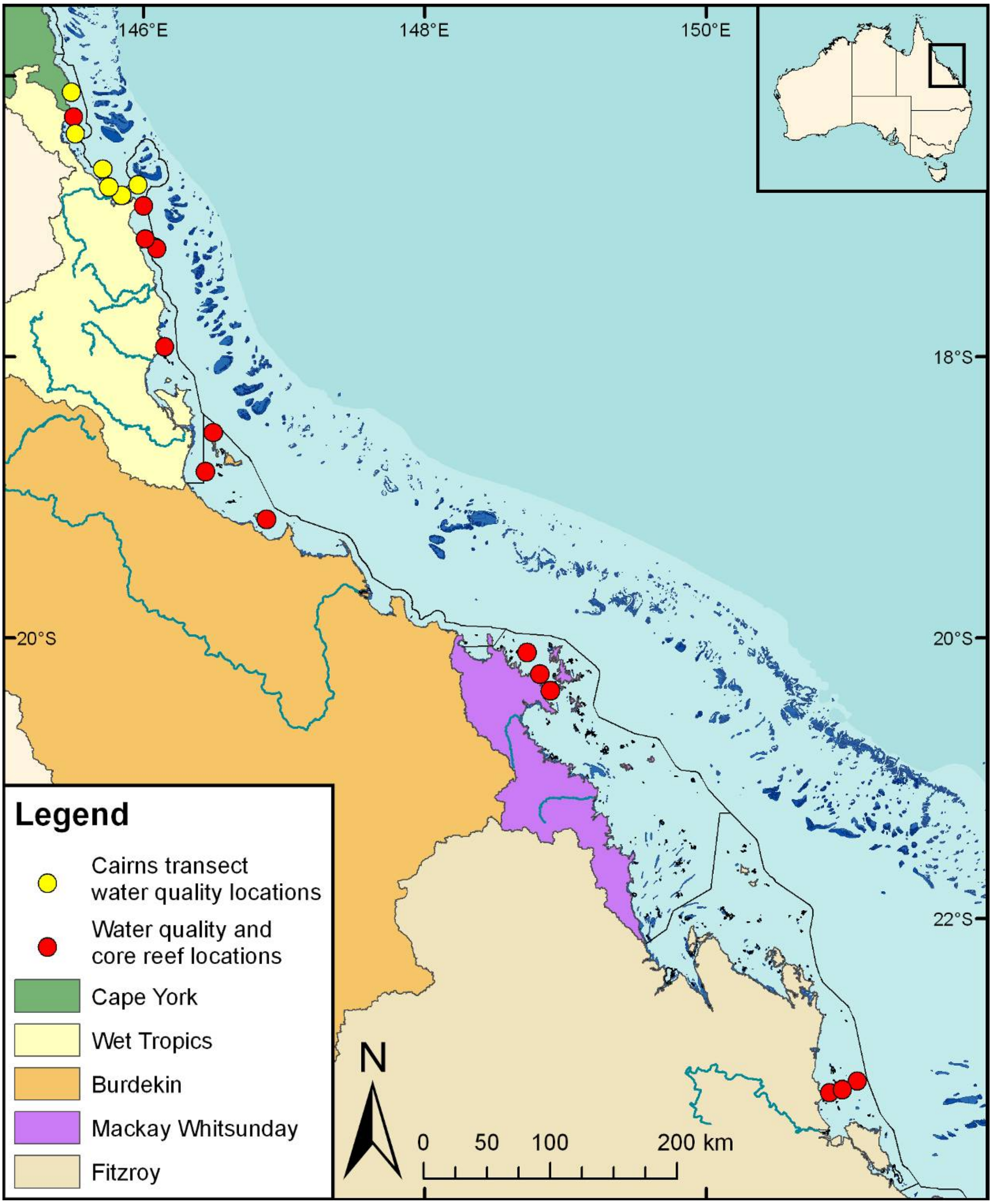


Figure 2.1 Sampling locations under the Reef Rescue MMP inshore marine water quality task. Red symbols indicate the 14 locations where autonomous water quality instruments (temperature, chlorophyll and turbidity) were deployed and regular water sampling was undertaken; these locations are also "Core reef locations" under the inshore coral reef monitoring task (see Chapter 3). Yellow symbols are the locations of the "Cairns coastal transect", which have been sampled by AIMS from 1989-2008.

Direct water sample collection, preparation and analyses

At each location, vertical profiles of water temperature and salinity were measured with a Conductivity Temperature Depth profiler (CTD) (Seabird SBE25 or SBE19). The CTD was fitted with an *in situ* fluorometer for chlorophyll a (WET Labs) and a beam transmissometer (Sea Tech, 25cm, 660nm) for turbidity.

Immediately following the CTD cast, discrete water samples were collected from two to three depths through the water column with Niskin bottles. Sub-samples taken from the Niskin bottles were analysed for dissolved nutrients and carbon (NH_4, NO_2, NO_3, PO_4, $Si(OH)_4$), DON, DOP, DOC), particulate nutrients and carbon (PN, PP, POC), suspended solids (SS) and plant pigments (chlorophyll a, phaeophytin). Subsamples were also taken for laboratory salinity measurements using a Portasal Model 8410A Salinometer. Temperatures were measured with reversing thermometers from at least 2 depths.

In addition to the ship-based sampling, water samples were collected subtidally by diver-operated Niskin bottle sampling, i) close to the autonomous water quality instruments (see below) and ii) within the adjacent reef boundary layer. These samples were otherwise processed in the same way as the ship-based samples.

The sub-samples for dissolved nutrients were immediately filtered through a 0.45µm filter cartridge (Sartorius Mini Sart N) into acid-washed screw-cap plastic test tubes and stored frozen (-18°C) until later analysis ashore. DOC samples were acidified with 100 µl of AR-grade HCl and stored at 4°C until analysis.

Inorganic dissolved nutrients (NH_4, NO_2, NO_3, PO_4, $Si(OH)_4$) concentrations were determined by standard wet chemical methods (Ryle *et al.* 1981) implemented on a segmented flow analyser (Bran and Luebbe, 1997) after return to the AIMS laboratories (Section 3). Analyses of total dissolved nutrients (TDN and TDP) were carried using persulphate digestion of water samples (Valderrama, 1981), which are then analysed for inorganic nutrients, as above. DON and DOP were calculated by subtracting the separately measured inorganic nutrient concentrations (above) from the TDN and TDP values.

To avoid potential contamination during transport and storage, analysis of ammonium concentrations in triplicate subsamples per Niskin bottle were also immediately carried out on board the vessel using a fluorometric method bases on the reaction of ortho-phthal-dialdehyde with ammonium (Holmes *et al.*, 1999). These samples were analysed on fresh unfiltered seawater samples using specially cleaned glassware, because AIMS experience shows that the risk of contaminating ammonium samples by filtration, transport and storage is high. If available, the NH_4 values measured at sea were used for the calculation of DIN.

Dissolved organic carbon (DOC) concentrations were measured by high temperature combustion (680°C) using a Shimadzu TOC-5000A carbon analyser. Prior to analysis, CO_2 remaining in the sample water is removed by sparging with O_2 carrier gas.

The sub-samples for particulate nutrients and plant pigments were collected on pre-combusted glass fibre filters (Whatman GF/F). Filters were wrapped in pre-combusted aluminium foil envelopes and stored at -18°C until analyses.

Particulate nitrogen (PN) is determined by high-temperature combustion of filtered particulate matter on glass fibre filters using an ANTEK 707/720 Nitrogen Analyser (Furnas *et al.*, 1995). The analyser is calibrated using AR Grade EDTA for the standard curve and marine sediment BCSS-1 as a control standard.

Particulate phosphorus (PP) is determined spectrophotometrically as inorganic P (PO_4: Parsons *et al.*, 1984) after digesting the particulate matter in 5% potassium persulphate (Furnas *et al.*, 1995). The method is standardised using orthophosphoric acid and dissolved sugar phosphates as the primary standards.

The particulate organic carbon content (POC) of material collected on filters is determined by high temperature combustion (950°C) using a Shimadzu TOC-V carbon analyser fitted with a SSM-5000A solid sample module. Filters containing sampled material are placed in pre-combusted (950°C) ceramic sample boats. Inorganic C on the filters (e.g. $CaCO_3$) is removed by acidification of the sample with 2M hydrochloric acid. The filter is then introduced into the sample oven (950°C), purged of atmospheric CO_2 and the remaining organic carbon is then combusted in an oxygen stream and quantified by IRGA. The analyses are standardised using certified reference materials (e.g. MESS-1).

Chlorophyll *a* and phaeophytin concentrations are measured fluorometrically using a Turner Designs 10AU fluorometer after grinding the filters in 90% acetone (Parsons *et al.*, 1984). The fluorometer is calibrated against chlorophyll *a* extracts from log-phase diatom cultures (chlorophyll *a* and *c*). The extract chlorophyll concentrations are determined spectrophotometrically using the wavelengths and equation specified by Jeffrey and Humphrey (1975).

Sub-samples for suspended solids were collected on pre-weighed 0.4µm polycarbonate filters. SS concentrations are determined gravimetrically from the difference in weight between loaded and unloaded 0.4 µm polycarbonate filters (47mm diameter, GE Water & Process Technologies) after the filters had been dried overnight at 60°C.

Details about QAQC procedures are given in Appendix 2.

Autonomous Water Quality Loggers

Instrumental water quality monitoring is undertaken using WETLabs Eco FLNTUSB Combination Fluorometer and Turbidity Sensors. Details about deployment periods and description of instrument failures that led to data losses are summarised in Appendix 1, Table A1-2.1.

The Eco FLNTUSB Combination instruments used in the inshore water quality under MMP perform simultaneous *in situ* measurements of chlorophyll fluorescence, turbidity and temperature. 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 ($\mu g\ L^{-1}$ for chlorophyll fluorescence, NTU for turbidity, °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). After removal of spikes and other unreliable data, short gaps in the record are filled by linear interpolation. 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 (see Appendix 2).

Coastal and Lagoon Chlorophyll a Concentrations

Community sampling network

The monitoring of chlorophyll concentrations is still the most robust and broadly applied indicator for water quality (esp. nutrient availability) in the GBR lagoon. This component of the Reef Rescue MMP is a continuation of a large-scale chlorophyll monitoring program that has been in place since 1992 (implemented by the GBRMPA) and managed by AIMS since 1999.

Sampling of the Long-Term Lagoon Chlorophyll Monitoring Program has involved, in most cases, monthly sampling at stations along inshore-offshore transects. After revision of the Reef Plan MMP sampling design in 2006/07, four transects and a number of coastal sites were established, commencing in July 2006, to be sampled by community and industry groups. This sampling continued at most of the sites during 2007/08, however at a number of sites very irregularly. In 2008/09 the sampling network declined further due to unavailability of community samplers or quality issues with the samples collected. The current sampling sites in 2008/09 are listed in Table 2.2, however, this is likely to change in the future changing due to discontinuation of existing and starting of new samplers.

Since 2007/08, GBRMPA has had a stronger role in communicating and liaising with the sampler organisations (tourism operators and community groups). The GBRMPA is now coordinating training of selected officers of their Regional Engagement and Planning group (REP) and of new sampler organisations or groups. The new training includes changes to the sampling process already decided in 2007/08 but never rolled out due to the above-mentioned problems, for example, i) actual geographical positions to be recorded by the samplers, and ii) Secchi-discs readings to be included in the sampling. GBRMPA has also had responsibility for transporting samples to AIMS. AIMS contributes to the technical aspects of the program, as required, including provision of regularly updated manuals, sampling kits and training sessions. A full copy of the manual provided in 2008/09 was included in the Methods and QAQC Report (Schaffelke 2009).

The main scientific purpose of the long-term monitoring has changed from a continuous time series to the provision of validation data for the remote sensing component of the Reef Rescue MMP. Data provision to our project partners at CSIRO Land and Water has been occurring on a regular basis.

Sample collection, preparation and analyses

A surface water sample is collected at each site every month. Replicate samples are to be collected every 3 months by transect samplers. Each sample is subsampled and filtered onto 2 replicate GF/F filters and stored at -18°C until analysis (refer to methods for lagoon water quality, above).

The following parameters were also measured at each site at the time of sampling: salinity (with a refractometer), water temperature (with a manual thermometer), the presence of *Trichodesmium*, information about the weather, wind and tides, and Secchi depth and water depth (depth sounder) and the actual geographic position using a GPS.

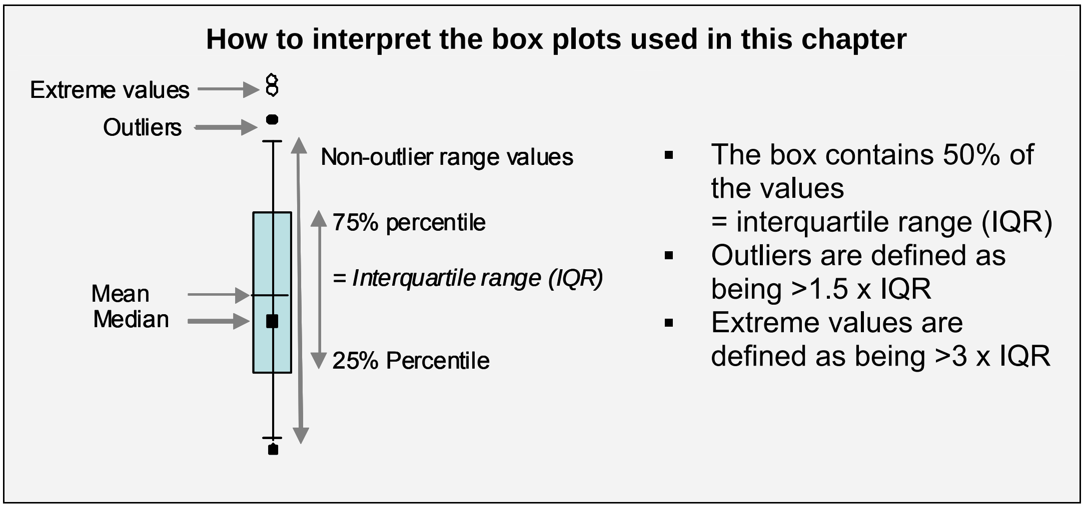
Table 2.2 Details of the Long-term chlorophyll monitoring network sampling in 2008/09.

NRM Region	No of sites	Sampler	Comment
Cape York	2	Mike Ball Dive Expeditions	Started in March 09
Mackay Whitsunday	3	FantaSea	ongoing
Burnett Mary	5	Woongarra Marine Park Monitoring & Education Project	Discontinued in Dec 08 when WMPMEP sampling program disbanded, GBRMPA currently looking for a replacement.

Data analysis

Values for water quality parameters at each station were calculated as depth-weighted means. This included the samples collected by divers directly above the reef surface and the depth-profile station collected from the research vessel. Data were pooled after exploration by principal component analysis showed no difference between samples collected on reef and in the water column close to the reef or between depths at each depth-profile station. Summary statistics of these depth-weighted mean values are presented as box and whisker plots (see box below for definitions and details of the box plots used) for each of four NRM regions: the Wet Tropics, Burdekin, Mackay Whitsunday and Fitzroy NRM Regions (using the marine boundaries of each NRM region).

The data presentation of the direct water sampling results was changed from the previous three annual Reef Plan MMP reports. Data summaries are now presented for the water quality constituents for which GBRMPA Water Quality Guideline trigger values (GBRMPA 2008, see also below) are available: TN, TP, chlorophyll, SS and Secchi depth. All available data for each of the 14 sampling locations are combined (2005/06 to 2008/09) and summarised separately for dry and wet seasons. This allows for characterisation of the water quality at each sites and along regional gradients away from the coast and for an appropriate application of the GBRMPA Water Quality Guideline trigger values, which are based on mean values. Complete data are reported in the Appendix.



Annual, seasonal and regional differences in water quality and all higher level interactions among these primary factors were determined by an unbalanced, three-way, fixed-factor, multivariate analysis of variance which employed permutation methods and was based on the Gower Metric association measure (PERMANOVA, Anderson *et al.* 2008). The factor 'Year' contained four levels (2005/06, 2006/07, 2007/08, 2008/09), the factor 'Season' contained two levels (wet and dry) and the factor 'Region' contained four levels (NRM regions - Wet Tropics, Burdekin, Mackay Whitsunday, Fitzroy). Replication varied from 3 sites within the Fitzroy, Mackay Whitsunday and Burdekin regions to 15 sites within the Wet Tropics region during both the wet and dry seasons in 2006/07 and the wet season in 2007/08 (see Table 2.1 and Fig. 2.1 for location details in 2008/09). Water quality was defined by concentrations of chlorophyll a, total suspended solids, PN, PP, POC and DOC and the physical characteristics of temperature, salinity, and Secchi disc depth. Dissolved nutrients were not included in the analysis as they are often highly variable at small spatial and temporal scales and unlikely to resolve existing spatial and temporal patterns. The Gower Metric was deemed the most appropriate resemblance measure as the water quality variables employed in the analyses are essentially environmental in nature rather than biological; the variables are on different scales and there are not many zero values, and; the various physical and chemical variables should be given equal weight (e.g., equal differences between values have the same influence on association, regardless of scale).

Subsequent to the MANOVA, the Gower Metric resemblance matrix was subjected to a multivariate multiple regression procedure to investigate relationships between the water quality variables and a set of explanatory variables (DISTLM, Anderson *et al.* 2008). The explanatory variables were: Year and Month of sampling, Latitude (proxy for NRM region), Longitude (proxy for cross-shelf position), Nearest River (the distance from each sampling station to the nearest river mouth in nautical miles), River Flow (the average flow of the closest river to the south of each sampling station during the month previous to sampling in ML d-1) and Resuspension Index [an index for water column mixing based on either a fetch-limited or duration-limited formula (Ozger and Sen 2007) employing a critical wave period of Tc = (4πD/g)0.5 where g = 9.8 ms-1and D = station depth (m) (Booth *et al.* 2000)]. The results were represented in a two-dimensional, distance-based redundancy biplot. The critical probability level for significance testing was set a priori at 5% for all analyses.

Data from the 'Cairns Coastal Transect', which has been regularly sampled by AIMS since 1989, is the only available long-term dataset for a comprehensive range of water quality parameters in the GBR lagoon (other than chlorophyll, see below) with which to conduct temporal trend analyses. Water quality parameters were measured at eleven locations from 1989 – 2009. Each site was typically visited twice per year but sampling varied from none to four visits per year. From 2008/09 only six of the initially 11 sites were continued to be sampled after a statistical analysis indicated that this reduced number of stations would provide enough information for a continued time series analysis.

The water quality parameters measured include the whole suite of nutrients measured at all fixed lagoon sampling locations. For the analysis of temporal trends we chose a subset of six parameters, chlorophyll *a* (Chl, μgL^{-1}), particulate nitrogen (PN, μgL^{-1}), particulate phosphorus (PP, μgL^{-1}), suspended solids (SS, mgL^{-1}), total dissolved nitrogen (TDN, μgL^{-1}) and total dissolved phosphorus (TDP, μgL^{-1}). These six parameters have shown temporal trends over sampling years in previous analysis (De'ath 2005, CRC Reef Consortium 2006, Schaffelke *et al.* 2007 and 2008) or are most likely to show temporal trends because they are less variable over small spatial and temporal scales and are considered to integrate water column processes. The primary objective of this analysis was to assess the long-term trend of these six water quality parameters in the GBR lagoon over the observation period.

Initially, data were screened for outliers and for non-positive values that were subsequently replaced by their limit-of-detection values, defined here as half the smallest positive observed value. The data were then averaged across duplicates and depth because i) depth effects appeared to be small and sampling was fairly well-balanced and ii) depth effects were not of interest in this study. Preliminary analysis of the variation between sites showed them to be also consistent over time. That is, the long-term trend for each water quality variable was similar at each site. Hence, the data were averaged over sites for subsequent analysis. Temporal trends in the six parameters were assessed using log-linear models (quasi-Poisson) with the temporal effects being decomposed into variation across years (thin plate regression splines) and within years by months (cyclical trends). The smoothness of the fitted trends was selected using cross-validation. The significance of the terms was based on F-tests. The analyses were carried out using the statistical package R (R_Development_Core_Team 2007).

Comparison with trigger values from the draft GBR Water Quality Guideline

The Water Quality Guideline for the Great Barrier Reef Marine Park (GBRMPA 2009), developed in 2008 based on De'ath and Fabricius (2008), provides a useful framework to interpret the water quality values obtained at the fourteen core sampling sites and to identify areas/locations with potential water quality issues. The table below gives a summary of the Guideline values in four cross-shelf regions and has the suggested seasonal adjustments applied. These values were applied to seasonal average values at each of the 14 water sampling locations.

Table 2.2 Guideline trigger values from the GBRMPA Water Quality Guideline for the Great Barrier Reef Marine Park (GBRMPA 2009). Seasonal adjustments have been calculated according to the information provided in the guideline document.

	Water Body			
Parameter	Enclosed coastal (Wet Tropics/Central Coast)	Open coastal	Midshelf	Offshore
Chlorophyll a (µg L^{-1})				
Annual mean	2.0	0.45	0.45	0.40
Summer mean	2.8	0.63	0.63	0.56
Winter mean	1.4	0.32	0.32	0.28
Secchi (m)				
Annual mean	1.0/1.5	10.0	10.0	17.0
Suspended solids (mg L^{-1})				
Annual mean	5.0/15.0	2.0	2.0	0.7
Summer mean	6.0/18.0	2.4	2.4	0.8
Winter mean	4.0/12.0	1.6	1.6	0.6
Particulate nitrogen (µg L^{-1})				
Annual mean	n/a	20.0	20.0	17.0
Summer mean		24.0	24.0	20.4
Winter mean		16.0	16.0	13.6
Particulate phosphorus (µg L^{-1})				
Annual mean	n/a	2.8	2.8	1.9
Summer mean		3.4	3.4	2.3
Winter mean		2.2	2.2	1.5

2.3 Results and Discussion

The results from both the direct marine water quality sampling and the water quality measurements using autonomous loggers are reported separately for each of the four NRM regions.

Region Reports: Wet Tropics Region

The Wet Tropics NRM region comprises 10 river catchments, the Daintree, Mossman, Barron, Trinity Inlet, Russell, Mulgrave, Johnstone, Tully/Murray, Hinchinbrook and Herbert catchments. The main primary land uses in the region are cane, bananas, dairy, grazing, horticulture and forestry. The region has a higher proportion of forest and National Park areas than the other four regions considered here (Brodie *et al.* 2003).

The five water quality sampling sites in the Burdekin region are located along the coast to capture influence of the main rivers in this region (Figure 2.2; see table 2.1 for details). There are also six additional open water sampling locations along the Cairns coastal transect (Figure 2.1). The major rivers in the Wet Tropics Region had above median discharge since the start of the MMP monitoring, whereas the year 2004/05 was below the long-term median (Table A1-2.2 in Appendix 1). Noteworthy were major flood events of the Barron in 2007/08 and the Herbert in 2008/09.

Seasonal means over four years of monitoring for the water quality parameters for which guideline trigger values were available (GBRMPA 2009) were mostly below these values (Figure 2.3). An exception is Dunk Island, which generally had the highest seasonal means of all locations in this region, and all means, except for PN, exceeded trigger values (Figure 2.3). Russell Island in the Franklands group had the lowest concentrations of all four variables and the highest Secchi depth readings. All other Wet Tropics locations had Secchi readings above the trigger value for this parameter (10m). Detailed results for all water quality variables for the sampling year 2008/09 are in Appendix 1, Tables A1-2.3 to A1-2.8.

The instrumental water quality monitoring data showed essentially the same pattern for the variables chlorophyll and turbidity as the direct water sampling results (Figure 2.4). All locations had annual and seasonal means below GBRMPA trigger values, again with the exception of Dunk Island which had chlorophyll values above the trigger values when considering the mean over the instrumental sampling period (October 2007 to February 2009) and the mean during the dry season periods (Table 2.3). Annual and seasonal turbidity means for Snapper and Dunk Island were above the trigger value for SS (after conversion to NTU, see Appendix 2 for details). This is also reflected in these two sites having the lowest Secchi depth readings in the manual water sampling (Figure 2.3). At Snapper and Dunk islands, the turbidity readings were above the suggested 5 NTU limit for severe coral photo-physiological stress (Cooper *et al.* 2007, 2008) for 7% and 11% of daily records over the whole period (October 2007 to February 2009), respectively, indicating moderate light limitation of corals at these two locations. This light limitation is not limited to flood events but the data record indicates that resuspension throughout the year during strong winds lead to frequent high turbidity events. Resuspension is recognised as one of the major drivers of turbidity in the inshore GBR lagoon (e.g. Larcombe *et al.* 1995, Wolanski *et al.* 2007).

The instrumental data also show clear flood signals for both the 2008 and 2009 wet seasons. High values for both chlorophyll and turbidity coincide with discharge from the nearest River (Figure 2.4).

Instrument failures led to data losses from two deployment periods at Fitzroy Island (see Appendix 1, Table A1-2.1 for details).

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Figure 2.2 Reef Rescue MMP water quality sampling sites (blue squares) in the Wet Tropics NRM Region at Snapper Island, Fitzroy Island, High Island, Russell Island and Dunk Island.

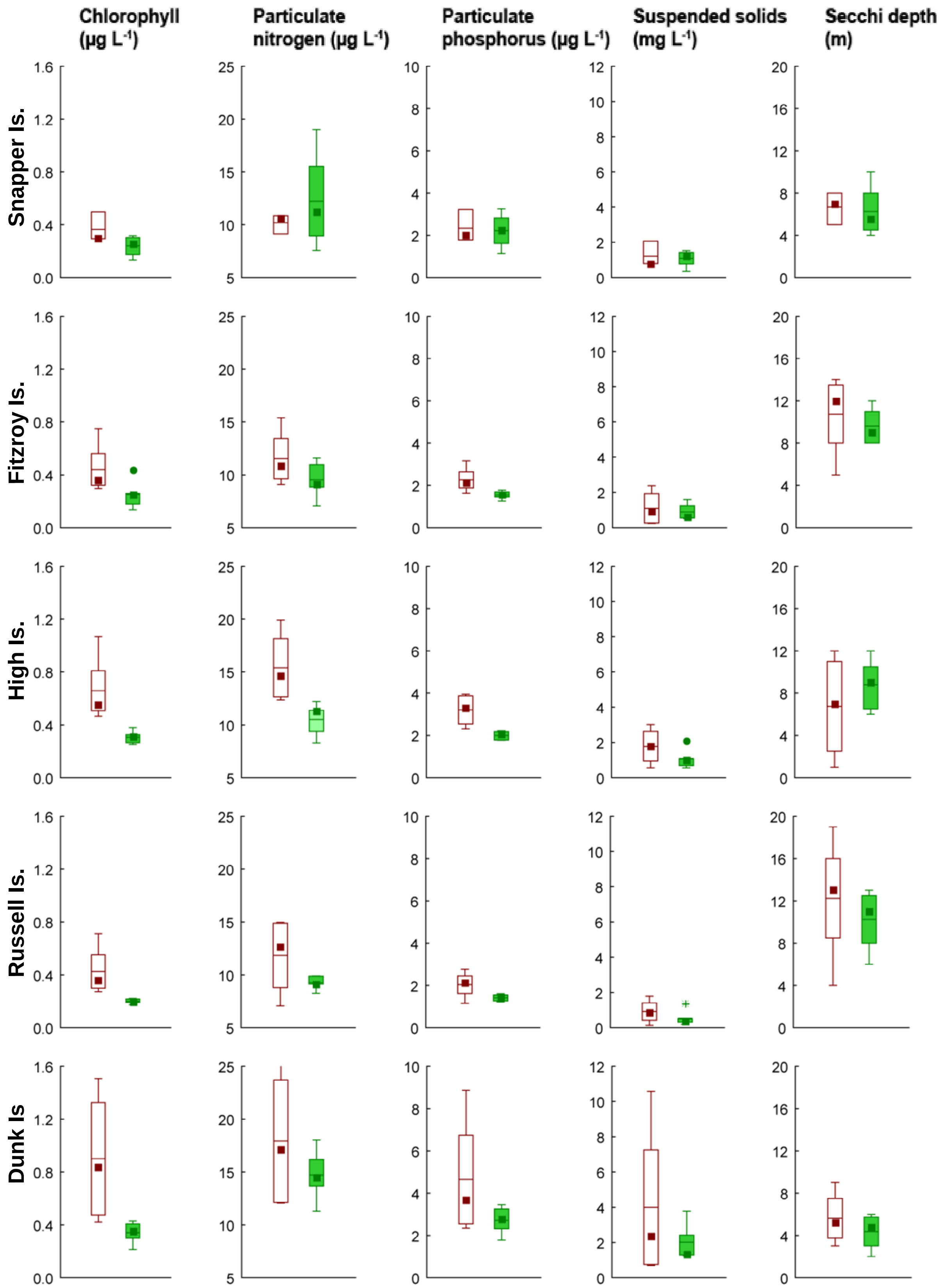

Figure 2.3 Summary of concentrations of chlorophyll, particulate phosphorus, particulate nitrogen (µg L-1), suspended solids (mg L-1) and Secchi depth (m) at sampling sites in the Wet Tropics Region over four sampling years (2005/06 to 2008/09). Dry season values (May- Oct) = shaded boxes, wet season (Nov-Apr)= white boxes. See page 9 for more details about the box plot presentation.

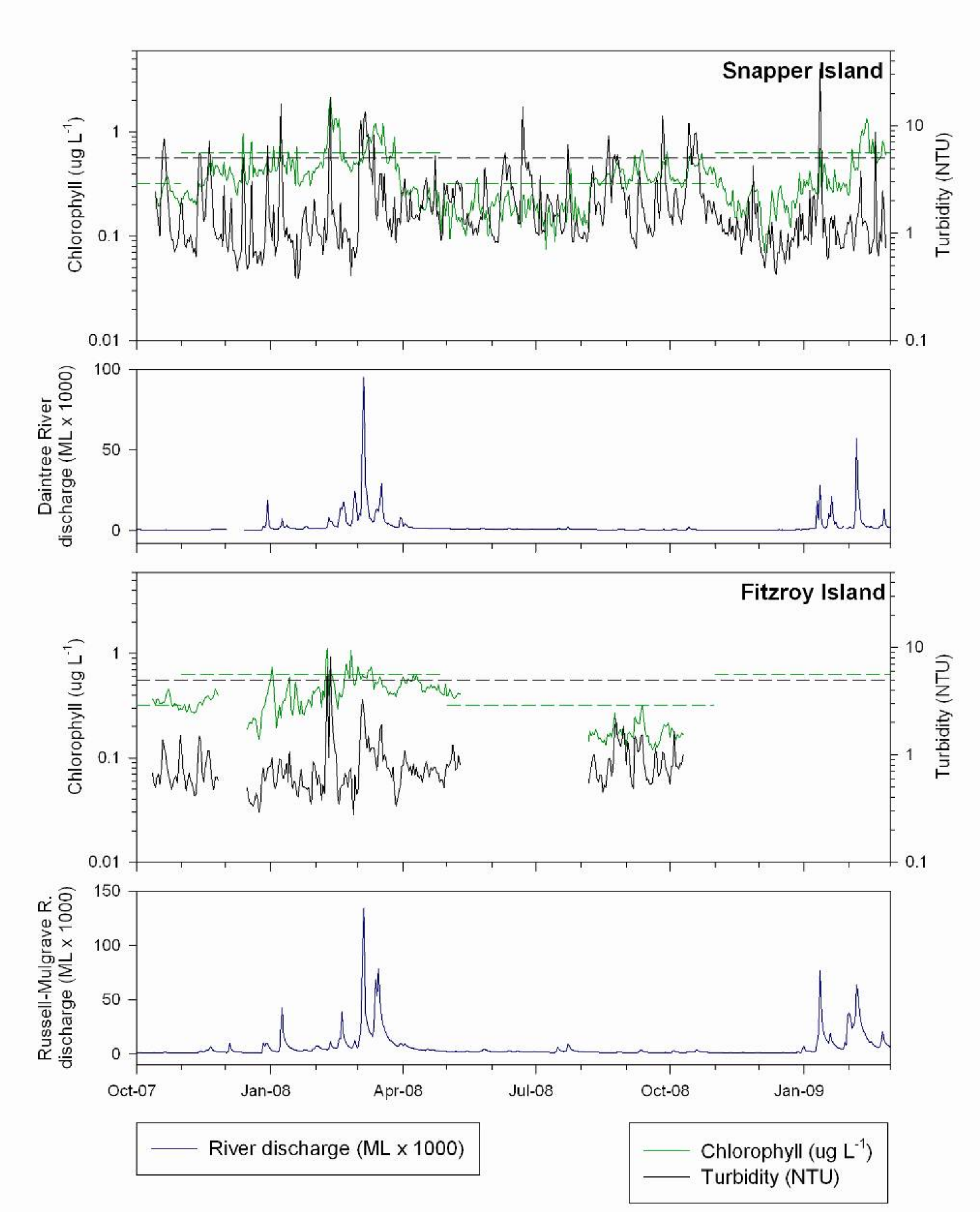

Figure 2.4 Time series of daily means of chlorophyll (µg L^{-1}, green line) and turbidity (NTU, black line) collected by Eco FLNTUSB instruments at Snapper, Fitzroy, High, Russell and Dunk islands in the Wet Tropics NRM Region. Additional panel represents the daily discharge from the closest river (ML x 1000, blue line). Green horizontal dashed lines are chlorophyll GBRMPA Guideline trigger values (seasonally adjusted, GBRMPA 2009), black dashed lines are a suggested turbidity 'threshold' of 5 NTU (Cooper *et al.* 2008).

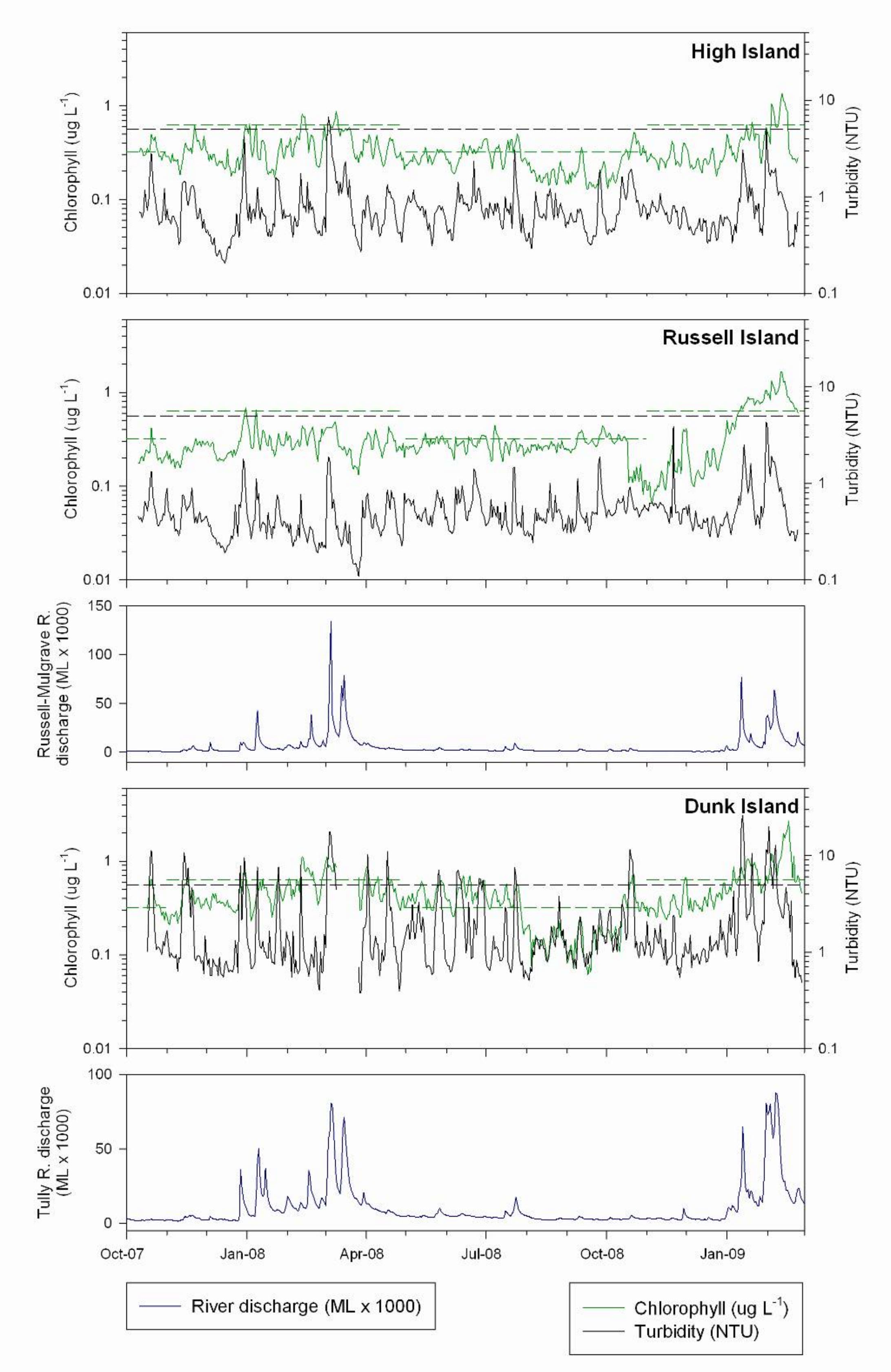

Figure 2.4 continued

Cairns Long-term water quality transect

The long-term time series of water quality parameters sampled since 1989 along the 'AIMS Cairns Coastal Transect' (see Figure 2.1 and Table 2.1 for sampling locations) was continued and all data were reanalysed. All parameters, except chlorophyll *a*, showed significant long-term patterns (Figure 2.10, Table 2.5). Long-term trends in particulate nitrogen (PN) and suspended solids (SS) were non-linear, while particulate phosphorus (PP) showed a linear trend of declining values over time. SS concentrations increased in the early to late 1990s, peaked around 1999 and then declined. Particulate nitrogen (PN) and chlorophyll levels fluctuated over years, which may be an indication of a multi-year cycling, had high values around 1999 but generally decreased over time. An analysis of driving factors is underway and results so far indicate that flood events and resuspension events at the time of sampling are the most prominent drivers of the water quality variables at the Cairns transect locations (Schaffelke *et al.* in prep). The highest concentrations were measured in periods of with above median flood events over several years (e.g. 1989 -91 and 1999-2001). There is currently no indication that the temporal pattern is related to changes in land use. Modelled suspended sediment and nutrient loads for the Barron River do not indicate a change over the period of time the Cairns transect was samples are predominantly related to river flow variability (John Armour, pers. comm.). However, more catchment-related data are sought to include in the analysis.

In addition to the long-term trends, some variables had recurring seasonal trends (Table 2.5, data not presented in a figure). SS steadily increased from January to August/September and then declined. Chlorophyll rose from January to March/April and then steadily declined. PN, PP, TDN and TDP showed no significant variation across months.

Table 2.3 Cairns long-term water quality transect. Analyses of variance assessing the significance of trends over time, by years and months. Df= degrees of freedom, F= Variance ratio, P= probability.

Response Variable	Source	df	F	P	Deviance explained (%)
Particulate Nitrogen	Years	6	6.526	0.00007	60
	Months	3	2.212	0.093	
	Residuals	39			
Particulate Phosphorus	Years	1	5.476	0.0133	26.8
	Months	3	1.634	0.1892	
	Residuals	43			
Suspended Solids	Years	2	6.547	0.00196	48.8
	Months	3	4.232	0.0083	
	Residuals	38			
Chlorophyll *a*	Years	5	2.19	0.06993	44.9
	Months	3	4.428	0.00635	
	Residuals	40			

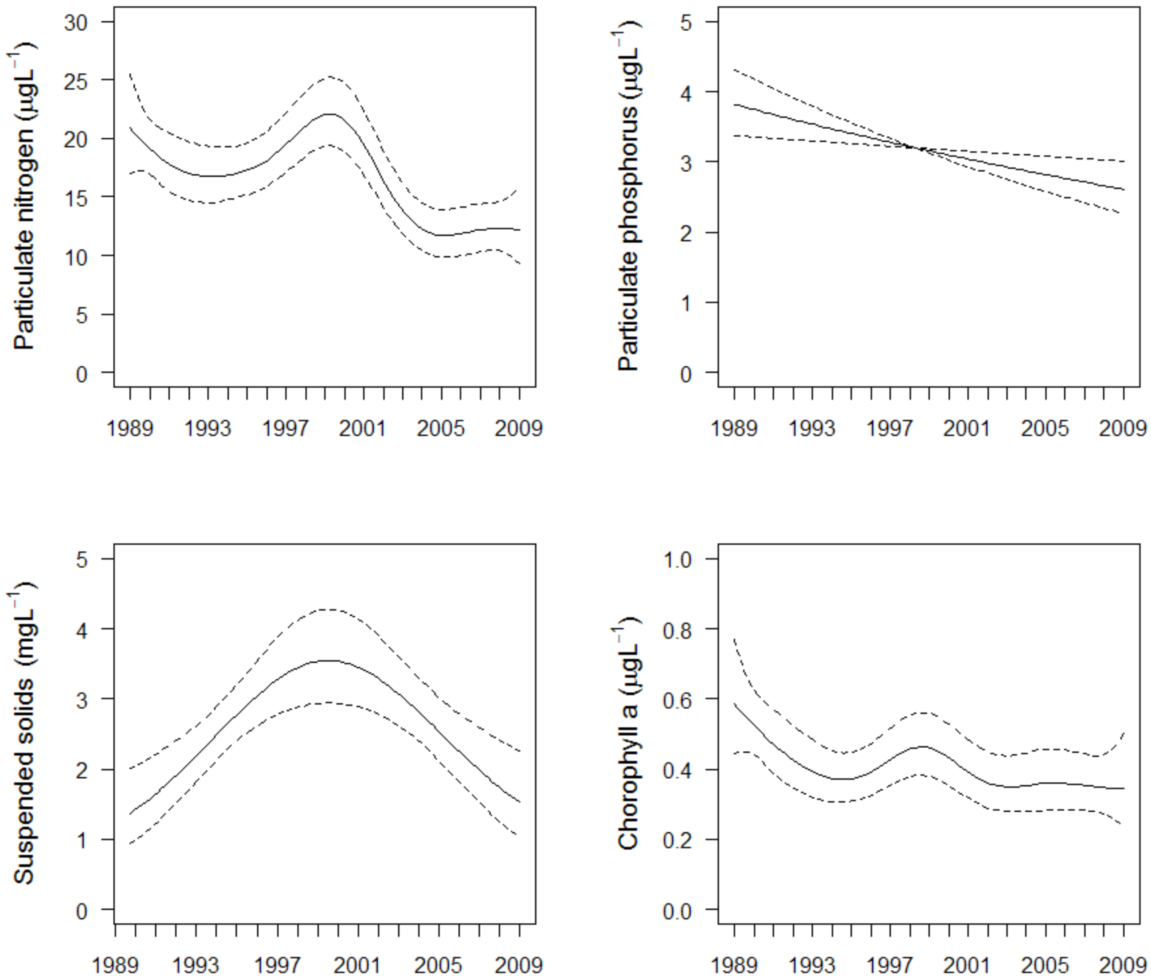

Figure 2.10 Smooth trends over sampling years from 1989 to2008 (partial effects) for the water quality parameters dissolved organic nitrogen (µg L^{-1}), dissolved organic phosphorus (µg L^{-1}), particulate nitrogen (µg L^{-1}), particulate phosphorus (µg L^{-1}), suspended solids (mg L^{-1}) and chlorophyll a (µg L^{-1}).

Region Reports: Burdekin Region

The Burdekin Region is one of the two large dry tropical catchment regions in the GBR Region with cattle grazing as the primary land use. There is also extensive irrigated planting of sugarcane on the floodplains of the Burdekin and Haughton Rivers. Fluctuations in climate and cattle numbers greatly affect the state and nature of vegetation cover, and therefore, the susceptibility of soils to erosion, which leads to runoff of suspended sediments and associated nutrients.

The three water quality sampling sites in the Burdekin region are located on a gradient away from the Burdekin River mouth (Figure 2.4). The Burdekin River had major flood events in 2008 and 2009, after annual flows had been below the long-term median since 2001(Table A1-2.2 in Appendix 1).

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Figure 2.4 Reef Rescue MMP water quality sampling sites (blue squares) in the Burdekin NRM Region at Pelorus Island, Pandora Reef and Geoffrey Bay.

Seasonal means over four years of monitoring for the water quality parameters for which guideline trigger values were available (GBRMPA 2009) are presented in Figure 2.5. Trigger values were exceeded at all three locations for wet season means of chlorophyll *a* and Secchi depth in both seasons. Geoffrey Bay, Magnetic Island, generally had the highest seasonal means of all locations in this region, and the means of all variables, except for PN in the wet season, exceeded trigger values (Figure 2.5). Pelorus Island in the Palm Islands group had the lowest concentrations of all four variables and the highest Secchi depth readings in this region. Detailed results for all water quality variables for the sampling year 2008/09 are in Appendix 1, Tables A1-2.3 to A1-2.8.

The instrumental water quality monitoring data showed essentially the same pattern for the variables chlorophyll and turbidity as the direct water sampling results (Figure 2.6). The instrumental turbidity readings confirm the clear gradient of locations away from the Burdekin River mouth. Turbidity readings were highest at Geoffrey Bay, which is closest to the Burdekin mouth and lowest at Pelorus Island, the location furthest away. Annual and seasonal turbidity means for Geoffrey Bay were above the trigger value for SS (Table 2.4; after conversion to NTU, see Appendix 2 for details), and 12% of daily records over the whole period (October 2007 to February 2009) were above the suggested 5 NTU limit for severe coral photo-physiological stress (Cooper *et al.* 2007, 2008). Most of the turbidity maxima were associated with flood influences during the 2008 and 2009 wet seasons (Figure 2.6).

Chlorophyll trigger values for annual and dry season means were exceeded at all sites, and wet season means at Geoffrey Bay and Pelorus Island (Table 2.3). The instrumental data also show clear flood signals for both the 2008 and 2009 wet seasons. High values for both chlorophyll and turbidity coincide with discharge from the Burdekin River (Figure 2.6). Wet season exceedances were significant in Geoffrey Bay with 66% of all daily chlorophyll records above the trigger value during the wet seasons. At Pandora Reef and Pelorus Island wet season chlorophyll values were clearly associated with flood events, however, it is noteworthy that more than half of the daily records during the dry season were above the chlorophyll trigger value.

