Water Quality and Ecosystem Monitoring Programme Reef Water Quality Protection Plan

Final Report 2007/08




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Contents

List of Figures and Tables

Acronyms

AIMS	Australian Institute of Marine Science
COTS	Crown-of-thorns starfish
RRRC	Reef and Rainforest Research Centre
GBRMPA	Great Barrier Reef Marine Park Authority
LAT	Lowest Astronomical Tide
LTMP	Long-term Monitoring Program
MTSRF	Marine and Tropical Research Facility
NRM	Natural Resource Management
QA/QC	Quality Assurance and Quality Control
QPWS	Queensland Parks and Wildlife Services
Reef Plan MMP	Reef Water Quality Protection Plan Marine Monitoring Program
Reef Plan	Reef Water Quality Protection Plan
WQIP	Water Quality Improvement Plan

Executive Summary

The AIMS Reef Plan monitoring activities reported in this Final Report largely continued the Reef Plan Marine Monitoring Programme tasks from 2004 to 2007. A number of significant changes to the sampling approach and design were decided by the Scientific Advisory Panel in April/May 2007, in collaboration and agreement with the current monitoring providers, including AIMS, and GBRMPA.

The key change was to focus water quality and inshore reef monitoring on 12 'core' reefs, three in each of four NRM Regions (Wet Tropics, Burdekin, Mackay\Whitsunday and Fitzroy). Specific activities on these reefs were:

- Continuous monitoring of water quality by autonomous instruments and twice-yearly, ship-based water quality sampling were undertaken.
- Annual surveys of the reef status were continued.
- Monitoring of coral recruitment was carried out at only 5 m depth.
- Coral surveys of the 20 'non-core' sites will only be undertaken every other year. Snapper Island, at the northern end of the Wet Tropics NRM region, was made an exception so as to continue the annual, long-term data set for this reef.
- Passive samplers for pesticide monitoring were deployed during the period of mass coral spawning (ca. October to December), for analyses by EnTox.
- Two additional sites were selected for the new, more intensive water quality monitoring: Snapper Island - as the most northern sampling site and to complement ongoing annual coral surveys; and, Dunk Island – as a site regularly affected by Tully River flood waters, and to complement an ongoing large collaborative research effort under the Tully WQIP and MTSRF.

The third year of monitoring under Reef Plan MMP provided a reliable understanding of spatial patterns of water and sediment quality and first indications of their relationships with benthic coral reef communities.

For the most part, water quality parameters measured in the Reef Plan MMP lagoon monitoring from 2005/06 to 2007/08 were within the ranges historically reported for inshore waters of the Great Barrier Reef. The observed seasonal changes also followed historical trends with higher concentrations of most parameters (e.g. chlorophyll *a*, suspended solids and nutrient species) measured during the wet season.

While the lagoon data exhibited no distinct spatial patterns during the wet season sampling periods, clear regional scale differences in dry season water quality characteristics between NRM regions were noted. These differences may be largely driven by regional sources and sinks of nutrients or by short term disturbances (wind-driven resuspension) during or immediately prior to the time of sampling. The current design of the lagoon water quality monitoring task based upon manual, ship-based sampling at discrete times is unsuitable to resolve the frequency and magnitude of these short-term events, which are recognised as

driving factors for the resilience of coastal coral communities. However, monitoring with autonomous instruments, which was fully implemented as a routine component of Reef Plan MMP in 2007/08, has immensely improved our capacity to measure key water quality parameters in close proximity (ca. 1 m) to corals and other benthic communities and to record short-term variability in water quality associated with flood plumes and wind-driven resuspension events.

Ambient dissolved nutrient concentrations in the GBR lagoon are inherently variable, and are often present at concentrations close to detection limits, especially during the dry season. Because dissolved nutrients are rapidly recycled through uptake and assimilation by phytoplankton, plant pigments, such as chlorophyll a, and particulate nutrients are used as proxy indicators for the quantity of nutrients circulating in the system. Draft guidelines for water quality trigger values for chlorophyll, suspended solids, particulate nutrients and Secchi depth (a proxy measure for turbidity) are now available (GBRMPA 2008). By not exceeding these trigger values biodiversity of GBR coral reef communities should be maintained. However, seasonal and annual means, averaged over all stations and three years of sampling, exceeded the GBRPMA trigger values for chlorophyll *a*, suspended solids and Secchi depth. The annual and wet season means for particulate phosphorus also exceeded the trigger value. On a regional basis, annual and seasonal means for chlorophyll were mainly exceeded in the Burdekin, Mackay/Whitsunday and Fitzroy regions, with the latter two exceeding trigger values predominantly in the wet season. The Secchi depth trigger value was exceeded at more than half the locations across all 4 regions in both dry and wet season of 2007/08. Other water quality variables exceeded trigger values only at single locations or during one season, often due to flood events. Our data suggest that high chlorophyll concentrations and high turbidity levels are the main water quality issues in the GBR. The continuous monitoring of chlorophyll and turbidity by in situ instruments will deliver important information for determining 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.

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 Great Barrier Reef lagoon between Cape Tribulation and Cairns since 1989; and was continued under Reef Plan MMP in 2007/08. For the first time, all parameters, except chlorophyll *a*, showed significant long-term patterns, generally decreasing since the early 2000s. The understanding of the causes of the observed fluctuations is incomplete and analysis of the relationship of the Cairns coastal water quality with Barron River flow patterns (the closest river influencing the sampling stations), land use data and weather data is still pending.

Twenty-four of the 35 original coral reef locations were resurveyed in 2007/08, reflecting the changes in sampling design to twelve "core reefs" with annual sampling of the coral communities including coral settlement assessments. Coral settlement tiles were deployed for the first time on three reefs in the Burdekin Region along with the continued assessment of settlement in the three other regions. The remaining "cycle reefs" will be surveyed biannually with the exception of three discontinued reefs along the Cape Tribulation coast.

The expansion of the coral settlement study to include reefs in the Burdekin region allows for a more detailed, albeit preliminary, assessment of the environmental parameters influencing coral settlement. At the scale of individual reefs, variation in sediments explained some of the variability in the number of spat settling onto terracotta tiles, however, this relationship was not strong. In 2007, the average settlement of coral spat was substantially higher on Wet Tropics reefs than in either 2005 or 2006 and also much higher than in the other regions. It is likely that this increase reflects the growth and maturation and, hence, fecundity of *Acropora* colonies in the region. Conversely, settlement in the Fitzroy NRM Region was lower than in 2006. The reason for this decline is not clear. However, a spawning delay due to very overcast conditions may have played a role in reducing settlement. The regional and reef-level availability of fertile adult corals is also important for successful larval production and subsequent settlement, a finding that has substantial ramifications as to how we might expect the process of recovery to progress after severe disturbance events.

Coral community characteristics changed little between 2006 and 2007 surveys. There were slight increases in average coral cover in most regions as would be expected given that no major disturbances impacted on survey reefs in the period between surveys. The only sub-region not showing an increase in coral cover between 2006 and 2007 was the Tully Catchment where recovery from Cyclone Larry is slow. The cover of macroalgae was substantially higher both in this region and on reefs in the Fitzroy region, as macroalgae continued to occupy space available after reductions in coral cover associated with Cyclone Larry and coral bleaching during the 2006/07 summer.

The number of juvenile coral colonies declined between 2005 and 2006 both on reefs exposed to disturbance events and on those for which no disturbance was recorded. While we do not know the reason for this decline it did not continue through to 2007 with numbers of juvenile colonies similar in 2007 to those observed in 2006.