The spikiness of the record indicates that Geoffrey Bay and Pandora Reef are regularly experiencing wind-driven resuspension, which leads to frequent spikes in turbidity and may also bee the cause of generally high chlorophyll concentrations in the water. The Pelorus Island sampling location is more protected from prevailing winds and shows generally lower turbidity. However, the relatively high chlorophyll concentrations at this site are surprising and may be driven by other factors than resuspension.

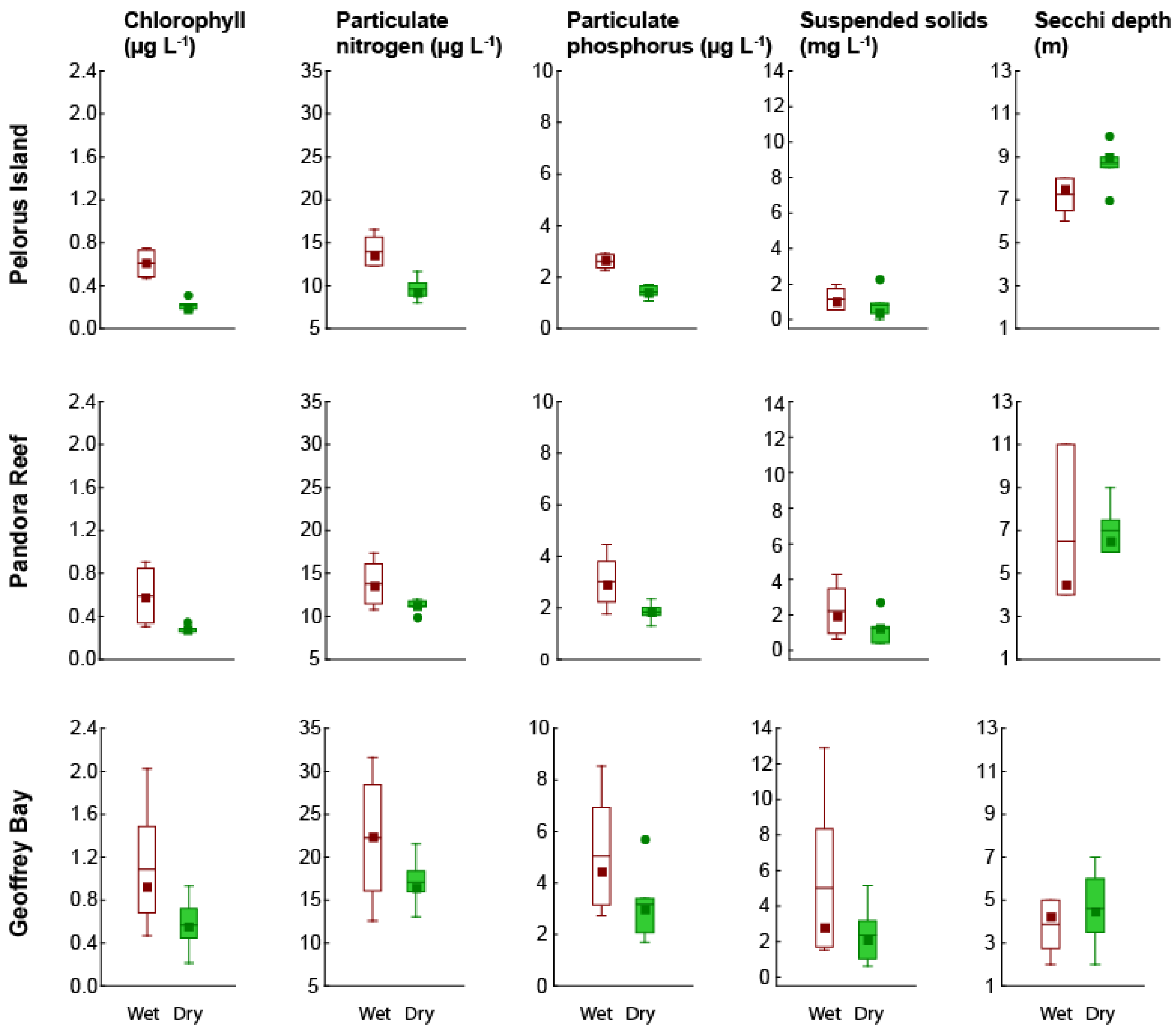

Figure 2.5 Summary of concentrations of chlorophyll, particulate phosphorus, particulate nitrogen (µg L-1), suspended solids (mg L-1) and Secchi depth (m) at sampling sites in the Burdekin Region over four sampling years (2005/06 to 2008/09). Dry season values (May- Oct) = shaded boxes, wet season (Nov-Apr)= white boxes. See page 9 for more details about the box plot presentation.

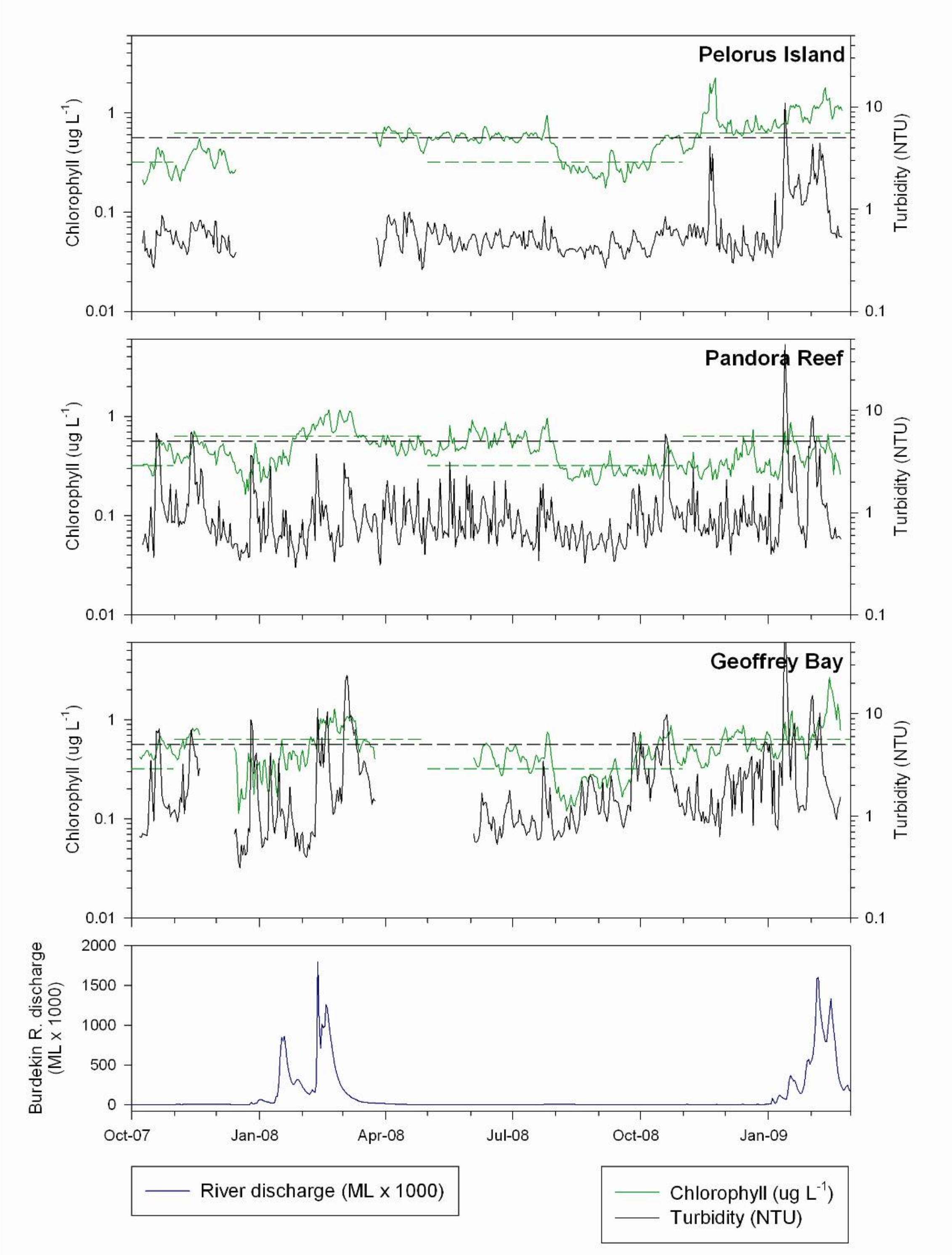

Figure 2.6 Time series of daily means of chlorophyll (µg L^{-1}, green line) and turbidity (NTU, black line) collected by Eco FLNTUSB instruments at Pelorus Island, Pandora Reef and Geoffrey Bay in the Burdekin NRM Region. Additional panel represents the daily discharge from the Burdekin River (ML x 1000, blue dashed line). Green horizontal dashed lines are chlorophyll GBRMPA Guideline trigger values (seasonally adjusted, GBRMPA 2009), black dashed lines are a suggested turbidity 'threshold' of 5 NTU (Cooper *et al.* 2008).

Region Reports: Mackay Whitsunday Region

The Mackay Whitsunday Region is located in the central section of the GBR and comprises four major river catchments, the Proserpine, O'Connell (both flowing into Repulse Bay), Pioneer and Plane catchments. The climate in this region is wet or mixed wet and dry and the catchment land use is dominated by agriculture such as cropping (mainly sugarcane on coastal plains), some grazing in the upper catchments and minor urbanisation along the coast (Furnas 2003). The adjacent coastal and inshore marine areas have a large number of high continental islands with well-developed fringing reefs. Tides in the Whitsunday Region are semidiurnal and the tidal range can exceed 4.0 m, which is higher than most other areas on the GBR.

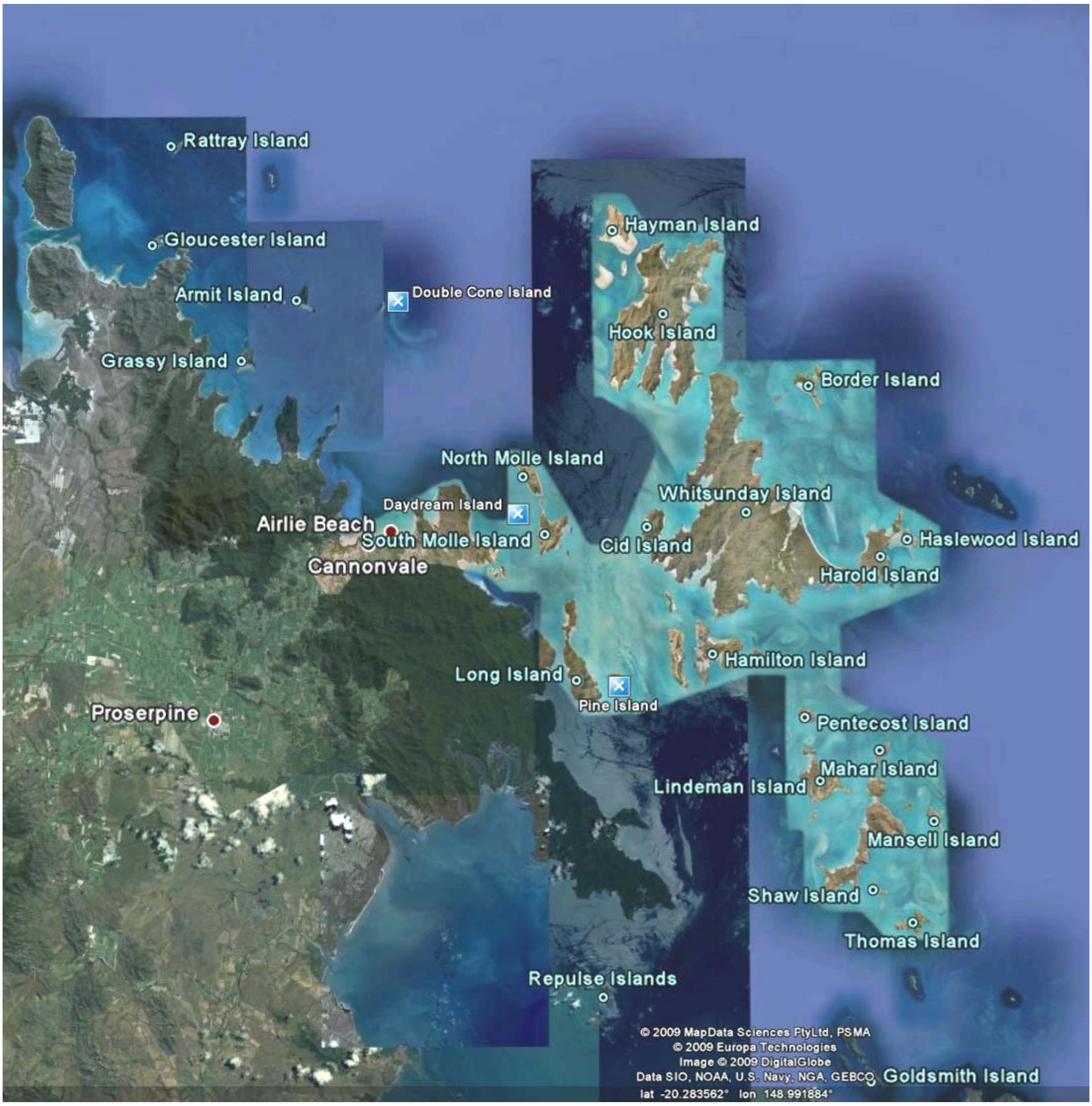

Figure 2.7 Reef Rescue MMP water quality sampling sites (blue squares) in the Mackay Whitsunday NRM Region at Double Cone Island, Daydream Island and Pine Island.

The three sampling locations in the Mackay Whitsunday Region are located away from riverine influence of the three major rivers in this region (Figure 2.7). The Proserpine, O'Connell and Pioneer rivers had above long-term median flows during the past three years and major floods during the 2008 wet season (Table A1-2.2 in Appendix 1).

Seasonal means over four years of monitoring for the water quality parameters for which guideline trigger values were available (GBRMPA 2009) are presented in Figure 2.8. Trigger values were exceeded at all three locations for dry season means of chlorophyll *a* and Secchi depth in both seasons (except for Daydream Island in the wet season). Suspended solids means exceeded dry season trigger values at both Daydream and Pine Island.

Of locations in this region, Pine Island generally had the highest seasonal means of all variables, closely flowed by Daydream Island (Figure 2.8). Double Cone Island generally had lower values, which is not surprising as this monitoring location is furthest away from both the mainland coast and the influence of the rivers in this Region. Detailed results for all water quality variables for the sampling year 2008/09 are in Appendix 1, Tables A1-2.3 to A1-2.8.

The instrumental water quality monitoring data showed essentially the same pattern for the variables chlorophyll and turbidity as the direct water sampling results (Figure 2.9). The instrumental readings confirm the clear gradient of locations away from riverine influence. Concentrations of chlorophyll *a* and turbidity values were highest at Pine Island and lowest at Double Cone Island (Figure 2.9).

Annual and seasonal turbidity means for Pine and Daydream islands were above the trigger value for SS (Table 2.4; after conversion to NTU, see Appendix 2 for details), and 12% and 7%, respectively, of daily records over the whole period (October 2007 to February 2009) were above the suggested 5 NTU limit for severe coral photo-physiological stress (Cooper *et al.* 2007, 2008). Most of the turbidity maxima were associated with flood influences during the 2008 and 2009 wet seasons (Figure 2.9). However, especially at Pine and Daydream islands, the turbidity records show a regularity that implies a strong tidal influence and high turbidity values are associated with the summer king tides (Schaffelke *et al.* in prep). These two sites are relatively protected in prevailing winds and wind-driven resuspension rarely occurred over the instrumental monitoring period. The spikiness of the record indicates that Double Cone Island was regularly experiencing wind-driven resuspension, which masks the tidal signal, but turbidity was in general low (Figure 2.9, Table 2.4).

Chlorophyll trigger values for annual and dry season means were exceeded at all sites, and wet season means at Pine Island (Table 2.3). At the three locations, between 65 and 100% of the dry season chlorophyll values were above the trigger value, which is higher than in any other region monitored. The instrumental chlorophyll data did not show clear flood signals for both the 2008 and 2009 wet seasons at any of the three locations (Figure 2.9). Wet season exceedances were significant only at Pine Island with 58% of all daily chlorophyll records above the trigger value during the wet seasons. Higher chlorophyll values were observed throughout the summer and seem to be coinciding with turbidity spikes. The tidal influence on chlorophyll values in this region is currently being explored (Schaffelke *et al.* in prep).

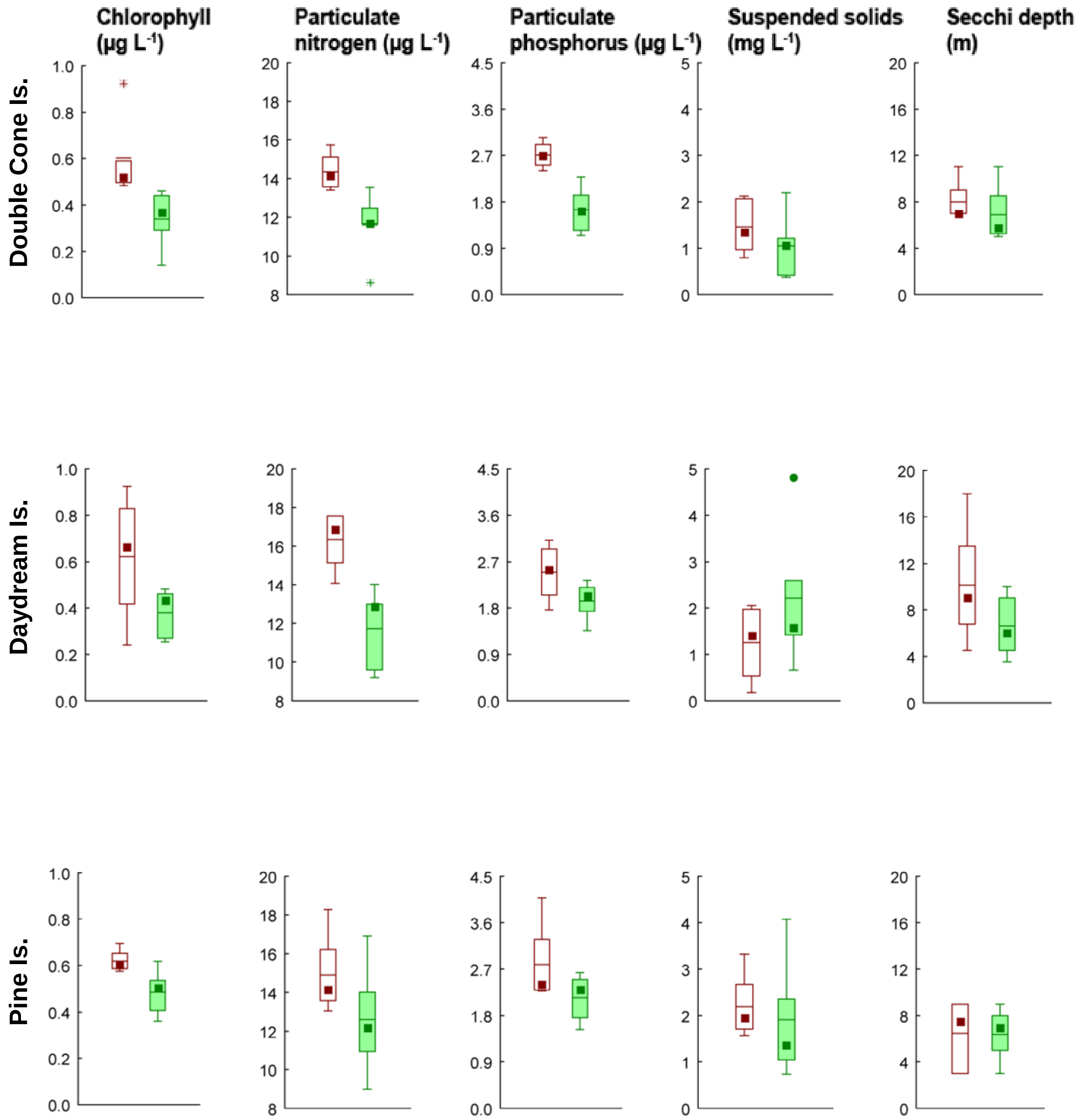

Figure 2.8 Summary of concentrations of chlorophyll, particulate phosphorus, particulate nitrogen (µg L-1), suspended solids (mg L-1) and Secchi depth (m) at sampling sites in the Mackay Whitsunday Region over four sampling years (2005/06 to 2008/09). Dry season values (May- Oct) = shaded boxes, wet season (Nov-Apr)= white boxes. See page 9 for more details about the box plot presentation.

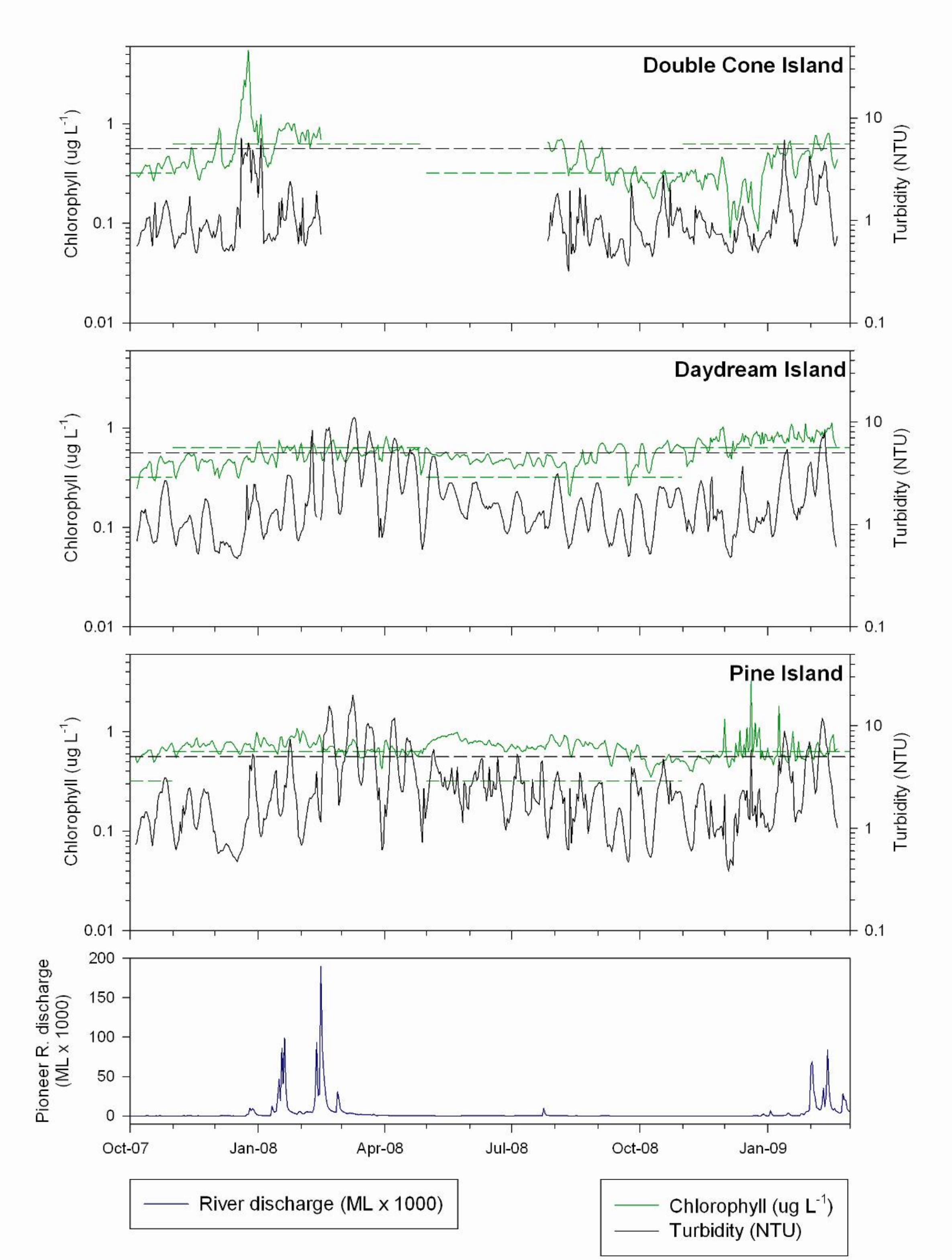

Figure 2.9 Time series of daily means of chlorophyll (µg L^{-1}, green line) and turbidity (NTU, black line) collected by Eco FLNTUSB instruments at Double Cone, Daydream and Pine islands in the Mackay Whitsunday NRM Region. Additional panel represents the daily discharge from the closest river (ML x 1000, blue line). Green horizontal dashed lines are chlorophyll GBRMPA Guideline trigger values (seasonally adjusted, GBRMPA 2009), black dashed lines are a suggested turbidity 'threshold' of 5 NTU (Cooper *et al.* 2008).

Region Reports: Fitzroy 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 (Brodie *et al.* 2003). Fluctuations in climate and cattle numbers greatly affect the state and nature of vegetation cover, and therefore, the susceptibility of soils to erosion, which leads to runoff of suspended sediments and associated nutrients.

The three sampling locations in Keppel Bay are located on a gradient away from the Fitzroy River mouth (Figure 2.10). The Fitzroy River had only one major flood event during the monitoring period, in 2008 (Table A2-2.2 in Appendix 1). For most of the past 10 years flows were below the long-term median.

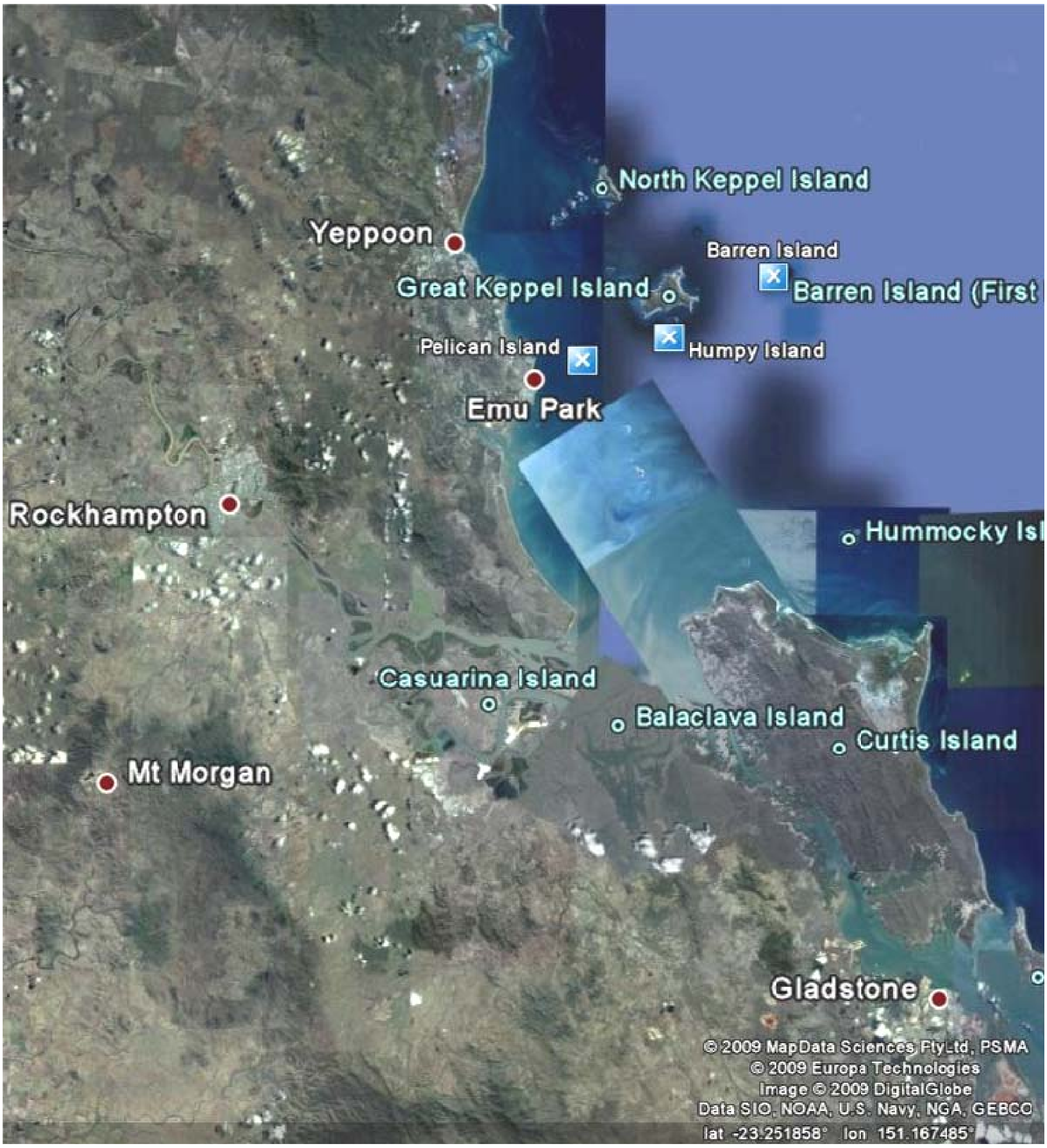

Figure 2.10 Reef Rescue MMP water quality sampling sites (blue squares) in the Fitzroy NRM Region at Pelican Island, Humpy Island and Barren Island.

Seasonal means over four years of monitoring for the water quality parameters for which guideline trigger values were available (GBRMPA 2009) are presented in Figure 2.11. All variables showed highest values at Pelican Island, the most inshore location. Trigger values were exceeded at Pelican Island for all parameters, except for PN in the dry season. The water quality at Barren Island, the location furthest offshore, was within trigger values, while Humpy Island only exceeded the chlorophyll *a*, PP and Secchi depth wet season trigger values. Detailed results for all water quality variables for the sampling year 2008/09 are in Appendix 1, Tables A1-2.3 to A1-2.8.

The instrumental water quality monitoring data showed essentially the same pattern for the variables chlorophyll and turbidity as the direct water sampling results (Figure 2.12). The instrumental readings confirm the clear gradient of locations away from the Fitzroy River mouth. Chlorophyll trigger values for annual and seasonal means were exceeded at Pelican Island, and dry season means at Humpy Island (Table 2.3). Seasonal exceedances were significant at this location with 42% and 52% of all daily chlorophyll records for wet and dry seasons, respectively, above the trigger value. Humpy and Barren also had high chlorophyll for a substantial part of the dry seasons (Table 2.3).

Turbidity readings were highest at Pelican Bay, which is closest to the Fitzroy mouth and lowest at Barren Island, the location furthest away. Annual and seasonal turbidity means for Pelican Island were above the trigger value for SS (Table 2.4; after conversion to NTU, see Appendix 2 for details), and 31% of daily records over the whole period (October 2007 to February 2009) were above the suggested 5 NTU limit for severe coral photo-physiological stress (Cooper *et al.* 2007, 2008). Pelican Island had the highest turbidity of all 14 inshore GBR monitoring locations. Most of the turbidity maxima were associated with the major flood event during the 2008 wet season, however, Pelican Island was regularly experiencing wind-driven resuspension, which led to frequent spikes in turbidity (Figure 2.12). The annual and seasonal mean turbidity readings at Humpy and Barren Island were below SS trigger values and the water was generally very clear, especially during the dry seasons (Table 2.4).

High values for both chlorophyll and turbidity at all three locations coincided with discharge from the Fitzroy River in 2008 (Figure 2.12). 2009 had below median flow from the Fitzroy River and high chlorophyll and turbidity values during the wet season are more likely to be associated with wind-driven resuspension. All three sampling locations are relatively exposed to the prevailing winds and the spikiness of the record indicates that Pelican and Humpy islands regularly experienced resuspension events, leading to spikes in turbidity. However, Barron Island is further offshore and the reefal sediments had a very low proportion of clay-silt-sized particles (see Chapter 3), which is likely to result in lower turbidity during wind-driven resuspension events.

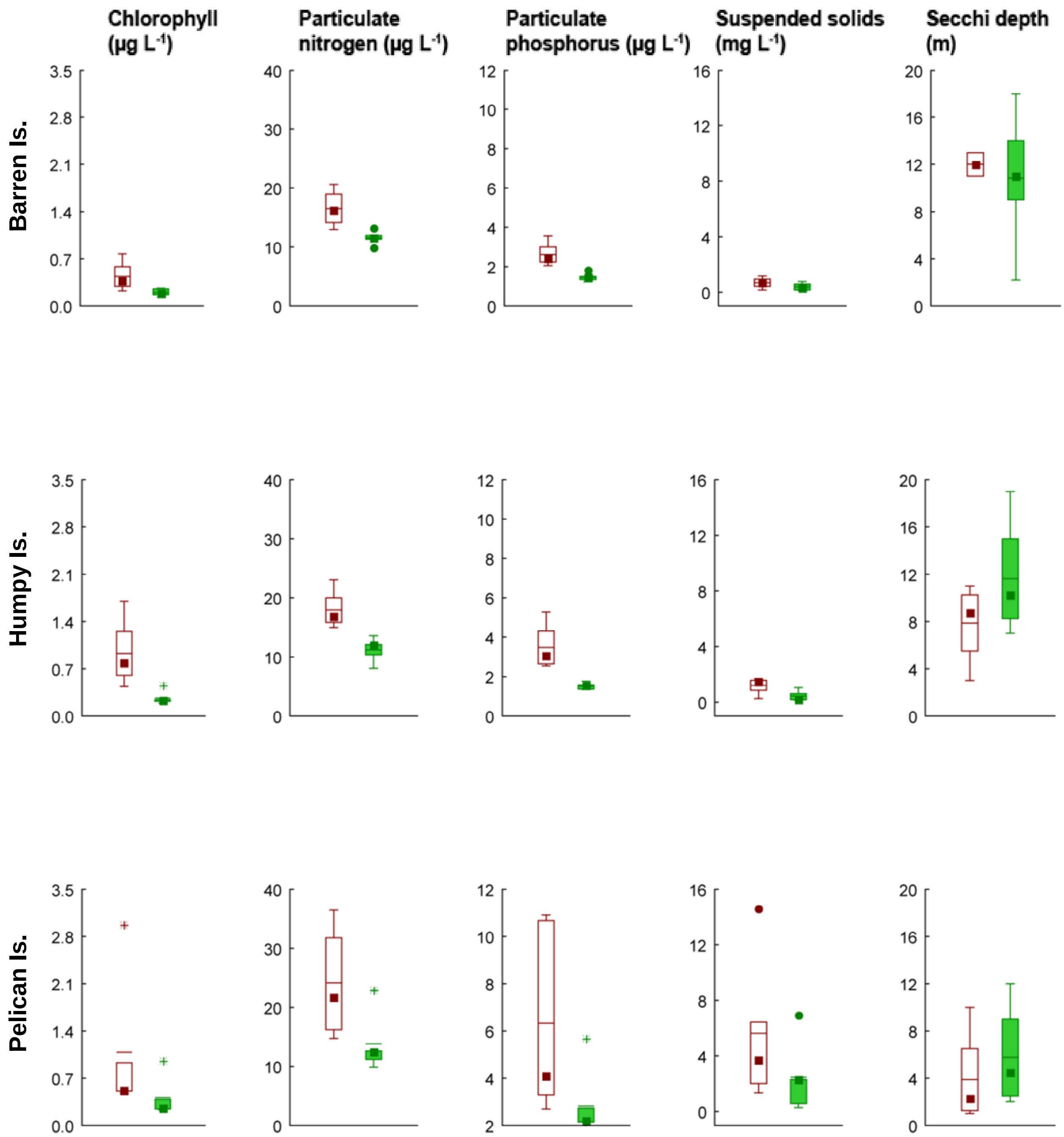

Figure 2.11 Summary of concentrations of chlorophyll, particulate phosphorus, particulate nitrogen (µg L-1), suspended solids (mg L-1) and Secchi depth (m) at sampling sites in the Fitzroy Region over four sampling years (2005/06 to 2008/09). Dry season values (May- Oct) = shaded boxes, wet season (Nov-Apr)= white boxes. See page 9 for more details about the box plot presentation.

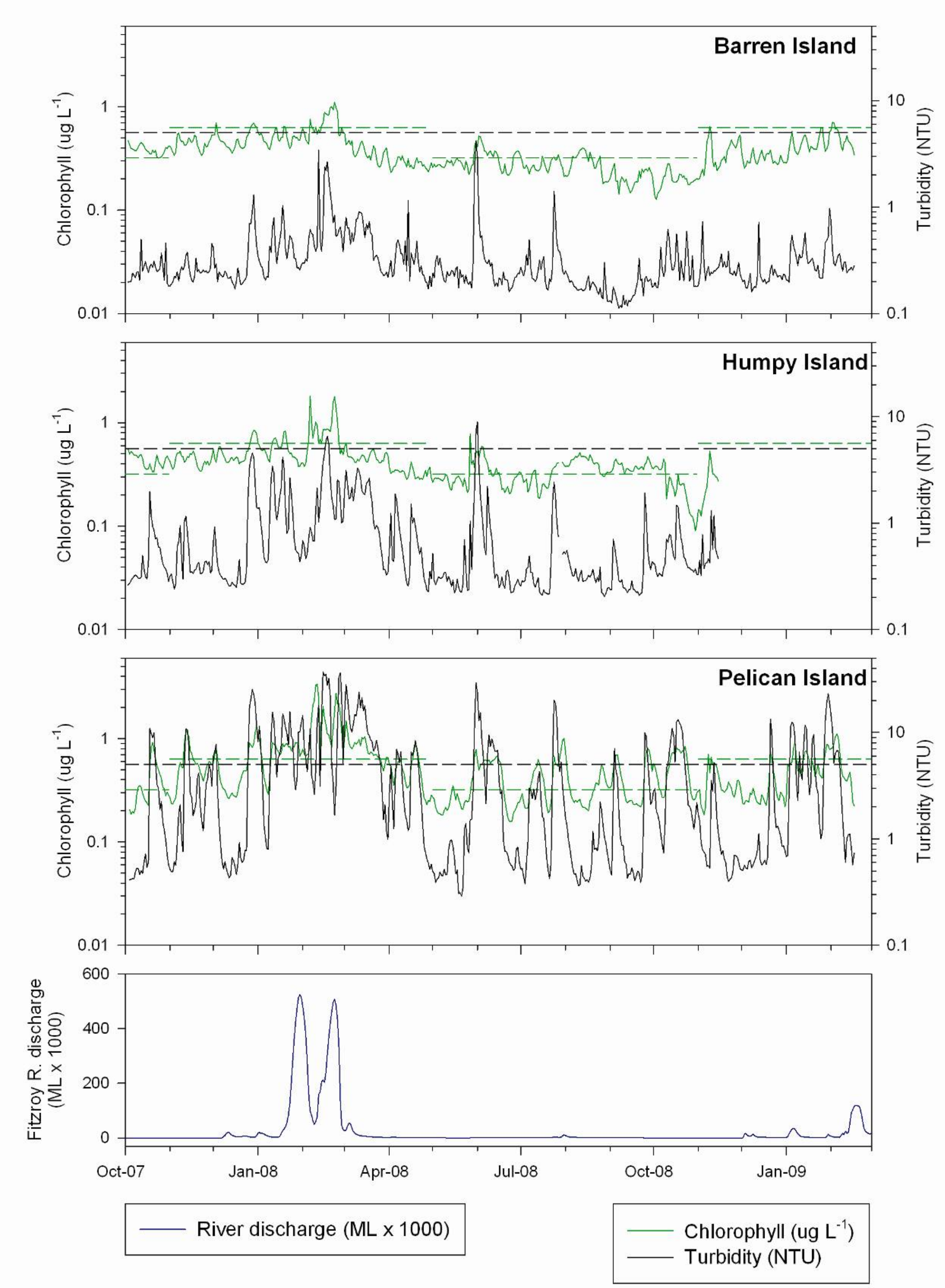

Figure 2.12 Time series of daily means of chlorophyll (µg L^{-1}, green line) and turbidity (NTU, black line) collected by Eco FLNTUSB instruments at Barren, Humpy and Pelican islands in the Fitzroy NRM Region. Additional panel represents the daily discharge from the closest river (ML x 1000, blue line). Green horizontal dashed lines are chlorophyll GBRMPA Guideline trigger values (seasonally adjusted, GBRMPA 2009), black dashed lines are a suggested turbidity 'threshold' of 5 NTU (Cooper *et al.* 2008).

Table 2.4 Summary of chlorophyll (µg L^{-1}) data from deployments of WET Labs Eco FLNTUSB Combination Fluorometer and Turbidity Sensors at 14 inshore reef sites. N= number of daily means in the reported time series (October 2007 to February 2009); SE= standard error; "> trigger value" refers to the percentage of days with mean values above the chlorophyll trigger values (seasonally adjusted) in the GBRMPA Water Quality Guideline for the Great Barrier Reef Marine Park (GBRMPA 2009). Shading highlights the annual or seasonal means that are above the trigger values.

NRM Region	Location	Chlorophyll *a* Annual mean	SE	N	Chlorophyll *a* Wet season mean	SE	> trigger value (wet season)	Chlorophyll *a* Dry season mean	SE	> trigger value (dry season)
Wet Tropics	Snapper Island	0.375	0.011	502	0.435	0.016	17	0.286	0.009	42
	Fitzroy Island	0.365	0.011	259	0.442	0.012	9	0.235	0.010	28
	Russell Island	0.327	0.010	504	0.367	0.016	15	0.269	0.004	19
	High Island	0.336	0.007	503	0.379	0.010	7	0.273	0.006	31
	Dunk Island	0.456	0.013	484	0.549	0.018	23	0.322	0.012	58
Burdekin	Pelorus Island	0.574	0.015	404	0.710	0.025	20	0.443	0.011	64
	Pandora Reef	0.463	0.008	503	0.480	0.012	24	0.437	0.012	58
	Geoffrey Bay	0.527	0.014	411	0.627	0.021	66	0.393	0.012	32
Mackay Whitsunday	Double Cone Island	0.497	0.024	342	0.568	0.036	25	0.370	0.012	65
	Daydream Island	0.567	0.007	501	0.620	0.010	15	0.494	0.007	95
	Pine Island	0.690	0.008	505	0.687	0.012	58	0.695	0.009	100
Fitzroy	Barren Island	0.371	0.007	504	0.437	0.009	9	0.281	0.005	31
	Humpy Island	0.423	0.010	408	0.506	0.017	18	0.345	0.007	59
	Pelican Island	0.549	0.017	503	0.654	0.026	42	0.404	0.014	52

Table 2.5 Summary of turbidity (NTU) data from deployments of WET Labs Eco FLNTUSB Combination Fluorometer and Turbidity Sensors at 14 inshore reef sites. N= number of daily means in the reported time series (October 2007 to February 2009); SE= standard error; "> 5 NTU" refers to the percentage of days with mean values above the suggested turbidity threshold for coral light limitation of 5 NTU (Cooper *et al.* 2008). Shading highlights the annual and seasonal means that are above the suspended solids trigger values (GBRMPA 2009) after conversion to NTU (see text and Appendix 2 for details).

NRM Region	Location	Turbidity Annual mean	SE	N	> 5 NTU	Turbidity Wet season mean	SE	Turbidity Dry season mean	SE
Wet Tropics	Snapper Island	2.109	0.114	502	7	1.861	0.163	2.478	0.145
	Fitzroy Island	0.849	0.044	259	1	0.834	0.066	0.875	0.036
	Russell Island	0.543	0.018	504	0	0.539	0.028	0.548	0.017
	High Island	0.821	0.028	503	1	0.840	0.044	0.793	0.028
	Dunk Island	2.244	0.134	484	11	2.427	0.205	1.983	0.137
Burdekin	Pelorus Island	0.686	0.039	404	0	0.893	0.077	0.489	0.008
	Pandora Reef	1.205	0.104	503	2	1.363	0.171	0.980	0.061
	Geoffrey Bay	2.660	0.238	411	12	3.318	0.401	1.781	0.126
Mackay Whitsunday	Double Cone Island	1.163	0.052	342	1	1.294	0.076	0.931	0.040
	Daydream Island	1.962	0.076	501	7	2.261	0.123	1.547	0.052
	Pine Island	2.748	0.118	505	12	3.166	0.192	2.167	0.077
Fitzroy	Barren Island	0.352	0.016	504	0	0.396	0.021	0.291	0.026
	Humpy Island	0.839	0.052	408	1	1.147	0.081	0.550	0.059
	Pelican Island	4.701	0.282	503	31	5.951	0.422	2.987	0.296

Analysis of spatial and temporal patters in water quality data

The concentrations of water quality parameters measured in the GBR inshore lagoon over four years were in the expected range (e.g., Schaffelke et al. 2003, Furnas 2005, Furnas et al. 2005, Cooper et al. 2007, De'ath and Fabricius 2008). The observed seasonal changes also followed recognised patterns; with higher concentrations of most parameters (chlorophyll a, suspended solids and nutrient species), other than salinity, measured during the wet season (ibid.).

The water quality data from four years of direct water sampling were analysed for temporal and spatial differences using multivariate analysis of variance. The MANOVA resulted in significant high-level interactions between sampling years, seasons and regions indicating that the effects of each factor were not consistent across levels of the other factors (Table 2.6). This means that no single factor can be considered in isolation.

Table 2.6 Results of PERMANOVA[1] applied to annual, seasonal and regional differences in water quality. df= degrees of freedom, SS= sum of squares, MS= mean square.

Source	df	SS	MS	Pseudo-F	P(perm)	Unique permutations
Year	3	1022.1	340.71	5.7395	0.0004	4984
Season	1	4737.3	4737.3	79.804	0.0002	4988
NRM Region	3	1026.3	342.1	5.7628	0.0002	4978
Year x Season	3	1318.7	439.57	7.4049	0.0002	4990
Year x Region	9	1680.4	186.71	3.1453	0.0002	4985
Season x Region	3	1947.3	649.11	10.935	0.0002	4988
Year x Season x Region	9	1467	163	2.7458	0.001	4974
Residual	147	8726.2	59.362			
Total	178	22609				

To investigate possible sources of variation the data were further explored with a multivariate multiple regression procedure between the water quality variables and an expanded set of explanatory variables which included month and year of sampling for temporal aspects, latitude and longitude for spatial aspects and a resuspension index and river flow of the nearest river as potential environmental drivers (see the Materials & Methods section for more detail about the selection of the explanatory variables). The results are presented in a series of two-dimensional, distance-based redundancy biplots (Figures 2.13 to 2.16), each highlighting a different aspect of the data.

The sequential conditional test indicated that 40% of the variation in the water quality data set was explained by the variables of Month (19.9%), Resuspension Index (7%), River Flow (6.2%) Latitude (3.8%) and Year (3.5%) (Table 2.7). Longitude and distance to Nearest River did not make a significant contribution ($p>0.05$) to the regression model. Most variation was explained by the factor

[1] Table 2.6 can be read and interpreted analogous to traditional analyses of variance. Pseudo-F is a test statistic with a frequency distribution generated from the data through a permutation process which randomly allocates factor labels with the dissimilarity matrix; P(perm) is the probability associated with the test statistics calculated as the proportion of randomly generated pseudo-F values greater than or equal to the pseudo-F statistic obtained from the true, nonrandom labeling; unique permutations is the number of permutations used to obtain the pseudo-F distribution.

of Month highlighting the clear separation of the data into wet season and dry season sampling occasions (Figures 2.13 and 2.14, Table 2.7). The seasonal separation is mainly due to the physical variables of temperature and salinity, and to a lesser extent by higher concentrations of DOC during the wet season which were highly correlated with increased River Flow at that time (Figure 2.13 and 2.14).

During the dry season the data were clearly separated by geographical regions (Fig 2.15, table 2.7), while during the wet season there was some overlap in the regional confidence ellipses. These differences are due to higher concentrations of particulate water quality constituents in the dry tropical catchments (Burdekin and Fitzroy) due, most likely, to greater resuspension in these regions. Resuspension Index was correlated with Latitude (Figure 2.15) as Fitzroy sites have a greater exposure of to the prevailing easterly winds.

The four sampling years from 2005/06 to 2008/09 were all very different with regard to the amount and regional distribution of riverine input. This pattern is clearly visible in the separation of sampling sites within years during the wet season (Figure 2.16). 2005/06 and 2006/07 were relatively dry years (Table A2-2.2 in Appendix 1). Discharge rates in the Wet Tropics rivers were just above the long-term median flow in 2005/06 and 2006/07. In 2006/07 also the Burdekin had above median flow but not a major flood event. In contrast, 2007/08 and 2008/09 were very wet years. Major flood events occurred in the Barron, Burdekin and Fitzroy rivers in 2007/08, and the Herbert and Burdekin rivers in 2008/09. The dry season samples are more tightly clustered between years, highlighting again the importance of river flow as a driving factor for seasonal differences.

In summary, differences within the water quality data were mainly driven by temporal and spatial factors, both inherent (i.e. summer vs. winter months) and extrinsic (i.e. spatio-temporal differences in 'resuspension' which is a function of local wind speed and direction and site characteristics such as depth and 'river flow' which is a proxy measure for land run-off constituents transported into the inshore GBR lagoon). The biplots clearly show the temporal (season and year) and spatial (region and resuspension/exposure) gradients in the data. Elevated nutrient concentrations in inshore waters usually indicate nutrient release from wind-forced re-suspension of coastal sediments (Walker 1982; Ullman and Sandstrom 1987; Furnas et al. 1997) and/or nutrient input from rivers (Devlin et al. 2001; Devlin and Brodie 2005).

As only 40% of total variability was explained, there are mostly likely other factors affecting water quality that were not considered. Factors such as tidal forcing, variability in the quantity and quality of adjacent riverine input of sediment and nutrients and regional sediment grainsize may all impact on water quality.

Table 2.7 Results of multivariate multiple regression (DISTLM) applied to water quality variables over four years of sampling (2005/06 to 2008/09) testing for the effects of the explanatory variables Year, Month, Resuspension Index, River Flow, Latitude, Longitude and distance to the Nearest River. Only variables that explained a significant proportion of variability in the data were included in the regression model (see the Materials & Methods section for more detail about the selection of explanatory variables). BIC= Bayesian Information Criterion; SS (trace)= the explained sum of squares for the regression; Pseudo-F= see footnote on page 33; P=probability; df= degrees of freedom.

SEQUENTIAL TESTS							
Variable	BIC	SS(trace)	Pseudo-F	P	Proportion of variation explained	Cumulative proportion	Residual df
Month	866.08	4610.1	45.836	0.001	0.19943	0.19943	184
Resuspension Index	854.17	1628.4	17.656	0.001	7.04E-02	0.26987	183
River Flow	842.96	1427.7	16.818	0.001	6.18E-02	0.33163	182
Latitude	837.36	872.89	10.838	0.001	3.78E-02	0.36939	181
Year	831.97	808.85	10.574	0.001	3.50E-02	0.40438	180

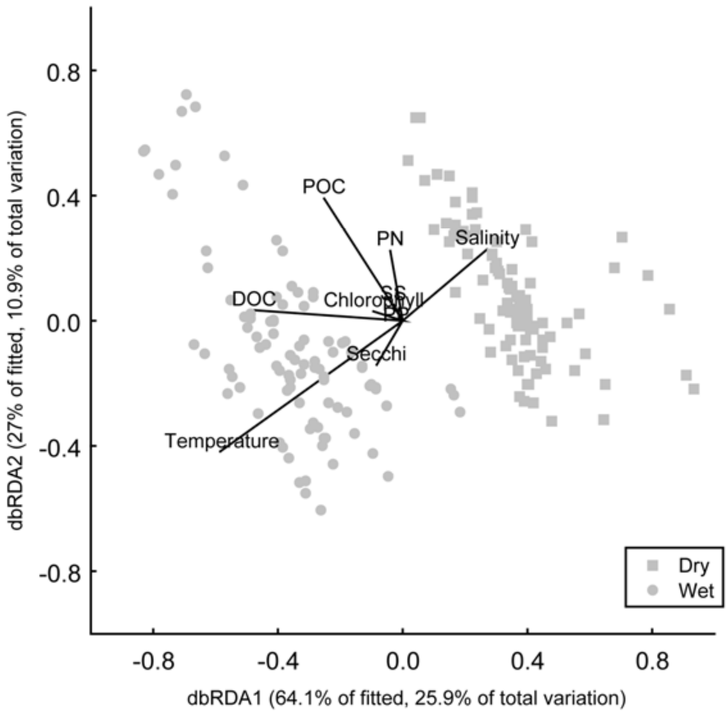

Figure 2.13 Two-dimensional biplot of the partial correlation coefficients of water quality variables with the primary axes from a distance-based redundancy analysis (dbRDA). The dbRDA was constrained by the statistically significant explanatory variables form a multivariate multiple regression analysis (DISLIM) based on four years of sampling (2005/06 to 2008/09). The first two axes explain over 90% of the variability in the fitted model and 36.8% of total variability in the data.

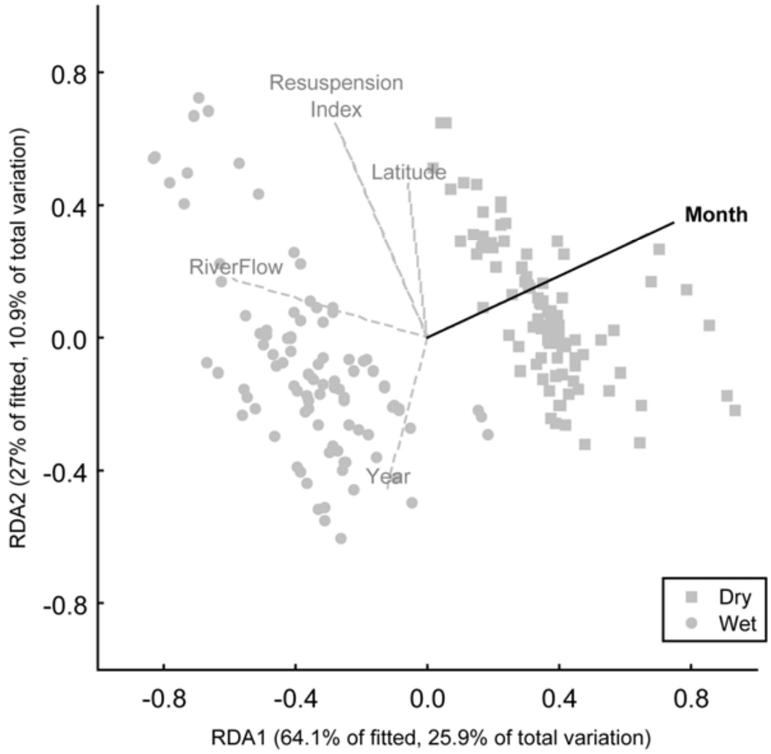

Figure 2.14 Biplot of a distance-based redundancy analysis constrained by significant explanatory variables form a multivariate multiple regression analysis based on four years of sampling. The explanatory variable of Month is highlighted to emphasize seasonal differences in the water quality data.

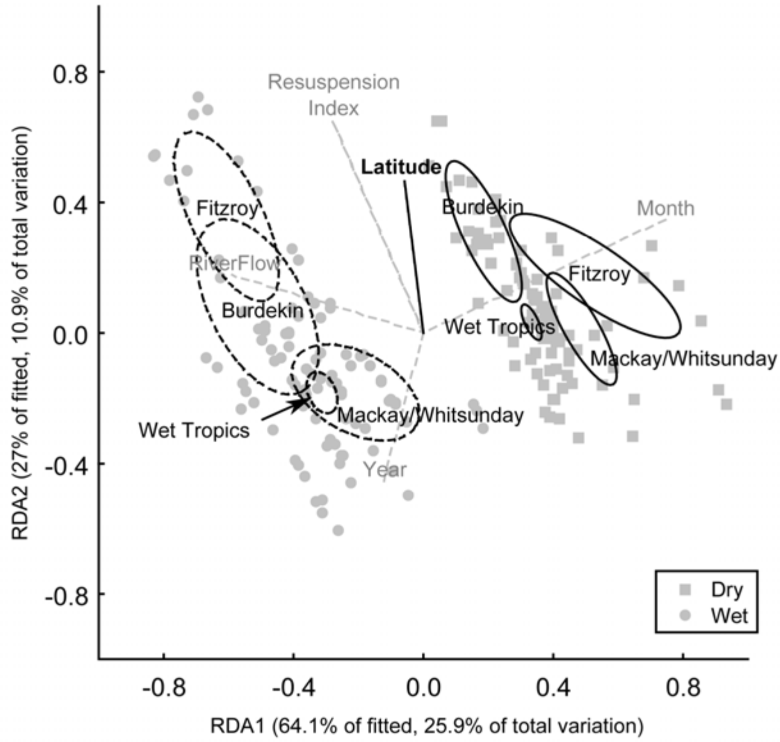

Figure 2.15 Biplot of a distance-based redundancy analysis emphasizing geographic gradients in the water quality data. Ellipses encompass 95% confident regions for the bivariate mean of coastal stations sampled in each NRM region. Dashed ellipses represent wet season sampling (November to April) and solid ellipses dry season sampling (May to October).

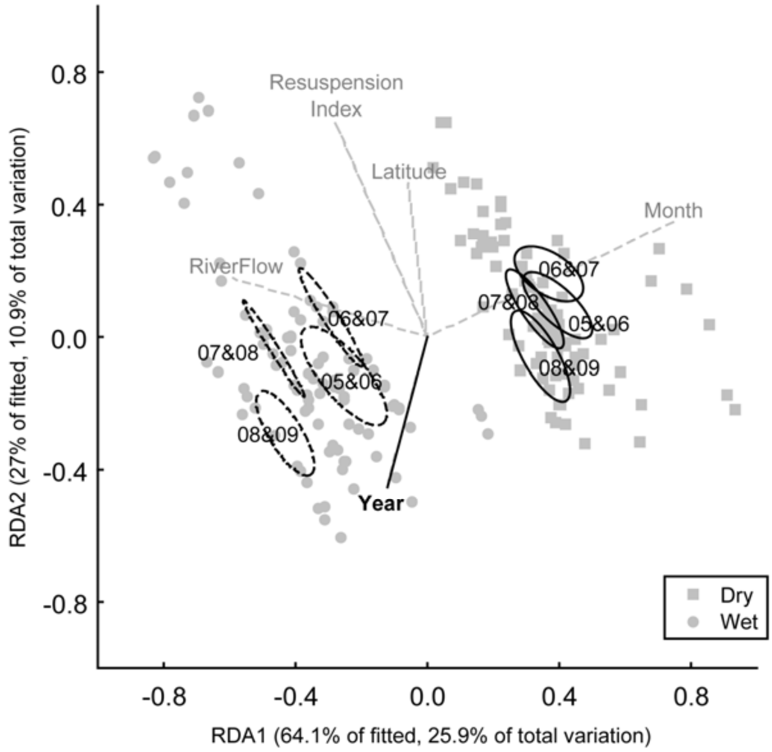

Figure 2.16 Biplot emphasizing yearly gradients in the water quality data. Ellipses encompass 95% confident regions for the bivariate mean of coastal stations sampled in each year. Dashed and solid ellipses as in Figure 2.15.

Coastal and Lagoon Chlorophyll a Concentrations

On 17 November 2008, RRRC notified AIMS about the decision by the GBRMPA that the long-term chlorophyll sampling by community/industry partners in 2008/09 would only include a reduced number of sites of the chlorophyll network. This decision was based on discussions in late 2008 about ongoing problems with a number of community and industry samplers, especially with regards to quality of samples and reliability of sample records. Sites selected for continuation (or as new sites) should also be useful from a scientific perspective, e.g. as validation sites for the remote sensing component of the Reef Rescue MMP. The majority of previously sampled sites did not serve this purpose as there were located too close to land, islands or reefs. These problems were reported in detail in the 2007/08 Final Reef Plan MMP Report to GBRMPA (Schaffelke *et al.*, 2008) and an urgent review of the long-term chlorophyll network was requested.

A workshop was held on 13 February 2009 including participants from GBRMPA, RRRC and the monitoring providers whose contracts have community sampling aspects. This workshop clarified the roles and responsibilities of the various parties involved in the community monitoring component of the Marine Monitoring Program (MMP) for the 2008 /09 sampling season. However, AIMS has not yet received the final document with these roles and responsibilities. Also discussed were problems associated with some of the sampling sites selected for 2008/09 (see further detail below).

The GBRMPA is now coordinating training of selected officers of their Regional Engagement and Planning group (REP) and of new sampler organisations or groups. The new training includes changes to the sampling process already decided in 2007/08 but never rolled out due to the above-mentioned problems, for example, i) actual geographical positions to be recorded by the samplers, and ii) Secchi-discs readings to be included in the sampling.

The sampling under the Long-term chlorophyll monitoring component has generally been very unsuccessful (see Table 2.7 summarising all samples received and analysed). Of the three identified major nodes of the network, Cape York (sampled by Undersea Explorer), Mackay Whitsunday (sampled by FantaSea) and Burnett Coast (sampled by Woongarra Marine Park Monitoring & Education Project), only the Mackay Whitsunday node is now still functional and is regularly sampled. For details refer to Table 2.6 and 2.7. Samples collected by FantaSea after February 09 had not yet been received by AIMS for analysis.

A reduced number of sites of the Far Northern node were sampled up to October/November 2008. In early 2009 Undersea Explore closed its business. The GBRMPA has since liaised with Mike Ball Dive Expeditions, who agreed to sample at two sites in the general region previously sampled by Undersea Explorer and AIMS has provided training to this new operator on 19 March 2009. The sampling of this new operator is not due to start before April 2009, which is the final month of the sampling schedule to be reported under the current Contract.

The coordinator of the Woongarra Marine Park Monitoring & Education Project left the Project in December 2008, without a suitable replacement. This group has carried out water quality sampling since 2000 including chlorophyll sampling, as part of their Coastcare project in collaboration with AIMS. In 2005 the chlorophyll sampling was incorporated into Reef Plan MMP. Analysis of samples from this region is complete to December 2008. The GBRMPA has not yet found a replacement for this very reliable group of samplers but is actively seeking community support for this component of the Reef Rescue MMP.

The results from this sampling are too sparse to warrant presentation as graphs or tables, as we did in previous reports. The data are held in an AIMS database to include in any future analyses and have been provided to Program partners at CSIRO Land and Water for validation of remote sensing data.

Table 2.6 Details of the Long-term chlorophyll monitoring network sampling in 2008/09. Transect/sites in bold print where decided by the GBRMPA to be continued in 2008/09.

NRM Region	Transect or site name	No of sites	Sampler	Sampling details
Cape York	Cooktown-Osprey	5	Undersea Explorer	Continued monthly sampling at 2 sites until Oct 08 when company closed down.
	Port Douglas	7	Undersea Explorer	Continued monthly sampling at 4 sites until Oct 08 when company closed down.
	Far Northern	3	Undersea Explorer	2 sites sampled in Nov 08
Wet Tropics	Wet Tropics	3	Fitzroy Island resort	Intermittent sampling until October 08 but no samples were suitable for analysis due to poor sample condition and record keeping.
Burdekin	Townsville	2	Sunferries	Discontinued in October 08 as only one sample collected in May 08
Burdekin	Picnic Bay, Magnetic island	1	GBRMPA	Monthly sampling until Nov 08 when it was discontinued.
Mackay Whitsunday	Whitsunday	3	FantaSea	Regular monthly sampling throughout year to Feb 09
	Shute Harbour	1	MWHW / Fantasea	One sample in April by MWHW and then taken over in Jan 09 by Fantasea as part of their 3 sites, analysis complete to Feb 09.
	Mackay Marina	1	MWHW	Regular monthly sampling until Dec 08, discontinued, analysis complete to Dec 08.
Fitzroy	Gladstone, Tannum-Boyne coast	6	Tannum Sands Coastcare	Regular monthly sampling; analysed but not included in database.
Burnett Mary	Burnett coast	5	Woongarra Marine Park Monitoring & Education Project	Regular monthly sampling, analysis complete to Dec 08. Discontinued in Dec 08 when WMPMEP sampling program disbanded.

Table 2.7 Details of the Long-term chlorophyll monitoring network sampling in 2008/09. Number of samples received and analyses and date ranges of sampling Locations in bold print were selected by the GBRMPA for continuation in 2008/09.

Region	Location	No. of samples	Sample date range	
Cape York	1 mile outside Codhole	1	Aug-08	
	Codhole	3	Jun-08	Oct-08
	Osprey ent. Channel	2	Aug-08	Oct-08
	Log Reef	1	Nov-08	
	Mantis Reef	2	Oct-08	Nov-08
	Rodda Reef	1	Oct-08	
Wet Tropics	Inside Agincourt 4 Reef	3	Jun-08	Oct-08
	Low Isles1	4	Jun-08	Oct-08
	Near Port Douglas	4	Jun-08	Oct-08
	Outside Agincourt 4 Reef	1	Aug-08	
	Rudder Reef	4	Jun-08	Oct-08
	Fitzroy Island Jetty	5	May-08	Sep-08
Burdekin	Magnetic - Picnic Bay	6	May-08	Oct-08
	North of Kelso Reef	1	May-08	
	Townsville Shipping Channel	1	May-08	
Mackay Whitsunday	Mackay Marina Wall	7	May-08	Oct-08
	Shute Harbour Jetty	3	May-08	Feb-09
	Dent Passage	8	Jul-08	Feb-09
	Hook Passage	7	Jul-08	Feb-09
	Line Reef	7	Jul-08	Feb-09
Fitzroy	Rosslyn Bay Marina Wall	1	May-08	
Burnett Mary	Woongarra Barolin Rocks	7	May-08	Dec-08
	Woongarra Burkitts Reef	7	May-08	Dec-08
	Woongarra Burnett River	7	May-08	Dec-08
	Woongarra Double Rock	7	May-08	Dec-08
	Woongarra Hoffman's Rocks	7	May-08	Dec-08

3. Inshore Coral Reef Monitoring

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3.1 Introduction

The objective of the biological monitoring of inshore reefs is to document spatial and temporal trends in the benthic reef communities on selected inshore reefs. Changes in these communities may be due to acute disturbances such as cyclonic winds, bleaching and crown-of-thorns starfish as well more chronic disturbances such as those related to runoff (e.g. increased sedimentation and nutrient loads) which disrupt processes of recovery such as recruitment and growth. The reef monitoring sites are close to the sampling locations for lagoon water quality to assess the relationship between reef communities and water quality as well as other, more acute impacts.

One salient attribute of a healthy ecological community is that it should be self-perpetuating and 'resilient', that is: able to recover from disturbance. One of the ways in which water quality is most likely to shape reef communities is through effects on coral reproduction and recruitment. Laboratory and field studies show that elevated concentrations of nutrients and other agrichemicals and levels of suspended sediment and turbidity can affect one or more of gametogenesis, fertilisation, planulation, egg size, and embryonic development in some coral species (reviewed by Fabricius, 2005). High levels of sedimentation can affect larval settlement or net recruitment of corals. Similar levels of these factors may have sub-lethal effects on established adult colonies. Because adult corals can tolerate poorer water quality than recruits and colonies are potentially long-lived, reefs may retain high coral cover even under conditions of declining water quality, but have low resilience. Some high-cover coral communities may be relic communities formed by adult colonies that became established under more favourable conditions. Such relic communities would persist until a major disturbance, but subsequent recovery may be slow if recruitment is reduced or non-existent. This would lead to long term degradation of reefs, since extended recovery time increases the likelihood that further disturbances will occur before recovery is complete (McCook *et al.*, 2001). For this reason, the surveys for the Reef Rescue MMP estimate cover of various coral taxa and also collect information on juvenile colony abundance as evidence for the extent of ongoing recruitment. In addition, settlement of corals is measured using settlement plates in all four NRM Regions.

Assessments of sediment quality and assemblage composition of benthic foraminifera were added to the routine coral reef monitoring in 2007/08, to provide additional information about the environmental conditions at the individual survey reefs (Schaffelke *et al.*, 2008). After discussions at the 2008 Reef Plan 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 (next time in 2009/10), with the option to analyse samples of the intervening years if a significant change was observed.

This component of the Reef Rescue MMP - 'Inshore Coral Reef Monitoring' aims to accurately quantify temporal and spatial variation in inshore coral reef community status in relation to variations in local reef water quality. This project is intrinsically linked to Reef Rescue MMP - 'Inshore Water

Quality Monitoring' (see Chapter 2) and components are also linked to current MTSRF projects, in particular Project 3.7.1 (Marine and estuarine indicators and thresholds of concern). This project will deliver water quality specific assessment of inshore coral reef health for the Reef Rescue MMP. In December 2008 this project submitted a detailed report (Thompson *et al.*, 2009) linking the consistent spatial patterns in coral community composition observed over the first three years of the project with environmental parameters. As temporal span of this project extends it is intended to shift the focus toward understanding and documenting the differences in community dynamics (status) across the spatial extent of the sampling rather than reiterating spatial differences in composition.

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

1. Provide annual time series of benthic community status 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. Toxicological assessment of chemical pollutants present at coral reef monitoring sites using a zooxanthellae biotest (to be carried out by Entox-UQ and reported separately);
4. Provide information about sea temperature and sediment quality as drivers of environmental conditions at inshore reefs;
5. Integrated reporting for the Reef Rescue Marine Monitoring Program.

This report presents data from the fourth annual survey of coral reef sites under Reef Rescue MMP (undertaken in the period from May 2008 to Feb March 2009; hereafter called "2008") and provides summaries of the monitored suite of community variables over the period 2005 to 2008.

Also presented is a preliminary assessment of the status of reef communities at both the scale of individual reefs and then aggregated up to the scale of NRM regions and sub-regions within the Wet Tropics NRM region. The objective of this status assessment is to provide the first step in the development of a process of status and change estimation. This first step is necessarily simplistic in that the dynamics of each coral community were assessed using a uniform set of decision rules. With improving understanding of the variability in community dynamics in different environmental settings and with varying taxonomic composition it is expected that decisions rules can be tailored for community-specific assessments of change.

3.2 Methods

In the following an overview is given of the sample collection, preparation and analyses methods. Detailed documentation of the AIMS methods used under Reef rescue MMP was provided to RRRC in a separate report in May 2009 (Schaffelke, 2009: Reef Rescue Marine Monitoring Program-Methods and Quality Assurance/Quality Control Procedures).

Sampling Design

The sampling design selected for the detection of change in benthic communities on inshore reefs aims to compare the response of benthic communities to improvements in water quality parameters associated to specific catchments or groups of catchments (Region). Within each Region, reefs are selected that represent a gradient in exposure to runoff, largely determined as increasing distance from river mouth in a northerly direction [Reef(Region)]. To account for spatial heterogeneity of benthic communities within reefs, two sites were selected (Site [Reef(Region)]). Observations on a number of near-shore reefs undertaken by AIMS in 2004 highlighted marked differences in community structure and exposure to perturbations, including floods, with depth and as such sampling within sites is stratified by depth (Depth). Within each site and depth fine scale spatial variability is accounted for by the use of five replicate transects (Transects (Depth*Site [Reef(Region)]). 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.

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 from river output.
2. Sampling locations were selected where there was evidence (in the form of carbonate-based substrate) that coral reef communities had been viable (net positive accretion of a carbonate substrate) 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 assumed to be similar. However, current regimes and hence flushing or accumulation of materials may be different. A list of reefs selected is presented in Table 3.1 and Figure 3.1.

Depth Selection

From observations of a number of near-shore reefs undertaken by AIMS in 2004, marked differences in community structure and exposure to perturbations, including floods, with depth were noted. The lower limit to depth stratification selected was 5m below datum, as the coral community rapidly diminishes below this depth at many reefs; 2m below datum was selected as the 'shallow' depth as this allowed survey of the reef crest. Shallower depths were considered and discounted for logistical reasons, including inability to use the photo technique in very shallow water, site markers creating a danger to navigation and difficulty in location of a depth contour on very shallow sloping substrates as typical of reef flats.

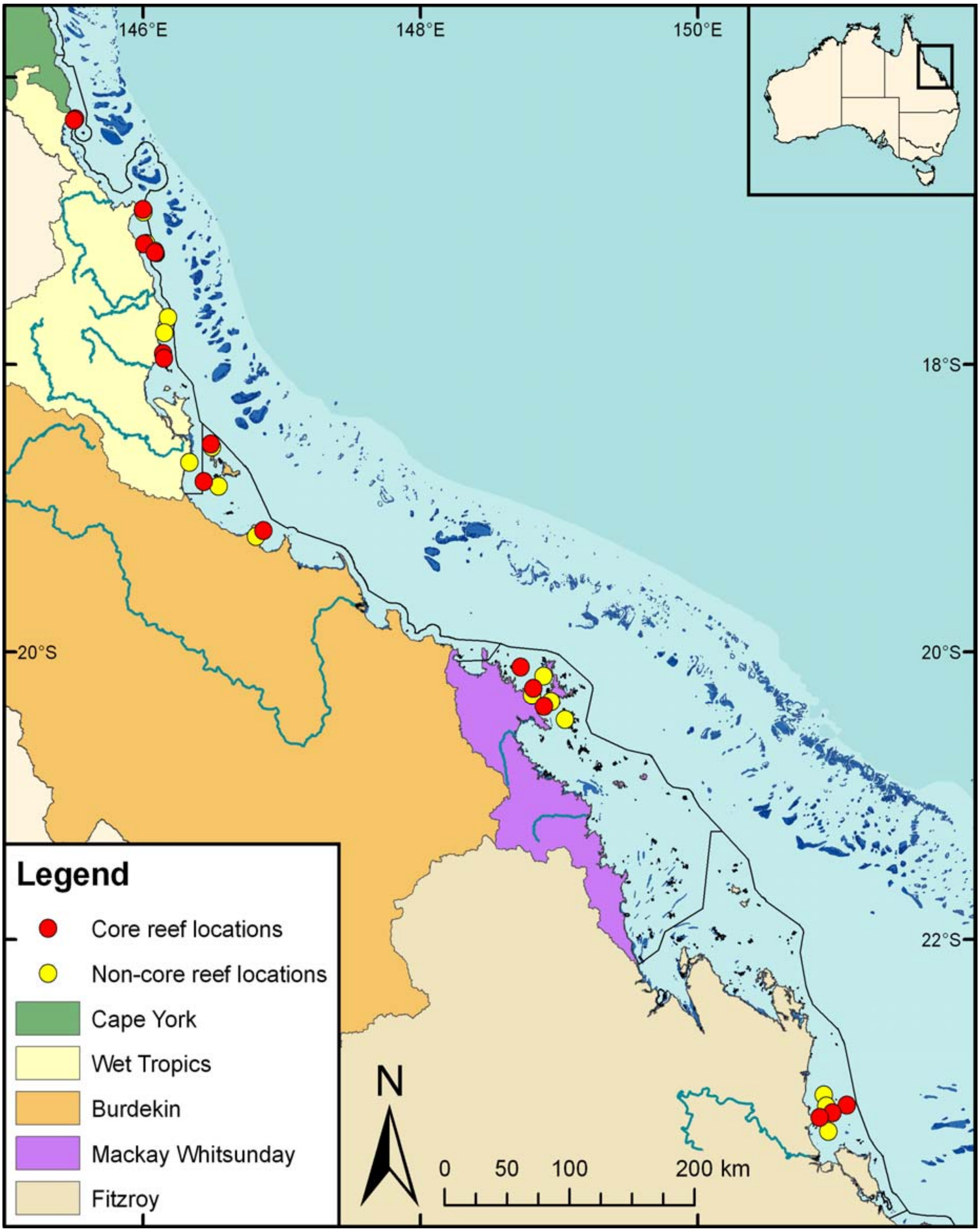

Figure 3.1 Sampling locations under the Reef Rescue MMP inshore marine water quality and coral monitoring tasks. Core reef locations have annual coral reef benthos surveys, coral settlement assessments and water quality monitoring (see Chapter 2). Non-core reef locations have benthos surveys every two years and no water quality assessments. Exceptions are Snapper Is and Dunk Is North (water quality monitoring, coral annual surveys, but no coral settlement). See Table 3.1 for the list of surveys completed in 2008.

Table 3.1 Inshore coral reef monitoring completed during the period May 2008 and March 2009 (✓). In additional to contractual requirements reefs identified by (I) were visited in Feb 2009 and the combined impact of flooding and bleaching assessed to aid interpretation of future trends.

NRM Region	Primary Catchment	Coral monitoring locations	Benthic Surveys	Tiles
Wet Tropics	Daintree	Snapper Island North	✓	
		Snapper Island South	✓	
	Russell-Mulgrave, Johnstone	Fitzroy Island West	✓ I	✓
		Fitzroy Island East	✓ I	
		High Island West	✓	✓
		High Island East	I	
		Frankland Group West	✓	✓
		Frankland Group East	I	
	Tully	King Reef	✓	
		Dunk Island North	✓ I	
		Dunk Island South	✓ I	
Burdekin	Herbert	Pelorus and Orpheus Island West	✓ I	✓
		Orpheus Island East	✓ I	
	Burdekin	Lady Elliot Reef	✓	
		Pandora Reef	✓	✓
		Geoffrey Bay	✓ I	✓
Mackay Whitsunday	Proserpine	Double Cone Island	✓	✓
		Hook Island	✓	
		Daydream Island	✓	✓
		Shute and Tancred Island	✓	
		Pine Island	✓	✓
Fitzroy	Fitzroy	Middle Island	✓	
		Barren Island	✓	✓
		Humpy & Halfway Island	✓	✓
		Pelican Island	✓	✓
		Peak Island	✓	

Field Survey Methods

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 coupled with distance along transects 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.

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 the text box and detailed descriptions below.

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 form which 160 points were sampled.	Full sampling design
Demography	Size structure of coral communities, density post settlement recruitment	34cm belt along the upslope side of the transect.	Full sampling design
Scuba Search	Incidence of factors causing coral mortality	2m belt centred on transect	Full sampling design
Settlement Tiles	Larval supply	clusters of six tiles in the vicinity of the start of the 1st, 3rd and 5th transects 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 Method (PPIT)

This method was used to gain estimates of the percent cover of benthic community components. The method follows closely that used by 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 at least genus level identification was achieved.

Juvenile coral surveys

This survey aims to provide an estimate of the number of coral colonies that were successfully recruiting to 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 broader range of size classes. As the focus narrowed to just juvenile colonies the number of size classes 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 due to these agents must be carefully considered as covariates for possible trends associated with response to Reef Plan outcomes. 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.

Settlement Tiles

This section of the study aims to provide a standardised estimate of the availability of numbers of coral spat competent for settlement at individual locations that can be compared among years for individual reefs, to assess e.g. recovery potential of an individual reef after disturbance, a key characteristics of reef health.

Tiles were deployed twice over the settlement period at each reef. The first deployment was to have tiles in place on all reefs by the full moon in October 2008. This allowed a period of between 1 to 2 weeks for tiles to condition before any settlement was expected. The tiles were left in place until the week prior to the full moon in December 2008 when they were exchanged with new tiles. Tiles were pre washed prior to deployment to reduce the levels of possible contaminants derived from tile manufacture or storage. The washing of tiles includes a vigorous hosing with fresh water to remove surface contaminants followed by immersion in saltwater for at least 12 hours prior to deployment to leach contaminants and promote the development of a biofilm. The second batch of tiles was retrieved 3-4 weeks after the January 2009 full moon. Deployment details for 2008/09 are given in Table 3.2 below.

Tiles were affixed to the substrate by attachment to small stainless steal base plates (these attached to the substrate with plastic masonry plugs or cable ties when no solid substrates into which masonry plugs can be attached 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 at each 5m depth site on core reefs. Upon collection base plates were left in-situ for use in the second deployment or subsequent year. Collected tiles were stacked onto holders consisting of a 15cm square of ply wood with a section of threaded rod of the same diameter as the bolts to which tiles were attached to the base plates. Tiles from each picket were stacked onto separate holders and tagged with date of collection and reef, site, picket of deployment. Small squares of low density foam (Yoga mat) were placed between tiles to prevent contact between tiles in transport and handling which may dislodge or damage the coral skeletons used for identification of spat. 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 for 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 with certainty: Acroporidae (not *Isopora*), Acroporidae (*Isopora*), Fungiidae, Poritidae, Pocilloporidae and "other families" achieved. As set of reference images pertaining to these categories has been complied.

Table 3.2 Locations and timing of coral settlement tile deployment.

NRM Region	Catchment	Coral monitoring locations	Coral settlement tile deployment
Wet Tropics	Russell-Mulgrave Johnstone	Fitzroy Is West	11-Oct-08 to 02-Dec-08
			02-Dec-08 to 28-Feb-09
		High Is West	11-Oct-08 to 01-Dec-08
			01-Dec-08 to 27-Jan-09
		Frankland Is Group West	11-Oct-08 to 01-Dec-08
			01-Dec-08 to 27-Jan-09
Burdekin	Burdekin	Geoffrey Bay	08-Oct-08 to 04-Dec-08
			04-Dec-08 to 13-Feb-09
		Pandora Rf	08-Oct-08 to 03-Dec-08
			03-Dec-08 to 20-Feb-09
		Orpheus Is & Pelorus Is West	09-Oct-08 to 03-Dec-08
			03-Dec-08 to 20-Feb-09
Mackay Whitsunday	Proserpine	Double Cone Is	02-Oct-08 to 06-Dec-08
			06-Dec-08 to 18-Feb-09
		Daydream Is	01-Oct-08 to 06-Dec-08
			06-Dec-08 to 19-Feb-09
		Pine Is	01-Oct-08 to 07-Dec-08
			07-Dec-08 to 19-Feb-09
Fitzroy	Fitzroy	Pelican Is	04-Oct-08 to 08-Dec-08
			08-Dec-08 to 17-Feb-09
		Humpy Is & Halfway Is	05-Oct-08 to 08-Dec-08
			08-Dec-08 to 17-Feb-09
		Barren Is	04-Oct-08 to 08-Dec-08
			08-Dec-08 to 17-Feb-09

Sediment quality

Sediment samples were collected from all reefs visited during 2008 (Table 3.1) for analysis of grain size and of the proportion of inorganic carbon, organic carbon and total nitrogen. At each 5m deep site six 30mm deep cores of surface sediment (representing 20ml of material) were collected haphazardly using syringe tubes along the 120m length of the site from available deposits. On the boat the excess sediment was removed to leave 10ml in each syringe. This represents the top centimetre of surface sediment. This sediment was transferred to the labelled sample jar, 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 was 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.

Sea Water Temperature

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 coral surveys. 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. Temperature data is logged to an inbuilt memory which is downloaded every 12 to 18 months, depending on the site. Loggers are double- or triple- calibrated against a certified reference thermometer after each deployment and are generally accurate to ± 0.2°C.

As a reference, long-term means for each week of the year where 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 in to 52 weekly estimates. These long-term means were derived from existing data sets (AIMS Long-term Temperature Monitoring Program) in combination with the first 3years of sampling from Reef Rescue MMP locations. In addition to Reef Rescue 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 Frankland Is 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.

Data analysis

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.* 2009). In this report results are presented to reveal temporal and spatial differences, however, an in-depth statistical analyses of these patterns is not repeated here.

We are working toward the development of appropriate statistical tools to more fully interrogate the temporal components of the data and to assess community status; these are as yet not sufficiently developed to be presented here. Further, temporal models will become more meaningful as the temporal span of the data set increases. Four 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.

Estimation of coral community status

The estimation of coral community status presented here represents an initial and necessarily simplistic first stage in the development of the concept. It is intended that the assessment of status is a living process that is continuously refined as our knowledge of the dynamics and environmental limitations to the range of benthic communities found on the reefs studied increases. In general, the estimation of status aims at assessing the observed dynamics of individual communities against informed expectations as to their dynamics.

Importantly, the timing and intensity of any disturbance events are key considerations that shape the expectations for a given community at a given point in time. In this initial assessment uniform expectations are applied to all reef communities because as yet insufficient data exist to do otherwise. This approach however will disproportionately influence the perception of status with, as just one example, increase in cover for communities with fast growing components such as *Acropora* considered similarly to those dominated by slower growing taxa such as *Porites*.

For each data type included in the assessment an impression of status was estimated for each reef. Three levels of status were defined:

- Positive, indicating a community that exhibits obvious signs of resilience to disturbance, or potential for increases in cover;
- Neutral, communities for which neither obvious signs of resilience or a lack of resilience could be concluded; and
- Negative, where community dynamics suggested a general lack of potential to recover from disturbance.

The status for a given community was taken as the sum of status assessments such that positive, assessments score one, neutral assessments zero and negative assessments minus one. Aggregating status from reefs up to sub-region or region took the modal estimate of status for each data type from the reefs in a region and then summed over these modal estimates to gain the regional equivalent of individual community assessments.

The decision rules put up as the “straw man” for this first assessment were as follow:

Cover of corals (combined HC and SC) considered as

- Positive if cover was stable and >50% or cover increased during no disturbance periods
- Neutral if cover was stable at 25-50% or cover declined due to acute disturbance
- Negative if cover was stable and <25%, or cover declined in the absence of acute disturbance.

Cover of macroalgae

- Positive if cover was <5%, or cover <10% and declining from a high point following disturbance
- Neutral if cover was stable at 5-15% or declining but in the range of 10-20%
- Negative if cover was stable at >15% or cover increased or cover decreased from a cover >20%

Density of Juveniles colonies (averaged over years)

- Positive if density per m^2 of available space was in the higher third of densities for reefs at that depth.
- Neutral if density per m^2 of available space was in the central third of densities for reefs at that depth.
- Negative if density per m^2 of available space was in the lower third of densities for reefs at that depth.

Settlement of coral spat to tiles: Averaged over 2006 and 2007 spawning seasons

- Positive if numbers of recruits where within the upper third of the range across all reefs.
- Neutral if numbers of recruits where within the central third of the range across all reefs.
- Negative if numbers of recruits where within the lower third of the range across all reefs.

3.3 Results

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 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 comparison of trajectories of the various variables between regions rather than consistent 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.* (2009).

The second section provides more detailed reef level data for each NRM region, and in the case of the Wet Tropics region, sub-regions based on major catchments. The data presented in this second section are used to attain preliminary estimates of reef status. These reef level estimates are in turn aggregated to form regional and sub regional assessments presented in Section 1 of the results.

3.3.1 Summary of changes in benthic communities between 2007 and 2008 with reference to changes since 2005

Sediment quality

This section provides a brief over view of the sediment data (complete results in Appendix Table A1-3.1).

From 2006 to 2008 the proportion of clay/silt, and the content of nitrogen, organic carbon, and inorganic carbon in reef sediments remained steady within the four catchments with only moderate fluctuations (Figure 3.2). The sediments on reefs in the Mackay Whitsunday region were consistently different to those in other regions. The proportion of clay/silt, nitrogen and organic carbon in Mackay Whitsunday sediments were significantly higher than found in other regions, while inorganic carbon was significantly lower. Of the three 'core reefs' within the Mackay Whitsunday region the less sheltered sites at Double Cone Island had consistently lower levels of clay/silt, nitrogen and organic carbon, and higher levels of inorganic carbon (Table AI-3.1a-d). An increase in nitrogen levels at this reef in 2007 increased the regional mean. A gradual increase in organic carbon at Daydream Island increased the regional mean and corresponded to a gradual decline in inorganic carbon as sediments respond to more terrigenous input, possibly related to the floods of the Pioneer River in 2007 and 2008. The overall increase in the proportion of clay/silt sized particles reflected progressively higher flows of the O'Connell and Proserpine rivers in the wet seasons preceding each sample. An increase in nitrogen levels from 2007 - 2008 was also observed in the Fitzroy region, which corresponded to the major flooding of the Fitzroy River in early 2008. Fluctuations in clay/silt and nitrogen in the Wet Tropics was driven by slight changes at Dunk Island North and the Frankland Group West.

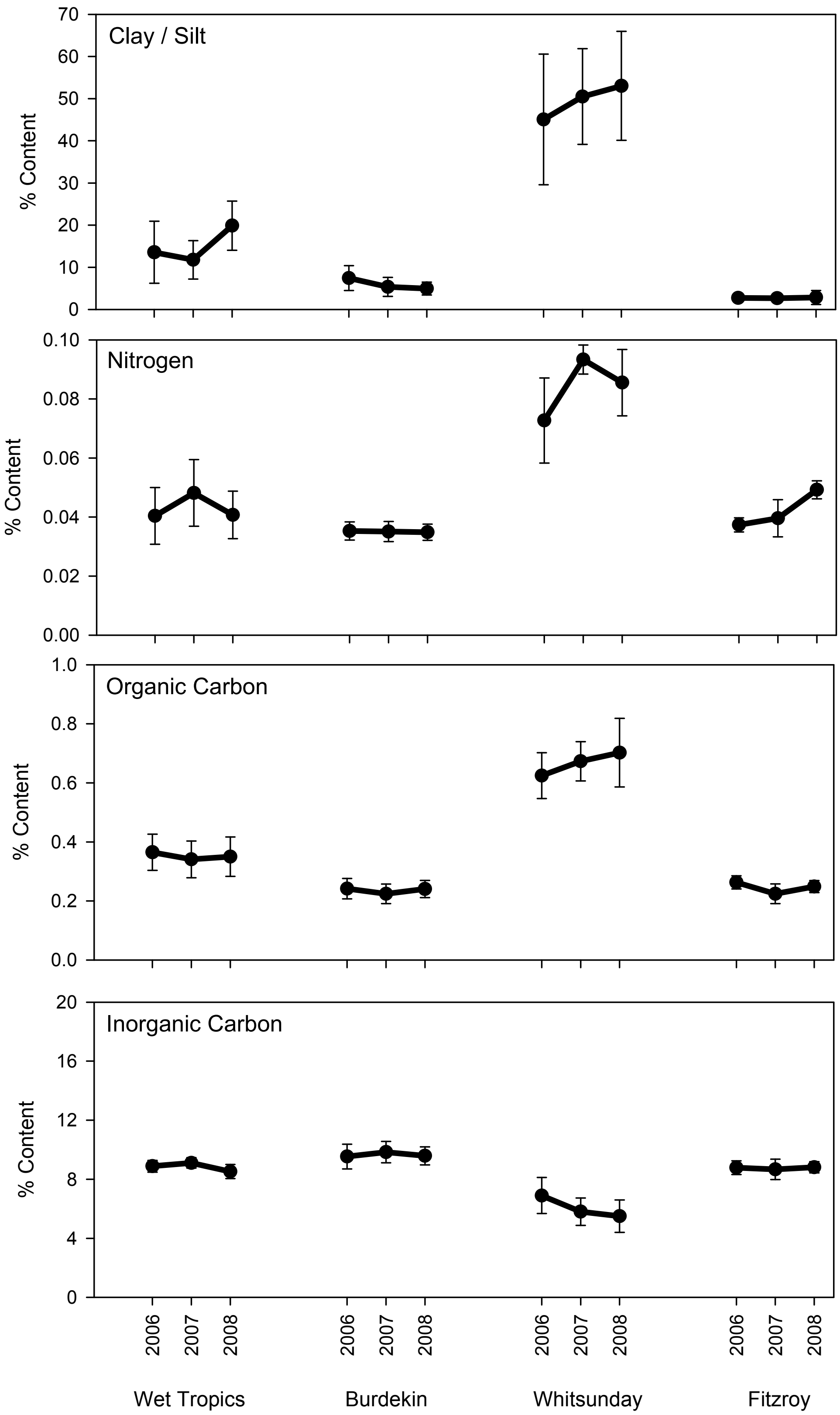

Figure 3.2 Average proportions of sediment consisting of Clay & Silt size grains, Nitrogen, Organic Carbon, and Inorganic Carbon for each NRM region (+/- standard error). For each region only reefs sampled in all years are included to ensure consistency among means.

Sea temperature monitoring

Temperature data are reported for the period of January 2005 to June 2008 (Figure 3.3), For each region data are represented as the deviation from long-term (10yr) 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 3.3). 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 Whitsunday Mackay region. 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 2008 have been relatively minor and unlikely to have caused stress to the corals in any regions.