All variables measured in the coral monitoring task (percent cover of hard corals, soft corals and macroalgae, the densities of juvenile corals, the numbers of spat settling to tiles and the numbers of genera present) varied greatly between the NRM regions and between reefs within these regions. The assessment of sediment quality at the reef locations was for the first time formally included in Reef Plan MMP, to provide additional environmental information for the interpretation of spatial patterns in coral communities. Comparing the variation in coral reef parameters with the chemical and granulometric composition of sediments collected from each reef explained some of the variation in most measures of the benthic communities. Sediment composition is largely controlled by the local hydrodynamic regime and by terrestrial inputs, and can vary over very small spatial scales. This relationship between coral communities and environmental variables suggest that frequent local monitoring of relevant environmental parameters needs to be continued, in conjunction with ongoing recording of local disturbance regimes, in order to improve our understanding of the processes shaping and or limiting inshore coral reef communities.

The assessment of benthic foraminifera assemblages was for the first time formally included in Reef Plan MMP to test their suitability as a bioindicator for water quality on a large spatial scale. The assemblage composition showed distinct regional patterns which reflected environmental conditions, and were, at least to some extent, related to water and sediment quality. Although slight changes in the community structure may have occurred over the last two years, our analysis showed that, overall, communities are stable, indicating relative stability of water quality conditions, as was suggested by the lagoon water quality sampling.

The high-frequent chlorophyll *a* and turbidity data from autonomous instruments will be essential in the future of the Reef Plan MMP, as they will serve as correlative environmental variables for analysis of spatial differences in coral reef community structure. Together with remote sensing data, the instrument data should enable the detection of long-term temporal trends in coastal water quality because of their high resolution of short-term variability that in the past has obscured long-term patterns by using low-frequent, manual sampling techniques.

1. Introduction to the Programme

The Australian Institute of Marine Science (AIMS) and the Great Barrier Reef Marine Park Authority (GBRMPA) entered into a co-investment contract on 07 January 2008 (received by AIMS on 18 January 2008) provide monitoring activities under the Reef Water Quality Protection Plan Marine Monitoring Programme (Reef Plan MMP). This agreement is referred to as the Contract in this report.

The Reef Plan MMP is grouped into two components:
- Schedule 1: Inshore Marine Water Quality Monitoring
- Schedule 2: Inshore coral reef monitoring

The AIMS Reef Plan monitoring activities in the current contract period were largely an extension of activities established under a previous arrangement from 2004 to 2007. However, significant changes to the sampling approach and design were decided by the Scientific Advisory Panel in April/May 2007, in collaboration and agreement with the current monitoring providers, including AIMS, and GBRMPA.

The key change is that the water quality and inshore reef monitoring focused on 12 'core' reefs (Figure 2.1). In particular:

- On these reefs, autonomous water quality instruments were continuously deployed and water quality sampling undertaken two times a year (three times from 2008/09);
- Annual surveys of the reef status were continued as before.
- Monitoring of coral recruitment was carried out, however, only at 5 m depth.
- Passive samplers for pesticide monitoring were deployed during the period of the mass coral spawning (ca. October to December), for later analyses by EnTox under their contract for Reef Plan MMP activities.
- Coral surveys of the 20 'non-core' sites will only be undertaken every other year. An exception to this is Snapper Island, at which annual surveys will be maintained to continue the long-term data set available for this reef.
- Two additional sites were selected for the new, more intense water quality monitoring: Snapper Island (as the one site at the northern end of the Wet Tropics NRM region and to complement ongoing annual coral surveys) and Dunk Island (because this site is regularly affected by Tully River flood waters, and the Tully NRM region has an ongoing large collaborative research effort under the Tully WQIP. Reef Plan MMP data have been regularly reported to the WQIP).

Water quality monitoring in the inshore lagoon was carried out twice in 2007-08 at 14 fixed locations in four NRM regions, the Wet Tropics, Burdekin, Mackay Whitsunday and Fitzroy regions. There are very few long-term datasets available for comparisons of the nutrient concentrations measured in the inshore lagoon under the current Reef Plan MMP monitoring. The longest time series of water quality data for the Great Barrier Reef was collected by AIMS in coastal waters between Cape Tribulation and Cairns from 1989 to the present. Sampling of these stations has been continued under Reef Plan MMP.

Surface chlorophyll concentrations in Great Barrier Reef waters have been measured since 1992 as part of a long-term monitoring program. The Reef Plan monitoring has been modified in 2006-07 to accommodate a change of sampling organisations from QPWS to tourism operators. Most sampling locations have been continued in 2007-08, but with varying degree of frequency, reliability and quality.

The coral monitoring program continued to survey the cover of benthic organisms, the numbers of genera and the number of juvenile sized coral colonies at 24 inshore reef locations in four NRM regions, the Wet Tropics, Burdekin, Mackay Whitsunday and Fitzroy regions. The coral recruitment monitoring was extended to now cover these four NRM regions.

This report provides details about the monitoring activities undertaken by AIMS as part of the Reef Plan MMP from May 2007 to April 2008.

2. Inshore Marine Water Quality Monitoring

(Schedule 1, Task 3.1)

Introduction

The biological productivity of the Great Barrier Reef 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 Reef (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 Great Barrier Reef ecosystem (Furnas *et al.* 2005).

Extensive water sampling throughout the Great Barrier Reef 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 2007). 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 Great Barrier Reef 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).

Analyses of the best available long-term time series datasets in Cairns coastal waters identified long-term net increases in suspended particulate matter and dissolved organic nutrient (N and P) concentrations (De'ath 2005; Furnas 2005, CRC Consortium 2006). No long-term changes in concentrations of dissolved inorganic nutrients (nitrate, phosphate, silicate), particulate nutrients or chlorophyll *a* have been identified (*ibid*.). Regional-scale monitoring of surface chlorophyll *a* concentrations in Great Barrier Reef 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 Great Barrier Reef, 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).

The aim of this Task is to continue long-term water quality monitoring at fixed sites in the inshore area of the GBRWHA, which were started under Reef Plan MMP in 2005. The task objectives are to:

- Determine persistent spatial patterns and, where long-term data are already available, long-term (decadal) trends in inshore water quality within the Great Barrier Reef lagoon, particularly in inshore habitats most directly affected by river runoff.
- Explore the usefulness of autonomous instruments for high-frequency measurements of local water quality at inshore reef sites.

Marine Water Quality Sampling

(Contract Attachment B Task 2.1)

METHODS

[Note: detailed documentation of methods was provided to GBRMPA in a separate report in October 2005: *Water Quality and Ecosystem Monitoring Programs - Reef Water Quality Protection Plan: Methods and Quality Assurance/Quality Control Procedures* (CRC Reef Consortium 2005)]

Sample collection, preparation and analyses

Sampling of all 14 locations specified under the Reef Plan MMP Contract was completed in both the dry season 2007 and the wet season 2007/08 (see Table 2.1 and Figure 2.1 for details). In addition, sampling was carried out along the AIMS Cairns Coastal Transect (see Figure 2.5 for a map of sampling locations), to continue the long-term time series since 1989. Dry season sampling was carried out in October 2007 (including stations of the Cairns Transect). Wet season sampling was carried out in February (sites south of Townville) and March 2008 (sites north of Townville, including stations of the Cairns Transect).

Table 2.1 Locations selected for inshore water quality monitoring. Water samples were collected at all locations during research cruises in October 2007 and February- March 2008.

NRM Region	Primary Catchment	Water quality monitoring locations	Water quality sampling	
Wet Tropics	Daintree, Barron	Snapper Island North	Oct 07	Mar 08
	Russell-Mulgrave, Johnstone	Fitzroy Island West	Oct 07	Mar 08
		High Island West	Oct 07	Mar 08
		Frankland Group West	Oct 07	Mar 08
	Tully	Dunk Island North	Oct 07	Mar 08
Burdekin	Herbert, Burdekin	Pelorus & Orpheus Is West	Oct 07	Mar 08
	Burdekin	Pandora Reef	Oct 07	Mar 08
		Geoffrey Bay	Oct 07	Mar 08
Mackay Whitsunday	Proserpine	Double Cone Island	Oct 07	Feb 08
		Daydream Island	Oct 07	Feb 08
		Pine Island	Oct 07	Feb 08
Fitzroy	Fitzroy	Barren Island	Oct 07	Feb 08
		Pelican Island	Oct 07	Feb 08
		Humpy & Halfway Island	Oct 07	Feb 08

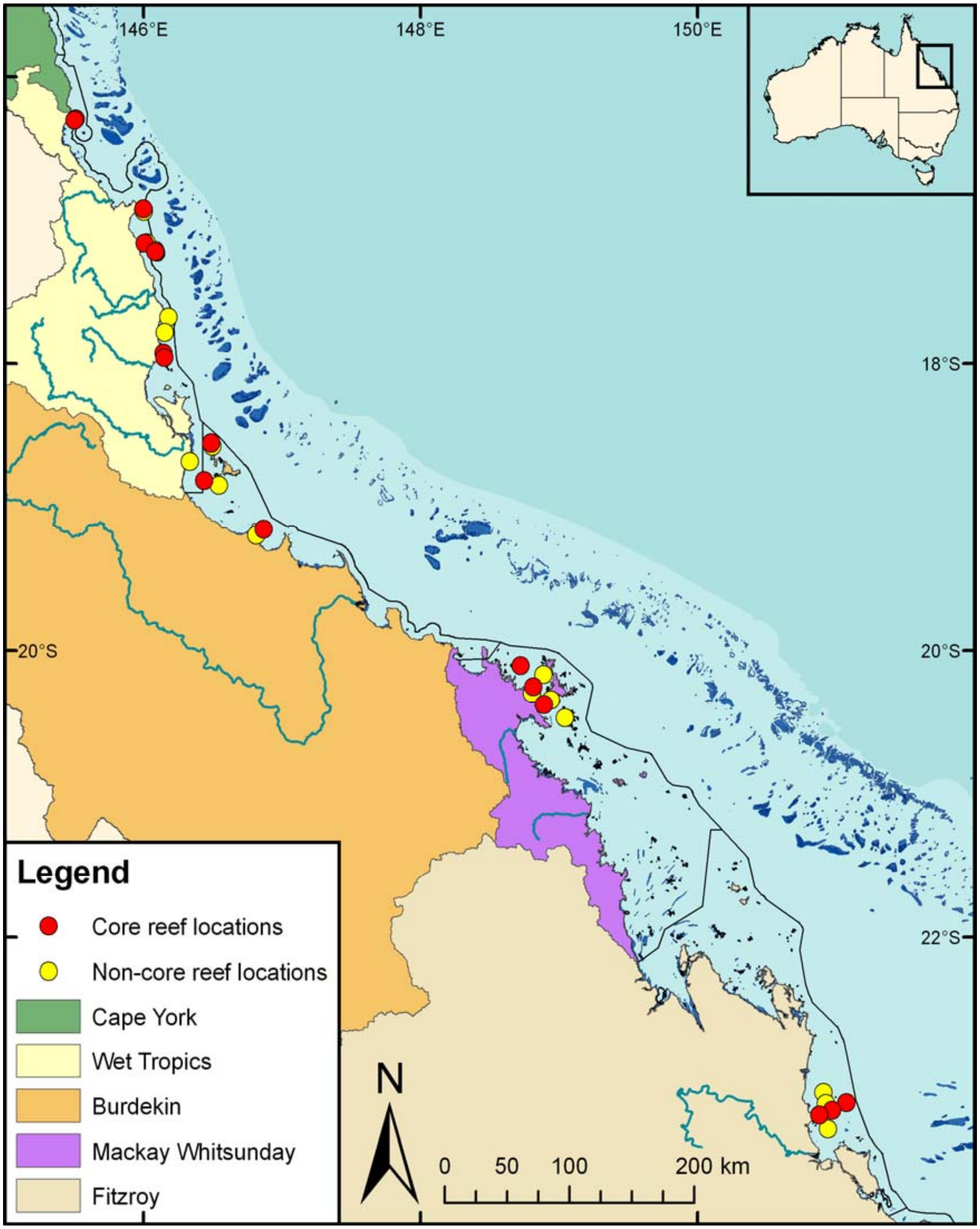


Figure 2.1 Sampling locations under the Reef Plan MMP inshore marine water quality and coral monitoring tasks. Core reef locations have annual coral reef benthos surveys, coral settlement assessments, autonomous water quality instruments (temperature, chlorophyll and turbidity) and regular water sampling. Non-core reef locations have benthos surveys every two years, no water quality assessments. Exceptions are Snapper Is (water quality instruments, regular water sampling, coral annual surveys, but no coral settlement) and Dunk Is (water quality instruments, regular water sampling, but coral surveys every other year).

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 (Treguer and LeCorre, 1975) implemented on a segmented flow analyser (Bran and Luebbe, 1997) after return to the AIMS laboratories.

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.

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.

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).

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.

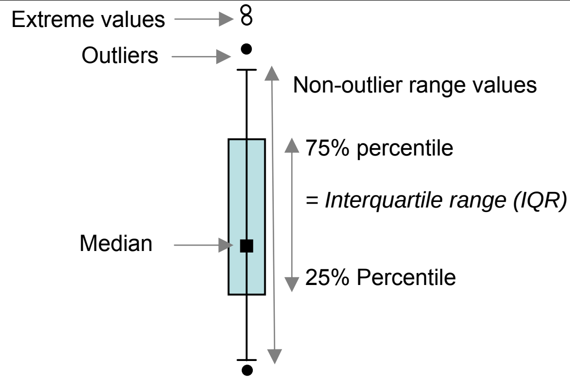
The particulate organic carbon content (POC) of material collected on filters is determined by high temperature combustion (950°C) using a Shimadzu TOC-V carbon analyser fitted with a SSM-5000A solid sample module. Filters containing sampled material are placed in pre-combusted (950°C) ceramic sample boats. After the sample inlet is purged of atmospheric CO_2, inorganic C on the filters (e.g. $CaCO_3$) is removed by addition of concentrated phosphoric acid and quantified by non-dispersive infra-red gas analysis (IRGA). After this quantification is completed, the filter is introduced into the sample oven (950°C) where the remaining organic carbon is combusted in an oxygen stream and again 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. Filters were wrapped in pre-combusted aluminium foil envelopes and stored at -18°C until analyses. 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.

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) for each of four NRM regions: the Wet Tropics, Burdekin, Mackay Whitsunday and Fitzroy NRM Regions (using the marine boundaries of each NRM region).