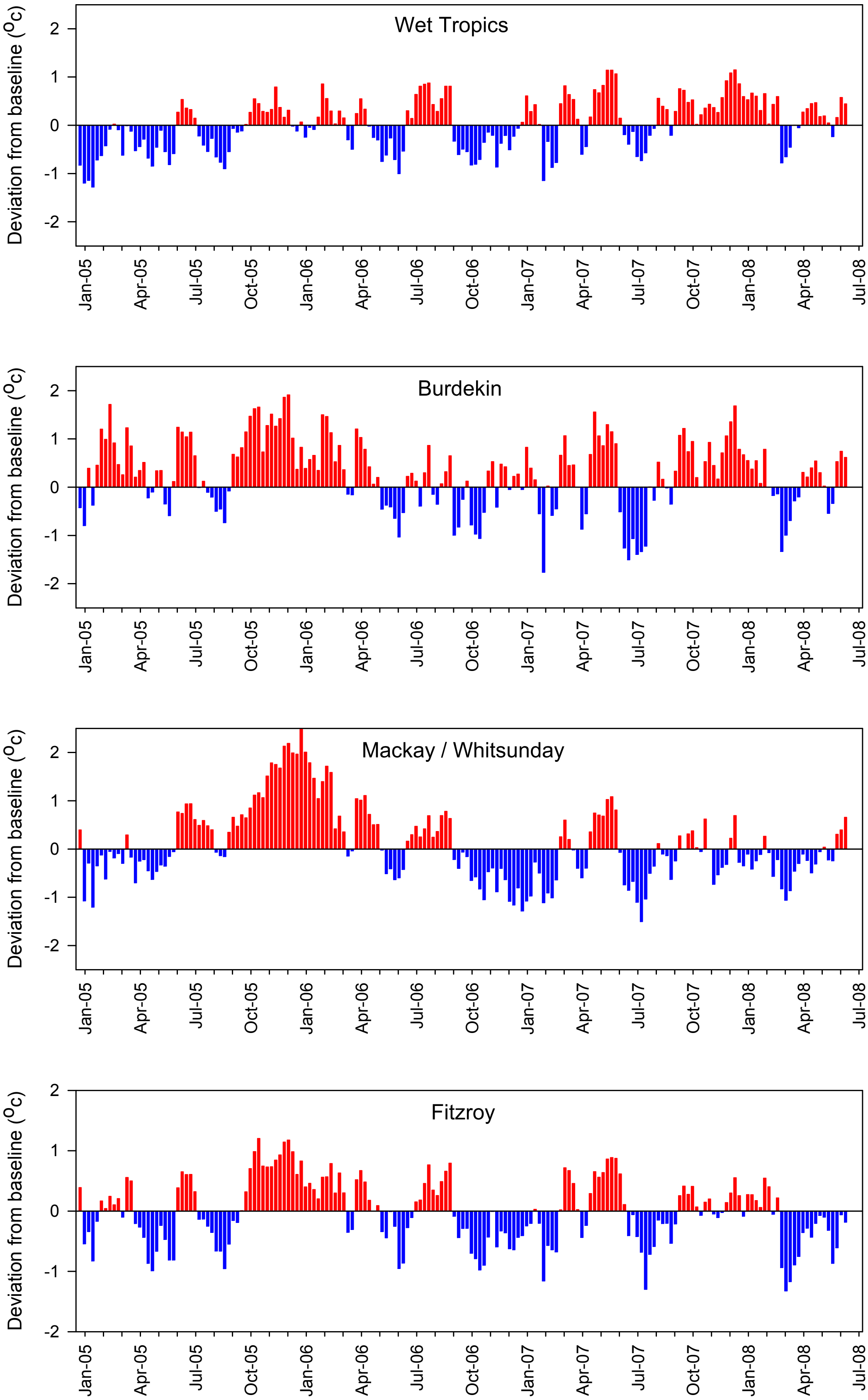

Figure 3.3 Sea temperature monitoring 2005 to 2008. Deviation from 10 year mean weekly temperature records (based on records from July 1998 to June 2008).

Inshore coral community status

The completion of the fourth inshore coral reef survey under Reef Rescue MMP allows a first assessment of the overall status of the inshore coral reef communities monitored. The assessment of coral reef community status presented here attempts to incorporate the dynamic nature of the communities by including both the measured community attributes and their trajectories of recovery. The underling assumption is that a 'healthy' community should show clear signs of recovery after inevitable acute disturbances, such as cyclones and coral bleaching events. It is important to note, however, that these estimates of status are based on a uniform set of criteria being applied to all reefs.

Regional estimates of status were derived based on the observed dynamics of benthic communities over the period 2005-2008 (Table 3.3) by aggregating reef level status scores within each region and sub-region (see section 3.3.2). In summary, the regional estimates of status were as follows:

- A positive score of coral community status was indicated for the Daintree and Johnstone-Russell/Mulgrave sub-regions of the Wet Tropics NRM region. Coral communities on average showed generally high coral cover that increased during periods without acute disturbance, and the reefs had low cover of macroalgae and relatively high densities of juvenile colonies.
- Coral communities in the Whitsunday Mackay NRM region also scored highly in terms of status. 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 and settlement of spat to tiles was moderate relative to other regions.
- 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 observed recovery in the Herbert Tully sub-region is inconclusive as insufficient time has elapsed since reefs were severely impacted by Cyclone Larry (2006) for any trend to emerge. However, the negative attributes are partly offset by moderate densities of juvenile colonies. No historical time series exist for these reefs from which recovery potential could be inferred. 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.
- The assessment of coral community status in the Fitzroy region was marginally positive. The positive attributes of high average coral cover with a clear capacity to recover following disturbance events along with high, albeit variable, settlement of spat 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, however, rapid recovery has been well documented (Sweatman *et al.* 2007, Diaz-Pulido *et al.* 2009). A decline in cover from 2007 to 2008 (Figure 3.4) was the result of a major flood of the Fitzroy river (February 2008) and a strong Northerly wind event (February 2008) affecting reefs in this region. The slight declines associated with these recent disturbances did not affect our overall assessment of status as regional hard coral cover was still high at approximately 40%.

Table 3.3 Regional estimates of coral community status based on the modal for status indicator assessed for each reef and depth within the region or sub-region. The over all status aggregates over four indicators, coral cover, macroalgal cover, juvenile hard coral density and settlement of coral spat. * Settlement data was not available for the Daintree or Tully sub-regions.

Region	Sub region	Overall Status	Coral		Macroalgae		Juveniles		Settlement	
			Cover (%)	Status	Cover (%)	Status	Density (m^{-2})	Status	# per tile	Status
Wet Tropics	Daintree*	***2.5 +***	55	+	2.6	+	9	0.5+		
	Johnstone	**2.5 +**	55.5	+	3.8	+	14.6	0.5+	**74**	neutral
	Tully*	**0.5 -**	17.6	neutral	29.4	-	11.5	0.5+		
Burdekin		**2 -**	31.8	neutral	19.8	0.5 -	8.8	0.5 -	28	-
Mackay Whitsunday		**2 +**	51.8	+	2.1	+	13	neutral	46	neutral
Fitzroy Basin Association		**0.5 +**	40.1	+	14.3	neutral	5.8	-	55	+

There are several caveats that should be considered in relation to the status estimates presented above. Firstly the approach taken does not take into account the considerable variation in taxonomic composition of the communities. It is well documented that both susceptibility to disturbance and environmental condition and also growth and mortality rates vary among coral taxa (see also the recent analysis in Thompson *et al.* 2009). A uniform set of criteria, as used here, will be insensitive to gross differences in community composition. For example, very low numbers of juvenile colonies in a community dominated by large colonies of relatively resilient taxa (*Porites* for example) may provide adequate replacement for colonies lost to mortality whereas for more susceptible taxa (*Acropora* for example) that suffer higher rates of mortality may require far greater levels of recruitment to maintain a status quo. At this point insufficient data exist for us to derive individual expectations for the various community attributes for the principal community types found on inshore reefs.

A further caveat is the use of comparative levels of some attributes to define status. It is possible, for example, that the median density of juvenile colonies on some reefs or in some regions is insufficient or conversely exceeds the density required to replace lost cover. The current assessment provides a relative assessment among reefs and may point toward reefs most at risk of decline. However, it is possible that 'best-scored' reef may be in chronic decline or conversely the 'worst' reef largely unaffected, as they have different community types.

As the time series extend it is expected that the estimation of status will evolve to allow assessments that explicitly include community composition. However, observations to date suggest the status as reported here is a fair approximation of the status of GBR inshore reefs.

Cover of hard corals

Of the reefs surveyed in both 2007 and 2008 there was no overall change in the cover of hard corals (mean hard coral cover over all regions was 36% in both years). Increases in cover on Wet Tropics region reefs were essentially cancelled out by decreases on Fitzroy region reefs (Figure 3.4). Reefs in the Wet Tropics region mostly showed increases in coral cover as reefs impacted by Cyclone Larry began to recover while those not impacted continued longer term increases. The localised disturbance (mostly likely due to a strong wind event, see Wet Tropics region summary) to the northern reef of Snapper Island was a notable exception with cover decreasing at both depths. Two further exceptions were King Reef 2m depth and Frankland Group West 5m where cover declined to 2008, in both cases macroalgae cover had increased.

Between surveys in 2007 and 2008 reefs in the Fitzroy region were variously impacted by flooding of the Fitzroy River and a strong northerly wind event that in combination account for the regional decline in cover observed in 2008. At Barren Island strong northerly winds in January 2008 caused substantial damage, and at Humpy Island & Halfway Island and Pelican Island flood waters caused a decline in coral cover at 2m.

In both the Burdekin and Mackay Whitsunday regions average coral cover on the core reefs remained stable between 2007 and 2008. In the Burdekin region cover has been consistently low over the period 2005-2008 with no 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 average hard coral cover on core reefs in the Whitsunday region has remained stable and relatively high (46% in 2008). Slight increases in cover from 2006 at Pine Island and Double Cone Island are countered by declines at Daydream Island, where disease has played a role in reducing the cover of hard corals (Scuba search data not presented here).

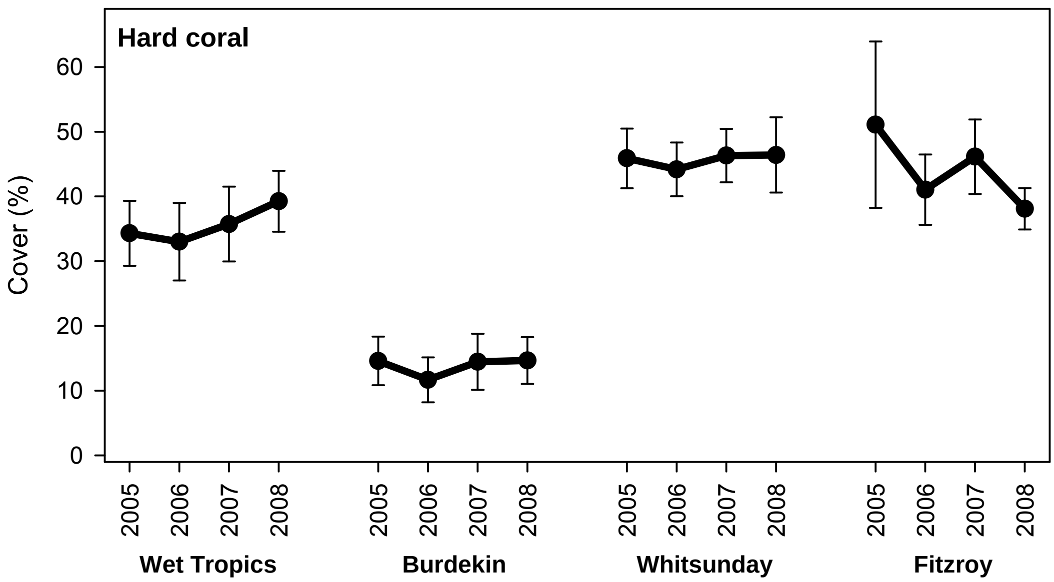

Figure 3.4 Average cover of hard coral on reefs for each NRM region (+/- standard error). For each region only reefs sampled in all years are included to ensure consistency among means.

Cover of soft corals

The average cover of soft corals has been stable between 2005 and 2008 on core reefs in both the Wet Tropics and Mackay Whitsunday regions (Figure 3.5). In the Fitzroy region a slight decline observed in 2008 is the result of physical removal of colonies at Barren Is likely as a result of a strong wind event in February 2008. In the Burdekin region the regional average reflects the cover at just one location, Pelorus Island & Orpheus Island West with cover elsewhere 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.

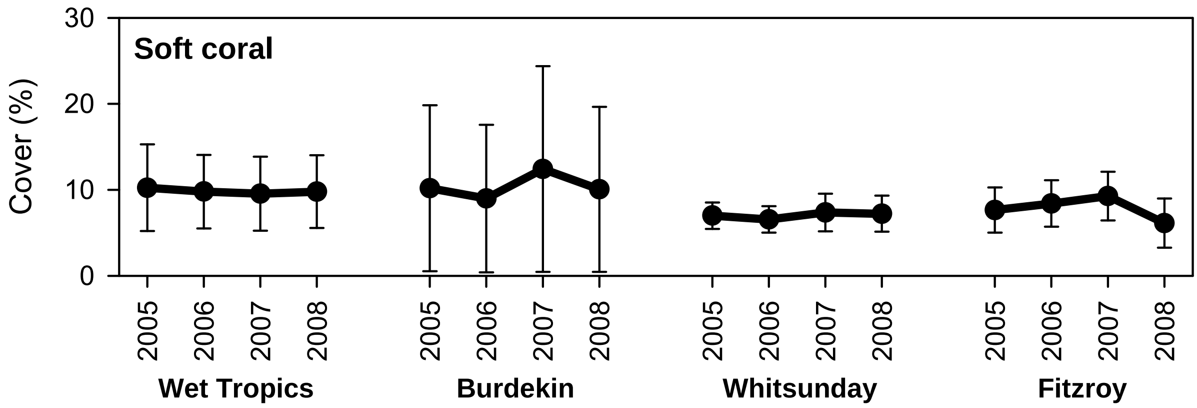

Figure 3.5 Average cover of soft coral on reefs for each NRM region (+/- standard error). For each region only reefs sampled in all years are included to ensure consistency among means.

Cover of macroalgae

The cover of macroalgae is generally variable through time compared to that of corals, primarily due to short life spans of individual thalli or life history stages, seasonality and the potential for high growth rates. The overall average cover of macroalgae on core reefs declined from 11% in 2007 to 9% in 2008 marking a reverse in the increasing cover observed between 2005 and 2007. These overall averages mask the variable profiles of algae cover at the regional level (Figure 3.6) and also the reefs with each region.

In the Wet Tropics region macroalgae cover is typically low on reefs in the Daintree and Johnstone/Russell–Mulgrave sub-regions and mostly comprised red algae that colonise rubble and spaces between coral branches. In 2008, those algae had increased in cover among *Porites* colonies at the Frankland Group West location, and decreased at Snapper Island North. In the Tully/Herbert sub-region brown algae are more common and have followed the general trajectory of high cover in 2005, a reduction in 2006 following the passage of Cyclone Larry followed by a subsequent increase through to 2008.

In the Burdekin region brown algae have had consistently high cover at both Geoffrey Bay and Pandora Reef for the period 2005 to 2008 though cover has shown slight decreases at 2m since 2006. In the Mackay Whitsunday region macroalgae are common only at Pine Island and the regional level plot largely reflects the variability in the cover of brown algae at this reef.

In the Fitzroy region, macroalgal communities differ markedly between Peak and Pelican Islands and the Islands further from shore. The regional increase between 2005 and 2007 was due to the rapid colonisation by *Lobophora* of coral skeletons exposed as a result of coral bleaching mortality on the more offshore reefs in early 2006 (Diaz-Pulido *et al.* 2009). Declines 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.

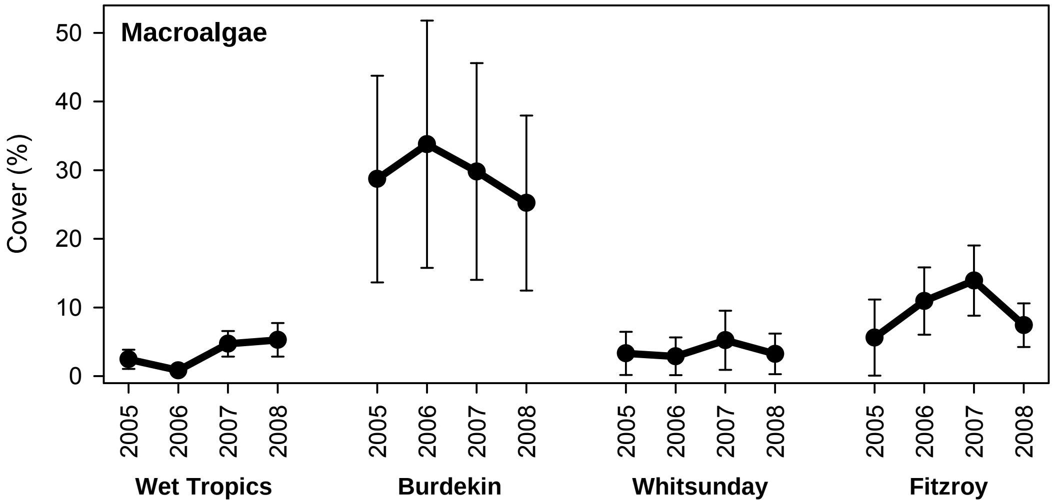

Figure 3.6 Average cover of macroalgae on reefs for each NRM region (+/- standard error). For each region only reefs sampled in all years are included to ensure consistency among means.

Density and count of juvenile colonies

On the core reefs the average density of juvenile colonies per m^2 has reduced from a high of 5.8 in 2005 to a low of 3.9 in 2008. This decline has been observed in all regions (Figure 3.7). 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 in the lower density of juvenile colonies in the following years. The decline in density of juvenile corals corresponded river flow data. With the exception of the Burdekin region were density of recruits was highest in 2006, all regions showed highest density of colonies in 2005. River flow data (Table A1-2.2 in Appendix 1) 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 and Pioneer rivers 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. In each region flows were above median levels over the period of declining density of juvenile colonies. In particular, flooding of the Burdekin, Pioneer and Fitzroy Rivers in 2007/08 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 removal.

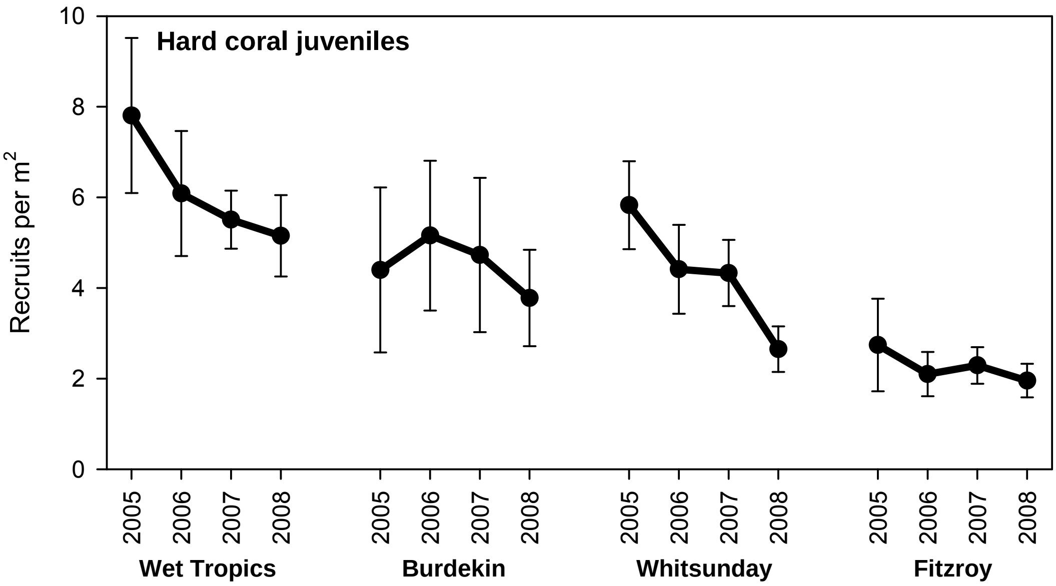

Figure 3.7 Average number of hard coral colonies < 10cm in diameter per m^2 on reefs within each NRM region (+/- standard error). For each region only reefs sampled in all years are included to ensure consistency among means.

Richness of hard coral genera

A possible result of environmental degradation is the loss of diversity as susceptible taxa that die are not replaced. Over the period 2005-2008 the average number of hard coral genus recorded on photo transects on the core reefs has remained relatively stable or even increased slightly in 2008 (Figure 3.8). 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 species level. Specious genera such as Acropora may see changes in richness that can not be differentiated from the data available.

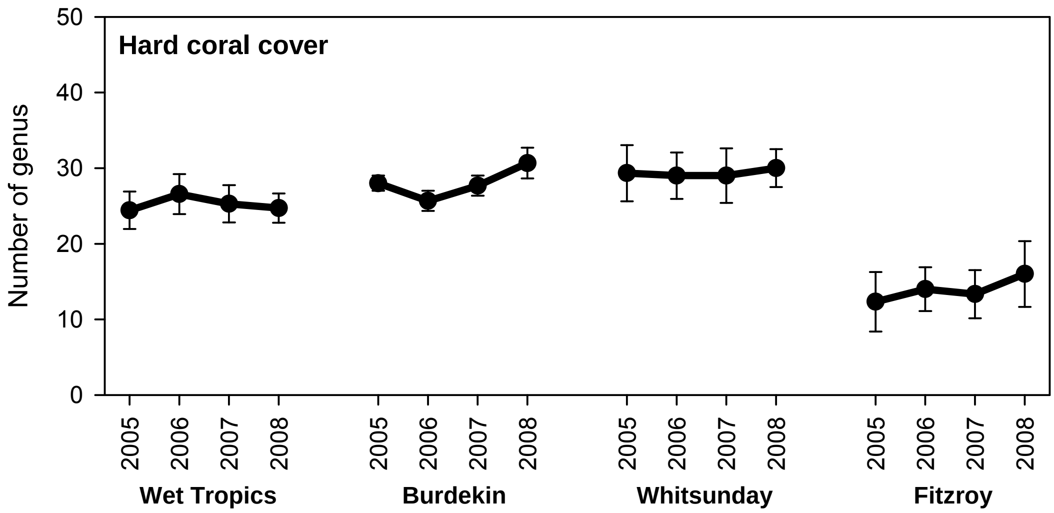

Figure 3.8 Average number of hard coral genera per reef observed on photo transects for each NRM region (+/- standard error).

Richness of juvenile (<10cm) hard coral colonies

Estimates of the richness of juvenile corals from 2007 and 2008 are not directly comparable to those from previous years due to a doubling of the transect area. Increasing the area of transects will likely result in increased richness as individuals of rare genera are more likely to occur. Hence, the observed increase in richness from 2006 to 2007 in all regions compared to 2005 and 2006 estimates cannot be interpreted (Figure 3.9).

Regional richness of hard coral recruits remained relatively stable between 2007 and 2008 in both the Burdekin and Fitzroy regions with reef level richness differing by between 1 and 3 genera at all reefs. There was a substantial decline in the number of genera represented by juvenile sized colonies in the Whitsunday region with between 8 and 9 fewer genera per reef observed in 2008 than in 2007. The genera missing from 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 3.9).

In the Wet Tropics Region, differences in richness between 2007 and 2008 varied more strongly between reefs. Richness was higher in 2008 at both Fitzroy Is West (5 genera) and East (3 genera) but lower at all other reefs by 4-9 genera. Again these declines are consistent with declines in overall abundance of juveniles at most reefs. 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-stage.

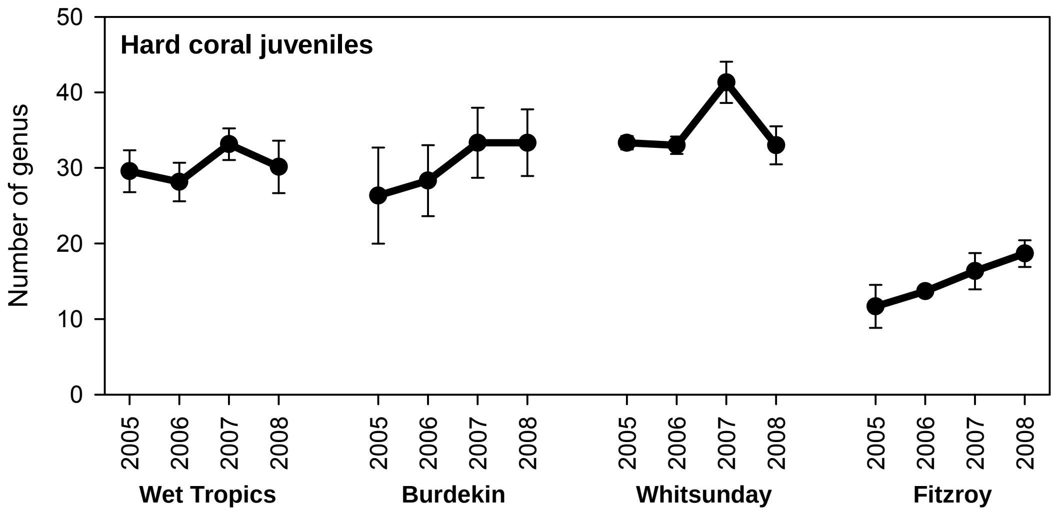

Figure 3.9 Average number of hard coral genera per represented by colonies < 10cm in diameter observed during transect searches for juvenile colonies (+/- standard error). Note that data from 2005 and 2006 are not directly comparable to later years due to a doubling in transect area searched.

The number of recruits to tiles

At a regional level the pattern of spat settlement is closely mirrored between the Wet Tropics and Mackay Whitsunday (Figure 3.10) with the overall numbers higher in the Wet Tropics. In the Wet Tropics increasing settlement from 2005 to 2007 reflects increasing cover of the family Acroporidae (Figure 3.16) suggesting a link between local broodstock and settlement. This is not however the case in the Whitsunday region where there was no obvious increase in the cover of Acroporidae in the period 2005 to 2007. A further possible link between regional broodstock and settlement was observed in the Burdekin region where settlement and the cover of Acroporidae (Figure 3.23) and hard coral in general (Figure 3.4) is consistently lower than in other regions. In these three regions settlement was lower in 2008 than previously observed; this decline does not correspond to declines in broodstock in any of the regions.

In the Fitzroy region settlement has also fluctuated between years (Figure 3.10), with this fluctuation not corresponding to the regional cover of potential broodstock (Figure 3.4, 3.31). In this region a high proportion of Acroporidae were bleached white in early 2006. Bleaching of corals in other areas has been shown to reduce fecundity in the following season (Ward *et al.* 2000). It was unexpected then that the highest settlement recorded over the three years of monitoring occurred in the settlement period following the major bleaching. The implied rapid recovery from bleaching related stress is consistent with rapid increase in cover following bleaching mortality observed in this region (Sweatman *et al.* 2007, Diaz-Pulido *et al.* 2009).

While possible links to local availability of broodstock are implicated in the Wet Tropics 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 there in). Hydrodynamics are a key factor likely to influence larval availability in the nearshore environment with variation in both local wind conditions and the influence of larger scale currents (Brinkman *et al.* 2001) likely to cause substantial variability in larval transport between years. In addition, wind conditions are a primary cause of turbidity in nearshore waters (Larcombe *et al.* 1995) with high turbidity shown to be detrimental to survival of coral larvae (as reviewed by Fabricius 2005).

The coral spat settling to tiles are dominated by the Acroporidae with less common families Poritidae and the brooder Pocilloporidae routinely identified. The high proportion of Acroporidae settling to tiles does not typically reflect the varied composition of the adult communities at the tile deployment sites (see reef level presentation of community composition in the following section). It is well documented that coral larvae are selective in their choice of settlement location with various cues including environmental factors such as light (Mundy and Babcock 1998), depth (Baird *et al.* 2003) and, probably related, biochemical signatures derived from bacteria (e.g. Negri *et al.* 2002) implicated in promoting settlement. It is probable that the high proportion of Acroporidae settling to tiles relative to the proportion of Acroporidae in the Juvenile or adult communities is due in part to a higher acceptance of tiles as a settlement substrate by Acroporidae larvae than some other species. The question remains: how much of the difference is due to selectivity of tiles as a settlement substrate verses the success in surviving settlement to recruit into the juvenile community?

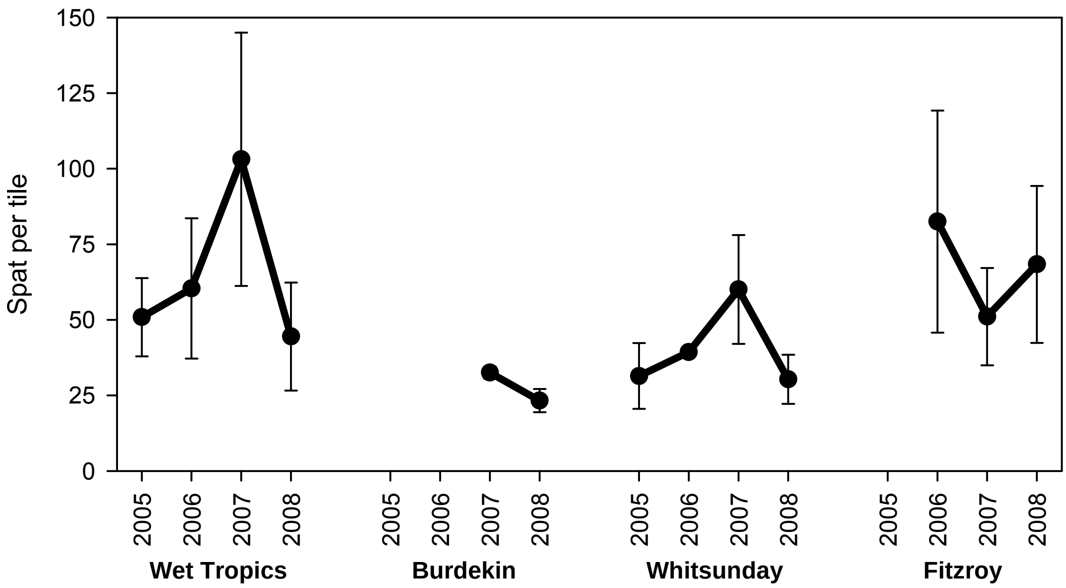

Figure 3.10 Average number of hard coral recruits per tile on core reefs in each NRM region. Estimates are for 5m depth tile deployments only.

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

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 3.11). These reefs have been monitored by Sea Research since 1995. This historical data show that while the benthic communities have experienced several disturbances (Table A1-3.2) they showed resilience with coral cover tending to increase in inter-disturbance periods (Ayling and Ayling 2005). This potential for recovery is maintained 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 shallower 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 did suffer a substantial reduction in cover in 1999 as a result of Cyclone Rona (Ayling and Ayling 2005).

Over the period 2005 to April 2009 the only disturbance to have impacted these reefs was an unidentified storm event (possibly associated with Cyclone Hamish in March 2009) that caused physical damage to corals at Snapper Is North. It is likely that this disturbance caused the slight reduction in cover of hard coral, soft coral and macroalgae, all of which had been increasing in previous surveys (Figure 3.12).

At Snapper Is South cover of hard coral and to a lesser extent soft coral has increased annually to 2009. 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 2009 the cover of *Acropora* had begun to increase (Figure 3.14). This increase in *Acropora* cover at Snapper Is South 2m is likely to accelerate given the very high density of juvenile colonies (mostly *Acropora*) recorded in 2009 (Figure 3.13). The number of juveniles at 5m was however low. At Snapper Is North the density of juvenile colonies has been similar to the overall average for all reefs in most years (Figure 3.13).

Sediments at Snapper Is North had above average levels of clay & silt sized particles, organic carbon (Figure 3.12) and nitrogen (Table AI-3.1a-c). Conversely inorganic carbon was low (Table AI-3.1d) in combination these results suggesting the accumulation of terrigenous components. The more exposed Snapper Is South had lower accumulation of fine sediments with inorganic carbon higher indicative of more reef derived components.

Turbidity levels at Snapper Is North exceed average levels throughout the year (Figure 3.12). High turbidity translates to rapid attenuation of light in the water column. This rapid attenuation of light results in a steep environmental gradient across depth as evidenced by the marked compositional difference between coral communities at 2m and 5m depth (Figure 3.14). Average chlorophyll levels are below trigger values for coastal reefs (GBRMPA 2008) which likely explains the low cover of macroalgae at Snapper Island.

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Figure 3.11 Reef Rescue MMP inshore coral reef monitoring sites (blue squares) in the Barron-Daintree subregion of the Wet Tropics Region: Snapper Island.

The overall impression of status for both Snapper Is North and Snapper Is South is positive based on;

- high coral cover with demonstrated potential for increase during non-disturbance periods;
- low cover of macro algae; and
- moderate densities of juvenile colonies at 2m in general with high density at Snapper South in 2009.

Table 3.4 Reef by depth estimates of coral community status of reefs in the Daintree sub-region of the Wet Tropics region. The over all status aggregates over the three indicators of coral cover, macroalgal cover and Juvenile hard coral density. Coral cover trend indication: u="up", s= "stable", d="decreasing".

Reef	Depth (m)	Overall Status	Coral		Macroalgae		Hard coral Juveniles			Settlement		
			Cover trend	Status	Cover trend	Status	Density	rank	Status	#per tile	rank	Status
Snapper Is North	2	+++	60.9 u	+	6 d	+	10.4	8	+	N/A		
	5	++	57.4 u	+	0.7 s	+	9.1	15	neutral			
Snapper Is South	2	+++	33.3 u	+	0.9 s	+	11.3	7	+			
	5	+	68.4 u	+	2.6 s	+	5.3	21	-			

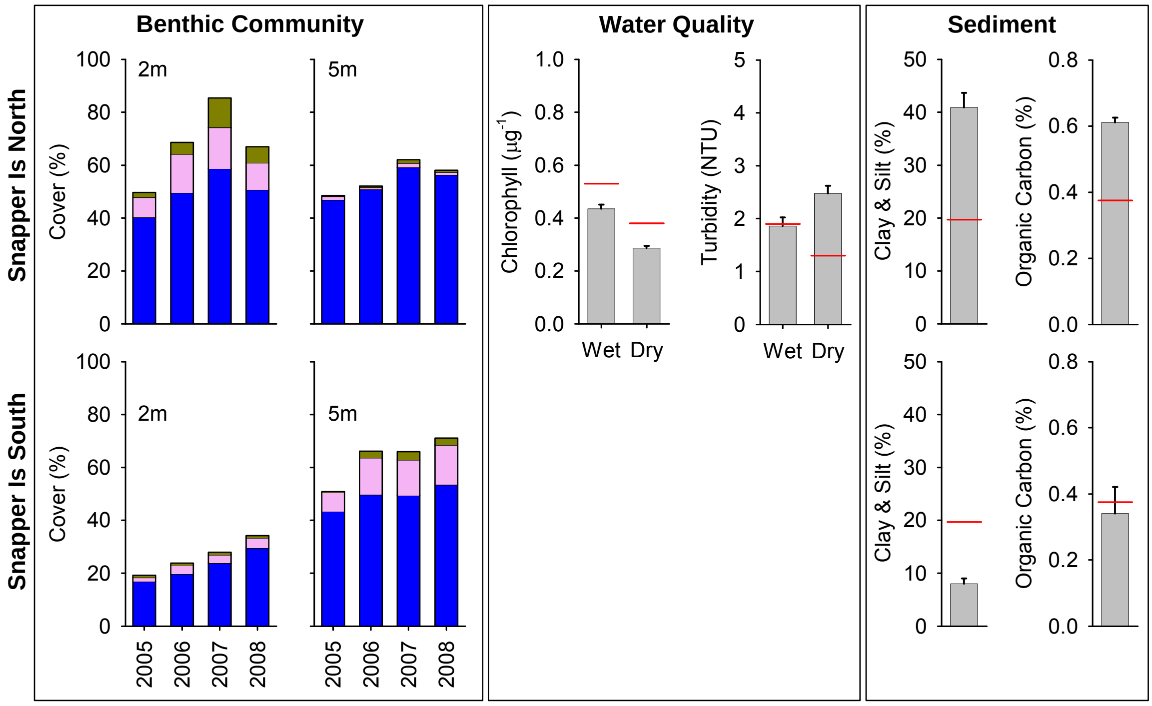

Figure 3.12 Percent cover estimates of major benthic groups, hard coral (blue), soft coral (pink) and macroalgae (green) and water quality and sediment quality parameters on reefs in the Barron Daintree sub-region of Wet Tropics NRM region. Red reference lines indicate the average values of environmental data from core reefs.

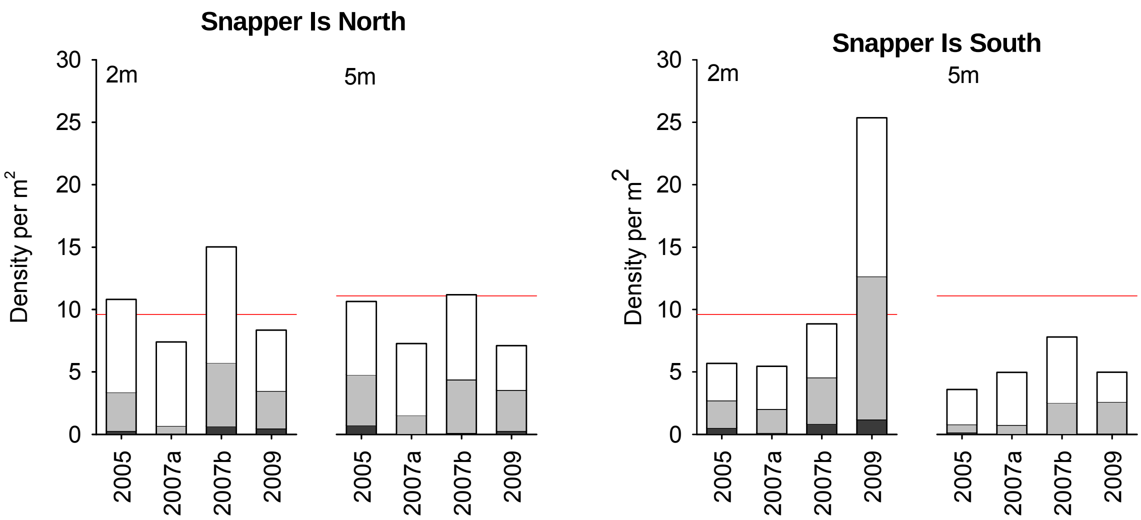

Figure 3.13 Density of juvenile hard coral colonies standardised to the area of available substrate for settlement on reefs in the Barron Daintree sub-region of the Wet Tropics NRM region. Bars are cumulative densities over the three size classes, <2cm (dark grey), 2-5cm (pale grey) and >5cm to 10cm (white). Red reference lines indicate the average density at each depth over all years from all reefs and NRM regions.

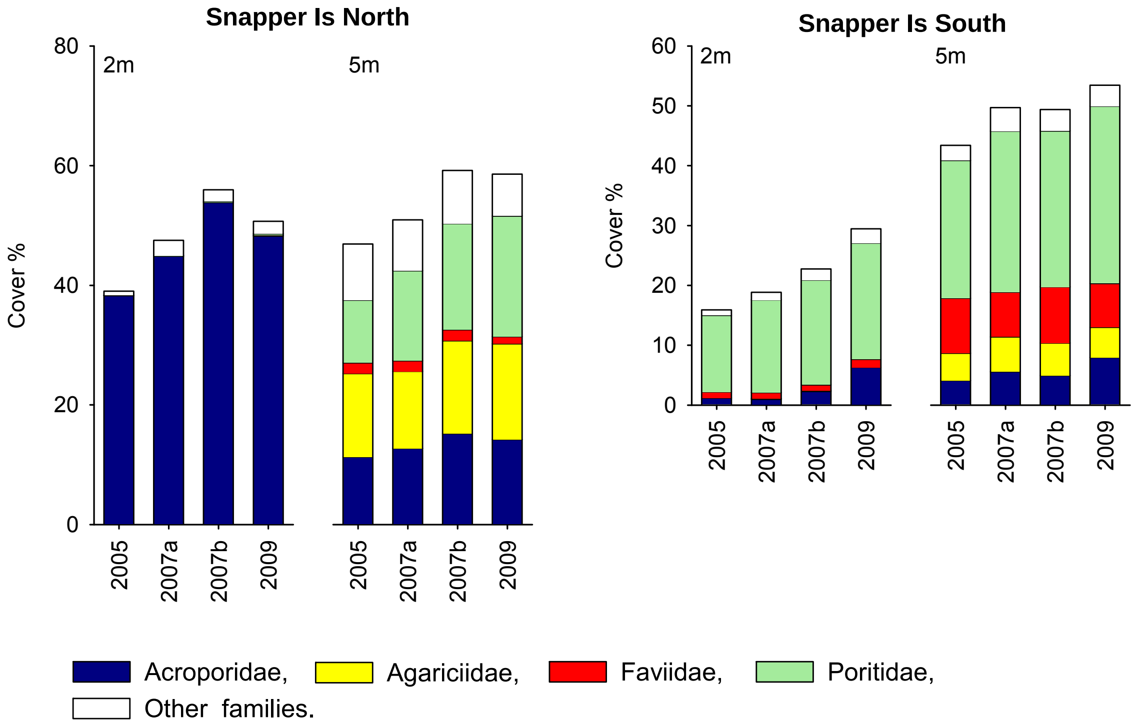

Figure 3.14 Composition of hard coral communities on reefs in the Barron Daintree sub-region of the Wet Tropics NRM region. Bars are the cumulative cover of dominant families within the region. Families are indicated by colour of bar section. Only families for which cover exceeded 4% cover on at least one reef at one depth in one year are differentiated; all other families are aggregated into the 'Other families' group (white bars).

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

Of the reefs surveyed in this sub-region (Figure 3.15) 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 (TableA1-3.2). 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 reef were 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.* 2005), however there were no marked impacts on coral cover directly attributable to these events at the depth of monitoring sites. It is possible however coral communities in shallower water than those monitored may have suffered some mortality during these flood events. Certainly observations taken from these reefs in February 2009 following flooding of the Russell-Mulgrave strongly suggested fresh water had impacted shallow reef flat communities at some locations (AIMS unpublished data). Temporal profiles of coral cover for Fitzroy Island and the Frankland Group are presented in Sweatman *et al.* (2007), and show periods of recovery to 2005 following these multiple disturbances. No disturbances were identified for the period between the 2007 and 2008 observations presented here.

The reefs in this area are subject to outflows from the Johnstone and the Russell-Mulgrave rivers. The majority of reefs surveyed have sediments with moderately low levels of clay/silt, organic carbon (Figure 3.16) and nitrogen (Table AI-3.1a-c) indicating low residence or accumulation of sediment components derived from these rivers. The exception is Frankland Group West with higher than average levels of clay / silt, organic carbon and nitrogen. This 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 chance of resuspension of these sediments.

Within this sub-region turbidity is low (Figure 3.16). Low turbidity results in less attenuation of light with depth. That coral communities share similar compositions at 2m and 5m (Figure 3.18) is consistent with light not being a strong limiting factor for these coral communities.

In the period 2005 to 2008 both the western and eastern reefs of Fitzroy Is have shown marked increases in hard coral cover (Figure 3.16). At both reefs increases in cover are largely resulting from the increase in the cover of the family Acroporidae (Figure 3.18), a family particularly susceptible to the types of disturbances recorded at this reef over the last 10 years. Underpinning this recovery is the relatively high density of recruits recorded on the western reef and from 5m depth on the eastern reef. This strong increase in cover along with above average densities of juveniles leads to a positive impression of the status of benthic communities at Fitzroy Island (Table 3.5).

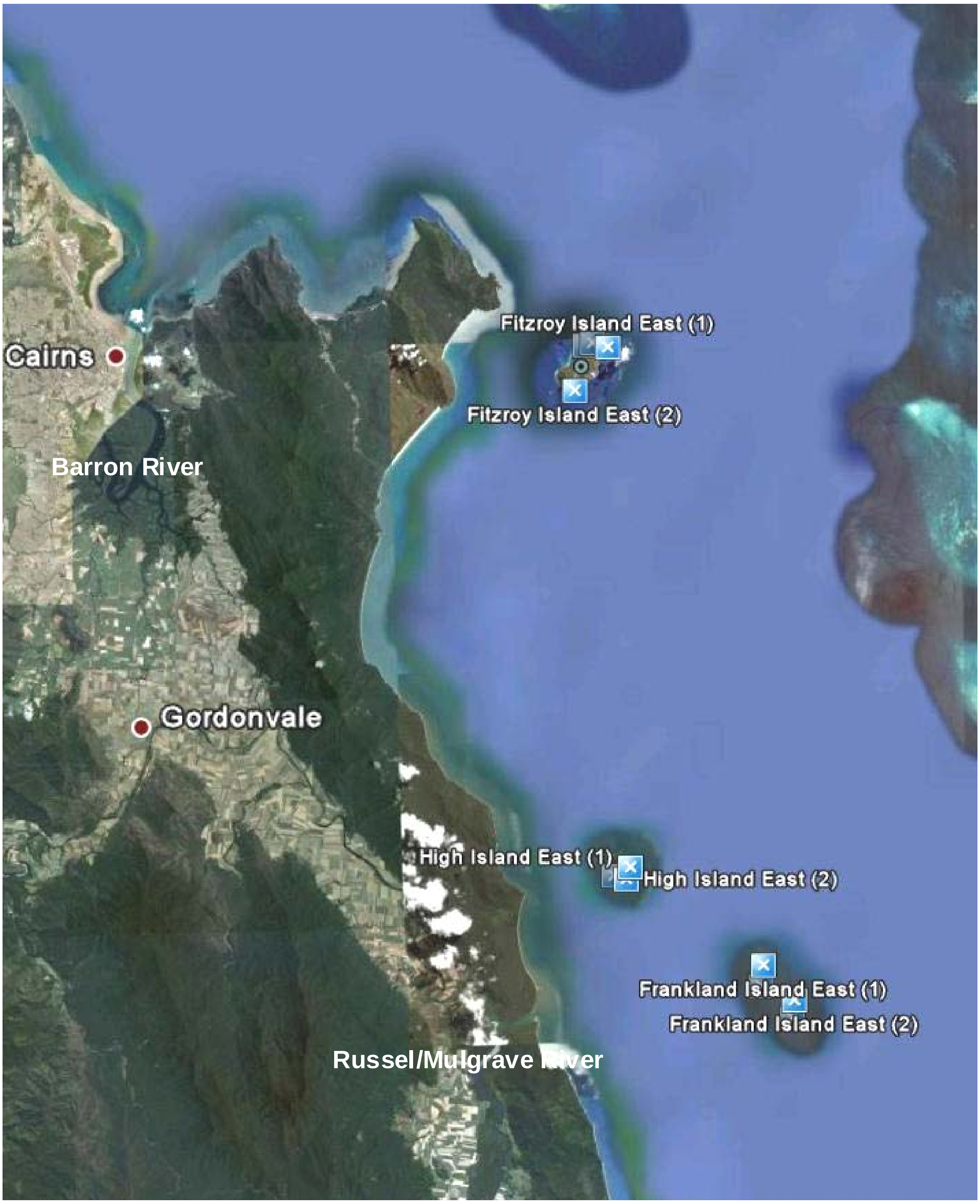

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Figure 3.15 Reef Rescue MMP inshore coral reef monitoring sites (blue squares) in the Johnstone and Russell/Mulgrave subregion of the Wet Tropics Region: Fitzroy Island, Frankland Group and High Island.