Template for box plots in this chapter:

- *The box contains 50% of the values = interquartile range (IQR)*
- *Outliers are defined as being >1.5 x IQR*
- *Extreme values are defined as being >3 x IQR*

For comparison, data from 2005/06 and 2006/07 for the same 14 stations are included in the report. Please note that 2005/06 and 2006/07 results reported here are slightly different to those reported earlier (CRC Reef Consortium 2006; Schaffelke *et al.* 2007) because those reports included more stations than the now selected 14 "core" stations (see Table 2.1 for station details).

Temperature, salinity, Secchi disc depth, total suspended solids, PP, PN, DOC and chlorophyll concentration from all three sampling years (2005/06, 2006/07, 2007/08) were subjected to a Principal Component Analysis (PCA) in order to classify the water column at the various sampling locations along the GBR coast (see Table 2.1 and Fig. 2.1 for locations). 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 patterns. The distributions of a number of these parameters were skewed by high, outlier, values and either a square root or fourth root transformation was used to convert distributions to normality. To place all parameters on a common scale, each variable was standardised by subtracting its mean from each value and dividing by the standard deviation. Pearson correlation coefficients were calculated between the first two PCA axes and a range of explanatory variables: i) "Nearest River": the distance from each sampling station to the nearest river mouth (in nautical miles), ii) "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}), iii) "Wind": the wind strength (in knots) at the time of sampling and iv) "Mixing Index: "an index for water column mixing ($(gT^2/\pi)*D^{-1}$, where g = 9.8 ms^{-1}, T = wave period (s), D = station depth (m)). The PCA results and correlations with nearest river, river flow, wind and water column mixing were summarised by a two-dimensional biplot.

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 – 2008. Each site was typically visited twice per year but sampling varied from none to four visits per year. 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) 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 Draft Water Quality Guideline for the Great Barrier Reef Marine Park (GBRMPA 2008) has been developed during the reporting year (based on De'ath and Fabricius 2008) is now available for public consultation. This Guideline 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 Trigger values from the GBRMPA Draft Water Quality Guideline for the Great Barrier Reef Marine Park (GBRMPA 2008).

	Water body			
Parameter	Enclosed coastal	Coastal	Inshore	Offshore
Chlorophyll (µg L^{-1})	2.0	0.32 / 0.63*	0.28 / 0.56*	0.28 / 0.56*
Secchi depth (m)	1.0 / 1.5**	10	11	17
Suspended solids (mg L^{-1})	5.0 / 15**	1.6 / 2.4*	1.4 / 2.0*	0.6 / 0.8*
Particulate nitrogen (µg L^{-1})	not available	16 / 24*	16 / 24*	13.6/20.4*
Particulate phosphorus (µg L^{-1})	not available	2.2 / 3.4*	2.0 / 3.0*	1.5 / 2.3*

*Seasonal adjustment: Summer/winter

**Geographical adjustment: Wet Tropics/Central Coast

RESULTS

Data for the most "robust" inshore water quality parameters (Secchi depth, suspended solids, particulate nitrogen and phosphorus species) are summarised for each NRM region, by year (2005/06 2006/7 and 2007/08) and season (dry and wet season) (Figures 2.2 and 2.3). Chlorophyll data are graphically presented later in the report, combined with data from the community-based monitoring. Data for all water quality parameters for 2007/08 for each sampled reef are summarised in Tables 2.3 to 2.7, grouped by NRM regions. In general, higher values were found for a number water quality parameters during the wet season 2007/08 compared with the dry season 2007, e.g. for DIN, PN, PP, DOC, POC, chlorophyll, suspended solids and Si (Tables 2.3 to 2.7). Salinity values were lower in the wet season due to river influx (Table 2.7). Higher or similar values during the dry season were measured for DON, PO_4 (DIP), DOP and Secchi depths (Tables 2.3, 2.4 and 2.7).

The water column nitrogen in the dry and wet seasons was dominated by DON, followed by PN and DIN being the smallest component. In contrast, water column phosphorus differs between season and is dominated by dissolved phosphate (DIP), with DIP> DOP> PP in the dry season and DIP> PP> DOP during the wet season. Organic carbon in the water column is also strongly dominated by dissolved forms (DOC) compared to POC.

Similar to the two previous years, the carbon-nitrogen-phosphorus (C:N:P) ratios of the particulate fraction were slightly elevated compared to the Redfield ratio (106:16:1), which is a representation of the general average molecular ratio of carbon, nitrogen and phosphorus in assumedly phytoplankton. Averaged over all 14 Reef Plan MMP locations, the C:N:P ration in the dry season was 160:17:1, in the wet season: 133:11:1. This indicates higher carbon concentrations than expected (possibly in the form of detrital particles and marine snow that are collected on the filters in addition to phytoplankton cells) and higher phosphorus availability during the wet season. C:N:P ratios of the dissolved species indicate high carbon and nitrogen concentrations compared to the Redfield ratio (averaged over all 14 stations in the dry season: 402:32:1, in the wet season: 457:22:1). However, the composition of dissolved organic mater in GBR waters is unknown and we cannot assume that the high concentrations of organic carbon and nitrogen are bio-available for plankton production. Ratios of the readily bio-available inorganic N and P species indicate that GBR waters have a very high availability of phosphate (DIP); DIN to DIP ratios were ~1:1 in the dry season and 4:1 in the wet season, compared to the 16:1 Redfield ratio.

The 2008 wet season yielded at or above average flows for a number of Reef Plan priority rivers (Barron, Burdekin, Pioneer, Fitzroy were above long-term average; Normanby, Tully, Herbert were close to average). Low salinity and high silicate values indicate the influence of river water at the sampling locations. The Fitzroy and Pioneer rivers had distinct flood peaks at the time the wet season inshore water quality sampling was carried out at these locations. A number of variables showed strong signals of flood plume influence (low salinity values and high values of Si, suspended solids, chlorophyll, DOC, POC, PP, PN and DIN; Tables 2.3 to 2.7). The sampling of locations north of Townsville occurred end of March 2008, 2-3 weeks after the last peak of the wet season flows of the northern rivers, but inshore waters still showed distinct signals of flood plume influence (as above for southern rivers).

We compared the seasonal average values for each sampling location which trigger values set in the GBRMPA Draft Water Quality Guideline for the Great Barrier Reef Marine Park (GBRMPA 2008). Levels for PN were rarely exceeded (two locations where the dry season value was just exceeded, and Pelican Island, the location closest to the Fitzroy River mouth, which was sampled twice during and after the Fitzroy flood; Table 2.4). The dry season trigger value for PP was exceeded at Dunk Island, and wet season values were exceeded by all wet season samples from the Fitzroy region and at Pine Island, the location closest to the Pioneer River mouth in the Mackay Whitsunday Region (Table 2.5). Chlorophyll dry season trigger values were exceeded at six out of 14 locations, one or two in each region, while wet season values were exceeded at two Mackay Whitsunday and all Fitzroy Region locations (Table 2.6). A closer inspection of chlorophyll trigger value exceedances is presented in the section about automated water quality loggers (below). While Secchi depth trigger values are often not met (Secchi depth values that do not meet the Guideline are lower than the trigger value, due to the nature of the parameter). Suspended solids trigger levels were only exceeded at Pine Island (Fitzroy Region) during and after the Fitzroy flood (Table 2.7).