The cover of soft corals has remained stable over the period 2005 to 2008 with cover of this group regionally high at both depths of Fitzroy Is West.

The western reefs of both High Is and the Frankland Group have not shown similar increases despite avoiding substantial disturbances in the period 2005-2008. The exception may be High Is West 5m where cover appears to have increased in 2008 following slight declines between 2005 and 2006 and also 2006 to 2007. The cause of the decline to 2006 is assumed to have been due to the toppling of some reef slope colonies during the passage of Cyclone Larry the subsequent decline to 2007 remains unexplained. The communities at both High Is 2m and Frankland Group 5m have high coral cover with communities including a high proportion of the family Poritidae (Figure 3.18). Members of this family are relatively slow growing and so their high representation may limit the potential for rapid increases in cover. Slight declines in coral cover at Frankland Group West 5m have occurred since 2006 and are largely due to the colonisation of spaces between branches of *Porites cylindrica* and *Porites rus* by red algae rather than any acute disturbance event. Despite this increase the cover of macroalgae remains low on all reefs in this sub-region.

At Frankland Group West 2m past monitoring data indicates the community included a high component 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. In part this lack of recovery seems linked to a lack of larval supply or settlement avoidance with settlement to tiles at this reef substantially lower than that observed at other reefs in the sub-region (Figure 3.19). This low recorded settlement may also explain the low density of juvenile colonies observed in 2007 and 2008 (Figure 3.17).

Regionally, settlement to tiles increased annually over the period 2005 to 2007. While the increase in overall settlement predominantly reflects numbers of *Acropora* spat, a genus that consistently accounts for approximately 90% of spat settling to tiles, settlement of both *Pocillopora* and *Porites* was also higher in 2007 than previously observed. This regional increase in recruitment was driven by increases in settlement at both Fitzroy Is West and High is West (Figure 3.19). The regional increase in settlement likely reflects the increasing cover of corals particularly the genus *Acropora* that has seen rapid increases particularly on the Eastern reefs of High Island and Fitzroy Island. This higher cover is largely due to the growth of colonies and equates to a large increase in larval supply. This relationship did not continue in 2008 with low settlement recorded at each reef while regionally the cover of Acroporidae continues to increase.

Settlement at Frankland Group West is starkly lower than at the other two reefs, and showed no evidence of the increases observed over 2005-2007. The taxonomic composition of spat settling to tiles also varies with a relatively high proportion of the family Pocilloporidae. Many species of the family Pocilloporidae brood their larvae internally enabling the larvae to be competent to settle as soon as released from the adult polyp. This is in contrast to many other families, including the Acroporidae, for which larvae are released into the water column and dispersed by the currents for at least several days. The combination of a high proportion of brooded spat and very low numbers of spawned spat relative to nearby reefs suggest the low settlement to tiles and also density of juvenile colonies at Frankland Group West is due to isolation from the local larval pool, possibly due to local hydrodynamic conditions.

The overall impression of status for reefs in this sub-region is positive for all locations other than Frankland Group West at 5m (Table 3.5). The impression of status at Frankland group West 5m is negative despite high coral cover. The observed decline in coral cover and increase in the cover of macroalgae that can not be associated with acute disturbance, along with consistently low densities of juvenile colonies influence the negative assessment of community status.

The positive impression of status for coral communities at both Fitzroy Island West and Fitzroy Is East reflect observed increases in cover in absence of disturbance, a lack of or very low cover of macroalgae and high density of juvenile colonies to areas of available substrate.

For High Is West the positive impression of status reflects consistently low cover of macroalgae at both depths and consistently high cover of corals at 2m. Moderate densities of juvenile hard corals and moderate cover of corals at 5m (that include a decline associated with acute disturbance) are treated as neutral in determination of the status of these communities.

For Frankland Group West 2m moderate cover of corals and density of juveniles are considered neutral in our impression of status with positive status arising due to the low cover of macroalgae. It should be noted however that the cover of macroalgae is only marginally below the level (5%) that would have resulted in a neutral assessment of this community component and therefore an overall neutral assessment of the status of this community.

Table 3.5 Reef by depth estimates of coral community status of reefs in the Johnstone Russell-Mulgrave sub-region of the Wet Tropics region. The over all status aggregates over the three indicators of coral cover, macroalgal cover and Juvenile hard coral density. Settlement of coral spat is also considered where sampled. Coral cover trend indication: u="up", s= "stable", d= "decreasing".

Reef	Depth (m)	Overall Status	Coral		Macroalgae		Hard coral Juveniles			Settlement		
			Cover trend	Status	Cover trend	Status	Density	rank	Status	#per tile	rank	Status
Fitzroy Is West	2	+++	75.1 u	+	0.1 s	+	26.0	1	+			
	5	++++	58.6 u	+	0.4 s	+	21.6	2	+	131	1	+
Fitzroy is East	2	+++	46.4 u	+	0.6 s	+	11.8	5	+			
	5	+++	56.7 u	+	0.2 s	+	21.7	1	+			
Frankland Group West	2	+	44.4 s	neutral	6 s	+	8.6	13	neutral			
	5	- - -	62.4 d	-	18 u	-	6.5	18	-	36	6	neutral
High Is West	2	++	65.7 s	+	2.9 s	+	10.2	9	neutral			
	5	+	26.9 s	neutral	2 s	+	10.4	13	neutral	55	5	neutral

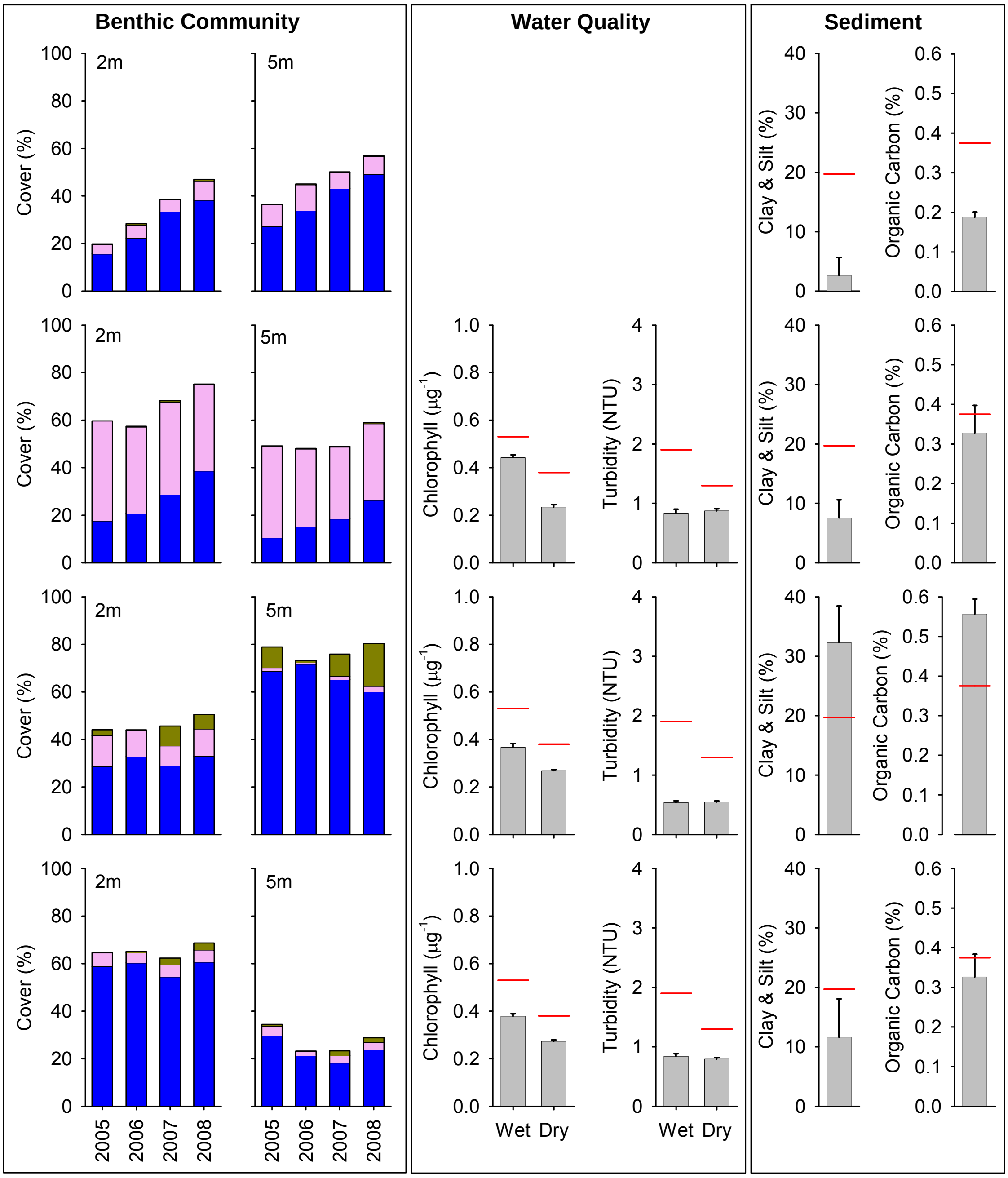

Figure 3.16 Percent cover estimates of major benthic groups, hard coral (blue), soft coral (pink) and macroalgae (green) and water quality and sediment quality parameters on reefs in the Johnstone Russell / Mulgrave sub-region of Wet Tropics NRM region. Red reference lines indicate the average values of environmental data from core reefs.

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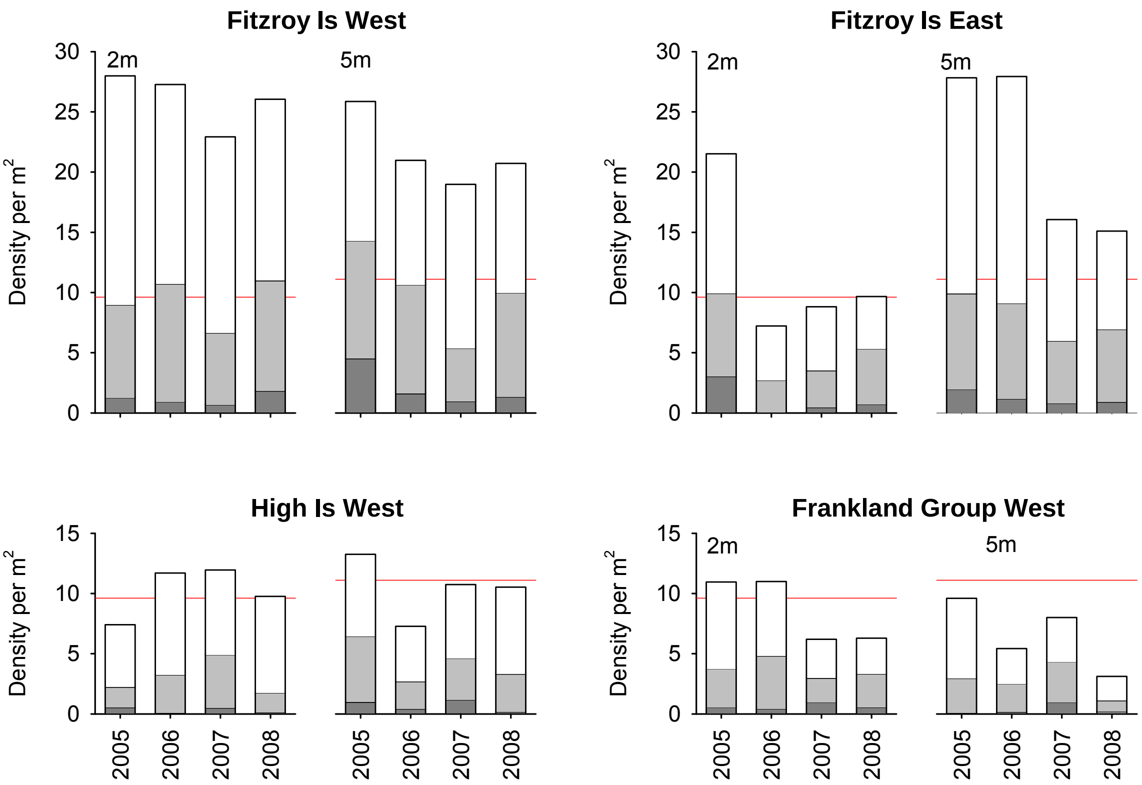

Figure 3.17 Density of juvenile hard coral colonies standardised to the area of available substrate for settlement on reefs in the Johnstone Russell / Mulgrave sub-region of the Wet Tropics NRM region. Bars are cumulative densities over the three size classes, <2cm (dark grey), 2-5cm (pale grey) and >5cm to 10cm (white). Red reference lines indicate the average density at each depth over all years from all reefs and NRM regions.

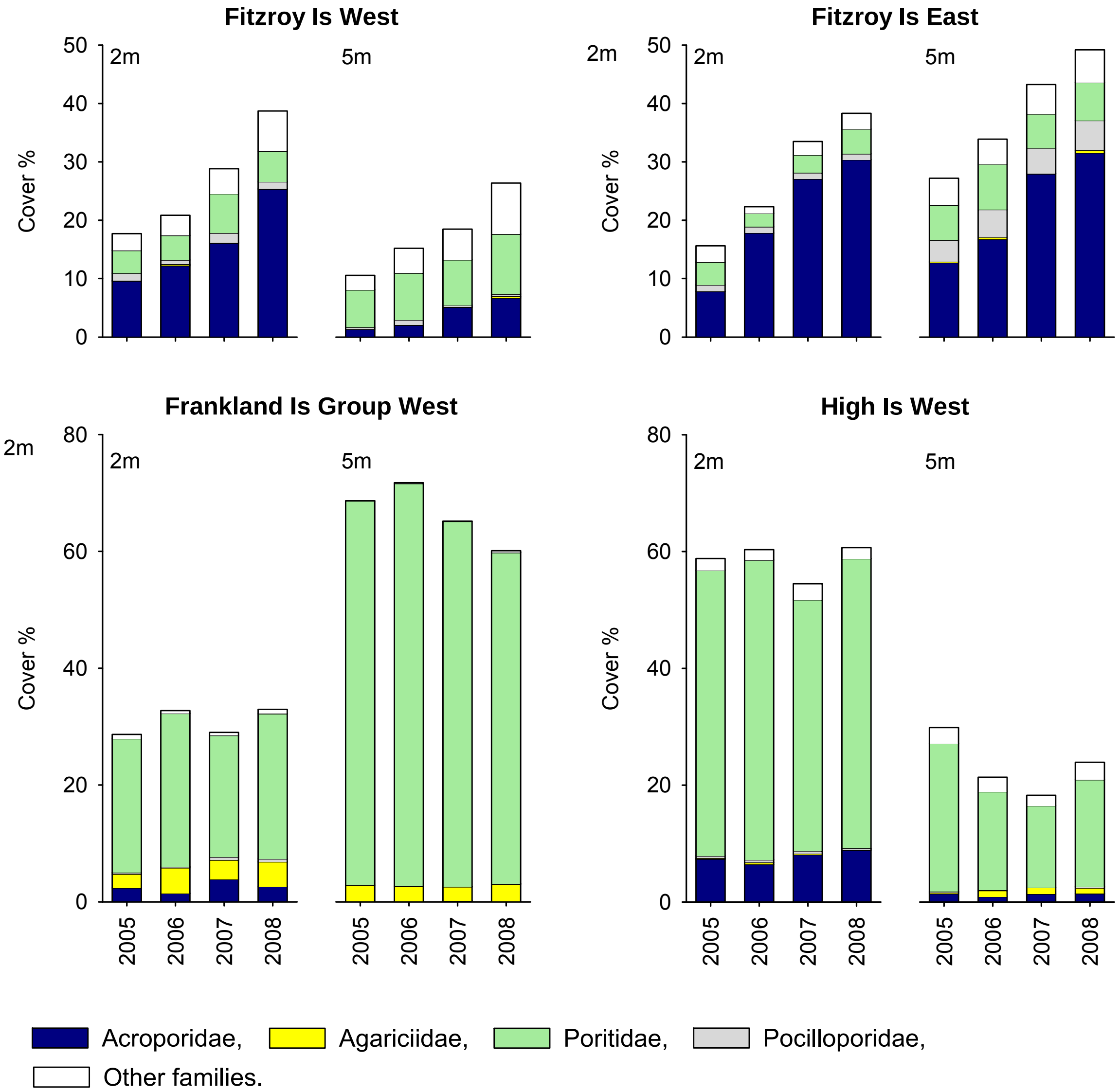

Figure 3.18 Composition of hard coral communities on reefs in the Johnstone Russell-Mulgrave sub-region of the Wet Tropics NRM region. Bars are the cumulative cover of dominant families within the region. Families are indicated by colour of bar section. Only families for which cover exceeded 4% cover on at least one reef at one depth in one year are differentiated; all other families are aggregated into the 'Other families' group (white bars).

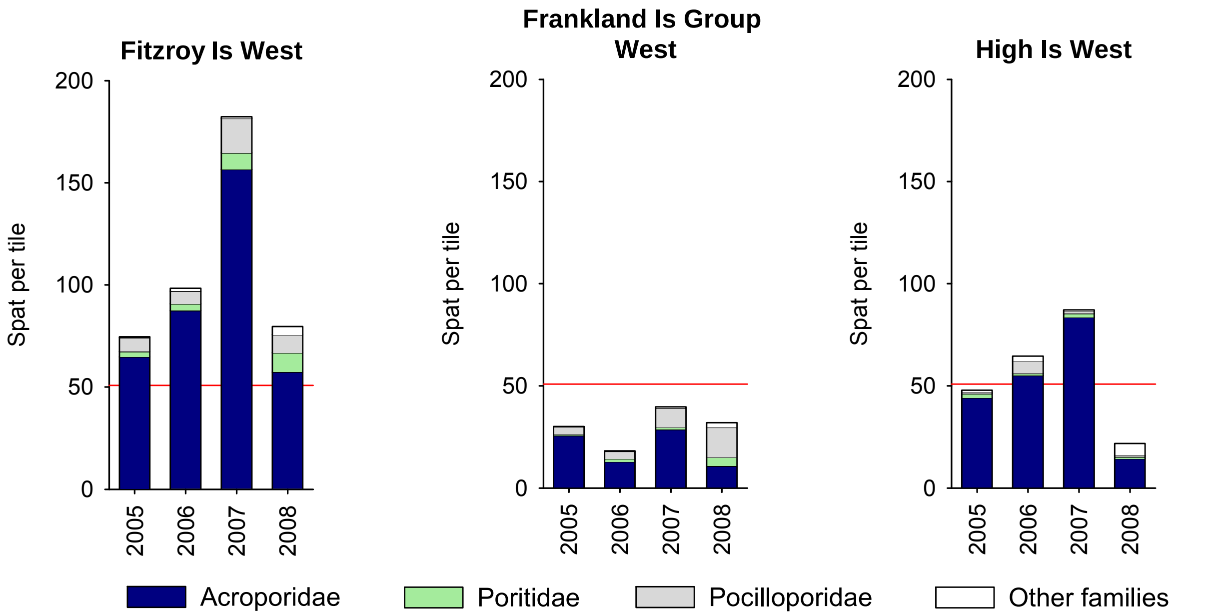

Figure 3.19 Average number of coral recruits per tile on reefs in the Johnstone Russell-Mulgrave sub-region of the Wet Tropics NRM region. Data are from 5m tile deployments. Average values from all reefs and NRM regions sampled in 2007 and 2008 are indicated by red reference lines.

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, though AIMS does hold unpublished data from Dunk Island (K. Fabricius pers. com). 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 A1-3.2) though the impacts on the benthic communities are unknown.

Recent modelling work indicates hard coral communities in this sub-region were all likely to have been impacted by coral bleaching in 1998 and 2002 (Table A1-3.2). Similar reductions in hard coral cover (43%) to those observed by Ayling and Ayling (2005) at the Frankland Island Group in 1998 are possible.

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. The levels of fine sediment, nitrogen, and organic carbon are average lower than average among all regions (Table AI-3.1a-c). This suggests a low residence time for fine sediment at these reefs. At Dunk Is North the clay/silt component in 2008 had more than doubled from previous years. This along with high turbidity may indicate a process of frequent resuspension and transport of sediments.

In March 2006 Cyclone Larry severely impacted Dunk Island North resulting in a substantial reduction in the cover of hard and soft corals and also macroalgae (Figure 3.21). 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 3.21). 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 and bleaching rather than the physical damage observed at sites open to the north and east. In 2008 only minor recovery had occurred at Dunk Is North with slight increases in the cover of the family Acroporidae and at Dunk Is South 5m where cover of Acroporidae and Dendrophylliidae had increased marginally (Figure 3.23). No recovery was evident at King or Dunk Is South 2m.

The density of juvenile colonies has tended to decline over the period 2006 to 2008 with very low densities observed at King Reef and also Dunk Is South 2m (Figure 3.22). The only exception was Dunk Is North 5m where a strong recruitment of *Turbinaria* observed as <2cm size colonies were recorded in 2008. Local reductions in adult coral populations as a result of Cyclone Larry and the ensuing high cover of macro algae are both plausible explanations for these generally low densities of juvenile colonies.

The cover of macroalgae increased between 2006 and 2008 at all locations with the exception of Dunk Is North 5m though cover here also increased between 2007 and 2008 (Figure 3.21). As a generality high macroalgae cover is limited to reefs with high levels of chlorophyll. The chlorophyll levels at Dunk Island North are marginally below the 0.45μg^{-L} trigger value for chlorophyll in coastal waters set in the GBRMPA Water Quality Guideline for the Great Barrier Reef Marine Park (GBRMPA 2009) and are the lowest of any of the fourteen logger sites to be associated with a reef community including a high macroalgal component.

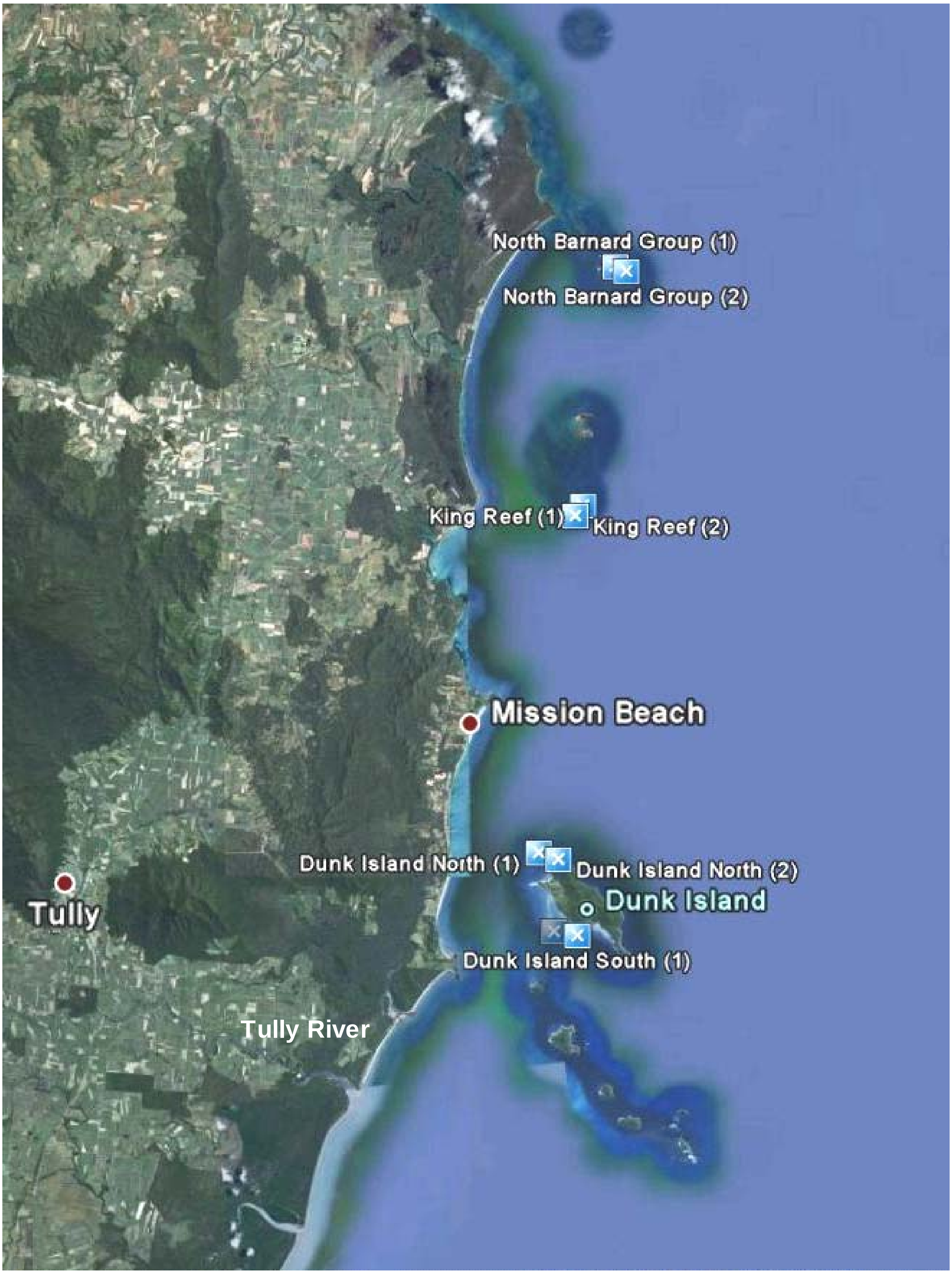

Figure 3.20 Reef Rescue MMP inshore coral reef monitoring sites (blue squares) in the Herbert Tully subregion of the Wet Tropics Region: North Barnard Group (not surveyed in 2008), King Reef and Dunk Island.

It will be informative to document how future chlorophyll levels compare and also the longevity of the relatively high proportion of macroalgae in the community as chlorophyll levels here seem close to the critical concentration required for persistent macroalgal communities. Comparing chlorophyll concentrations from discrete water sampling events indicate that levels are higher at King Reef (Thompson *et al.* 2009), where macroalgal communities are flourishing, than at Dunk Island.

The overall impression of status for reefs in this sub-region varied among reefs (Table 3.6). The impression for Dunk Is North was positive reflecting relatively high average densities of juvenile hard corals. It should be noted that the trend in hard coral juvenile density is not considered in the assessment of status and as such the decline observed through to 2008 at 2m is not influencing this assessment other than reducing the over all mean. At 2m the slight recovery in hard coral is compensating for the negative assessment of status attracted by the high cover of macroalgae. At 5m macroalgae cover is lower but there is also no evidence of recovery with the coral cover stable at moderate levels and as such these components of the community are not strongly influencing the assessment of status.

For Dunk Is South only the high cover of macroalgae at 2m strongly influences the negative impression of status for this community with algae at 5m lower and the dynamics of the coral community and density of juvenile colonies not providing clear impressions in any direction.

For King Reef the impression of status was negative with high cover of macroalgae at both depths and coral cover very low and showing no signs of recovery. This is especially true at 2m where the density of juveniles is also extremely low. At 5m the density of juveniles averaged over the pre and post disturbance observations is, as at Dunk Is North 2m, perhaps giving a false impression of the current status of the community relative to this variable.

Table 3.6 Reef by depth estimates of coral community status of reefs in the Herbert Tully sub-region of the Wet Tropics region. The over all status aggregates over the three indicators of coral cover, macroalgal cover and Juvenile hard coral density. Coral cover trend indication: u="up", s= "stable", d= "decreasing".

Reef	Depth (m)	Overall Status	Coral		Macroalgae		Hard coral Juveniles			Settlement		
			Cover trend	Status	Cover trend	Status	Density	rank	Status	#per tile	rank	Status
Dunk Is North	2	+	13.4 u	+	25.7 u	-	12.2	4	+	N/A		
	5	+	16.9 s(d)	neutral	7.9 s	neutral	19.7	4	+			
Dunk Is South	2	-	20.6 s	neutral	26.1 u	-	10.0	11	neutral			
	5	neutral	44.7 s	neutral	10.7 s	neutral	10.6	12	neutral			
King	2	- - -	0.5 d(d)	-	79.9 u	-	3.2	22	-			
	5	-	9.8 s(d)	-	25.8 u	-	13.1	7	+			

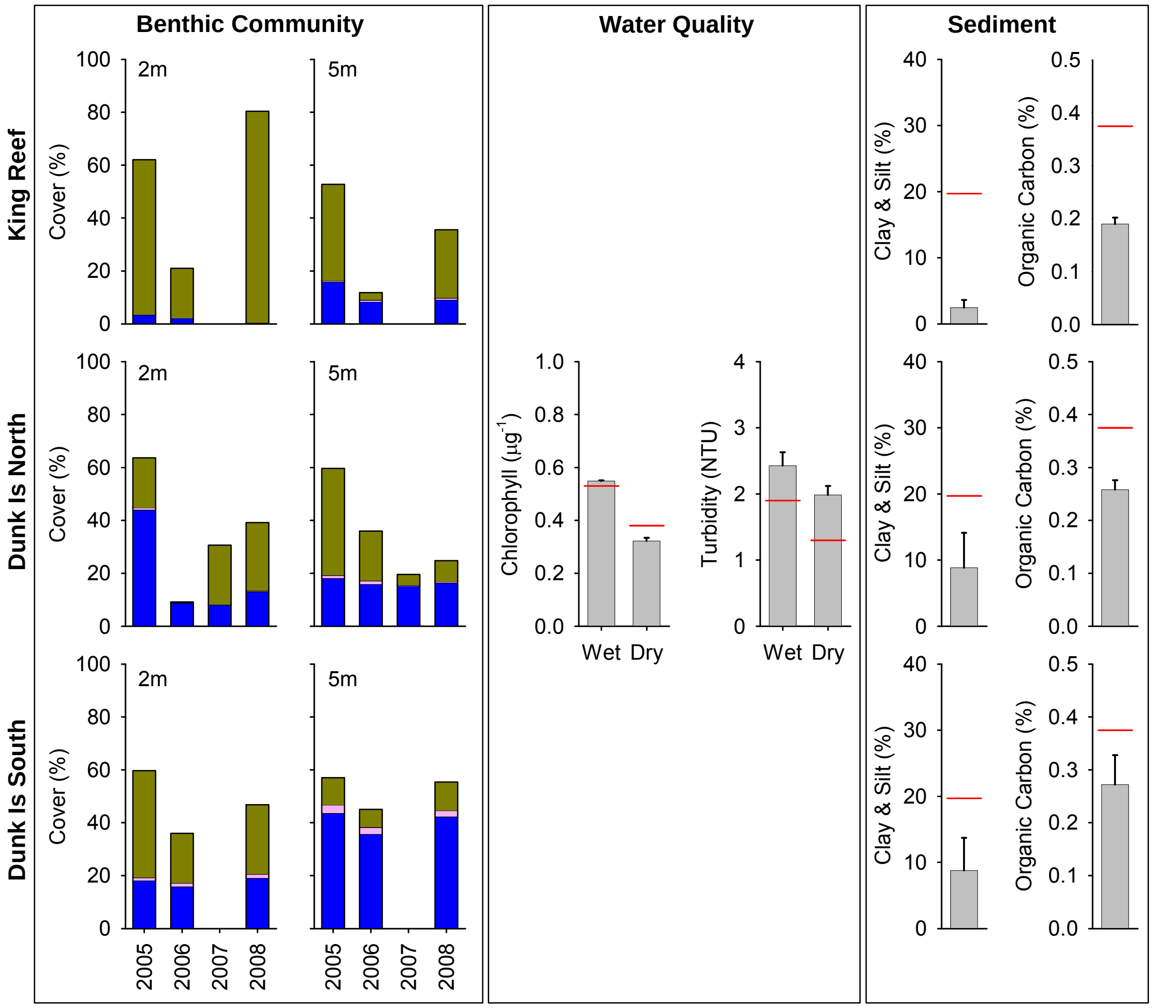

Figure 3.21 Percent cover estimates of major benthic groups, hard coral (blue), soft coral (pink) and macroalgae (green) and water quality and sediment quality parameters on reefs in the Herbert Tully sub-region of Wet Tropics NRM region. Red reference lines indicate the average values of environmental data from core reefs.

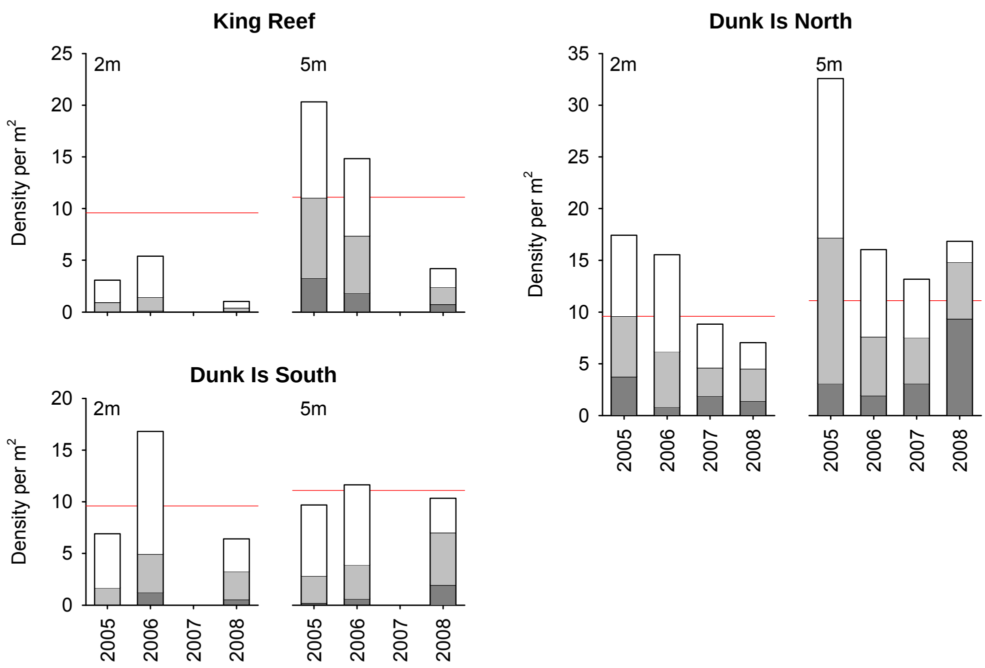

Figure 3.22 Density of juvenile hard coral colonies standardised to the area of available substrate for settlement on reefs in the Herbert Tully sub-region of the Wet Tropics NRM region. Bars are cumulative densities over the three size classes, <2cm (dark grey), 2-5cm (pale grey) and >5cm to 10cm (white). Red reference lines indicate the average density at each depth over all years from all reefs and NRM regions.

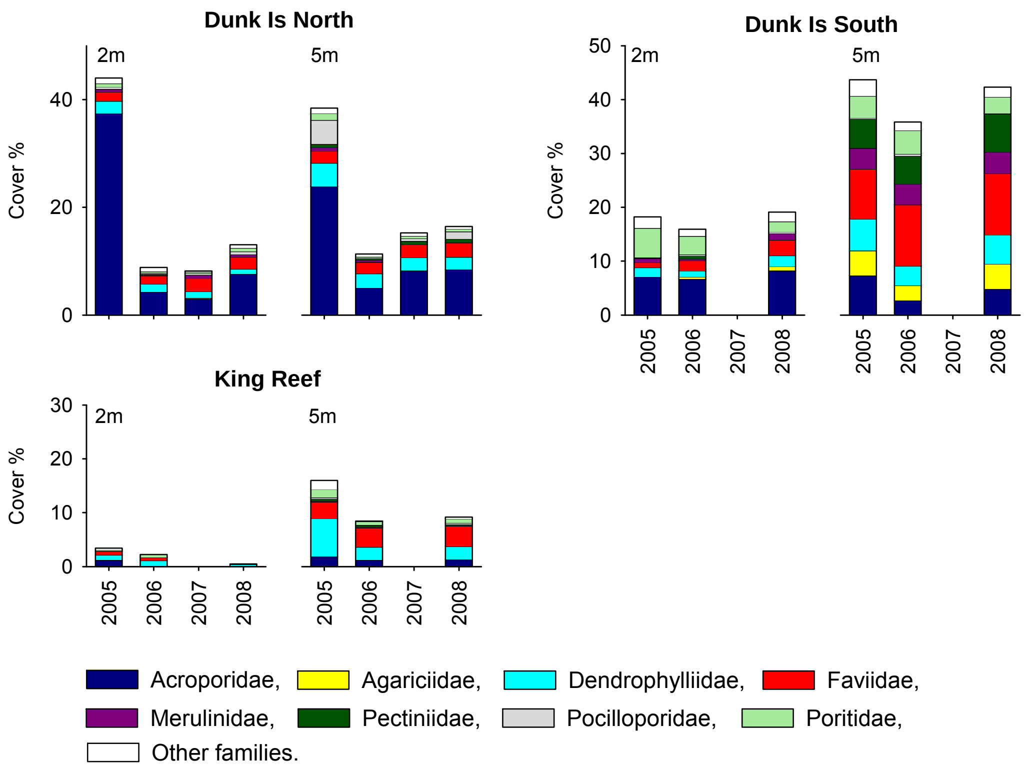

Figure 3.23 Composition of hard coral communities on reefs in the Herbert Tully sub-region of the Wet Tropics NRM region. Bars are the cumulative cover of dominant families within the region. Families are indicated by colour of bar section. Only families for which cover exceeded 4% cover on at least one reef at one depth in one year are differentiated; all other families are aggregated into the 'Other families' group (white bars).

Burdekin NRM region

Reefs in the Burdekin Region have been monitored since 1989 under a variety of projects and three locations are monitored since 2005 under Reef Rescue MMP (Figure 3.24). 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 A1-3.2). 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 A1-3.2). In 2002 bleaching was less severe than 1998 but still affected the majority of coral communities (Table A1-3.2). 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 COTS 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. Even though disturbance has been severe and frequent on the majority of reefs monitored in this sub-region, there has been evidence of increasing coral cover between disturbances. This increase has, however 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).

Given the frequency and severity of disturbances to reefs in this region over the preceding decade it is not surprising that the regional average cover of hard coral was lower and cover of macroalgae higher than all other regions in 2005 (see Figures 3.4 and 3.6). There were no substantial disturbances between surveys in 2005 and 2008, nor however, were there substantial indications of recovery of the coral communities with the cover of the major benthic groups relatively stable on most reefs (Figure 3.25). The only exception was at Lady Elliot Reef 2m were hard coral cover increased markedly between 2005 and 2008 due mostly to an increase in the cover of Acroporidae (Figure 3.27).

Interestingly, the density of juvenile hard coral colonies was higher at Lady Elliot Reef 2m than at any other reef in the region. It is not then difficult to assume that the lack of recovery of the hard coral community at least at Pandora, Orpheus Is East and Geoffrey Bay 2m may be partly due to the extremely low densities of juvenile colonies observed (Figure 3.26). Although the density of juveniles observed at Pelorus Is and Orpheus Is West has been consistently close to the average density over all core reefs these juveniles have resulted in increases in hard coral cover. This may be due in part to the taxonomic composition of the juveniles with relatively few colonies of the fast growing Acroporidae represented, especially at the 5m depth.

Macroalgae cover at Pandora Reef, Geoffrey Bay and at Lady Elliot Reef 2m was consistently high over the period 2005-2008. At both Pandora and Geoffrey Bay the macroalgal community included a high proportion of robust brown algae. This is different to the community at Lady Elliot Reef where a high proportion of the community was comprised of finer red algae most notably *Hypnea sp*. As with other regions high macroalgae occurs on reefs for which the annual average chlorophyll level was approximately 0.5 $\mu g\ L^{-1}$, which supports the validity of the 0.45 $\mu g\ L^{-1}$ trigger values for chlorophyll set in the GBRMPA Water Quality Guideline for the Great Barrier Reef Marine Park (GBRMPA 2009) as a biologically relevant level of chlorophyll.

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Figure 3.24 Reef Rescue MMP inshore coral reef monitoring sites (blue squares) in the Burdekin Region: Orpheus Island, Pelorus Island, Havannah Island*, Lady Elliot Reef, Pandora Reef, Middle Reef* and Geoffrey Bay (Magnetic Island). *not monitored in 2008

While we do not have intensely sampled chlorophyll data for Lady Elliot Reef, comparisons between discrete water samples indicate that chlorophyll levels at Lady Elliot were between the levels observed at Geoffrey Bay and Pandora Reef (Thompson *et al.* 2009). However, the high chlorophyll levels at Pelorus and Orpheus West are noteworthy (see also Chapter 2) but did not coincide with high cover of macroalgal communities.

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. Prevailing winds drive these waters northwards for 57 km before reaching the first established coral reef at Geoffrey Bay. Despite the large input, the reefs in the Burdekin region have sediments with below average clay/silt, organic carbon and nitrogen components (Table AI-3.1a-c).

Settlement of coral spat to tiles was low on all core reefs relative to the mean observed in other regions (Figure 3.28). This regionally low settlement is consistent with the regionally low cover of hard corals and especially of the family Acroporidae (Figure 3.27); suggesting broodstock limitation to the number of spat settling to these reefs. In 2008 settlement at both Pelorus Is and Orpheus Is and Pandora Reef was particularly low. The reason for this level of variability between years is unknown. At each reef spat settling to tiles are consistently dominated by the family Acroporidae. This bears little relationship to the composition of the juvenile communities (Table A1-3.6) indicating either a sampling bias of tiles or strong differences among families in survival of recruits in their first few years.

The overall impression of coral community status for reefs in this region was lower than for the Wet Tropics to the north and Whitsundays to the south (Table 3.7). The communities at Geoffrey Bay and Pandora Reef scored very poorly with high cover of macroalgae, low coral recruitment and move evidence of increases in cover despite a lack of disturbance all indicating poor community status. Status at Orpheus Island East is ambiguous and while the overall combined cover of hard and soft corals is moderately high, there has been no evidence for growth over the period 2005-2008. Macroalgal cover is very low, but there were also extremely low densities of coral recruits. Pelorus Is & Orpheus Is West scored better than Orpheus Is East due to higher densities of hard coral juveniles especially at 2m.

For Lady Elliot reef the impression of status was positive at 2m where increasing coral cover and high density of juvenile colonies outweighed the negative influence of high macroalgal cover. At 5m the moderately high and stable coral cover, above average density of juvenile colonies and more moderate cover of macroalgae also led to a positive impression of community status.

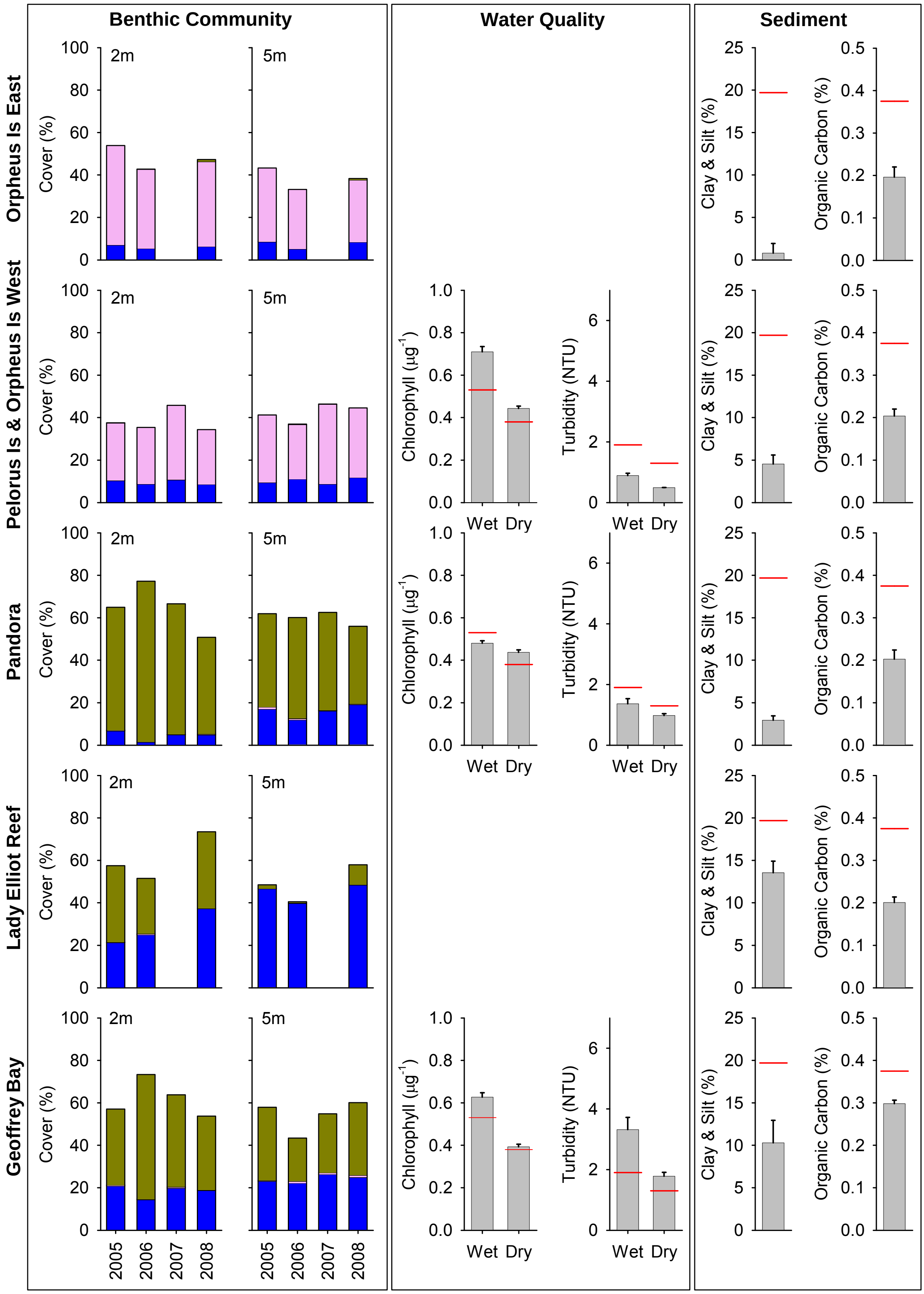

Figure 3.25 Percent cover estimates of major benthic groups, hard coral (blue), soft coral (pink) and macroalgae (green) and water quality and sediment quality parameters on reefs in the Burdekin NRM region. Red reference lines indicate the average density at each depth over all years from all reefs and NRM regions.