Concentrations of most water quality parameters varied between the three sampling years within each of the four regions and for overall GBR averages. A summary of total GBR averages for the Reef Plan MMP inshore sampling locations over three years and comparative data are presented in Table 2.8. Mean values over the three samplings years of chlorophyll, suspended solids and Secchi depth were higher (lower for Secchi depth) than comparative long-term, large-scale GBR coastal zone values. Seasonal and annual means of these parameters and wet season and annual means of particulate phosphorus also exceeded the GBRMPA Draft Water Quality Guideline values (GBRMPA 2008). Only particulate nitrogen was lower than the comparative values as well as below the Guideline value.

Water column profiles of salinity, temperature and turbidity (as optical backscatter) were obtained at all sampling stations as additional information about the actual physical conditions during sampling, to aid interpretation of the measured values in the discrete-depth water samples (e.g., re-suspension due to strong winds, surface flood waters). Representative profiles for a pair of stations per region and season, representing different settings or conditions (generally one close to the nearest river mouth or coast, one further away from the coast), are shown in Figures A1-2.1 to AI-2.4 (Appendix 1). All dry season depth-profiles show a generally well-mixed water column, with the exception of chlorophyll fluorescence which slightly increases with depth. An exception is Double Cone Island in the Mackay Whitsunday NRM Region, which shows a thermocline in both seasons. In the wet season, the Wet Tropics stations show reduced surface salinity values (sampling occurred about 2 weeks after the last flood peak of the Wet Tropics rivers) and chlorophyll and turbidity readings that increased with depth (Figure A1-2.1). Wet season profiles in the Burdekin region were well-mixed with slightly reduced salinity and low turbidity (sampling occurred about 4 weeks after the last flood peak of the Burdekin River), while chlorophyll fluorescence increased with depth (Figure A1-2.2). The same applies to the wet season profiles of the two Mackay Whitsunday stations even though these were samples at the second major flood peak of the Pioneer River; the chlorophyll fluorescence was variable throughout the profiles (Figure A1-2.3). The two stations in the Fitzroy Region showed the clearest flood signature, they were sampled during the second major flood peak of the Fitzroy River. Surface salinity was much reduced (to 18 PSU at Pelican Island, 33 PSU at Barron Island), surface turbidity is very high at Pelican Island (which was inundated by the flood plume) and chlorophyll values are high and variable throughout the profile (Figure A1-2.4).

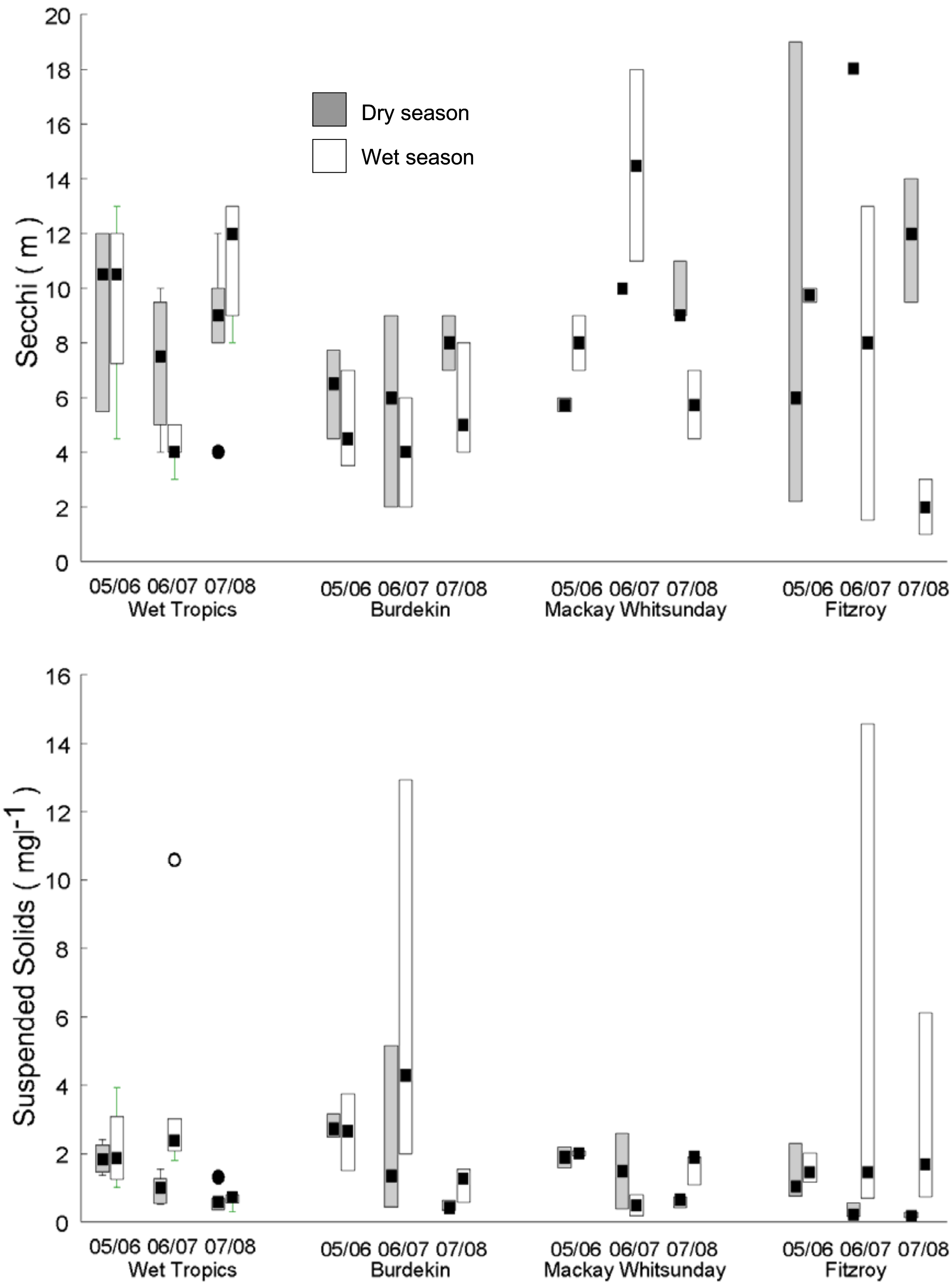
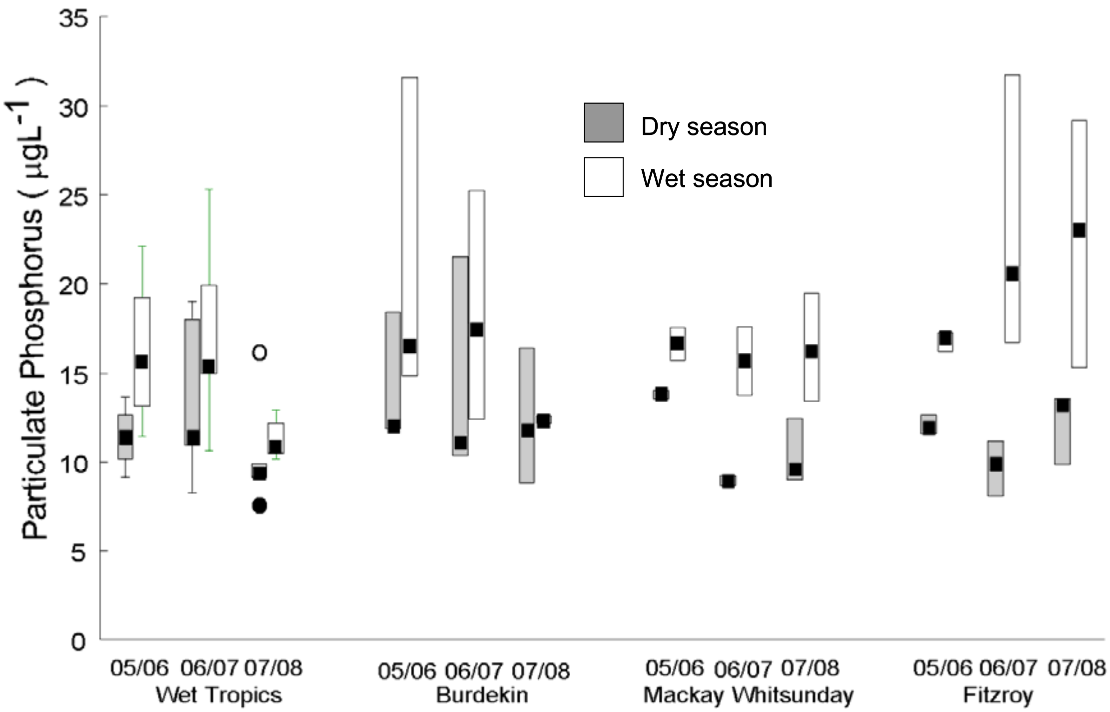