Table 3.7 Reef by depth estimates of coral community status of reefs in the Burdekin region. The over all status aggregates over the three indicators of coral cover, macroalgal cover and Juvenile hard coral density. Settlement of coral spat is also considered where sampled. Coral cover trend indication: u="up", s= "stable", d= "decreasing".

Reef	Depth (m)	Overall Status	Coral		Macroalgae		Hard coral Juveniles			Settlement		
			Cover trend	Status	Cover trend	Status	Density	rank	Status	#per tile	rank	Status
Geoffrey Bay	2	- - -	18.9 s	-	34.8 d	-	6.4	18	-			
	5	- - -	26 s	-	34.1 u	-	10.9	11	neutral	30	9	-
Lady Elliot	2	+	37.4 u	+	36.1 u	-	20.1	3	+	N/A		
	5	+	48.6 s	neutral	9.3 u	neutral	13.1	8	+			
Orpheus Is	2	neutral	46.3 s	neutral	0.9 s	+	3.6	21	-			
	5	neutral	37.7 s	neutral	0.7 s	+	6.2	20	-			
Pandora	2	- - -	5.2 s	-	45.6 d	-	0.7	24	-			
	5	- - - -	19.3 s	-	36.7 d	-	2.7	24	-	26	11	-
Pelorus Is & Orpheus Is West	2	++	34.4 s	neutral	0	+	11.7	6	+			
	5	neutral	44.6 s	neutral	0	+	12.9	9	neutral	28	10	-

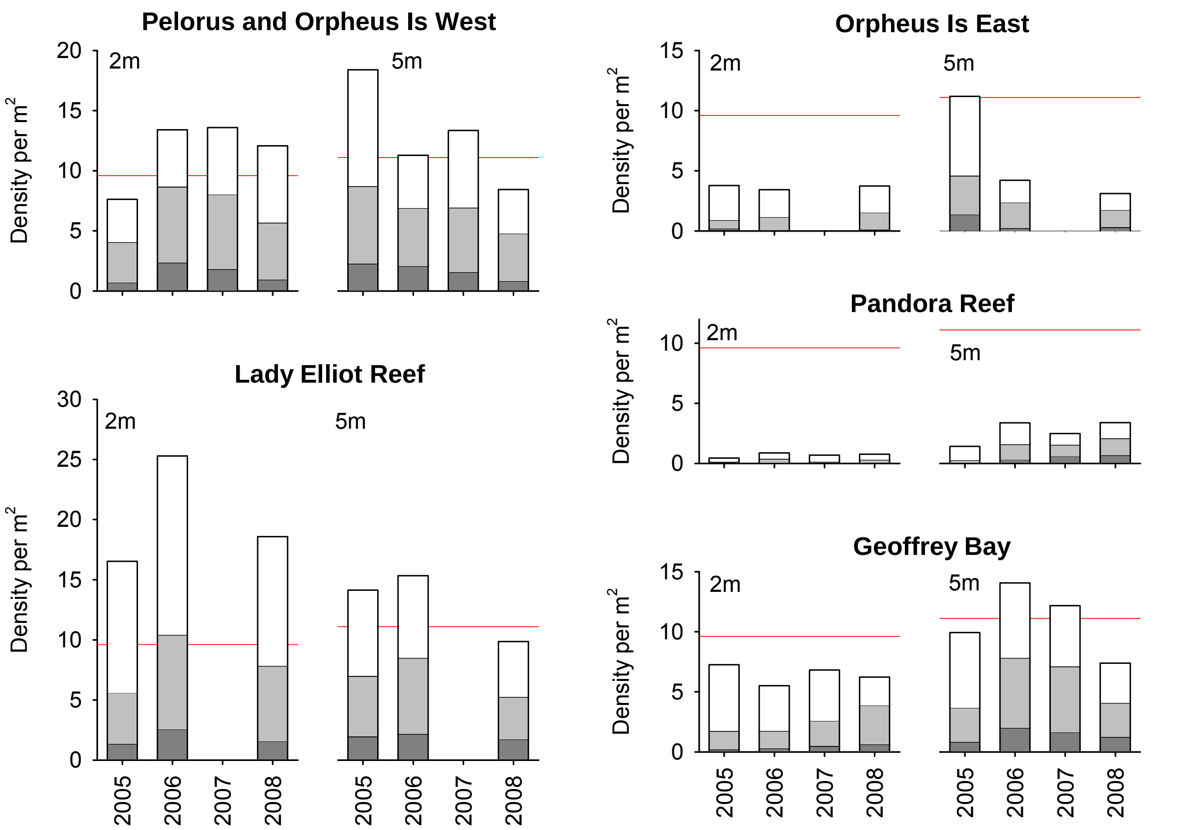

Figure 3.26 Density of juvenile hard coral colonies standardised to the area of available substrate for settlement on reefs in the Burdekin NRM region. Bars are cumulative densities over the three size classes, <2cm (dark grey), 2-5cm (pale grey) and >5cm to 10cm (white). Red reference lines indicate the average density at each depth over all years from all reefs and NRM regions.

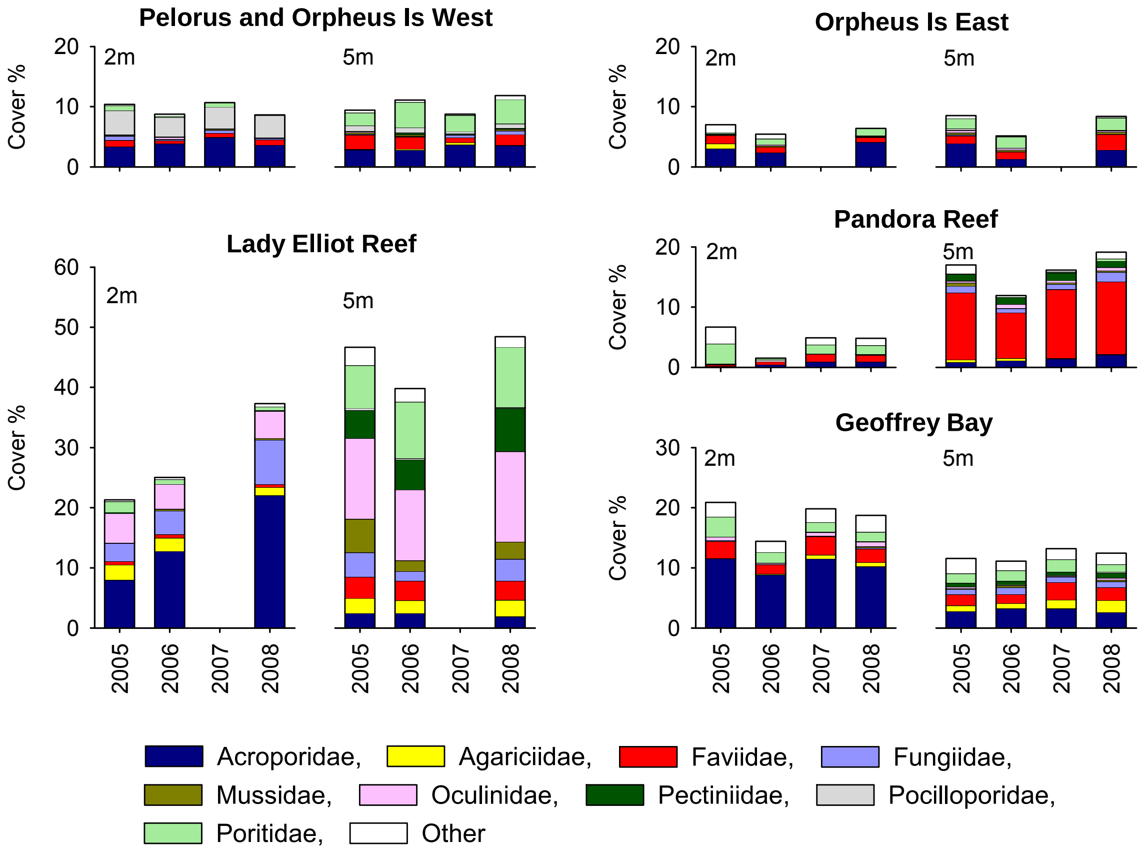

Figure 3.27 Composition of hard coral communities on reefs in the Burdekin NRM region. Bars are the cumulative cover of dominant families within the region. Families are indicated by colour of bar section. Only families for which cover exceeded 4% cover on at least one reef at one depth in one year are differentiated; all other families are aggregated into the 'Other families' group (white bars).

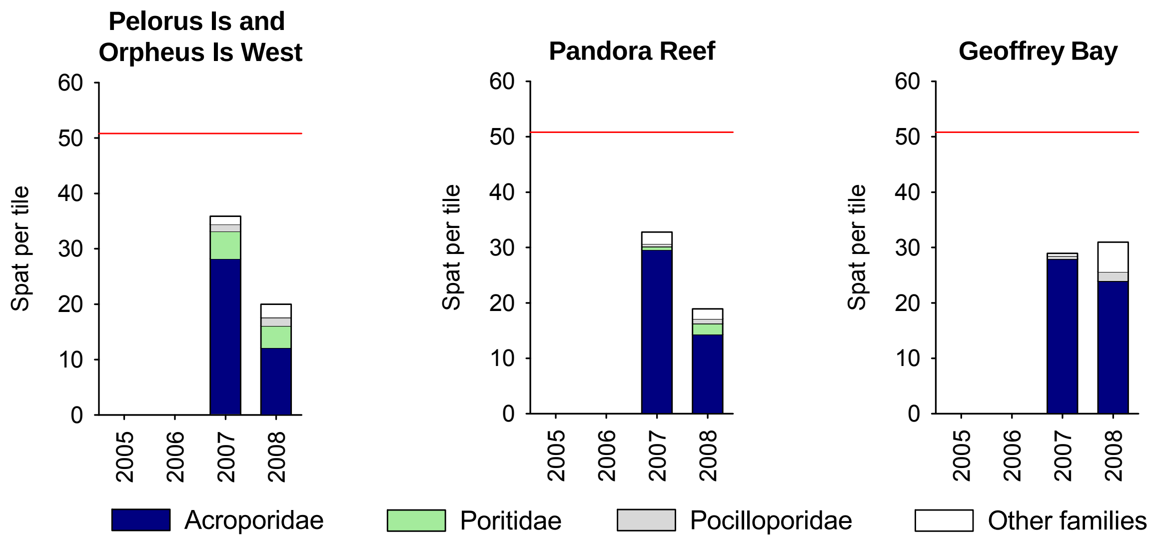

Figure 3.28 Average number of coral recruits per tile on reefs in the Burdekin NRM region. Average values from all reefs and NRM regions sampled in 2007 and 2008 are indicated by red reference lines.

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 altered land-use and reefs in this area are considered to be at high risk from agricultural runoff (Brodie and Furnas 2001). The group of reefs monitored under Reef Rescue MMP (Figure 3.29) have the highest levels of clay / silt, nitrogen and organic carbon in sediments across all regions (Table AI-3.1a-c). Further, levels of inorganic carbon, associated with reefal deposits, are the lowest among catchments and years (Table AI-3.1d). This suggests that a high proportion of fine terrigenous material is present and that the residence time for these clay /silt deposits is much longer than in other catchments.

The Whitsunday inshore reef sites are steep-sloped and relatively sheltered by the surrounding continental islands. Fine terrigenous sediments accumulate between and below coral colonies without extensive smothering. The influence of the sediment environment is significant in this catchment, and, as it changes with increasing exposure and /or light levels northward to Double Cone Island, so the dominance of functional coral groups changes. Pine Is, the core reef closest to the rivers, has a diverse coral community of sediment-tolerant corals, reflecting lower light levels and higher turbidity, particularly at 5m. This is in contrast to the other core reefs in the catchment, where coral communities are dominated by either the Acroporidae (Daydream Is) or Poritidae families (Double Cone Is) (Figure 3.26).

There is limited historical 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 likely affected all reefs monitored by this programme (Table A1-3.2). Between 2005 and 2008 there were no major acute disturbances to the reefs in this region.

Despite the lack of acute disturbance, cover of the coral community remained relatively stable over the period 2005 to 2008 though slight increases were evident at 2m at both Double Cone Is and Shute Is & Tancred Is and both depths of Pine Is (Figure 3.30). Conversely cover of hard corals at Daydream Island decreased to 2008. At each reef showing discernible changes in hard coral cover the majority of the change is accounted for by changes in the family Acroporidae (Figure 3.32). Observations from scuba search surveys indicated coral disease as a probable cause of decline in cover amongst the Acroporidae at Daydream Island. The lack of increase in coral cover at some reefs may be due to the already high cover of large colonies approaching the carrying capacity for cover at the location, Double Cone Is at 5m for example.

There were no substantial changes to the cover of either soft corals or macroalgae over the period 2005-2008 (Figure 3.30). The cover of macroalgae has remained consistently low on all reefs with the exception of Pine Is 2m. As with other regions the presence of persistent macroalgal communities occurs on reefs with annual mean chlorophyll levels at or above the 0.45μm^{-L} trigger level (GBRMPA 2009) with the exception of Double Cone is where chlorophyll levels are above this threshold but macroalgae largely absent.

Figure 3.29 Reef Rescue MMP inshore coral reef monitoring sites (blue squares) in the Mackay Whitsunday Region: Double Cone Island, Hook Island*, Daydream Island, Shute Island, Dent Island*, Pine Island and Seaforth Island*. *not monitored in 2008.

The density of juvenile colonies over the period 2005 to 2008 has declined from moderate levels in 2005-2006 to low levels in 2008 (Figure 3.31). The obvious exception to this was Shute Is and Tancred Is where the density of hard coral juveniles has been consistently high. Despite this regionally high density of juvenile colonies cover at Shute Is and Tancred Is 5m has not increased potentially indicating high mortality rates or a lack of growth of these small colonies.

Settlement of spat tile tiles has been reasonably consistent across the reefs in this region though punctuated by the occasional high or low estimate at some reefs in some years (Figure 3.33). That the relative settlement between years differs for each reef suggests local scale influences or simply stochasticity of larval supply rather than regional scale environmental influence. At each reef spat settling to tiles are consistently dominated by the family Acroporidae. This bears little relationship to the composition of the juvenile communities (Table A1-3.6) indicating either a sampling bias of tiles or strong differences among families in survival of recruits in their first few years.

In the assessment of status coral communities in this region scored highly with generally high cover of corals and low cover of macroalgae (Table 3.8). The only community to not return a positive assessment of status was Pine Is 2m which was the only location to have had a persistently high cover of macroalgae. However, despite this persistence of macroalgae cover and the highly turbid water and fine grained sediment, cover of hard corals has increased from 38.6% to 45.9% over the three year period between 2005 and 2008 (Figure 3.30).

Table 3.8 Reef by depth estimates of coral community status of reefs in the Mackay Whitsunday region. The over all status aggregates over the three indicators of coral cover, macroalgal cover and Juvenile hard coral density. Settlement of coral spat is also considered where sampled. Coral cover trend indication: u="up", s= "stable", d= "decreasing".

Reef	Depth (m)	Overall Status	Coral		Macroalgae		Hard coral Juv			Settlement		
			Cover trend	Status	Cover trend	Status	Density	rank	Status	#per tile	rank	Status
Daydream Is	2	+	40.9 s	neutral	0.9 s	+	8.1	14	neutral			
	5	++	45.8 d	-	0	+	16.3	5	+	73	3	+
Double Cone Is	2	++	56.9 u	+	0.1 s	+	7.6	16	neutral			
	5	++	77.1 s	+	0.1 s	+	11.7	10	neutral	33	7	neutral
Hook Is	2	++	50.1 s	+	1.4 s	+	8.9	12	neutral	N/A		
	5	+	51.6 s	neutral	0.4 s	+	9.8	14	neutral			
Pine Is	2	neutral	48 u	+	13.9 s	-	10.1	10	neutral			
	5	+++	53.1 u	+	4.4 s	+	13.2	6	+	33	8	neutral
Shute Is & Tancred Is	2	+++	60.8 u	+	0.1 s	+	24.1	2	+	N/A		
	5	++	33.5 s	neutral	0.1 s	+	20.4	3	+			

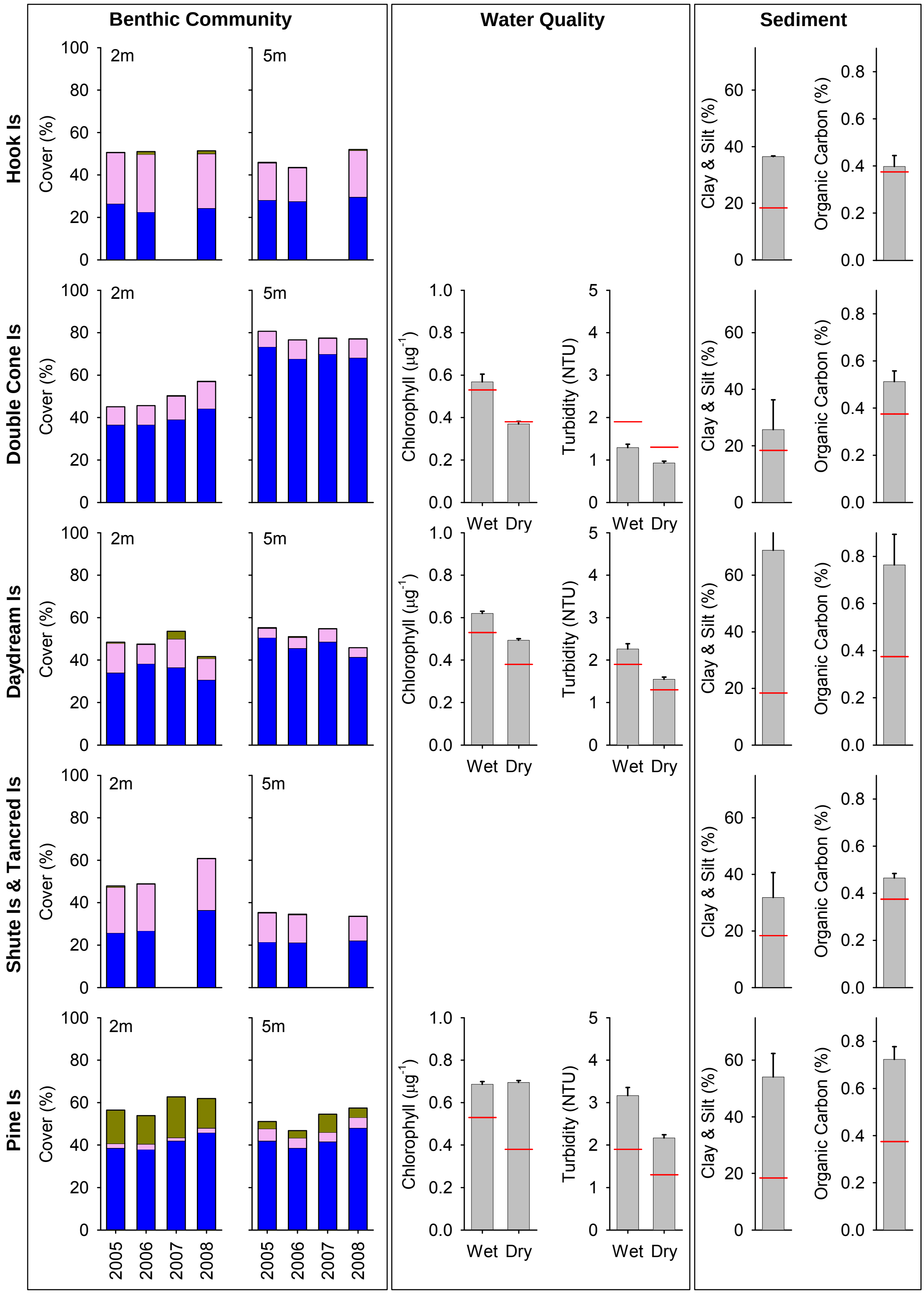

Figure 3.30 Percent cover estimates of major benthic groups, hard coral (blue), soft coral (pink) and macroalgae (green) and water quality and sediment quality parameters on reefs in the Mackay Whitsunday NRM region. Red reference lines indicate the average values of environmental data from core reefs.

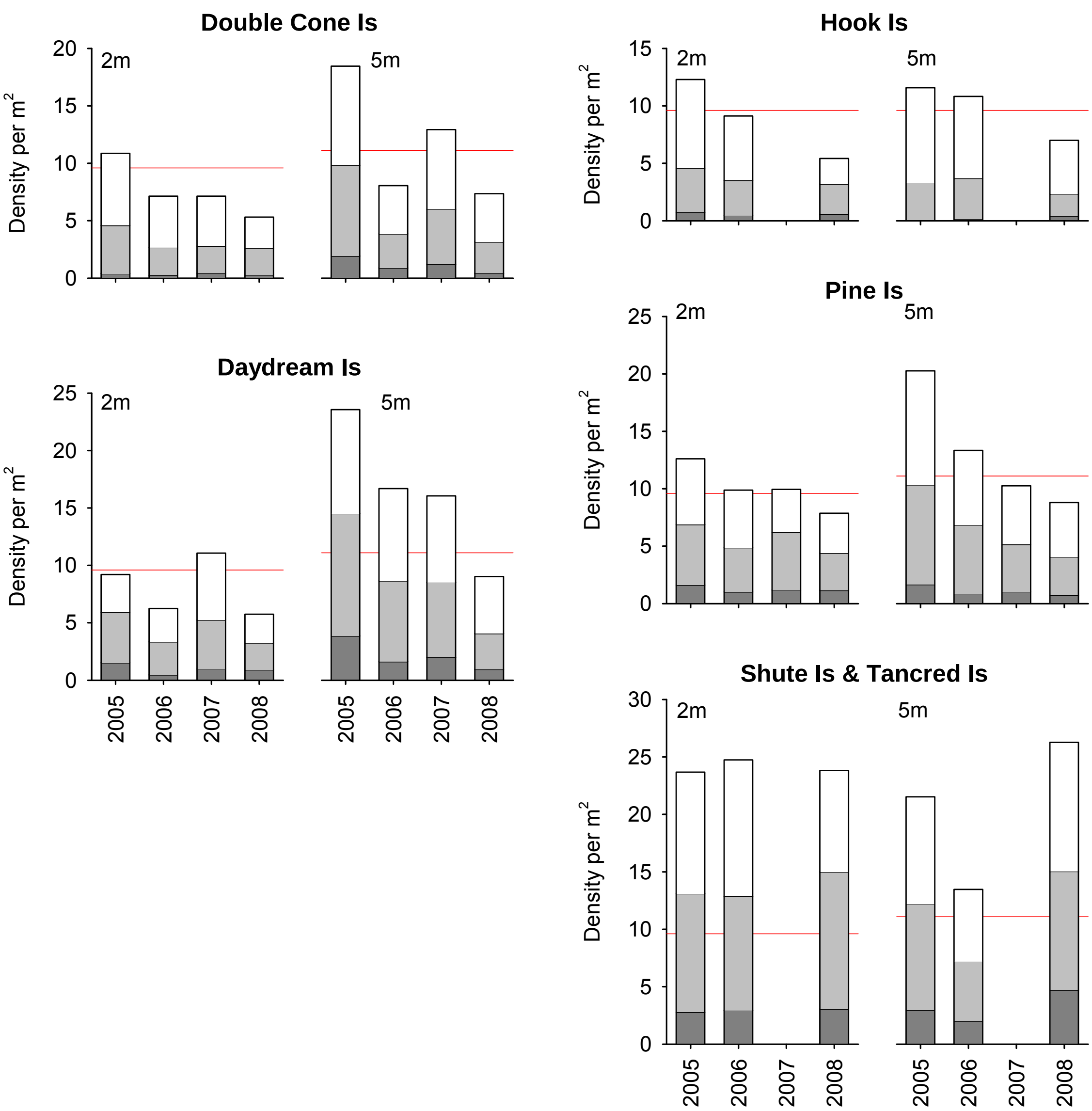

Figure 3.31 Density of juvenile hard coral colonies standardised to the area of available substrate for settlement on reefs in the Mackay Whitsunday NRM region. Bars are cumulative densities over the three size classes, <2cm (dark grey), 2-5cm (pale grey) and >5cm to 10cm (white). Red reference lines indicate the average density at each depth over all years from all reefs and NRM regions.

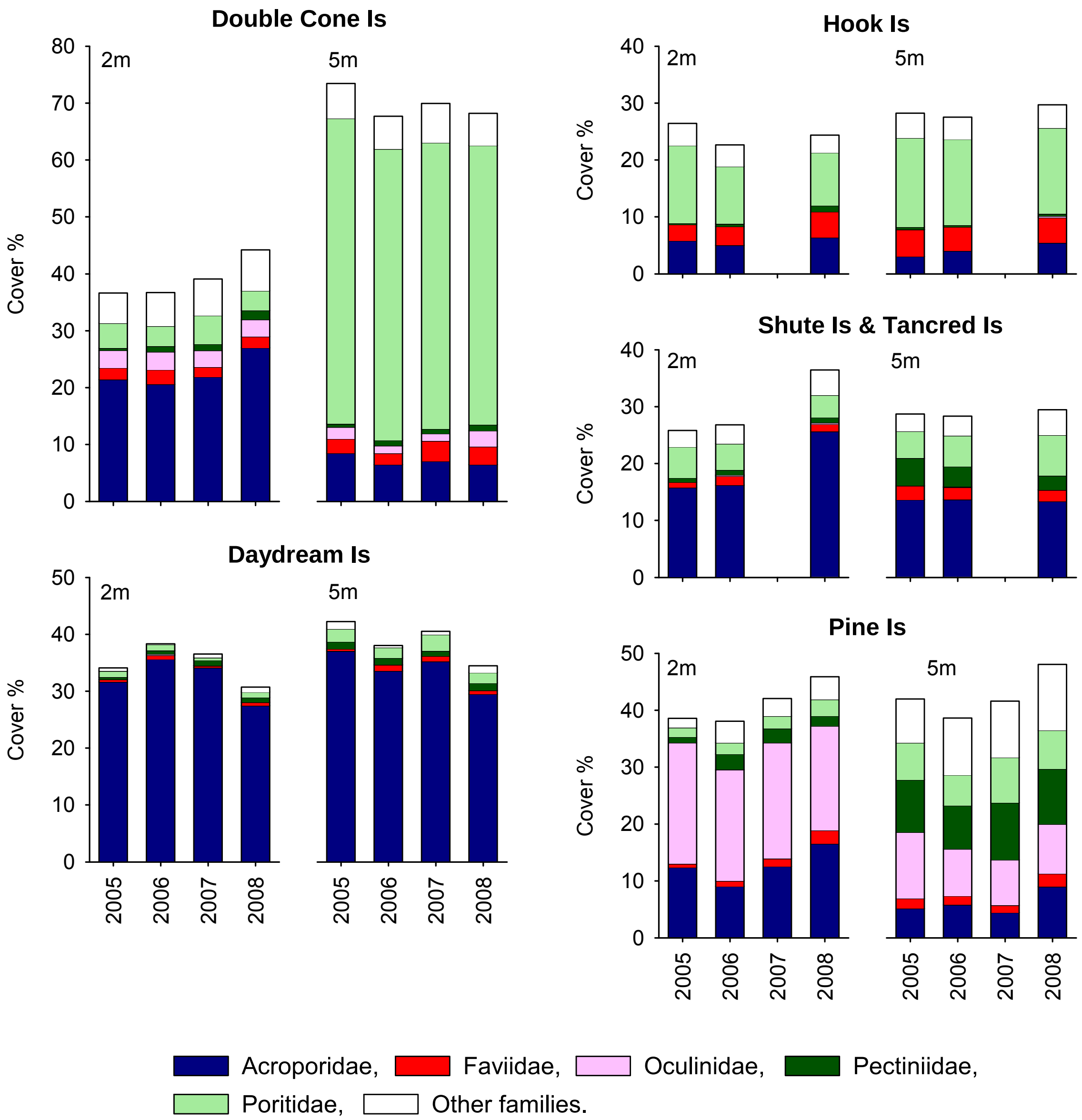

Figure 3.32 Composition of hard coral communities on reefs in the Mackay Whitsunday NRM region. Bars are the cumulative cover of dominant families within the region. Families are indicated by colour of bar section. Only families for which cover exceeded 4% cover on at least one reef at one depth in one year are differentiated; all other families are aggregated into the 'Other families' group (white bars).

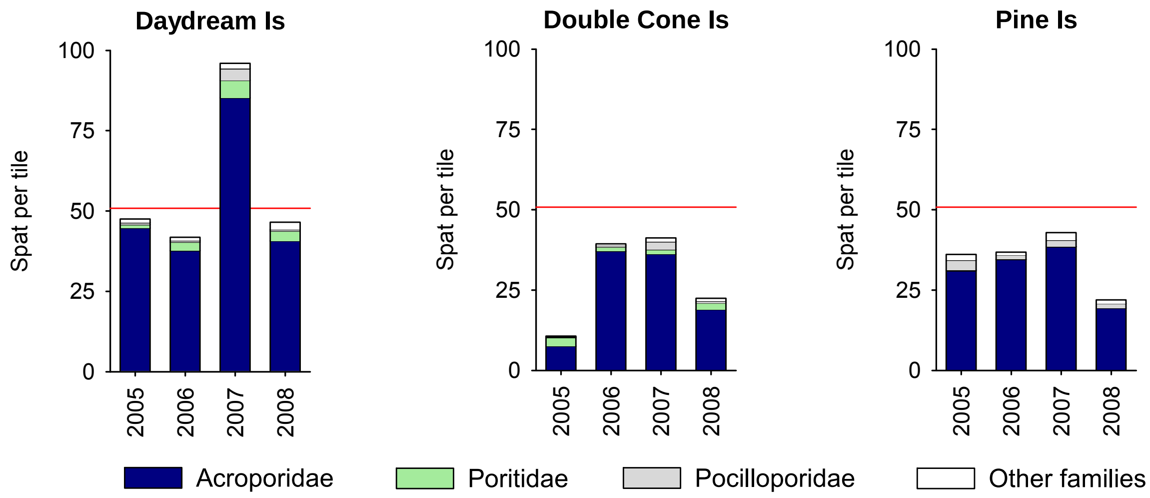

Figure 3.33 Average number of coral recruits per tile on reefs in the Mackay Whitsunday NRM region. Data are from 5m tile deployments. Average values from all reefs and NRM regions sampled in 2007 and 2008 are indicated by red reference lines.

Fitzroy NRM region

The main river system influencing reefs in this region is the Fitzroy River. Three locations away from the Fitzroy River mouth were monitored under the Reef Rescue MMP (Figure 3.34). The sediments at the reefs in this group have the lowest clay/silt levels of all catchments (Table AI-3.1a-c). Levels of organic carbon are low, while nitrogen levels remain average with a modest increase in 2008, 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 turbidity and chlorophyll (Figure 3.35). Clear distinction between coral communities at Peak Is and Pelican Is and those on the reefs further form shore (Middle Is, Humpy Is & Halfway Is, and Barren Is) reflect the sharp difference in environmental setting between these otherwise nearby reefs (Figure 3.37). Turbidity at Pelican Is was extremely high over the wet season of 2007/08 (Figure 3.35) and on average exceeded 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 complete shift in community composition between 2m and 5m sites (Figure 3.37). Combined with low silt levels this suggests that most fine sediment seldom settles and that increases in turbidity are the result of resuspension.

Historical data on benthic communities are available for three of the six reefs selected in this region. Humpy Is, Halfway Is and Middle Is reefs were first monitored in 1989 and 1991 as part of an impact study into the effects the 1991 Fitzroy River flood (Van Woesik 1991). Sites on these reefs have been monitored by staff of Queensland Parks and Wildlife Service (QPWS) from 1993 (Middle Is) or 1996 (Halfway Is) (Sweatman *et al.* 2007)

Between 1991 and 2006, several disturbance events have caused reductions in the coral cover at reefs monitored in this region. The most severe disturbance was the Fitzroy River flood in 1991. At depths of less than 1.5m, hard coral cover declined by 85% at Humpy Is, Halfway Is and Middle Is; where mainly the dominant Acroporidae and Pocilloporidae were lost (Van Woesik 1991). Subsequent declines in hard coral cover were associated with coral bleaching in 1998, in 2002 and again in 2006 (Table A1-3.2). Coral cover showed rapid recovery following bleaching in 1998 and 2002 (Sweatman *et al.* 2007).

The propensity for the branching *Acropora* dominated hard coral communities in this region to recover from disturbance was evident in 2007 with coral cover increasing at Barren Is and at 2m at Humpy Is & Halfway Is following declines in 2006 due to bleaching (Figure 3.35, Diaz-Pulido *et al.* 2009). These increases were reversed by 2008 as the combined impacts of an unusually strong northerly wind (Barren Island) and severe flooding of the Fitzroy River again reduced the cover of hard corals at Barren Is, Humpy Is & Halfway Is and we presume Middle Is, though this reef was not surveyed in 2007 (Figure 3.35). At Pelican Is and Peak Is the coral communities differ in being more diverse and not dominated by large stands of the branching corals *Acropora muricata* and *A. intermedia*. This difference in community composition (Figure 3.37) is due to a strong gradient in turbidity between Pelican Is and the more offshore islands (compare turbidity plots for Pelican and Humpy & Halfway Figure 3.35). The turbidity at Peak Is was generally higher than at Pelican Island. On these more turbid reefs coral cover was not impacted by the 2006 bleaching event with slight increases in cover observed at 2m and cover remaining unchanged at 5m between 2005 and 2006 (Figure 3.35).

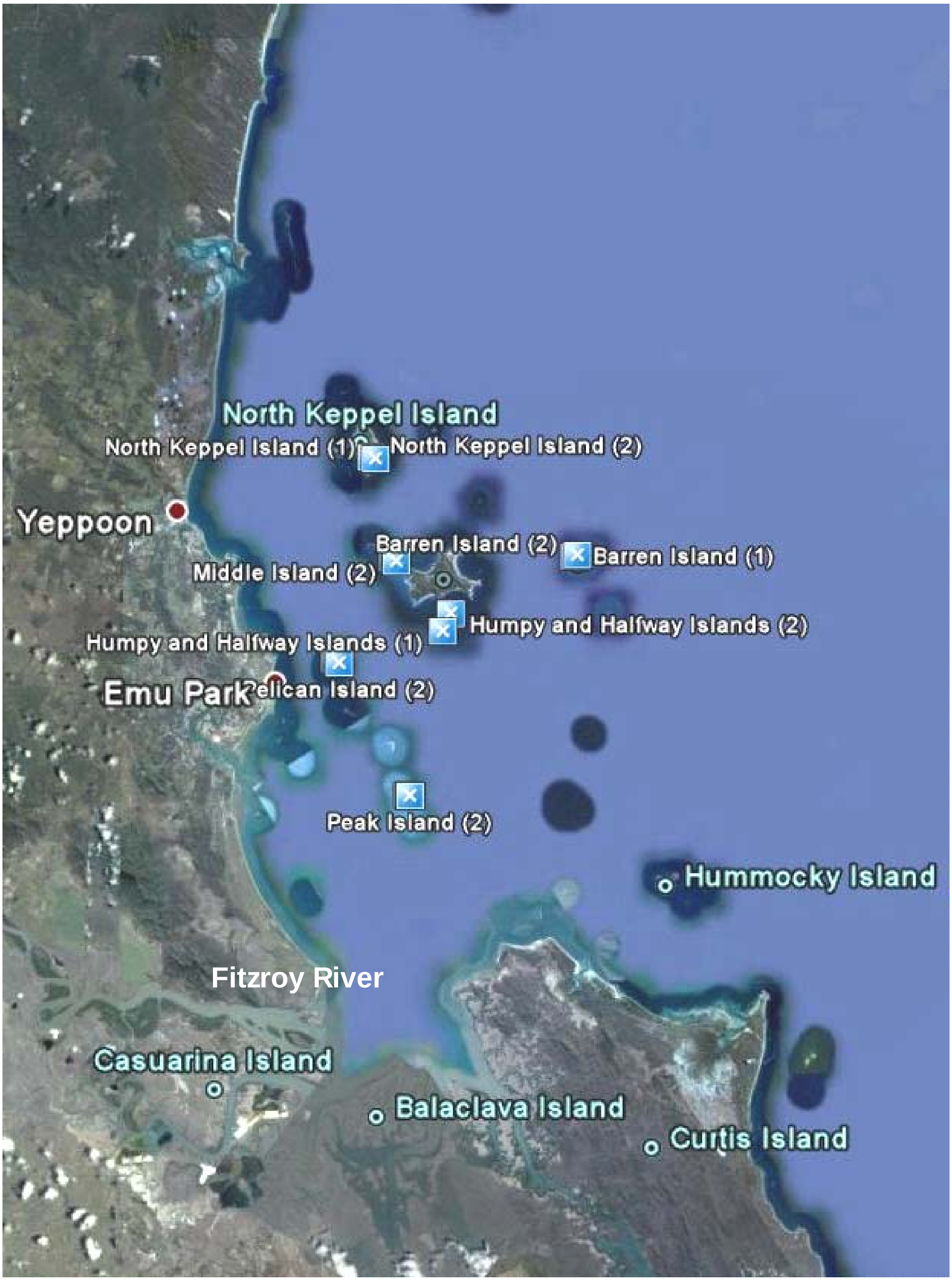

Figure 3.34 Reef Rescue MMP inshore coral reef monitoring sites (blue squares) in the Fitzroy Region: North Keppel*, Middle, Barren, Humpy & Halfway, Middle, Pelican and Peak islands. *Not monitored in 2008.

Cover continued to increase at Pelican Is 2m to 2007. In 2008 cover at 2m at both inshore islands had dropped, almost certainly as a result of inundation by the Fitzroy river flood plume while the 5m coral communities remained stable.

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 in 2008 the cover of *Lobophora* had decreased on all these reefs (see macroalgae cover (Figure 3.35). The macroalgae communities at Pelican Is and Peak Is are 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 flood. As with other regions the pattern of persistent macroalgae communities on reefs with chlorophyll levels that exceed the annual of trigger level 0. 45μm L^{-1} set for coastal reefs (GBRMPA 2008).

Regionally, the density of hard coral recruits was low (Figure 3.36). This along with the rapid increase in cover following disturbances to the branching *Acropora* communities indicates recovery was largely due to the growth of colonies surviving disturbance rather than the recruitment and subsequent growth of new colonies. A possible exception is at 2m at Pelican Island were surveys in 2004 (Sweatman *et al.* 2007) recorded high numbers of small *Acropora* colonies and subsequent observations indicate it is the growth of this cohort that resulted in the increase in cover to 2007. Very high densities of juvenile colonies in 2005 at Middle Is 5m and Barren Is 5m should be viewed with caution as the coral cover was so high that the correction for available space disproportionately weights the occurrence of the relatively few juveniles actually observed compared with other reefs with a higher proportion of space available.

Settlement of coral spat to tiles varies substantially among the core reefs in this region. At Barren Island the numbers of spat settling are the lowest of any reef in any region (Figure 3.38); likely explaining the low numbers of juvenile colonies at this reef. The consistently low settlement of spat observed at Barren Is relative to the above average levels at the more inshore reefs 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 availability settlement competent larvae (Figure 3.38). This premise is reinforced in that particularly high settlement at Humpy Is & Halfway Is in 2006 has not resulted in substantial numbers of juvenile corals in 2008 as might have been expected.

Assessment of coral community status indicated lower than expected values for reefs in this region (Table 3.9) especially if one considers the rapid recovery from disturbances recorded in past monitoring studies (Sweatman *et al.* 2007) and short term studies (e.g. Diaz-Pulido *et al.* 2009). The low scores generally resulted from high cover of macroalgae and low densities of juvenile colonies over the period 2006-2008. 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. Similarly, the low-diversity coral communities at the more offshore reefs have proven resilient to disturbance despite low numbers of juveniles with recovery of cover stemming from the growth of surviving fragments (Diaz-Pulido *et al.* 2009) rather than settlement and growth of new colonies. However this does raise the question whether these communities would recover from slightly more severe disturbance that would cause total mortality of colonies and reduce the scope for recovery by re-growth from fragments.

Table 3.9 Reef by depth estimates of coral community status of reefs in the Fitzroy Basin Association region. The over all status aggregates over the three indicators of coral cover, macroalgal cover and Juvenile hard coral density. Settlement of coral spat is also considered where sampled. Coral cover trend indication: u="up", s= "stable", d= "decreasing".

Reef	Depth (m)	Overall Status	Coral		Macroalgae		Hard coral Juv			Settlement		
			Cover trend	Status	Cover trend	Status	Density	rank	Status	#per tile	Rank	Status
Barren Is	2	+	30.8 d(d)	+	0.4	+	4.7	19	-			
	5	neutral	57 d (d)	+	2.2 d	+	8.5	17	-	20	12	-
Humpy Is & Halfway Is	2	neutral	57.9 n(d)	+	11.1 d	neutral	7.1	17	-			
	5	neutral	32.6 d(d)	neutral	13.1 d	neutral	4.3	22	-	67	4	+
Middle Is	2	-	33.7 u	+	20.5 d	-	4.1	20	-	N/A		
	5	+	51.4 u	+	7.2 d	neutral	8.9	16	neutral			
Peak Is	2	- - -	17.7 s	-	49.5 d	-	2.3	23	-			
	5	- -	33.4 s	neutral	21.1 s	-	3.7	23	-			
Pelican Is	2	+	49.6 u	+	11.9 d	neutral	7.6	15	neutral			
	5	neutral	37.3 s	neutral	5.7 d	+	6.4	19	-	79	2	+

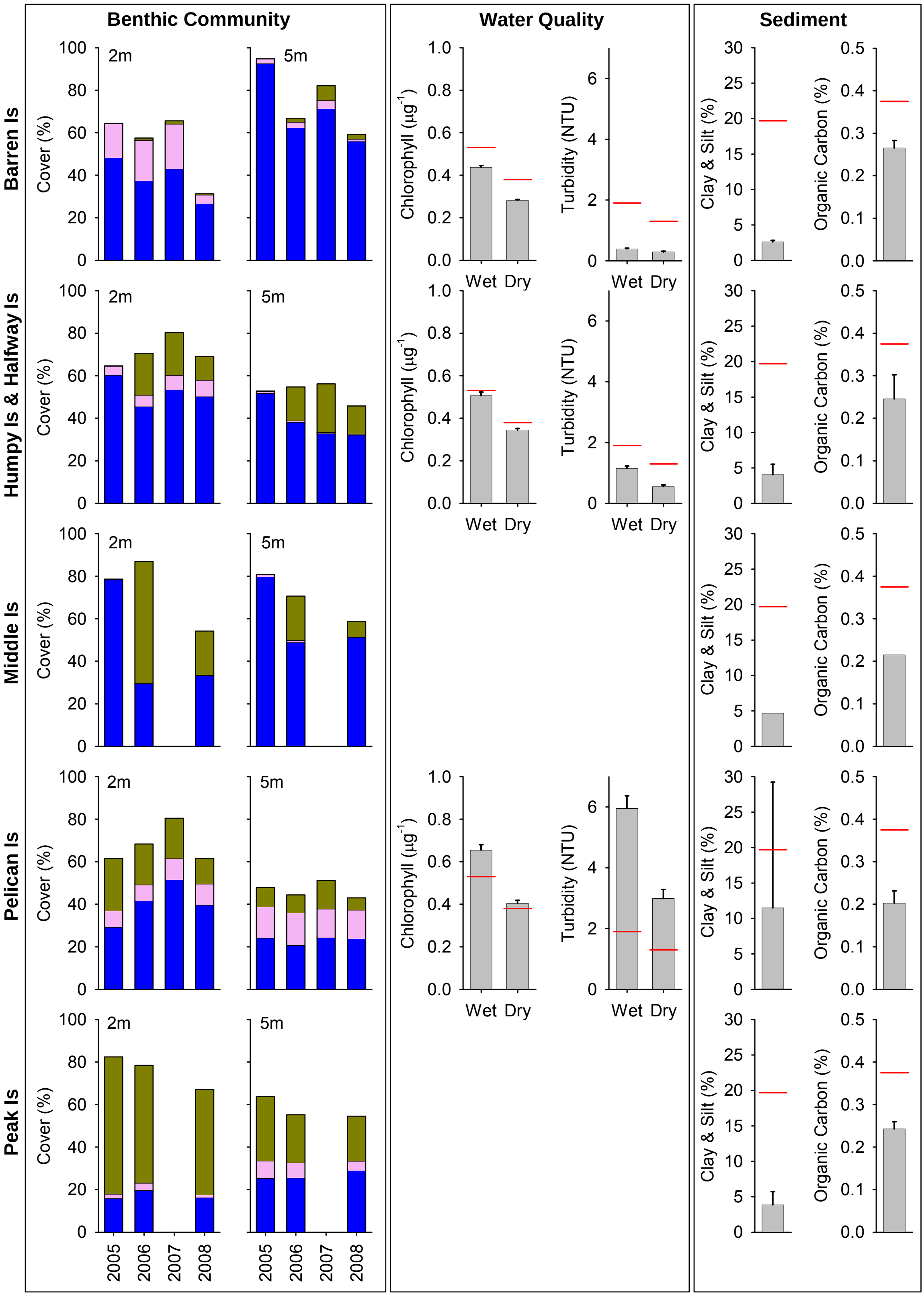

Figure 3.35 Percent cover estimates of major benthic groups, hard coral (blue), soft coral (pink) and macroalgae (green) and water quality and sediment quality parameters on reefs in the Fitzroy NRM region. Red reference lines indicate the average values of environmental data from core reefs.

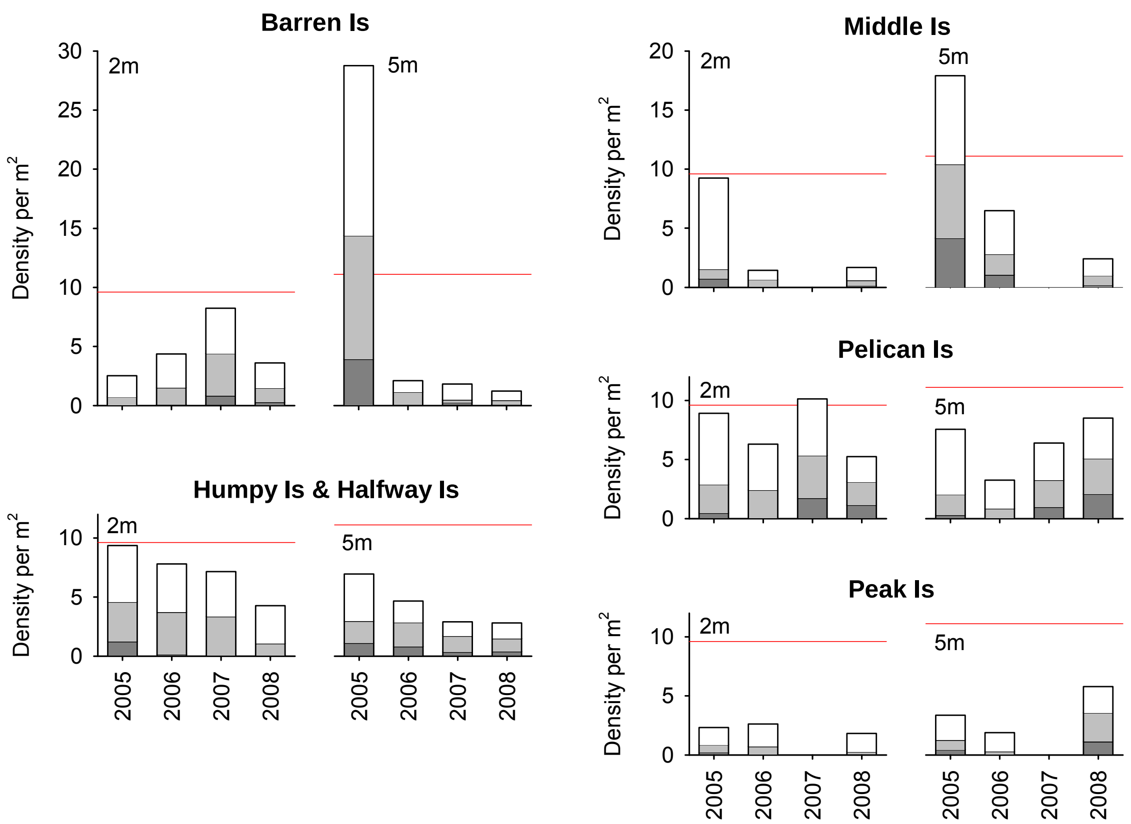

Figure 3.36 Density of juvenile hard coral colonies standardised to the area of available substrate for settlement on reefs in the Fitzroy NRM region. Bars are cumulative densities over the three size classes, <2cm (dark grey), 2-5cm (pale grey) and >5cm to 10cm (white). Red reference lines indicate the average density at each depth over all years from all reefs and NRM regions.

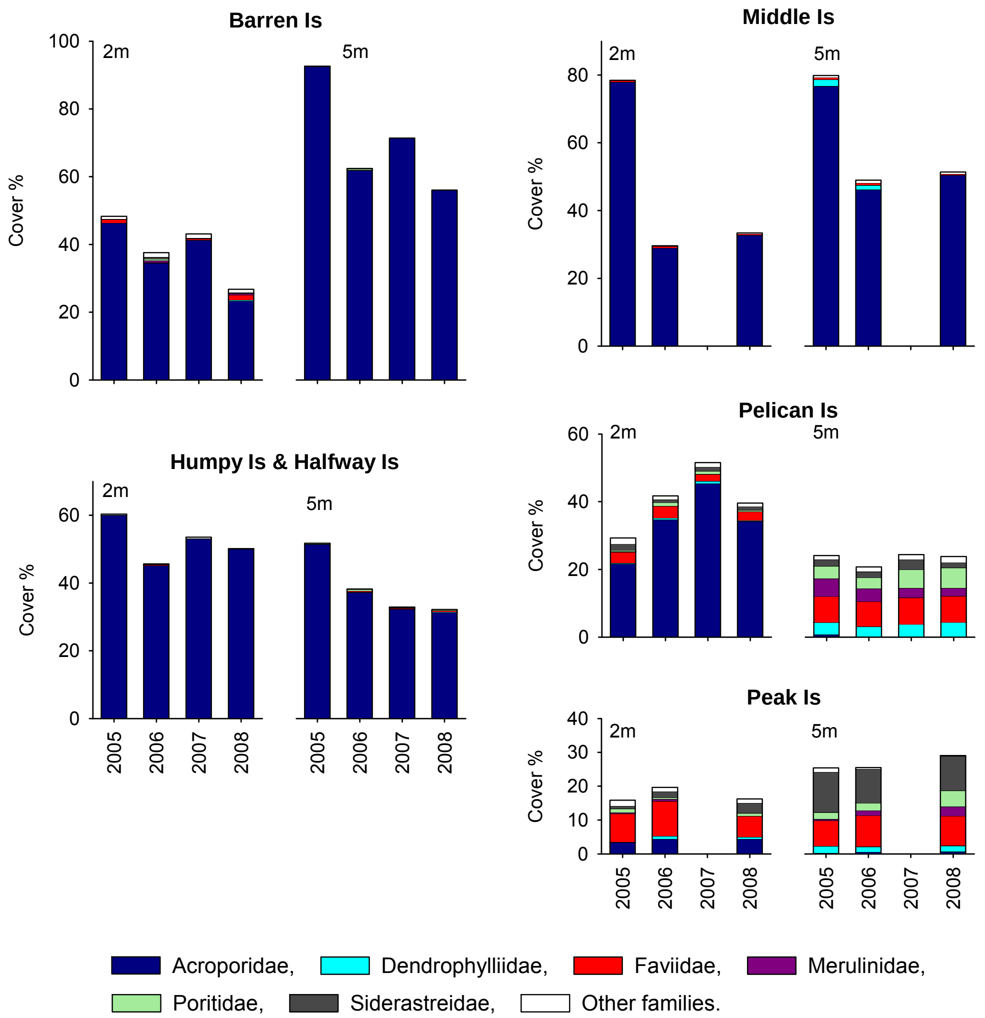

Figure 3.37 Composition of hard coral communities on reefs in Fitzroy NRM region. Bars are the cumulative cover of dominant families within the region. Families are indicated by colour of bar section. Only families for which cover exceeded 4% cover on at least one reef at one depth in one year are differentiated; all other families are aggregated into the 'Other families' group (white bars).

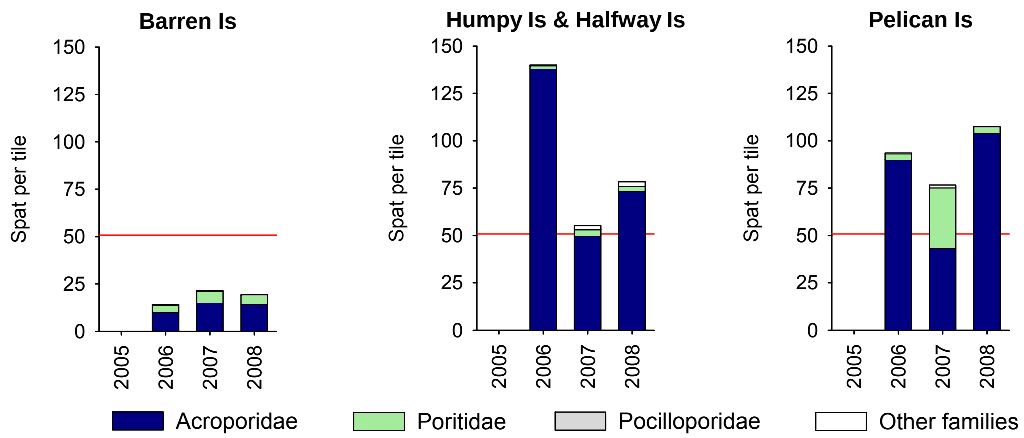

Figure 3.38 Average number of coral recruits per tile on reefs in the Fitzroy NRM region. Data are from 5m tile deployments. Average values from all reefs and NRM regions sampled in 2007 and 2008 are indicated by red reference lines.

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 Reef Rescue MMP lagoon water quality data were compared with the GBRMPA Guidelines for Water Quality trigger values (GBRMPA 2009). Direct water sampling indicated that most water quality variables at Dunk Island (Wet Tropic Region), Magnetic Island (Burdekin Region) and Pelican Island (Fitzroy Region) did not comply with GBRMPA Water Quality Guidelines trigger values. Instrumental monitoring indicated that additionally Daydream and Pine Islands in the Mackay Whitsunday Region had chlorophyll *a* and turbidity levels exceeding trigger values. Our data suggest that high chlorophyll and turbidity levels are the main water quality issues in the GBR. The continued instrument monitoring of these two parameters will deliver important information to determine the trajectories of these important water quality variables and whether management options may be required for some individual locations or regions that continue to show high values.

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). Within the inshore zone is also a threshold beyond which environmental conditions are not suitable for coral reef development, indicated for example by the historical lack of corals from hard substrates in some areas. Where reefs can develop, variation in environmental conditions, such as water quality, explains some of the considerable variation in coral community composition (van Woesik and Done 1997, van Woesik *et al.* 1999, Fabricius *et al.* 2004, Thompson *et al.* 2009) and most likely reflects species-specific environmental tolerances (e.g. Stafford-Smith & Ormond 1992, Anthony and Fabricius 2000, Anthony and Connolly 2004, Anthony 2006). The processes shaping biological communities, however, are complex and variable on spatial and temporal scales and are likely to include local interactions of various factors such as environmental conditions like water quality, climate change and physical disturbance. This complexity may obscure the relationships between coral communities and environmental conditions and has hampered the identification and quantification of anthropogenic impacts to inshore coral communities.

An unambiguous indication of environmental stress to coral reef communities is the documented change in a parameter to which benthic community composition has been shown to respond. For example, reefal sediments in the Mackay Whitsunday region have had consistently high levels of fine grained particles, compared to other regions, and these values have increased since 2005. Densities of juvenile corals in the Mackay Whitsunday Region have declined corresponding to the observed changes in sediment composition. The increase in fine grain sediment particles corresponded to changes in river flows of the nearest rivers (Proserpine, O'Connell and Pioneer); flows were below long-term medians for several years prior to 2005 and since 2006 were substantially higher than median flow. Sediment loads from the catchment lead to local changes in sediment composition. 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. Juvenile corals are most susceptible to turbidity and sedimentation (Fabricius 2005). 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. In the future, the MMP water quality monitoring using instruments deployed in the reef matrix will allow the tracking of turbidity levels after flood years. 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 resuspension and how water clarity changes throughout the year, especially after flood events at a given wind speed/wave height (Wolanski *et al.* 2008, Fabricius *et al.* in prep.).

Inshore coral reef community composition also showed a relationship to water column chlorophyll *a* levels at ten of the 14 cores reefs. Where the annual mean trigger values for chlorophyll a of 0.45 μL^{-1} was exceeded (see Table 2.3) reefs have high cover of macroalgae. Where annual means were below the trigger value macroalgal cover was very low. The exceptions to this pattern were Barren and Humpy islands in the Fitzroy Region which had high cover of the brown macroalga *Lobophora variegata* despite low chlorophyll concentrations, and Pelorus (Burdekin) and Double Cone and Daydream (Mackay Whitsunday) islands which exceeded the chlorophyll trigger value but currently have only low macroalgal cover. It would be interesting to see how these communities change after an acute disturbance opens up substratum for algal colonisation (see Done *et al.* 2007, Diaz-Pulido *et al.* 2009).

Coral communities clearly vary along the steep environmental gradients within the inshore zone, which are documented e.g. by the MMP water quality monitoring results from sites that are within a region generally located on a gradient away from a major river mouth (see also De'ath and Fabricius 2008). Communities will be susceptible to any deterioration in environmental conditions such as 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 would change over time to reflect the improved conditions (De'ath and Fabricius 2008). While 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*. 2009, Uthicke *et al*. in press), responses to herbicide exposure are only well studied in controlled laboratory experiments (e.g. Negri *et al*. 2005). Inshore reefs are regularly exposed to high concentrations of herbicides during flood plumes (Lewis *et al.* 2009) and concentrations at inshore reefs are measurable during both the wet and dry season (Prange 2008). The consequences of this chronic exposure are currently unknown.

However, chronic stress by water quality conditions is likely to manifest as either an increase in the susceptibility of corals to disturbance events such as thermal bleaching (Wooldridge 2009) or inhibition of their recovery potential following disturbance. Either or both of these outcomes would result in a change in community composition consistent with the changed environmental setting of the community. Such shifts are most likely to occur after disturbance events as species suited to the current conditions will predominantly re-colonise available space. This differs from non-disturbed communities where gradual shifts in environmental conditions may be masked by physiological (Anthony and Fabricius 2000) and morphological (Anthony *et al.* 2005) plasticity of corals that allow existing colonies to persist in conditions they would not be able to recruit into, forming relic communities.

Perhaps most 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 and severe mortality events of coral reefs (Hoegh-Guldberg 1999, Wilkinson 2004). The poor status of coral reef communities for reefs in the Burdekin NRM region almost certainly reflects the consequences of coral mortality during the mass bleaching event in the summer of 1998 (Berkelmans 2004, Sweatman *et al.* 2007) and subsequent limited recovery. The negligible increase in coral cover is likely due to a lack of larval supply and low survival, indicated by regionally low settlement of spat to settlement tiles and low density of hard coral juveniles. With frequency and severity of disturbance events projected to increase in response to continuing rise in greenhouse gases (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.

The monitoring of settlement to tiles, juvenile coral abundance and adult community cover was intended to provide insight into coral community dynamics and effects of environmental conditions on these key life stages. Based on the information to date, increases in adult cover during non-disturbance periods are generally due to increases in the cover of the family Acroporidae, both through the growth of existing colonies and settlement and growth of juvenile colonies. The family Acroporidae is well known for its rapid growth, which gives it a short-term competitive advantage over slower growing taxa (e.g. Baird and Hughes 2000). It is, however, more susceptible to disturbance than many other taxa (Woodley *et al.* 1981, Baird and Marshall 2000, Sweatman *et al.* 2007). Adult coral cover has not increased on reefs with few juvenile and adult Acroporidae, despite a lack of disturbance. Exceptions are reefs in the Johnstone-Russell/Mulgrave sub-region of the Wet tropics where the cover of *Porites* has shown capacity to increase. In communities with already high cover a lack of increase may simply reflect the lack of space into which corals can grow or recruit. When cover is moderate or low, space is available, and a lack of increase during periods with no disturbance suggests a lack of resilience, likely to be in part related to the environmental, including water quality, conditions at the locations. On reefs that show recovery, juvenile colonies of a wide range of taxa are found on reefs, but not on settlement tiles, indicating sufficient broodstock at local and regional scales. In contrast, larvae of Acroporidae predominantly settle on tiles but are only strongly represented in the juvenile and adult communities of a few reefs, predominantly those with generally low turbidity (Thompson *et al.* 2009). It appears that spat availability alone does not translate into recruitment into the juvenile community. Inability to settle on the natural reef substratum, e.g. due to high sedimentation, or post settlement mortality of spat could both explain this observation.

The now recognised differences in coral reef communities provide a useful starting point for the detection of long-term trends in coral reef benthos. Our results indicate that the 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 associated changes in coral reef communities. High frequency water quality monitoring by instruments, including autonomous loggers and remote sensing, will improve this assessment.

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Appendix 1: Additional Information

Appendix 1 to Chapter 2 - Inshore Water Quality Monitoring

Table A1-2.1 Details of deployments and log of failures of WETLabs ECO FLNTUSB instruments deployed at inshore reef locations for water quality monitoring.

NRM Region	Location	Deployment	Retrieval	Instr. no	Comments
Wet Tropics	Snapper	14-Oct-07	30-Mar-08	827	
	Snapper	30-Mar-08	07-Aug-08	838	
	Snapper	07-Aug-08	11-Oct-08	827	
	Snapper	11-Oct-08	26-Feb-09	828	
	Snapper	26-Feb-09	16-Jun-09	827	
	Fitzroy	12-Oct-07	16-Dec-07	826	Logger failed during deployment, presumed due to fouling. Data recovered for 12 Oct - 26 Nov 2007.
	Fitzroy	16-Dec-07	27-Mar-08	838	
	Fitzroy	27-Mar-08	06-Aug-08	826	Logger failed during deployment. Data recorded 27 March - 10 May 2008.
	Fitzroy	06-Aug-08	10-Oct-08	837	
	Fitzroy	10-Oct-08	25-Feb-09	826	Failed during deployment. Records recovered 10 - 22 Oct 2009, but bad data. Instrument returned to Wetlabs.
	Fitzroy	25-Feb-09	14-Jun-09	837	
	High	11-Oct-07	17-Dec-07	825	
	High	17-Dec-07	27-Mar-08	839	
	High	27-Mar-08	05-Aug-08	841	
	High	05-Aug-08	10-Oct-08	840	
	High	10-Oct-08	24-Feb-09	841	
	High	24-Feb-09	14-Jun-09	825	
	Russell	10-Oct-07	17-Dec-07	824	
	Russell	17-Dec-07	27-Mar-08	840	
	Russell	27-Mar-08	05-Aug-08	824	
	Russell	05-Aug-08	10-Oct-08	825	
	Russell	10-Oct-08	24-Feb-09	824	
	Russell	24-Feb-09	14-Jun-09	840	
	Dunk	17-Oct-07	18-Dec-07	828	
	Dunk	18-Dec-07	26-Mar-08	841	
	Dunk	26-Mar-08	04-Aug-08	828	
	Dunk	04-Aug-08	13-Oct-08	353	
	Dunk	13-Oct-08	27-Feb-09	838	
	Dunk	27-Feb-09	17-Jun-09	353	
Burdekin	Pelorus	09-Oct-07	15-Dec-07	823	
	Pelorus	15-Dec-07	25-Mar-08	829	No data recovered. Logger died - 'cracked head'.
	Pelorus	25-Mar-08	03-Aug-08	818	
	Pelorus	03-Aug-08	09-Oct-08	823	
	Pelorus	09-Oct-08	23-Feb-09	818	
	Pelorus	23-Feb-09	17-Jun-09	823	
	Pandora	09-Oct-07	15-Dec-07	822	
	Pandora	15-Dec-07	25-Mar-08	837	
	Pandora	25-Mar-08	02-Aug-08	815	
	Pandora	02-Aug-08	08-Oct-08	822	
	Pandora	08-Oct-08	22-Feb-09	819	
	Pandora	22-Feb-09	13-Jun-09	822	
	Geoffrey	07-Oct-07	14-Dec-07	821	Failed during deployment, attributed to fouling as draped with hydroids
	Geoffrey	14-Dec-07	24-Mar-08	351	

	Geoffrey	24-Mar-08	03-Jun-08	821	Failed during deployment.
	Geoffrey	03-Jun-08	01-Aug-08	839	
	Geoffrey	01-Aug-08	08-Oct-08	352	
	Geoffrey	08-Oct-08	22-Feb-09	839	
	Geoffrey	22-Feb-09	12-Jun-09	352	
Mackay Whitsunday	DoubleCone	06-Oct-07	15-Feb-08	820	
	DoubleCone	15-Feb-08	04-Apr-08	353	Negative Chl & NTU values, data records deleted, sent for service
	DoubleCone	27-Jul-08	02-Oct-08	1043	Incorrect tuning: 0-25 NTU, 0-50 ug/l Chl, instead of 0-100 NTU, 0-50 ug/l Chl.
	DoubleCone	02-Oct-08	20-Feb-09	351	
	DoubleCone	20-Feb-09	11-Jun-09	845	
	Daydream	06-Oct-07	15-Feb-08	819	Logger failure at end deployment. Recovered data for 6 Oct 2007 - 12 Feb 2008. Lost data 13 & 14 Feb.
	Daydream	15-Feb-08	26-Jul-08	842	
	Daydream	26-Jul-08	01-Oct-08	819	
	Daydream	01-Oct-08	19-Feb-09	815	
	Daydream	19-Feb-09	10-Jun-09	846	
	Pine	05-Oct-07	15-Feb-08	818	
	Pine	15-Feb-08	26-Jul-08	843	
	Pine	26-Jul-08	01-Oct-08	1044	Incorrect tuning: 0-25 NTU, 0-50 ug/l Chl, instead of 0-100 NTU, 0-50 ug/l Chl.
	Pine	01-Oct-08	20-Feb-09	843	
	Pine	20-Feb-09	10-Jun-09	842	
Fitzroy	Barren	03-Oct-07	25-Feb-08	815	
	Barren	25-Feb-08	29-Jul-08	845	
	Barren	29-Jul-08	04-Oct-08	1091	Incorrect tuning: 0-25 NTU, 0-50 ug/l Chl, instead of 0-100 NTU, 0-50 ug/l Chl.
	Barren	04-Oct-08	17-Feb-09	845	
	Barren	17-Feb-09	08-Jun-09	816	
	Humpy	03-Oct-07	25-Feb-08	816	
	Humpy	25-Feb-08	30-Jul-08	844	Lost data records 28 & 29 July 2008.
	Humpy	30-Jul-08	05-Oct-08	816	
	Humpy	05-Oct-08	17-Feb-09	821	Failed during deployment. Records recovered for 5 Oct - 15 Nov 2009.
	Humpy	17-Feb-09	08-Jun-09	844	
	Pelican	04-Oct-07	03-Apr-08	817	
	Pelican	03-Apr-08	29-Jul-08	846	
	Pelican	29-Jul-08	04-Oct-08	817	
	Pelican	04-Oct-08	17-Feb-09	846	
	Pelican	17-Feb-09	08-Jun-09	817	

Table A1-2.2 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

Table A1-2.3 Summary values for dissolved inorganic nitrogen species (µg L^{-1}) from three sampling occasions in 2008/09.

Region	Location	Date	NH_4	NO_2	NO_3	Date	NH_4	NO_2	NO_3	Date	NH_4	NO_2	NO_3
Wet Tropics	Snapper Island	07/08/2008	1.923	0.348	0.790	11/10/2008	2.424	0.265	1.043	26/02/2009	7.140	0.435	5.687
	Fitzroy Island	06/08/2008	1.321	0.107	0.429	10/10/2008	1.316	0.251	1.430	25/02/2009	11.977	0.000	2.844
	High Island	05/08/2008	1.691	0.138	0.558	10/10/2008	0.730	0.187	1.312	24/02/2009	9.189	0.000	5.185
	Russell Island	05/08/2008	0.481	0.036	0.541	10/10/2008	1.769	0.187	2.002	24/02/2009	6.840	0.000	1.572
	Dunk Island	04/08/2008	0.374	0.029	0.101	13/10/2008	1.599	0.241	1.069	27/02/2009	3.952	0.074	1.156
Burdekin	Pelorus/Orpheus Island	03/08/2008	0.938	0.093	0.690	09/10/2008	0.000	0.084	1.023	23/02/2009	4.992	3.422	3.432
	Pandora Reef	02/08/2008	0.955	0.168	2.027	08/10/2008	0.000	0.329	4.629	22/02/2009	7.816	0.101	3.344
	Geoffrey Bay*	01/08/2008	1.248	0.167	0.492	08/10/2008	0.000	0.267	1.782	22/02/2009	5.018	0.415	6.653
Mackay Whitsunday	Double Cone Island	27/07/2008	1.509	0.037	1.767	02/10/2008	0.000	0.043	1.001	20/02/2009	5.534	1.027	3.122
	Daydream Island	26/07/2008	0.781	0.967	1.165	01/10/2008	0.000	0.074	0.880	19/02/2009	8.308	0.500	2.676
	Pine Island	26/07/2008	0.181	0.133	0.316	01/10/2008	0.272	0.067	1.329	20/02/2009	9.884	1.156	4.296
Fitzroy	Barren Island	29/07/2008	2.268	0.000	0.046	04/10/2008	0.000	0.093	1.328	17/02/2009	1.740	0.019	1.475
	Humpy Island	30/07/2008	2.792	0.303	0.923	05/10/2008	0.340	0.264	3.082	17/02/2009	6.774	0.195	1.535
	Pelican Island	29/07/2008	3.091	3.032	3.973	04/10/2008	0.000	0.249	3.031	17/02/2009	4.844	0.381	1.794

Table A1-2.4 Summary values for **total dissolved nitrogen** and **particulate nitrogen**, both in µg L^{-1} from three sampling occasions in 2008/09.

Region	Location	Date	TDN	PN	Date	TDN	PN	Date	TDN	PN
Wet Tropics	Snapper Island	07/08/2008	93.375	10.342	11/10/2008	64.942	12.049	26/02/2009	92.516	9.129
	Fitzroy Island	06/08/2008	86.405	7.053	10/10/2008	68.539	8.840	25/02/2009	104.608	9.076
	High Island	05/08/2008	97.746	8.287	10/10/2008	82.547	12.211	24/02/2009	105.398	12.365
	Russell Island	05/08/2008	78.0230	9.129	10/10/2008	87.136	9.901	24/02/2009	97.834	7.066
	Dunk Island	04/08/2008	101.824	11.298	13/10/2008	76.210	14.478	27/02/2009	101.532	12.061
Burdekin	Pelorus/Orpheus Island	03/08/2008	94.401	8.002	09/10/2008	76.174	9.202	23/02/2009	119.601	14.739
	Pandora Reef	02/08/2008	95.533	11.280	08/10/2008	94.171	9.971	22/02/2009	112.553	10.769
	Geoffrey Bay*	01/08/2008	95.622	13.061	08/10/2008	82.441	16.000	22/02/2009	122.494	19.581
Mackay Whitsunday	Double Cone Island	27/07/2008	58.745	11.675	02/10/2008	80.775	11.702	20/02/2009	88.367	14.489
	Daydream Island	26/07/2008	88.537	12.867	01/10/2008	92.532	12.996	19/02/2009	108.384	14.075
	Pine Island	26/07/2008	82.788	12.168	01/10/2008	86.468	14.013	20/02/2009	90.521	13.059
Fitzroy	Barren Island	29/07/2008	82.911	11.992	04/10/2008	87.204	11.106	17/02/2009	153.571	13.217
	Humpy Island	30/07/2008	97.269	12.112	05/10/2008	102.204	10.347	17/02/2009	115.573	15.491
	Pelican Island	29/07/2008	107.264	22.938	04/10/2008	111.088	12.414	17/02/2009	138.665	14.722

Table A1-2.5 Summary values for dissolved inorganic phosphorus (PO_4), total dissolved phosphorus (TDP) and particulate phosphorus (PP), all in µg L^{-1}, from three sampling occasions in 2008/09.

Region	Location	Date	PO_4	TDP	PP	Date	PO_4	TDP	PP	Date	PO_4	TDP	PP
Wet Tropics	Snapper Island	07/08/2008	2.978	5.342	2.090	11/10/2008	2.663	5.680	2.414	26/02/2009	0.868	6.946	1.790
	Fitzroy Island	06/08/2008	2.499	4.513	1.254	10/10/2008	2.432	5.196	1.449	25/02/2009	0.586	6.676	2.137
	High Island	05/08/2008	2.722	5.089	1.764	10/10/2008	2.395	4.824	2.177	24/02/2009	0.812	5.347	3.783
	Russell Island	05/08/2008	2.102	4.992	1.263	10/10/2008	2.195	5.132	1.547	24/02/2009	0.429	4.535	0.802
	Dunk Island	04/08/2008	1.960	4.087	1.774	13/10/2008	2.522	4.706	3.451	27/02/2009	0.000	4.607	2.758
Burdekin	Pelorus/Orpheus Island	03/08/2008	1.932	4.801	1.300	09/10/2008	2.186	5.119	1.397	23/02/2009	1.303	8.034	2.822
	Pandora Reef	02/08/2008	2.561	4.612	1.710	08/10/2008	3.281	5.483	1.819	22/02/2009	1.023	8.822	1.763
	Geoffrey Bay*	01/08/2008	2.789	3.425	1.698	08/10/2008	2.797	5.697	3.402	22/02/2009	5.285	11.920	3.563
Mackay Whitsunday	Double Cone Island	27/07/2008	3.395	6.370	1.927	02/10/2008	1.923	5.718	1.617	20/02/2009	1.817	8.068	2.613
	Daydream Island	26/07/2008	3.619	6.269	2.033	01/10/2008	2.790	6.181	2.336	19/02/2009	1.604	8.179	2.767
	Pine Island	26/07/2008	3.286	6.687	2.498	01/10/2008	2.533	6.329	2.635	20/02/2009	2.485	8.405	2.317
Fitzroy	Barren Island	29/07/2008	0.131	2.996	1.812	04/10/2008	2.321	5.653	1.345	17/02/2009	0.712	11.539	2.460
	Humpy Island	30/07/2008	2.218	2.766	1.769	05/10/2008	1.624	4.935	1.360	17/02/2009	0.431	9.736	2.601
	Pelican Island	29/07/2008	5.430	7.811	5.660	04/10/2008	4.456	7.620	2.726	17/02/2009	1.961	9.520	3.293

Table A1-2.6 Summary values for dissolved organic carbon (DOC), particulate organic carbon (POC), and silicate, all in µg L^{-1}, from three sampling occasions in 2008/09.

Region	Location	Date	DOC	POC	Si	Date	DOC	POC	Si	Date	DOC	POC	Si
Wet Tropics	Snapper Island	07/08/2008	697.171	74.961	120.517	11/10/2008	675.237	92.464	110.144	26/02/2009	808.414	77.780	143.090
	Fitzroy Island	06/08/2008	703.959	51.218	53.173	10/10/2008	643.459	66.739	60.278	25/02/2009	780.877	76.795	125.567
	High Island	05/08/2008	727.838	68.610	116.044	10/10/2008	664.017	84.029	63.685	24/02/2009	904.946	163.251	268.839
	Russell Island	05/08/2008	711.813	46.963	107.527	10/10/2008	644.293	71.466	57.817	24/02/2009	774.094	56.361	106.361
	Dunk Island	04/08/2008	729.405	85.462	116.862	13/10/2008	709.010	156.996	131.716	27/02/2009	1124.959	112.453	960.958
Burdekin	Pelorus/Orpheus Island	03/08/2008	660.404	55.014	72.470	09/10/2008	734.428	84.412	81.670	23/02/2009	1007.956	120.021	452.806
	Pandora Reef	02/08/2008	673.663	103.636	85.245	08/10/2008	746.831	90.543	102.630	22/02/2009	902.727	94.593	341.051
	Geoffrey Bay*	01/08/2008	706.572	75.443	125.547	08/10/2008	706.152	151.357	142.502	22/02/2009	1178.483	151.102	946.280
Mackay Whitsunday	Double Cone Island	27/07/2008	734.108	76.416	75.144	02/10/2008	662.869	112.356	105.860	20/02/2009	854.042	118.175	241.537
	Daydream Island	26/07/2008	704.469	93.533	88.385	01/10/2008	598.308	94.714	74.234	19/02/2009	978.100	161.218	299.570
	Pine Island	26/07/2008	726.764	98.857	79.182	01/10/2008	672.324	109.182	71.652	20/02/2009	756.567	91.664	214.787
Fitzroy	Barren Island	29/07/2008	696.543	103.703	17.320	04/10/2008	678.665	71.561	73.761	17/02/2009	866.950	107.918	60.630
	Humpy Island	30/07/2008	676.801	97.361	25.811	05/10/2008	734.905	67.643	51.604	17/02/2009	822.722	96.767	40.308
	Pelican Island	29/07/2008	770.812	196.979	91.064	04/10/2008	806.116	115.157	96.328	17/02/2009	1063.794	133.437	109.399

Table A1-2.7 Summary values for chlorophyll (in µg L^{-1}) from three sampling occasions in 2008/09.

Region	Location	Date	Chlorophyll	Date	Chlorophyll	Date	Chlorophyll
Wet Tropics	Snapper Island	07/08/2008	0.216	11/10/2008	0.317	26/02/2009	0.295
	Fitzroy Island	06/08/2008	0.135	10/10/2008	0.178	25/02/2009	0.343
	High Island	05/08/2008	0.252	10/10/2008	0.380	24/02/2009	0.550
	Russell Island	05/08/2008	0.191	10/10/2008	0.223	24/02/2009	0.272
	Dunk Island	04/08/2008	0.214	13/10/2008	0.407	27/02/2009	0.530
Burdekin	Pelorus/Orpheus Island	03/08/2008	0.187	09/10/2008	0.172	23/02/2009	0.750
	Pandora Reef	02/08/2008	0.255	08/10/2008	0.276	22/02/2009	0.307
	Geoffrey Bay*	01/08/2008	0.215	08/10/2008	0.446	22/02/2009	0.902
Mackay Whitsunday	Double Cone Island	27/07/2008	0.368	02/10/2008	0.291	20/02/2009	0.590
	Daydream Island	26/07/2008	0.431	01/10/2008	0.480	19/02/2009	0.924
	Pine Island	26/07/2008	0.536	01/10/2008	0.618	20/02/2009	0.611
Fitzroy	Barren Island	29/07/2008	0.182	04/10/2008	0.173	17/02/2009	0.396
	Humpy Island	30/07/2008	0.224	05/10/2008	0.241	17/02/2009	0.445
	Pelican Island	29/07/2008	0.957	04/10/2008	0.384	17/02/2009	0.477

Table A1-2.8 Summary values for Secchi depth (m), concentrations of total suspended solids (SS, in mg L-1) and practical salinity (dimensionless), from three sampling occasions in 2008/09.

Region	Location	Date	Secchi	SS	Salinity	Date	Secchi	SS	Salinity	Date	Secchi	SS	Salinity
Wet Tropics	Snapper Island	07/08/2008	5	1.31	34.96	11/10/2008	6	1.17	35.03	26/02/2009	7	0.79	31.84
	Fitzroy Island	06/08/2008	11	0.50	35.24	10/10/2008	8	1.25	35.09	25/02/2009	14	0.23	32.65
	High Island	05/08/2008	12	0.57	34.74	10/10/2008	7	1.08	35.01	24/02/2009	1	1.33	32.54
	Russell Island	05/08/2008	13	0.31	34.81	10/10/2008	6	0.18	35.02	24/02/2009	19	0.13	33.22
	Dunk Island	04/08/2008	6	1.30	34.88	13/10/2008	2	3.78	35.13	27/02/2009	6	0.69	26.00
Burdekin	Pelorus/Orpheus Island	03/08/2008	10	0.94	35.66	09/10/2008	9	0.00	35.29	23/02/2009	8	0.57	30.49
	Pandora Reef	02/08/2008	6	1.26	35.79	08/10/2008	8	0.41	35.53	22/02/2009	11	0.64	31.08
	Geoffrey Bay*	01/08/2008	6	1.03	35.51	08/10/2008	4	1.41	35.82	22/02/2009	5	1.88	27.93
Mackay Whitsunday	Double Cone Island	27/07/2008	6	1.06	35.03	02/10/2008	5	1.21	35.37	20/02/2009	7	1.35	33.25
	Daydream Island	26/07/2008	5	1.42	34.86	01/10/2008	4	4.80	35.59	19/02/2009	9	0.90	32.90
	Pine Island	26/07/2008	5	1.36	34.93	01/10/2008	3	4.08	35.66	20/02/2009	9	1.58	33.33
Fitzroy	Barren Island	29/07/2008	9	0.29	35.39	04/10/2008	11	0.48	35.55	17/02/2009	11	0.17	35.36
	Humpy Island	30/07/2008	7	0.61	35.60	05/10/2008	11	0.15	35.52	17/02/2009	11	0.25	35.29
	Pelican Island	29/07/2008	2	6.93	35.32	04/10/2008	3	2.30	35.49	17/02/2009	3	1.36	34.68

Appendix 1 to Chapter 3 - Inshore Coral Reef Monitoring

Tables A1-3.1a-d Sediment analysis results for reefs sampled between 2006 and 2008. Proportion of clay & silt, organic carbon, nitrogen and inorganic carbon as a percentage of the total sample.

Table AI-3.1(a) Clay & silt (c/s). Values are the proportion of the sample by weight consisting of sediment with grain sizes <0.063mm. Average (Ave) values for all sampled reefs in each year are provided in column headings for reference.

NRM Region	Catchment	Reef (aspect)	2006 c/s % Ave 18.84	2007 c/s % Ave 18.96	2008 c/s % Ave 16.67
Wet Tropics	Daintree	Cape Tribulation North	3.73		
		Cape Tribulation Middle	7.42		
		Cape Tribulation South	8.22		
		Snapper Island (back)	42.86		38.96
		Snapper Island (front)	8.73		7.25
	Johnstone	Fitzroy Island (back)	4.07	9.04	9.56
		Fitzroy Island (front)	4.77		0.57
		High Island (back)	9.95	6.20	18.74
		High Island (front)	8.69	0.58	
		Frankland Islands (back)	35.27	25.30	36.41
		Frankland Islands (front)	17.85	3.12	
	Tully	North Barnard Islands (front)	12.27	5.93	
		King (front)	3.27		1.64
		Dunk Island (back)	5.03	6.65	14.86
		Dunk Island (front)	12.27		5.28
Burdekin	Burdekin	Pelorus and Orpheus Islands (back)	5.76	3.97	3.89
		Orpheus Island (front)	1.60		0.00
		Lady Elliot (front)	14.50		12.57
		Pandora (front)	3.43	2.36	2.98
		Havannah Island (front)	7.62	7.45	
		Geoffrey Bay (front)	13.16	9.76	7.97
		Middle Reef (front)	80.48	54.92	
Mackay Whitsunday	Proserpine	Double Cone Island (front)	14.12	34.59	28.52
		Hook Island (back)	36.66		36.36
		Daydream Island (back)	61.56	72.46	72.39
		Shute and Tancred Islands (front)	38.07		25.60
		Dent Island (back)	58.15	52.93	
		Pine Island (back)	59.53	44.47	58.21
		Seaforth Island (front)	36.43	41.37	
Fitzroy Basin Association	Fitzroy	North Keppel Island (front)	14.38	8.94	
		Barren Island (back)	2.62	2.37	2.82
		Middle Island (back)			4.69
		Humpy and Halfway Islands (back)	3.26	3.14	5.74
		Pelican Island (back)	2.42	2.55	0.00
		Peak Island (front)	2.51		5.16

Table AI-3.1(b) Organic carbon content (OC) as a percentage of total sediment sample for each reef in each NRM region. Average (Ave) values for all reefs sampled in each year are presented in column headings for reference.

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

Table AI-3.1(c) Total nitrogen content (N) as a percentage of total sediment sample for each reef in each NRM regon. Average (Ave) values for all reefs sampled in each year are presented in column headings for reference.

NRM Region	Catchment	Reef (aspect)	2006 N % Ave 0.0435	2007 N % Ave 0.0534	2008 N % Ave 0.0465
Wet Tropics	Daintree	Cape Tribulation North	0.0388		
		Cape Tribulation Middle	0.0392		
		Cape Tribulation South	0.0416		
		Snapper Island (back)	0.0679		0.0508
		Snapper Island (front)	0.0146		0.0306
	Johnstone	Fitzroy Island (back)	0.0256	0.0416	0.0367
		Fitzroy Island (front)	0.0211		0.0240
		High Island (back)	0.0429	0.0381	0.0436
		High Island (front)	0.0180	0.0303	
		Frankland Islands (back)	0.0820	0.0814	0.0700
		Frankland Islands (front)	0.0203	0.0335	
	Tully	North Barnard Islands (front)	0.0374	0.0323	
		King (front)	0.0281		0.0225
		Dunk Island (back)	0.0288	0.0316	0.0293
		Dunk Island (front)	0.0334		0.0331
Burdekin	Burdekin	Pelorus and Orpheus Islands (back)	0.0345	0.0309	0.0312
		Orpheus Island (front)	0.0184		0.0282
		Lady Elliot (front)	0.0318		0.0209
		Pandora (front)	0.0304	0.0325	0.0332
		Havannah Island (front)	0.0234	0.0370	
		Geoffrey Bay (front)	0.0409	0.0419	0.0403
		Middle Reef (front)	0.1157	0.0756	
Mackay Whitsunday	Proserpine	Double Cone Island (front)	0.0439	0.0920	0.0640
		Hook Island (back)	0.0466		0.0574
		Daydream Island (back)	0.0860	0.1025	0.1020
		Shute and Tancred Islands (front)	0.0663		0.0720
		Dent Island (back)	0.0792	0.0886	
		Pine Island (back)	0.0883	0.0856	0.0906
		Seaforth Island (front)	0.0575	0.0750	
Fitzroy Basin Association	Fitzroy	North Keppel Island (front)	0.0300	0.0528	
		Barren Island (back)	0.0383	0.0520	0.0512
		Middle Island (back)			0.0365
		Humpy and Halfway Islands (back)	0.0410	0.0352	0.0532
		Pelican Island (back)	0.0329	0.0316	0.0433
		Peak Island (front)	0.0346		0.0519

Table AI-3.1 (d) Inorganic carbon content (IC) as a percentage of total sediment sample for each reef in each NRM region. Average (Ave) values for all reefs sampled in each year are presented in column headings for reference.

NRM Region	Catchment	Reef (aspect)	2006 IC % Ave 8.27	2007 IC % Ave 8.45	2008 IC % Ave 7.94
Wet Tropics	Daintree	Cape Tribulation North	7.87		
		Cape Tribulation Middle	8.53		
		Cape Tribulation South	8.21		
		Snapper Island (back)	6.99		5.98
		Snapper Island (front)	9.57		7.87
	Johnstone	Fitzroy Island (back)	9.80	9.47	9.35
		Fitzroy Island (front)	9.76		9.58
		High Island (back)	9.45	9.91	8.90
		High Island (front)	10.09	10.58	
		Frankland Islands (back)	8.12	8.39	7.63
		Frankland Islands (front)	10.62	10.37	
	Tully	North Barnard Islands (front)	8.95	9.43	
		King (front)	9.30		9.12
		Dunk Island (back)	8.47	8.65	7.15
		Dunk Island (front)	9.60		9.71
Burdekin	Burdekin	Pelorus and Orpheus Islands (back)	10.17	10.57	10.10
		Orpheus Island (front)	10.48		10.58
		Lady Elliot (front)	3.82		5.08
		Pandora (front)	10.56	10.55	10.27
		Havannah Island (front)	10.19	10.11	
		Geoffrey Bay (front)	7.88	8.40	8.36
		Middle Reef (front)	2.00	4.70	
Mackay Whitsunday	Proserpine	Double Cone Island (front)	9.31	7.49	7.61
		Hook Island (back)	8.73		8.27
		Daydream Island (back)	6.01	4.29	3.93
		Shute and Tancred Islands (front)	7.58		7.59
		Dent Island (back)	6.69	6.42	
		Pine Island (back)	5.37	5.62	4.97
		Seaforth Island (front)	8.40	7.79	
Fitzroy Basin Association	Fitzroy	North Keppel Island (front)	5.68	8.70	
		Barren Island (back)	9.64	9.81	9.49
		Middle Island (back)			3.74
		Humpy and Halfway Islands (back)	8.68	8.76	8.73
		Pelican Island (back)	8.03	7.42	8.21
		Peak Island (front)	6.76		8.38

Table A1-3.2 Known disturbances to coral communities at Reef Rescue Marine monitoring locations. Percentaces in brackets are the proportional loss of hard coral cover.

NRM region	Catchment	Reef	Bleaching 1998	Bleaching 2002	Flood plumes 1991-99	Other recorded disturbances
Wet Tropics	Daintree	Snapper Is (North)	0.92 (19%)	0.95 (Nil)	1994 (Burdekin River), 1996	Flood 1996 (20%), Cyclone Rona 1999 (74%), Storm ,appox. Mar 2009 (14% at 2m, 5% at 5m)
		Snapper Is (South)	0.92 (Nil)	0.95 (Nil)	1994 (Burdekin River), 1996	Flood 1996 (87%), Flood 2004 (32%)
	Russell-Mulgrave and Johnstone	Fitzroy Is (East)	0.92	0.95	1989 (LTMP)	Cyclone Felicity (75% manta tow data)
		Fitzroy Is (West)	0.92 (13%)	0.95 (15%)	1994 (Burdekin River), 1995, 1996, 1997,1999	Crown-of-thorns 1999-2000 (78%)
		Frankland Group (East)	0.92 (43%)	0.80 (Nil)	1994 (Burdekin River), 1997,1999	Unknown though likely crown-of-thorns 2000 (68%) Cyclone Larry 2006 (60% at 2m and 46% at 5m)
		Frankland Group (West)	0.93 (44%)	0.80 (Nil)	1994 (Burdekin River), 1997,1999	Unknown though likely crown-of-thorns 2000 (35%) Cyclone Larry 2006 (Nil)
		High Is (East)	0.93	0.80	1994 (Burdekin River), 1995, 1996, 1997,1999	Cyclone Larry 2006 (Nil)
		High Is (West)	0.93	0.80	1994 (Burdekin River), 1995, 1996, 1997,1999	Cyclone Larry 2006 (25% at 5m)
	Tully	North Barnard Group	0.93	0.80	1994 (Burdekin River), 1996, 1997	Cyclone Larry 2006 (95% at 2m and 86% at 5m)
		King Reef	0.93	0.85	1994 (Burdekin River), 1995, 1996, 1997	Cyclone Larry 2006 (21% at 2m and 43% at 5m)
		Dunk Is (North)	0.93	0.80	1994 (Burdekin River), 1995, 1996, 1997, 1998	Cyclone Larry 2006 (80% at 2m and 65% at 5m)
		Dunk Is (South)	0.93	0.85	1994 (Burdekin River), 1995, 1996, 1997, 1998	Cyclone Larry 2006 (2% at 2m and 18% at 5m)

Note: Included under bleaching are the estimated probability that each reef would have experienced a coral bleaching event in either 1998 or 2002 as calculated using a Bayesian Network model based on the methodology outlined by 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. Listed under Flood plumes are years for which flood plumes were observed to extend over reefs (Devlin *et al.*, 2001). Other observations are from various monitoring studies. All percentage changes are expressed as the proportional reduction in existing coral cover for a given disturbance.

Table A1-3.2 continued.