Figure 2.2 Summary of Secchi depth (m) and suspended solids concentrations (mg L-1) for the Wet Tropics, Burdekin, Mackay Whitsunday and Fitzroy NRM regions for the sampling period May 2005 to April 2006 (05/06), May 2006 to April 2007 (06/07) and May 2007 to April 2008 (07/08). Dry season (May- Oct)= shaded boxes, wet season (Nov-Apr)= white boxes. See page 12 for more details about the box plot presentation.



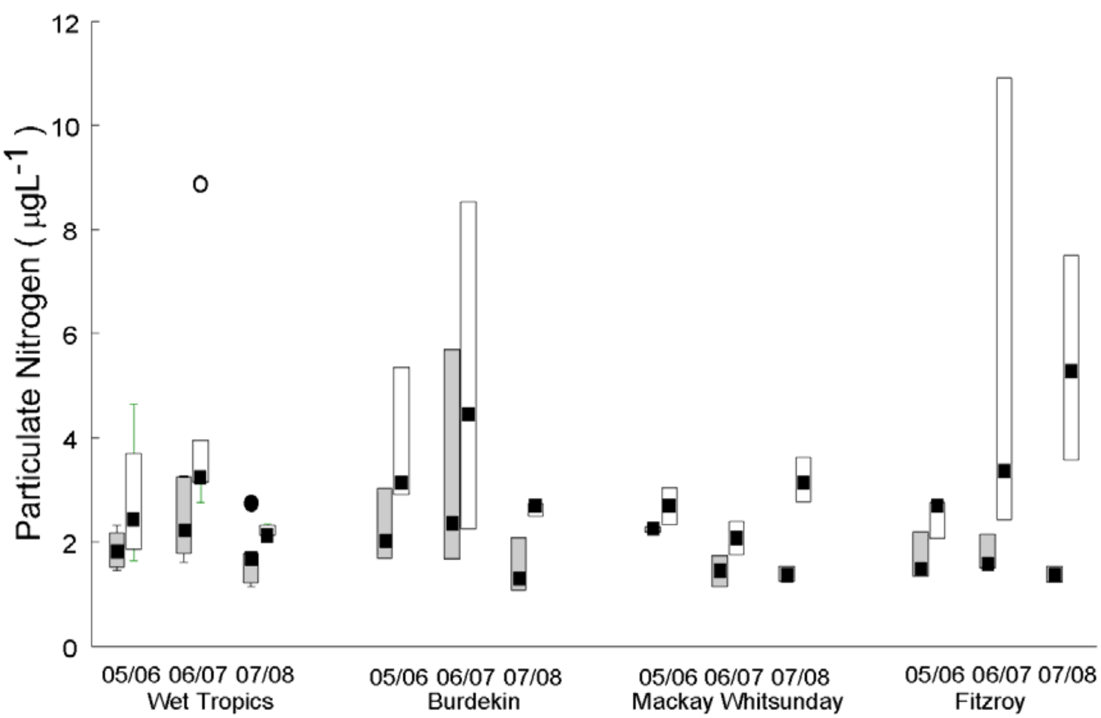


Figure 2.3 Summary of concentrations of particulate phosphorus and nitrogen (µg L-1) for the Wet Tropics, Burdekin, Mackay Whitsunday and Fitzroy NRM regions for the sampling period May 2005 to April 2006 (05/06), May 2006 to April 2007 (06/07) and May 2007 to April 2008 (07/08). Dry season (May- Oct)= shaded boxes, wet season (Nov-Apr)= white boxes. See page 12 for more details about the box plot presentation.

Table 2.3 Depth-weighted average values for **dissolved inorganic nitrogen** species (µg L^{-1}) for wet and dry seasons from May 2007 to April 2008. The GBRMPA Draft Water Quality Guideline for the Great Barrier Reef Marine Park (GBRMPA 2008) has no trigger values set for dissolved inorganic nitrogen species.

NRM Region	Location	Dry season 2007					Wet season 2007/08				
		Date	NH_4	NO_2	NO_3	DIN	Date	NH_4	NO_2	NO_3	DIN
Wet Tropics	Snapper Island*	14/10/2007	0.619	0.139	2.373	3.131	30/03/2008	0.924	0.203	0.977	2.103
	Fitzroy Island*	12/10/2007	0.517	0.000	0.490	1.007	27/03/2008	0.465	0.000	0.651	1.117
	High Island*	11/10/2007	0.518	0.018	0.112	0.649	27/03/2008	1.300	0.000	2.682	3.982
	Russell Island**	10/10/2007	0.376	0.024	0.408	0.808	27/03/2008	1.697	0.000	0.776	2.473
	Dunk Island*	17/10/2007	0.474	0.000	0.000	0.474	26/03/2008	0.225	0.000	0.207	0.432
Burdekin	Pelorus/Orpheus Island**	09/10/2007	0.671	0.000	0.228	0.900	25/03/2008	0.945	0.000	0.114	1.059
	Pandora Reef**	09/10/2007	0.279	0.000	0.686	0.964	25/03/2008	1.070	0.058	1.267	2.395
	Geoffrey Bay*	07/10/2007	0.052	0.000	0.121	0.174	24/03/2008	0.365	0.000	2.001	2.366
Mackay Whitsunday	Double Cone Island*	06/10/2007	0.752	0.000	0.279	1.031	15/02/2008	1.042	0.093	0.816	1.952
	Daydream/West Molle Island*	06/10/2007	0.986	0.000	0.075	1.061	15/02/2008	4.072	0.634	1.750	6.455
	Pine Island*	05/10/2007	0.232	0.029	0.260	0.521	15/02/2008	2.118	0.468	1.306	3.892
Fitzroy	Barren Island**	03/10/2007	0.579	0.000	0.843	1.422	25/02/2008	1.866	0.234	0.746	2.846
	Humpy Island*	03/10/2007	0.022	0.000	0.130	0.152	25/02/2008	1.710	0.358	0.000	2.069
	Pelican Island*	04/10/2007	0.499	0.000	0.689	1.189	25/02/2008	1.995	2.161	7.593	11.749
	Pelican Island*						03/04/2008	0.582	0.000	1.483	2.065

*station in coastal zone, **station in inshore zone, as defined in GBRMPA (2008)

Table 2.4 Depth-weighted average values for **total dissolved nitrogen**, **dissolved organic nitrogen** and **particulate nitrogen** (µg L^{-1}) for wet and dry seasons from May 2007 to April 2008. Shading indicates seasonal mean values that exceeded the relevant trigger values from the GBRMPA Draft Water Quality Guideline for the Great Barrier Reef Marine Park (GBRMPA 2008). See p. 13 for an overview of the trigger values. There are no trigger values set for TDN and DON.

NRM Region	Location	Dry season 2007				Wet season 2007/08			
		Date	TDN	DON	PN	Date	TDN	DON	PN
Wet Tropics	Snapper Island*	14/10/2007	68.660	65.529	7.573	30/03/2008	46.935	44.832	10.854
	Fitzroy Island*	12/10/2007	54.106	53.099	9.134	27/03/2008	41.796	40.679	10.158
	High Island*	11/10/2007	53.308	52.660	9.365	27/03/2008	45.264	41.282	12.943
	Russell Island**	10/10/2007	57.679	56.872	9.884	27/03/2008	45.288	42.815	10.503
	Dunk Island*	17/10/2007	61.848	61.374	16.176	26/03/2008	63.314	62.881	12.183
Burdekin	Pelorus/Orpheus Island**	09/10/2007	68.370	67.470	8.826	25/03/2008	30.316	29.257	12.261
	Pandora Reef**	09/10/2007	64.313	63.349	11.796	25/03/2008	33.940	31.544	12.210
	Geoffrey Bay*	07/10/2007	68.248	68.074	16.405	24/03/2008	40.184	37.818	12.603
Mackay Whitsunday	Double Cone Island*	06/10/2007	61.879	60.847	12.476	15/02/2008	35.008	33.057	13.401
	Daydream/West Molle Island*	06/10/2007	66.195	65.134	9.596	15/02/2008	41.791	35.335	16.211
	Pine Island*	05/10/2007	60.412	59.891	8.982	15/02/2008	44.298	40.406	19.454
Fitzroy	Barren Island**	03/10/2007	65.054	63.632	13.171	25/02/2008	68.295	65.449	15.317
	Humpy Island*	03/10/2007	64.470	64.318	13.567	25/02/2008	91.959	89.891	23.044
	Pelican Island*	04/10/2007	67.017	65.828	9.874	25/02/2008	172.951	161.203	36.466
	Pelican Island*					03/04/2008	64.766	62.701	21.609

*station in coastal zone, **station in inshore zone, as defined in GBRMPA (2008)

Table 2.5 Depth-weighted average values for dissolved inorganic phosphorus (PO_4), total dissolved phosphorus (TDP), dissolved organic phosphorus (DOP) and particulate phosphorus (PP), all in µg L^{-1}, for wet and dry seasons from May 2007 to April 2008. Shading indicates seasonal mean values that exceeded the relevant trigger values from the GBRMPA Draft Water Quality Guideline for the Great Barrier Reef Marine Park (GBRMPA 2008). See p. 13 for an overview of the trigger values. There are no trigger values set for PO_4, TDP and DOP.

NRM Region	Location	Dry season 2007					Wet season 2007/08				
		Date	PO_4	TDP	DOP	PP	Date	PO_4	TDP	DOP	PP
Wet Tropics	Snapper Island*	14/10/2007	3.479	4.736	1.610	1.140	30/03/2008	1.777	4.249	2.472	1.992
	Fitzroy Island*	12/10/2007	2.985	3.036	0.088	1.692	27/03/2008	0.442	4.198	3.756	2.127
	High Island*	11/10/2007	2.884	5.285	2.611	1.781	27/03/2008	1.303	3.833	2.530	2.320
	Russell Island**	10/10/2007	3.030	2.508	0.000	1.226	27/03/2008	1.390	4.361	2.971	2.134
	Dunk Island*	17/10/2007	2.748	6.715	3.967	2.749	26/03/2008	0.702	5.838	5.136	2.342
Burdekin	Pelorus/Orpheus Island**	09/10/2007	3.230	5.089	1.859	1.079	25/03/2008	0.306	4.768	4.462	2.482
	Pandora Reef**	09/10/2007	3.293	3.336	0.156	1.302	25/03/2008	1.778	5.225	3.447	2.688
	Geoffrey Bay*	07/10/2007	2.544	2.892	0.348	2.079	24/03/2008	2.798	5.785	2.987	2.736
Mackay Whitsunday	Double Cone Island*	06/10/2007	3.589	5.727	2.239	1.251	15/02/2008	0.487	2.631	2.143	2.770
	Daydream/West Molle Island*	06/10/2007	4.013	5.566	1.625	1.362	15/02/2008	2.448	3.189	0.772	3.121
	Pine Island*	05/10/2007	3.987	5.238	1.250	1.535	15/02/2008	2.668	3.429	0.847	3.621
Fitzroy	Barren Island**	03/10/2007	3.732	6.977	3.245	1.235	25/02/2008	4.467	5.173	0.864	3.576
	Humpy Island*	03/10/2007	2.675	4.103	1.428	1.532	25/02/2008	7.881	9.792	1.911	5.276
	Pelican Island*	04/10/2007	2.560	6.256	3.696	1.365	25/02/2008	31.153	33.526	2.372	10.670
	Pelican Island*						03/04/2008	1.621	7.600	5.979	4.074

*station in coastal zone, **station in inshore zone, as defined in GBRMPA (2008)

Table 2.6 Depth-weighted average values for dissolved organic carbon (DOC), particulate organic carbon (POC), chlorophyll and phaeophytin, all in µg L^{-1}, for wet and dry seasons from May 2007 to April 2008. Shading indicates seasonal mean values that exceeded the relevant trigger values from the GBRMPA Draft Water Quality Guideline for the Great Barrier Reef Marine Park (GBRMPA 2008). See p. 13 for an overview of the trigger values. There are no trigger values set for DOC and POC.

NRM Region	Location	Dry season 2007					Wet season 2007/08				
		Date	DOC	POC	Chlorophyll	Phaeophytin	Date	DOC	POC	Chlorophyll	Phaeophytin
Wet Tropics	Snapper Island*	14/10/2007	548.821	53.771	0.135	0.250	30/03/2008	824.685	65.305	0.299	0.178
	Fitzroy Island*	12/10/2007	588.393	78.360	0.260	0.139	27/03/2008	810.602	94.005	0.296	0.139
	High Island*	11/10/2007	628.302	79.606	0.324	0.170	27/03/2008	829.792	82.428	0.465	0.218
	Russell Island**	10/10/2007	637.243	56.012	0.191	0.104	27/03/2008	764.930	73.726	0.324	0.157
	Dunk Island*	17/10/2007	649.518	143.215	0.428	0.233	26/03/2008	892.338	77.747	0.420	0.190
Burdekin	Pelorus/Orpheus Island**	09/10/2007	645.587	59.207	0.192	0.104	25/03/2008	716.485	96.056	0.464	0.210
	Pandora Reef**	09/10/2007	709.569	80.891	0.248	0.109	25/03/2008	762.176	90.797	0.371	0.218
	Geoffrey Bay*	07/10/2007	942.014	137.274	0.930	0.309	24/03/2008	741.663	282.459	0.466	0.229
Mackay Whitsunday	Double Cone Island*	06/10/2007	634.776	96.352	0.439	0.214	15/02/2008	740.241	116.897	0.372	0.232
	Daydream/West Molle Island*	06/10/2007	636.497	89.550	0.269	0.181	15/02/2008	739.442	116.598	0.732	0.484
	Pine Island*	05/10/2007	639.946	90.710	0.407	0.312	15/02/2008	783.833	324.455	0.806	0.593
Fitzroy	Barren Island**	03/10/2007	656.746	139.619	0.268	0.125	25/02/2008	955.238	375.758	0.773	0.397
	Humpy Island*	03/10/2007	723.572	127.981	0.451	0.193	25/02/2008	1207.314	292.084	1.701	0.870
	Pelican Island*	04/10/2007	723.995	72.534	0.227	0.096	25/02/2008	2327.520	380.885	2.977	1.373
	Pelican Island*						03/04/2008	967.648	115.351	0.510	0.373