NRM region	Catchment	Reef	Bleaching 1998	Bleaching 2002	Flood plumes	Other recorded disturbances
Burdekin	Burdekin	Orpheus Is (East)	0.93	0.80	1994	
		Orpheus & Pelorus Is (West)	0.92 (83%)	0.80	1994, 1998	Unknown 1995-7 though possibly Cyclone Justin (32%)
		Lady Elliott Reef	0.93	0.85	1994, 1997, 1998	
		Pandora Reef	0.93 (21%)	0.85 (2%)	1994, 1997, 1998	Cyclone Tessie 2000 (9%),
		Havannah Is	0.93 (49%)	0.95 (21%)	1994, 1997, 1998	Combination of Cyclone Tessie and Crown-of-thorns 1999-2001 (66%)
		Middle Reef	0.93 (4%)	0.95 (12%)	1994, 1997, 1998	Cyclone Tessie 2000 (10%)
		Geoffrey Bay	0.93 (24%)	0.95 (37%)	1994, 1997, 1998	Cyclone Joy 1990 (13%), Bleaching 1993 (10%), Cyclone Tessie 2000 (18%)
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	1997 (Burdekin River)	
		Shute Is & Tancred Is	0.57	1.00	1997 (Burdekin River)	
		Pine Is	0.31	1.00	1997 (Burdekin River)	
FitzroyBasin Association	Fitzroy	Barren Is	1.00	1.00	1991, 2008	Coral Bleaching Jan 2006 (25% at 2m and 33% at 5m), Storm Feb 2008 (38% at 2m and 21% at 5m)
		North Keppel Is	1 (15%)	0.89 (36%)	1991, 2008 (not estimable)	Coral Bleaching Jan 2006 (60% at 2m and 44% at 5m)
		Middle Is	1 (56%)	1 (Nil)	1991, 2008 (not estimable)	Coral Bleaching Jan 2006 (62% at 2m and 38% at 5m)
		Humpy & Halfway Is	1 (6%)	1 (26%)	1991, 2008 (6% at 2m)	Coral Bleaching Jan 2006 (25% at 2m and 27% at 5m)
		Pelican Is	1.00	1.00	1991, 2008 (23% at 2m)	Coral Bleaching Jan 2006 (Nil)
		Peak Is	1.00	1.00	1991, 2008 (17% at 2m)	Coral Bleaching Jan 2006 (Nil)

Table A1-3.3 Composition of coral reef communities represented by common hard coral families (% cover)

Region	Catchment	Reef	Depth	Acroporidae	Agariciidae	Dendrophylliidae	Euphyllidae	Faviidae	Fungiidae	Merulinidae	Mussidae	Oculinidae	Pectinidae	Pocilloporidae	Poritidae	Siderastreidae	Unknown
Wet Tropics	Daintree	Snapper Is North	2	48.25	0	0	0	0.12	0	0.19	0	0.12	0	0.62	0.25	1.12	0
			5	14.22	16.02	0.08	0	1.17	0.55	0.94	0	0.62	2.11	2.66	20.16	0	0.08
		Snapper Is South	2	6.31	0	0.12	0	1.31	0.12	0	0.12	0.69	0	0.62	19.44	0.69	0
			5	7.94	5.06	0.25	0	7.31	0.81	0.25	0.44	0.19	0.06	0.12	29.62	1.37	0
	Johnstone	Fitzroy Is West	2	25.31	0.12	0	0	3.5	0.19	0.87	0.44	1.87	0	1.19	5.19	0	0
			5	6.69	0.31	0.19	0	1.94	0.12	1.31	2	1.94	0.81	0.37	10.25	0.44	0
		Fitzroy Is East	2	30.37	0	0	0	2.37	0	0.12	0.12	0.06	0	1	4.25	0	0
			5	31.52	0.44	0	0	3.75	0.19	0.31	0.06	0.94	0.25	5.13	6.51	0.06	0
		High Is West	2	8.87	0.06	0	0	0.81	0.5	0.06	0	0.37	0.12	0.25	49.62	0	0
			5	1.44	1	0	0	2.12	0.12	0	0	0.69	0.06	0.25	18.25	0	0
		Frankland Group West	2	2.62	4.25	0	0	0.25	0.12	0.06	0.12	0.19	0	0.5	24.81	0	0
			5	0.12	2.89	0	0	0.19	0.06	0	0	0.06	0	0.12	56.65	0	0
	Tully	Dunk Is North	2	7.69	0	0.87	0	2.25	0	0.44	0.06	0.19	0	0.56	0.62	0.37	0
			5	8.5	0	2.25	0	2.69	0.06	0.06	0.25	0.06	0.69	1.31	0.5	0.06	0
		Dunk Is South	2	8.25	0.81	2	0	2.87	0.31	1.25	0.56	0.81	0	0.31	1.87	0.06	0
			5	4.875	4.62	5.44	0	11.37	0.62	4	0.94	0.25	7.06	0.06	3.06	0	0
Burdekin	Burdekin	Pelorus Is and Orpheus Is West	2	3.69	0	0	0	0.87	0.19	0	0.06	0.06	0	3.69	0.06	0	0
			5	3.56	0.06	0.06	0	1.81	0.56	0.12	0.31	0.06	0.12	0.69	4.06	0.31	0.06
		Orpheus is East	2	4.12	0	0	0	0.81	0	0	0.12	0.06	0	0.06	1.19	0	0
			5	2.87	0	0.06	0	2.56	0	0.12	0.37	0.19	0.12	0	2.06	0	0
		Lady Elliot	2	22.06	1.37	0	0	0.5	7.37	0.5	0.25	4.5	0.12	0	0.62	0	0
			5	1.94	2.75	0.62	0.12	3.19	3.62	0.69	2.87	15	7.19	0.12	10.06	0.25	0
		Pandora	2	0.94	0	0	0	1.12	0	0.25	0	0.06	0	0.06	1.5	0.88	0
			5	2.12	0.06	0	0.37	12.06	1.56	0.69	0.25	0.56	1.06	0	0.37	0	0
		Geoffrey Bay	2	10.25	0.69	2.12	0	2.25	0.19	0.31	0.19	0.81	0	0.06	1.56	0.31	0
			5	5.31	4.01	2	0	4.25	1.94	1.56	0.56	0.63	1.69	0.37	2.45	0.12	0

Table A1-3.3 Continued

Region	Catchment	Reef	Depth	Acroporidae	Agariciidae	Dendrophylliidae	Euphyllidae	Faviidae	Fungiidae	Merulinidae	Mussidae	Oculinidae	Pectinidae	Pocilloporidae	Poritidae	Siderastreidae	Unknown
Mackay Whitsunday	Proserpine	Double Cone Is	2	27.03	0	2.19	0	1.94	0.5	2.94	1.25	3	1.63	0.25	3.44	0	0.06
			5	6.5	2.06	0.06	0.37	3.12	0.31	0.62	1.5	2.81	1.06	0.5	49.06	0	0.19
		Hook Is	2	6.37	0.69	0.5	0	4.56	0.06	0.25	0.25	0	1.06	1.12	9.31	0.12	0.06
			5	5.44	2.13	0.56	0.19	4.45	0.19	0.19	0.62	0.25	0.38	0.18	15.09	0	0
		Daydream Is	2	27.47	0.06	0	0	0.56	0.31	0	0.31	0	0.87	0.12	0.94	0	0.06
			5	35.40	0	0	0	0.75	0.06	0.38	0.25	0	1.57	0.6	2.2	0	0.13
		Shute Is and Tancred Is	2	25.63	0.87	0.19	0	1.315	1.25	0.56	0.88	0.19	1	0.69	3.88	0	0
			5	10.01	0.69	0.06	0.06	1.50	0.06	0.31	1.88	0.06	1.81	0.25	5.38	0	0
		Pine Is	2	16.56	0.75	0.06	0.25	2.31	1	1.19	0.31	18.37	1.75	0.19	2.88	0	0.25
			5	9	2.5	0.5	0.44	2.31	2.87	1.19	3.87	8.69	9.69	0.19	6.81	0	0
Fitzroy Basin Association	Fitzroy	Middle Is	2	32.83	0	0	0	0.37	0	0	0	0	0	0.19	0	0	0
			5	50.5	0	0	0	0.37	0	0	0.12	0	0	0.37	0	0	0
		Barren Is	2	23.31	0.25	0.31	0	1.56	0	0.31	0.06	0	0	0.62	0	0.31	0
			5	56.06	0	0	0	0	0	0	0	0	0	0	0	0	0
		Humpy Is and Halfway Is	2	50.06	0	0	0	0	0	0	0	0	0	0.06	0.0	0	0
			5	31.37	0	0.19	0	0.37	0	0	0	0	0	0	0.25	0	0
		Pelican Is	2	34.25	0	0.25	0	2.62	0	0	0.06	0	0	0.75	0.44	1.12	0.12
			5	0.25	0	4.19	0	7.75	0	2.37	0.62	0.25	0.25	0.5	6	1.62	0
		Peak Is	2	4.44	0	0.62	0	6.12	0	0.12	0.31	0	0	0.81	0.75	3.06	0
			5	0.69	0	1.75	0	8.81	0	2.75	0	0	0.06	0.06	4.75	10.19	0

Table A1-3.4 Composition of coral reef communities represented by common soft coral families (% cover)

Region	Catchment	Reef	Depth	Alcyoniidae	Briareidae	Clavulariinae	Ellisellidae	Unknown Gorgonians	Helioporidae	Nephtheidae	Tubiporidae	Xeniidae
Wet Tropics	Daintree	Snapper Is North	2	0.19	0.06	9.94	0	0	0	0	0	0.06
			5	0.08	0.86	0.08	0	0	0	0	0	0
		Snapper Is South	2	0.88	0.56	0	0	0	2.44	0	0	0
			5	0.13	10.63	0	0.13	0	4.13	0	0	0
	Johnstone	Fitzroy Is West	2	35.88	0.31	0	0	0.06	0	0	0.06	0.06
			5	32.13	0.06	0	0	0	0	0	0	0
		Fitzroy Is East	2	5.38	0.19	1.06	0	0	0	0.13	0	1.38
			5	5.44	1.94	0.13	0	0	0	0	0	0
		High Is West	2	2.25	0.06	0	0	0	2.75	0	0	0
			5	1.31	0.88	0	0	0	0.75	0	0	0
		Frankland Group West	2	6.38	0	4.94	0	0	0.19	0	0	0
			5	2.25	0	0	0	0	0	0	0	0
	Tully	Dunk Is North	2	0.19	0.06	0	0.06	0	0	0	0	0
			5	0.13	0.06	0	0	0.31	0	0	0	0
		Dunk Is South	2	0.25	1.19	0.06	0	0	0	0	0	0
			5	0.19	2.19	0	0	0	0	0	0	0
Burdekin	Burdekin	Pelorus Is and Orpheus Is West	2	22.88	0.56	1.00	0	0.06	0	0.75	0.06	0.44
			5	27.38	4.75	0.19	0	0.13	0	0.31	0	0
		Orpheus is East	2	39.88	0	0.06	0	0	0	0	0	0
			5	28.94	0.31	0.06	0	0	0	0	0	0
		Lady Elliot	2	0.13	0	0	0	0	0	0	0	0
			5	0.19	0	0	0	0	0	0	0	0
		Pandora	2	0	0	0.38	0	0	0	0	0	0
			5	0	0	0.19	0	0	0	0	0	0
		Geoffrey Bay	2	0.19	0	0	0	0	0	0	0	0
			5	0.44	0.56	0	0.06	0	0	0	0	0

Table A1-3.4 Continued

Region	Catchment	Reef	Depth	Alcyoniidae	Briareidae	Clavulariinae	Ellisellidae	Unknown Gorgonians	Helioporidae	Nephtheidae	Tubiporidae	Xeniidae
Mackay Whitsunday	Proserpine	Double Cone Is	2	7.57	4.88	0	0	0	0	0	0.25	0
			5	6.75	2.06	0	0	0	0	0	0.06	0
		Hook Is	2	23.63	1.81	0	0	0	0	0.19	0.06	0
			5	21.58	0.38	0	0	0	0	0	0	0
		Daydream Is	2	10.13	0	0	0	0	0	0	0	0
			5	4.45	0	0	0	0	0	0	0	0
		Shute Is and Tancred Is	2	22.79	0	0	0	0	0	0.75	0	0.75
			5	10.70	0	0	0	0	0	0.75	0	0
		Pine Is	2	1.25	0.88	0	0	0	0	0	0	0
			5	4.63	0.25	0	0	0	0	0.13	0	0
Fitzroy Basin Association	Fitzroy	Middle Is	2	0.31	0	0	0	0	0	0	0	0
			5	0	0	0	0	0	0	0	0	0
		Barren Is	2	0.19	0	0	0	0	0	0	0	3.88
			5	0.06	0	0	0	0	0	0	0	0.88
		Humpy Is and Halfway Is	2	0.13	0	0	0	0	0	0	0	7.63
			5	0.44	0	0	0	0	0	0	0	0
		Pelican Is	2	9.44	0	0	0	0	0	0.06	0.13	0.38
			5	9.75	0	0	0.25	3.06	0	0.13	0.25	0.06
		Peak Is	2	1.19	0	0	0	0.06	0	0	0.19	0
			5	2.81	0	0	0.06	1.25	0	0.06	0.06	0.13

Table A1-3.5 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 Reds (Rhodophyta), Greens (Chlorophyta) and Browns (Phaeophyta).

Region	Catchment	Reef	Depth	*Asparagopsis*	*Peyssonnelia*	*Hypnea*	Calcareous Rhodophyta	Other Rhodophyta	*Caulerpa*	*Halimeda*	Other Chlorophyta	*Dictyota*	*Lobophora*	*Padina*	*Sargassum*	Other Phaeophyta	Unknown Family
Wet Tropics	Daintree	Snapper Is North	2	0	3.13	0.06	0.75	1.44	0	0	0	0	0	0	0	0	0.63
			5	0	0	0	0	0.08	0	0	0	0	0	0	0	0	0.78
		Snapper Is South	2	0	0	0	0.13	0.19	0	0	0.38	0	0	0	0	0	0.19
			5	0	1.19	0.06	0.06	1.19	0	0	0.06	0	0	0	0	0	0.06
	Johnstone	Fitzroy Is West	2	0	0	0	0	0.06	0	0	0	0	0	0	0	0	0
			5	0	0	0.13	0	0.13	0	0	0	0	0	0	0	0	0.06
		Fitzroy Is East	2	0	0	0	0.06	0.38	0	0	0.06	0	0	0	0	0	0.06
			5	0	0	0	0	0.13	0	0	0	0	0	0	0	0	0.06
		High Is West	2	0	0.06	0.06	0	2.75	0	0	0	0	0	0	0	0	0.06
			5	0	0.13	0	0	1.81	0	0	0	0	0	0.06	0	0	0
		Frankland Group West	2	0	0	0.06	0.13	4.13	0	0.38	0.06	0	0	0.56	0	0.06	0.63
			5	0	0	0.13	0.31	16.20	0	0.38	0.63	0	0.06	0.06	0	0	0.19
	Tully	Dunk Is North	2	0	0.06	0.13	0.50	0.56	0	0	1.19	5.38	3.94	1.38	8.50	1.63	2.50
			5	0.06	0	0.13	1.06	0.38	0	0	0.06	3.56	0.38	0.56	0.69	0.25	0.75
		Dunk Is South	2	0	1.06	0.06	0.75	2.06	0	0.06	0.25	0.25	5.31	0.81	12.88	0.38	2.25
			5	0	0	0.19	0	0.63	0	0	0	0	8.75	0.31	0.69	0.06	0.13
Burdekin	Burdekin	Pelorus Is and Orpheus Is West	2	0	0	0	0	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
		Orpheus is East	2	0	0	0	0	0	0	0	0.88	0	0	0	0	0.06	0
			5	0	0	0	0	0.06	0	0	0.63	0	0	0	0	0	0
		Lady Elliot	2	0.44	11.69	0.63	0.19	20.38	0.06	0	0.81	1.00	0	0	0	0.06	0.81
			5	0	0.06	0.19	0	0.88	0	0	0.19	7.19	0	0	0	0.44	0.38
		Pandora	2	3.13	0	0.38	0	0.25	0	0	0	2.00	24.44	1.63	11.06	0.75	2.00
			5	1.94	0	0.38	0	0	0	0	0.06	11.38	12.69	1.81	4.56	1.63	2.25
		Geoffrey Bay	2	0	0.19	0.25	0.31	5.13	0	0	0	3.69	6.44	0.19	14.69	1.00	2.94
			5	0	0	0.56	0.19	0.69	0	0	0.06	3.19	1.06	0.13	19.88	1.81	6.56

Table A1-3.5 Continued

Region	Catchment	Reef	Depth	*Asparagopsis*	*Peyssonnelia*	*Hypnea*	Calcareous Rhodophyta	Other Rhodophyta	*Caulerpa*	*Halimeda*	Other Chlorophyta	*Dictyota*	*Lobophora*	*Padina*	*Sargassum*	Other Phaeophyta	Unknown Family
Mackay Whitsunday	Proserpine	Double Cone Is	2	0	0	0.06	0	0.06	0	0	0	0	0	0	0	0	0
			5	0	0	0	0	0	0	0	0	0	0.06	0	0	0	0
		Hook Is	2	0	0	0	0	0	0	0	1.38	0	0	0	0	0	0
			5	0	0	0	0	0.13	0	0	0.25	0	0	0	0	0	0
		Daydream Is	2	0	0	0.06	0	0	0	0	0	0	0.81	0	0	0	0
			5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Shute Is and Tancred Is	2	0	0	0.06	0	0	0	0	0	0	0	0	0	0.06	0
			5	0	0	0	0	0	0	0	0	0	0.06	0	0	0	0
		Pine Is	2	0	0.25	0.31	0.06	1.69	0	0	0	0	4.63	0	5.88	0.06	1.06
			5	0	0	0.31	0	0.19	0	0.19	0	0	3.44	0	0	0	0.25
Fitzroy Basin Association	Fitzroy	Middle Is	2	0	0	2.57	0	1.38	0	0	0	0	16.51	0	0	0	0
			5	0	0	0.88	0	0	0	0	0	0	6.38	0	0	0	0
		Barren Is	2	0	0	0.19	0	0.06	0	0	0	0	0.19	0	0	0	0
			5	0	0	0.63	0	0.13	0	0	0.06	0	1.44	0	0	0	0
		Humpy Is and Halfway Is	2	0.63	0	0.44	0	1.56	0	0	0	0.13	6.25	0.25	0	1.25	0.56
			5	0.69	0	0.69	0	1.13	0	0	0.19	0	10.44	0	0	0	0
		Pelican Is	2	0	0	0.38	0.31	1.19	0	0	0	0.19	6.00	0.63	3.06	0	0.19
			5	0	0	0.56	0.06	1.00	0	0	0	0.25	2.19	0.38	1.06	0.06	0.13
		Peak Is	2	0.13	0	0.38	2.69	15.69	0.56	0.63	0.13	0	2.31	0.69	25.44	0.06	0.81
			5	0	0	1.75	0.81	10.31	0.13	2.56	0	0	0.13	0	4.81	0	0.63

Table A1-3.6 Composition of juvenile hard coral communities represented by common families (count per 34m²)

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	54.5	0	0	0	0	0.5	27	0	0	0.5	0	0.5	4	20.5
			5	19	2.5	0	2.5	0.5	20	12	2	2.5	8	2.5	3.5	7.5	0
		Snapper Is South	2	378	1	0	1	0	26	17.5	0	1.5	14	0	33	49	29
			5	14	1	0	0.5	0	8.5	4.5	2.5	0.5	3	0.5	0.5	9	2.5
	Johnstone	Fitzroy Is West	2	50	0	0	0.5	1.5	73.5	14	3	6.5	13	1.5	11.5	30	2
			5	51	5	0	0.5	2	34.5	22.5	2	15	32	10.5	5.5	57.5	0.5
		Fitzroy Is East	2	36.5	0.5	0	0	0	82	0	3	4	4.5	0	5	23	1
			5	41	1	1	2	3	59.5	4	2	14	8.5	2	19.5	33	4
		High Is West	2	31.5	1	1.5	2	0.5	28	2	1.5	3	7.5	1.5	9	18.5	0.5
			5	20	14.5	0	2.5	1.5	56	10.5	5.5	5	18.5	7.5	0	51.5	3.5
		Frankland Group West	2	18	5	0	0	0	4	19.5	0	1.5	15.5	1	4.5	41.5	1
			5	2	7.5	0	0	0	1.5	9	1	1.5	3.5	1	1	10	0
	Tully	Dunk Is North	2	55	0	0	28.5	0	81	0	0.5	1	1	0	6	6	10
			5	64.5	0.5	0	137.5	0.5	56	2.5	1	0.5	1	1	20	13	19.5
		Dunk Is South	2	45	0.5	0	4	0	71.5	1.5	4	1.5	7	0.5	1.5	14	3
			5	49.5	1.5	0	16	1	37.5	5	1.5	6	4.5	9.5	5	29.5	1
Burdekin	Burdekin	Pelorus Is and Orpheus Is West	2	44.5	4.5	0.5	8.5	2.5	76	20	0.5	24.5	7.5	16	19	21.5	0
			5	12.5	3.5	1	2	0.5	57	2	1	11.5	1.5	27	3	9	0.5
		Orpheus is East	2	18	0.5	0	0.5	0	31.5	0	0	4	3	0	0	2	0
			5	12.5	0.5	0	0	0	21	0.5	0.5	4	5	1	3.5	8	0
		Lady Elliot	2	72	1	0	1.5	0	12.5	240.5	10	0.5	13	0	0	16	0
			5	8	0	0.5	12	0	39.5	21	1	2	4.5	4	0	8.5	1.5
		Pandora	2	12	0	0	0	1	3	2.5	0.5	0.5	2	0	0	2.5	0.5
			5	8.5	0.5	0	1	0	27	15	8.5	0.5	15	2.5	0	10	4.5
		Geoffrey Bay	2	26	5	0	17.5	0	48	3	3	2.5	7	0	0	18	10.5
			5	24.5	5	0	15	1.5	64	8.5	4	0.5	9	3.5	0.5	16	1

Table A1-3.6 Continued

Region	Catchment	Reef	Depth	Acroporidae	Agariciidae	Astrocoeniidae	Dendrophylliidae	Euphyllidae	Faviidae	Fungiidae	Merulinidae	Mussidae	Oculinidae	Pectiniidae	Pocilloporidae	Poritidae	Siderastreidae
Mackay Whitsunday	Proserpine	Double Cone Is	2	20.5	0	0	2	1	18.5	1.5	3	5	0	1.5	1.5	15.5	0.5
			5	4.5	2	0	3	2.5	10	1	1	2.5	7	5	0	10	2
		Hook Is	2	8.5	0	0	1	0	29.5	0.5	3	8	1	2	6	16.5	0
			5	11.5	1	0	5	0	38.5	1	1	11.5	1.5	5	1	13	1.5
		Daydream Is	2	22	1	0	3.5	0.5	11	7.5	7	17	1.5	10	2.5	5.5	0
			5	34	3.5	0	2	0.5	21	4	2.5	6	0.5	10.5	0.5	8	0
		Shute Is and Tancred Is	2	53.5	1.5	0	3.5	0.5	55.5	11	4.5	18	3	12	6	18	0.5
			5	66	1.5	0	7.5	0.5	64.5	6	4.5	15.5	1.5	15	1.5	11.5	1
		Pine Is	2	38.5	2	0	1	1.5	11.5	11	2	10	5.5	7	1.5	31.5	0.5
			5	16.5	6	0.5	6.5	3.5	19.5	9	5	10.5	6	16.5	1	16.5	1
Fitzroy Basin Association	Fitzroy	Middle Is	2	29.5	0	0	0	0	1	4.5	0	0	0	0	2.5	0	0
			5	27	0	0	2	0	3	3	0	0	0	0	1	0	0
		Barren Is	2	32.5	0.5	0	6.5	0	22	0.5	0	0.5	0	0	12.5	0	3
			5	12.5	0	0	0	0	1.5	0	0.5	0	0	0	3	0.5	0
		Humpy Is and Halfway Is	2	43	0	0	0	0	12.5	0	0	0.5	0	0	2	0	1.5
			5	19.5	0	0	5.5	0	26.5	0	0	1	0	0	0.5	7.5	2
		Pelican Is	2	31.5	0	0	4.5	0	18	0	0	11	0	0.5	2.5	9	0.5
			5	3.5	0	0	21.5	0.5	44	0	0.5	1.5	0	0	2.5	25.5	4
		Peak Is	2	25.5	0	0	3	0	4.5	0	0	4	0	0.5	2	4.5	4
			5	10.5	0	0	16	0	19.5	0	3.5	6	0	0.5	1.5	30	4

Table A1-3.7 Composition of juvenile soft coral communities represented by common families (count per 34m^2)

Region	Catchment	Reef	Depth	Alcyoniidae	Briareidae	Clavulariidae	Ellisellidae	Isididae	Nephtheidae	Nidaliidae	Xeniidae
Wet Tropics	Daintree	Snapper Is North	2	0	0	0.5	0	0	0	0	0
			5	3.5	1	0	0	0	0	0	0
		Snapper Is South	2	0	3.5	0	0	0	4.5	0	0
			5	1	2	0	0	0	0.5	0	0
	Johnstone	Fitzroy Is West	2	66.5	3	0	0	0	0	0	0
			5	69.5	1	0	0	0	0	0	0.5
		Fitzroy Is East	2	29.5	2.5	2.5	0	0	4	0	10.5
			5	28.5	6	2	0	0	0.5	0	0
		High Is West	2	13	0	0	0	0	0	0	0
			5	28	2	0	0	0	0	0	1.5
		Frankland Group West	2	15.5	0	12.5	0	0	0	0	4.5
			5	6	0	1	0	0	0	0	0
	Tully	Dunk Is North	2	5	1	0	0	0	0	0	0
			5	10	0	0	0	0	0	0	0.5
		Dunk Is South	2	7	4.5	1.5	0	0	0	0	0
			5	5	3	0	0	0	0	0	0.5
Burdekin	Burdekin	Pelorus Is and Orpheus Is West	2	80.5	10	14.5	0	0	12.5	0	11.5
			5	109	5	2.5	0	0	236.5	0	0
		Orpheus is East	2	23.5	1	0	0	0	1	0	0
			5	28	1.5	1	0	0	1.5	0	13
		Lady Elliot	2	0	0	0	0	0	0	0	0
			5	1.5	0	0	0	0	0.5	0	0
		Pandora	2	0.5	0	9	0	0	0	0	0
			5	7	0	7.5	0	0	0	0	0
		Geoffrey Bay	2	5	1.5	0	0	0	0	0	1
			5	15.5	0	0	0	0	0	0	0

Table A1-3.7 Continued

Region	Catchment	Reef	Depth	Alcyoniidae	Briareidae	Clavulariidae	Ellisellidae	Isididae	Nephtheidae	Nidaliidae	Xeniidae
Mackay Whitsunday	Proserpine	Double Cone Is	2	32.5	8.5	0	0	0	1.5	0	0.5
			5	39.5	2.5	0	0	0	0.5	0	3.5
		Hook Is	2	88.5	2.5	0	0	0	4.5	0	7
			5	64	4	0	0	0	6	0	0
		Daydream Is	2	84.5	0.5	0	0	0	0.5	0	0
			5	80	0	0	0	0	0	0	0
		Shute Is and Tancred Is	2	131	0	0	0	0	7	0	1.5
			5	131.5	0	0	0	0	7	0	3
		Pine Is	2	6	5.5	0	0	0	0	0	2
			5	16	1.5	0	0	0	0.5	0	0
Fitzroy Basin Association	Fitzroy	Middle Is	2	0	0	0	0	0	0	0	0
			5	3	0	0	0	0	0	0	0
		Barren Is	2	3	0	0	0	0	0	0	655.5
			5	0.5	0	0	0	0	0	0	168
		Humpy Is and Halfway Is	2	2.5	0	0	0	0	0	0	285
			5	2	0	0	0	0	0	0	1.5
		Pelican Is	2	22	0	0	0	0	6.5	0	28.5
			5	40	0	0	0	0	29	0	33.5
		Peak Is	2	25.5	0	0	0	0	8	0	10.5
			5	53.5	0	0	0	0.5	25	0	40.5

Appendix 2: QAQC Information

Appendix 2 to Chapter 2: Inshore Marine Water Quality Monitoring

Information pertaining to quality control and -assurance generally includes the assessment of the limit of detection (LOD), measurements of accuracy (e.g. using reference materials to assess recovery of known amount of analyte) and precision (the repeated analyses of the same concentration of analyte to check for reproducibility). Detailed QAQC data are contained as metadata in the data delivery CD.

Limits of detection

Limit of Detection (LOD) or detection limit, is the lowest concentration level that can be determined to be statistically different from a blank (99% confidence). LOD of water quality parameters sampled under the Reef Rescue MMP inshore marine water quality monitoring are summarised below:

Table A2-2.1 Limit of detection (LOD) for analyses of marine water quality parameters.

Parameter (analyte)	LOD
NO2	0.28 µg L^{-1}*
NO3+ NO2	0.70 - 1.4µg L^{-1}*
NH4	1.12 - 5.6 µg L^{-1}*
TDN	11 – 42 µg L^{-1}*
PN	1.0 µg $filter^{-1}$
PO4	0.9 – 1.6 µg L^{-1}*
TDP	0.9 - 2.5 µg L^{-1}*
PP	0.09 µg L^{-1}
Si	3.4 – 8.4 µg L^{-1}*
DOC	0.1 mg L^{-1}
POC	1.0 µg $filter^{-1}$
Chl	0.004 µg L^{-1}
SS	0.15 mg $filter^{-1}$
Salinity	0.03 PSU

*LOD for analysis of dissolved nutrients is estimated for each individual analytical batch, the range given is the range of LODs from batches analysed with samples collected in 2008/09.

Precision

The variation between results for replicate analyses of standards or reference material is used as a measure for the precision of an analysis. Reproducibility of samples was generally within a CV of 20%, with the majority of analyses delivering precision of results within 10% (Table A2-2.2)

Table A2-2.2 Summary of coefficients of variation (CV, in %) of replicate measurements (N) of a standard or reference material.

Parameter (analyte)	CV (%)	N
NO2	2-6*	6-10
NO3+ NO2	4-12*	6-10
NH4	6-15*	6-10
TDN	2-13*	4
PN	10	20
PO4	7-15*	6-10
TDP	1-13*	4
PP	2	8
Si	3-12*	6-10
DOC	3*	28-49
POC	4-8**	42-44
Chl	1	20
SS	n/a***	
Salinity	<1	4

*Precision for analysis of dissolved nutrients is estimated for each individual analytical batch, the range given is the range of CVs from batches analysed with samples collected in 2008/09.
** two different reference materials used in each batch
***n/a= no suitable standard material available for analysis of this parameter

Reproducibility of duplicate analytical units

From each water sample (station and depth) duplicate samples were prepared for the analyses of the various parameters. The variation between results for sample duplicates indicates the reproducibility of the analysis and also the effects of various sources of contamination and analytical error during collection, sample preparation and analyses. Before data analysis, results are generally averaged over duplicates.

Comparability between duplicate water samples was generally acceptable (Table A2-2.3). Average coefficients of variation (CV) were at or below 10% for samples analysed for TDN, PN, PP, DOC and chlorophyll. Average CVs were above 10% but below 20% for all other parameters. Some individual sample pairs had high CVs (see row N with CV > 20%). In the case of samples analysed for PN, PP, SS and Chl these are likely to be caused by the patchy presence of plankton organisms or detrital material in the water sample, which add material to one duplicate filter but not the other. In the case of dissolved nutrient analyses, high CV values also occurred when samples were close to the detection limit of the analyte. This results in more noisy readings, i.e., large variation but very small actual differences. In general, replication variation could be caused by a variety of causes during sample preparation and analyses. AIMS applies highly standardised procedures and a small number of staff carry out sample collection, preparation and analyses to reduce this variation s much as possible.

Table A2-2.3 Summary statistics of coefficients of variation (CV, in %) between duplicate water samples.

Parameter (analyte)	Average CV (%)	N duplicate pairs	N with CV >20% (as % of total N)
NO2	13.8	61	26
NO3+ NO2	15.8	170	27
NH4	14.9	154	29
TDN	9.5	279	11
PN	9.7	301	12
PO4	12.5	212	20
TDP	11.1	265	14
PP	7.4	307	6
Si	10.6	300	14
DOC	3.9	269	0-1
POC	10.5	268	14
Chl	6.9	311	5
SS	12.1	225	22
Salinity	n/a*		

*n/a: no replicate samples collected for salinity

Note: Duplicate pairs with one value below the detection limit (set to zero) and the other value was just above the detection limit where removed from the summary statistics as they would have erroneously inflated the summary values (CV= 141% if one duplicate= 0), this also applied where whole batches were below LOD.

Accuracy

Analytical accuracy is measured as the recovery (in %) of a known concentration of a certified reference material or analyte standard (where no suitable reference material is available, e.g. for PP), which is usually analysed interspersed between samples in each analytical run.

The recovery of known amounts of reference material is expected to be within 90-110% (i.e. the percent difference should be ≤ 20%) of their expected (certified) value for results to be considered accurate. The accuracy of analytical results for TDN, PN, PP, Si, chlorophyll and salinity was within this limit (Table A2-2.4). Analytical results for PP are adjusted using a batch-specific recovery factor that is determined with each sample batch. The accuracy of analytical results for dissolved nutrients varied, more than half of the reference material batches returned values within the required limit, and the others were just outside the 20% limit (Table A2-2.4). Reference batches for PO_4 and PP indicated a slight overestimate by 15% for 3 out 5 and 1 out 6 batches, respectively. Two out of four reference batches for NH_4 and 1 out of 5 batches for NO_x indicated an underestimate of up to 18%. One reason for the variable accuracy in dissolved nutrient analysis could be that the reference materials used (NLLNCT certified reference material) have much higher concentrations than the GBR lagoon samples and generally require analysis at a different sensitivity range. To assure that the monitoring results were accurate, additional QAQC samples were included in all batches (e.g. in-house reference seawater that allows for batch to batch comparison, added nutrient spikes) which usually return acceptable results.

Table A2-2.4 Summary of average recovery of known analyte concentrations.

Parameter (analyte)	Average recovery (%)	N
NO2	n/a	
NO3+ NO2	82-113	3-6
NH4	82-108	3-6
TDN	90-104	4-6
PN	108	20
PO4	104-115	3-6
TDP	90-115	4-6
PP	96	8
POC	98	42-44
Si	91-108	3-6
Chl	100	20
SS	n/a***	
Salinity	100	3

*Accuracy of analysis of dissolved nutrients is estimated for each individual analytical batch, the range given is the range of average recoveries from batches analysed with samples collected in 2007/08.
**PP: data are adjusted using a batch-specific efficiency factor (recovery)
***n/a= no suitable reference material available for analysis of this parameter

Procedural blanks

Wet filter blanks (filter placed on filtration unit and wetted with filtered seawater, then further handled like samples) were prepared during the on-board sample preparation to measure contamination during the preparation procedure for PN, PP, POC and chlorophyll. The instrument readings (or actual readings, in case of chlorophyll) from these filters were compared to instrument readings from actual water samples (Table A1-3.5). On average, the wet filter blank values were around or below 2% of the measured values for PN and chlorophyll and we conclude that contamination due to handling was minimal. Wet filter blanks (as well as filter blanks using pre-combusted filters) for PP and POC generally returned measureable readings, which indicates that the filter material contains traces of phosphorus and organic carbon. The blank values are relatively constant and were subtracted from sample results to adjust for the inherent filter component.
Wet filter blanks for SS analysis (filter placed on filtration unit and wetted with filtered seawater, rinsed with distilled water, then further handled like samples) were prepared during the on-board sample preparation. The mean weight difference of these filter blanks (final weight - initial filter weight) was 0.00015g (n=35). This value indicated the average amount of remnant salt in the filters ("salt blank"). The salt blank was about 15% of the average sample filter weight (Table A2-2.6). This value was included in the calculation of the amount of suspended solids per litre of water by subtraction from the sample filter weight differences.

Table A2-2.6 Comparison of instrument readings of wet filter blanks to actual sample readings

	PP (absorbance readings)	PN (instrument readings)	Chl (µg L^{-1})	SS (mg $filter^{-1}$)	POC (µg $filter^{-1}$)
Average of blank readings	0.004	651	0.004	0.19	5.24
N of blank readings	18	20	20	9	20
Average of sample readings	0.076	36731	0.345	1.24	31.5
N of sample readings	625	447	622	508	268
Average of blanks as % of average sample readings	6.6	1.8	1.2	15.1	15.2

Validation by alternative methods

Chlorophyll a

To validate the results of the chlorophyll analysis by fluorometry (which is the routinely applied standard method for samples collected under Reef Rescue MMP), a number of samples (collected separately from surface waters after the main Niskin cast) were analysed at AIMS by HPLC (a more elaborate technique yielding high resolution detection of various phytoplankton pigments). The results show a very good agreement between these two standard methods, however the fluorometry method showed values on average 20% lower than those obtained by the HPLC technique (Figure A2-3.1). This difference is subject to further investigations, however does not have a bearing on the reliability and usefulness of the results obtained by fluorometry which is an internationally accepted standard method that has been used at AIMS for about 20 years.

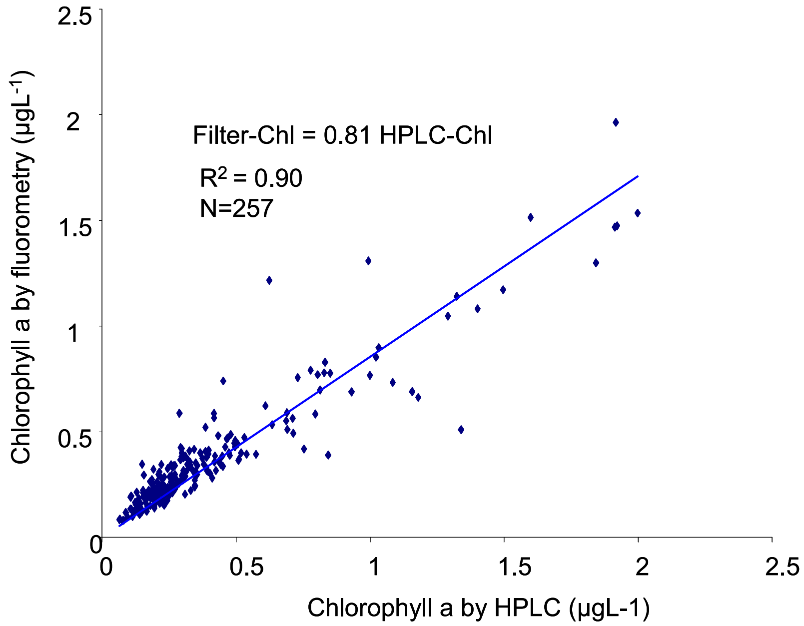
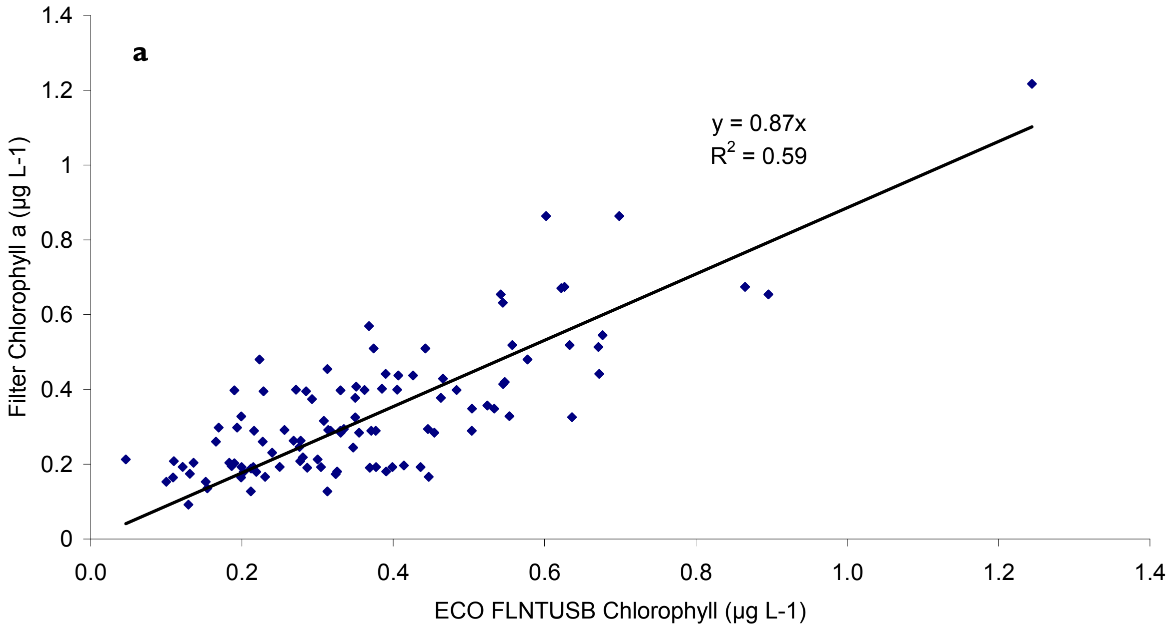


Figure A2-2.1 Match-up of duplicate samples analysed for chlorophyll a by fluorometry and HPLC.

Validation of ECO FLNTUSB instrument data

Direct water samples were collected and analysed for comparison to instrument data acquired at the time of manual sampling. The match-up of these data (Figure A2-2.2) showed relatively good correlations for both chlorophyll and turbidity (which was validated using suspended solids concentrations in the water column). The FLNTUSB loggers measured on average about 13% higher chlorophyll values than values obtained from water samples, which could be due to optical interference by fluorescent compounds abundant in dissolved organic matter (Wright and Jeffrey 2006), however, warrants further investigation. An overestimate was especially observed during the 2009 wet season. This may be due to interference of coloured dissolved organic matter, which is generally high in flood waters (McKinna in prep.). The impact of this overestimate on any conclusions drawn from these data (e.g. comparison to water quality guideline values) is considered to be minimal.

The relationship between optically measured turbidity and total suspended solids analysed on filters was significant, and the equation [TSS (mgL-1)] = 1.3 x FLNTUSB Turbidity (NTU)] can be used for conversion between these two variables. The equation has been the same in last year's estimates (Schaffelke *et al.* 2008).



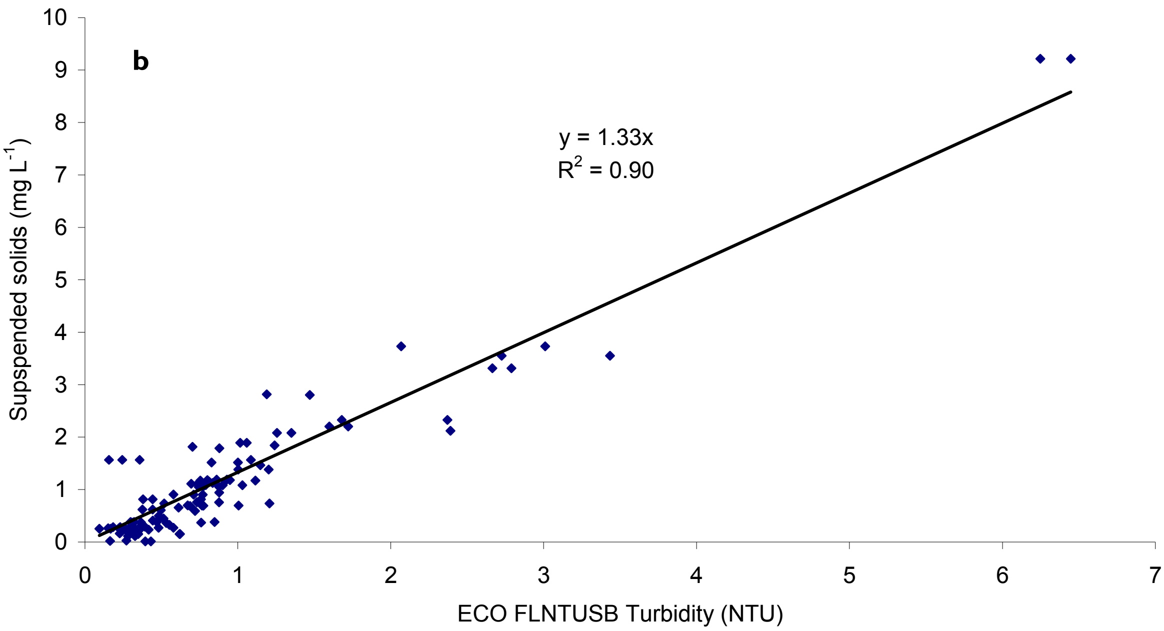


Figure A2-2.2 Match-up of instrument readings of a) chlorophyll a (µg L-1) and b) turbidity (NTU) from field deployments of WET Labs Eco FLNTUSB Combination Fluorometer and Turbidity Sensors with values from standard laboratory analysis of concurrently collected water samples.

Appendix 2 to Chapter 3 - Inshore Coral Reef Monitoring

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, 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.

Four observers collected juvenile coral count data in 2008. 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 near-shore coral reefs. He has 20 years experience surveying the sites on this reef, amongst many others. His taxonomic skills are undoubted at genus level and as such observer standardisation for demography and scuba search surveys are limited to detailed discussion of methodologies with AIMS observers and explicit following of the protocols listed here. Sea Research will also use the same pre-printed datasheets and data entry programs. The all other reefs were surveyed by experienced AIMS staff that have previously undergone training in the technique sufficient to ensure is 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 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%. Two experienced observers undertook the counts in 2008/09. Identification of the various taxa of spat was achieved by both comparison to a photographic reference set of spat encountered and identified in previous years and discussion and agreement between the two observers. To examine the percentage of spat overlooked each observer examined 12 tiles read by the other. As spat are marked during counting to avoid double counts spat missed by the first observer are easily identified (not marked). This comparison revealed that Observer 1 overlooked 7 from the total of 508 spat recorded on the second pass of the tiles done by Observer 2 representing the overlooking of 1.4% of spat. Observer 2 overlooked 36 of the 289 found by Observer 1 representing the overlooking of 12.5% of spat. This is slightly beyond the stated QA/QC goal of 10%. Further investigation of the data showed that this was mostly due to Observer 2 not recording 14 feint and nondescript skeletons for which designation as spat was subjective. Excluding these unknown "spat" brings the omission rate for observer 2 below the threshold of 10%.,

Appendix 3: List of Scientific Publications arising from the Programme

Schaffelke B (2008) Water Quality and Ecosystem Monitoring Program- Reef Water Quality Protection Plan. Progress Report Number 1. Australian Institute of Marine Science, Townsville. 18 p.

Schaffelke B (2008) Water Quality and Ecosystem Monitoring Program- Reef Water Quality Protection Plan. Progress Report Number 2. Australian Institute of Marine Science, Townsville. 20 p.

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

Uthicke S, Thompson A, Schaffelke B (in press) Effectiveness of benthic foraminiferal and coral assemblages as water quality indicators on inshore reefs of the Great Barrier Reef, Australia. Coral Reefs.