*station in coastal zone, **station in inshore zone, as defined in GBRMPA (2008)

Table 2.7 Depth-weighted average values for **Secchi depth** (m), concentrations of **total suspended solids** (SS, in mg L-1) and **silicate** (Si, in ugL-1) and **salinity** (PSU) for wet and dry seasons from May 2007 to April 2008. Shading indicates seasonal mean values that exceeded the relevant trigger values from the GBRMPA Draft Water Quality Guideline for the Great Barrier Reef Marine Park (GBRMPA 2008). See p. 13 for an overview of the trigger values. There are no trigger values set for Si and salinity.

NRM Region	Location	Dry season 2007					Wet season 2007/08				
		Date	Secchi	SS	Si	Salinity	Date	Secchi	SS	Si	Salinity
Wet Tropics	Snapper Island*	14/10/2007	10	0.356	58.001	35.22	30/03/2008	8	0.792	221.873	32.57
	Fitzroy Island*	12/10/2007	8	0.605	71.053	35.25	27/03/2008	13	0.295	233.735	32.96
	High Island*	11/10/2007	9	0.687	79.418	35.28	27/03/2008	12	0.566	328.648	32.03
	Russell Island**	10/10/2007	12	0.365	69.027	35.27	27/03/2008	13	0.737	227.174	33.21
	Dunk Island*	17/10/2007	4	1.312	94.581	35.21	26/03/2008	9	0.808	479.788	31.28
Burdekin	Pelorus/Orpheus Island**	09/10/2007	nd	0.347	65.818	35.27	25/03/2008	8	0.573	108.823	34.14
	Pandora Reef**	09/10/2007	9	0.431	98.406	35.37	25/03/2008	4	1.273	152.758	33.42
	Geoffrey Bay*	07/10/2007	7	0.633	98.206	36.96	24/03/2008	5	1.530	251.202	32.97
Mackay Whitsunday	Double Cone Island*	06/10/2007	11	0.425	56.058	35.30	15/02/2008	7	0.662	69.118	34.34
	Daydream/West Molle Island*	06/10/2007	9	0.659	88.576	35.48	15/02/2008	4.5	1.891	86.184	34.75
	Pine Island*	05/10/2007	9	0.734	51.166	35.49	15/02/2008	nd	1.905	172.178	34.28
Fitzroy	Barren Island**	03/10/2007	14	0.124	44.511	35.94	25/02/2008	nd	0.733	164.016	33.45
	Humpy Island*	03/10/2007	9.5	0.181	47.683	35.78	25/02/2008	3	1.701	350.330	31.67
	Pelican Island*	04/10/2007	12	0.273	68.773	35.65	25/02/2008	1	6.438	1848.195	22.43
	Pelican Island*						03/04/2008		3.733	122.908	

*station in coastal zone, **station in inshore zone, as defined in GBRMPA (2008)
nd= no data (current too strong to accurately measure Secchi depth)

Table 2.8 Seasonal and annual mean values for concentrations of nutrient species and chlorophyll (µg L^{-1}), total suspended solids (SS, in mg L^{-1}) and Secchi depth (m) averaged over all near-reef locations and three sampling years under Reef Plan MMP. [1]For comparison, annual means are listed which are based on a large dataset of GBR water quality spanning ~20 years (De'ath and Fabricius 2008; annual means for the GBR coastal zone). Shading indicates mean values that exceeded the relevant trigger values from the GBRMPA Draft Water Quality Guideline for the Great Barrier Reef Marine Park (GBRMPA 2008). See p. 13 for an overview of the trigger values.

	Dry season				Wet season					
	2005/06	2006/07	2007/08	Dry Season Mean	2005/06	2006/07	2007/08	Wet Season Mean	*Annual Mean*	GBR Mean[1] for comparison
DIN (µg L^{-1})	1.05	0.90	0.96	0.97	2.27	6.74	3.13	4.05	*2.51*	
DON (µg L^{-1})	62.23	90.31	62.01	71.51	84.16	88.87	54.61	75.88	*73.70*	
TDN (µg L^{-1})	62.30	91.15	62.97	72.14	86.98	95.46	57.74	80.06	*76.10*	
PN (µg L^{-1})	13.06	13.31	11.20	12.53	17.90	18.25	15.95	17.37	*14.95*	22.82
DIP (µg L^{-1})	3.11	3.42	3.20	3.24	1.41	3.44	4.08	2.98	*3.11*	
DOP (µg L^{-1})	20.51*	2.32	1.72	2.02	6.60	2.47	2.84	3.97	*3.19*	
TDP (µg L^{-1})	23.62*	5.70	4.82	5.26	7.87	5.91	6.91	6.90	*6.24*	
PP (µg L^{-1})	2.15	2.60	1.52	2.09	3.03	4.44	3.46	3.64	*2.87*	2.51
Silicate (µg L^{-1})	93.70	84.23	70.81	82.91	90.65	163.92	321.13	191.90	*137.40*	
DOC (µg L^{-1})	640.91	672.27	668.93	660.70	722.11	820.85	937.594	826.85	*743.78*	
POC (µg L^{-1})	126.66	139.82	93.22	119.90	159.89	303.50	172.30	211.90	*165.90*	
Chlorophyll (µg L^{-1})	0.34	0.33	0.34	0.34	0.66	0.82	0.73	0.74	*0.54*	0.40
SS (mg L^{-1})	2.37	2.11	0.51	1.66	2.23	4.49	3.73	3.48	*2.57*	1.70
Secchi (m)	7.4	7.1	9.5	8.0	7.4	5.0	7.3	6.56	*7.3*	11.4

*outlier values (unexplained reason), not included in seasonal and annual means.

The Principal Component Analysis on the physical, biological and chemical variables measured at the fixed water quality locations along the GBR in 2005/06, 2006/07 and 2007/08 separated sampling stations by wet and dry season (Figure 2.4). Samples collected at coastal sites during the wet season varied little, the major flood event in the Fitzroy Region changed the relationship between the regions only slightly to the one found in 2006/07. The results from the dry season sampling showed some geographic separation between NRM Regions. Sampling locations in the Burdekin region continue to be characterised by elevated values of chlorophyll, total suspended solids, PP and PN. The co-linearity between total suspended solids and index of water column mixing (Figure 2.4) suggests that elevated SS values were most likely due to re-suspension of lagoon floor sediments by the prevailing SE trade winds which blow strongest during the dry season (April to August). River flow was most important during the wet season, and was responsible for a drop in salinity at coastal sites and was co-linear with dissolved organic carbon concentrations (DOC). Distance to the nearest river mouth was not correlated with either PCA axis.

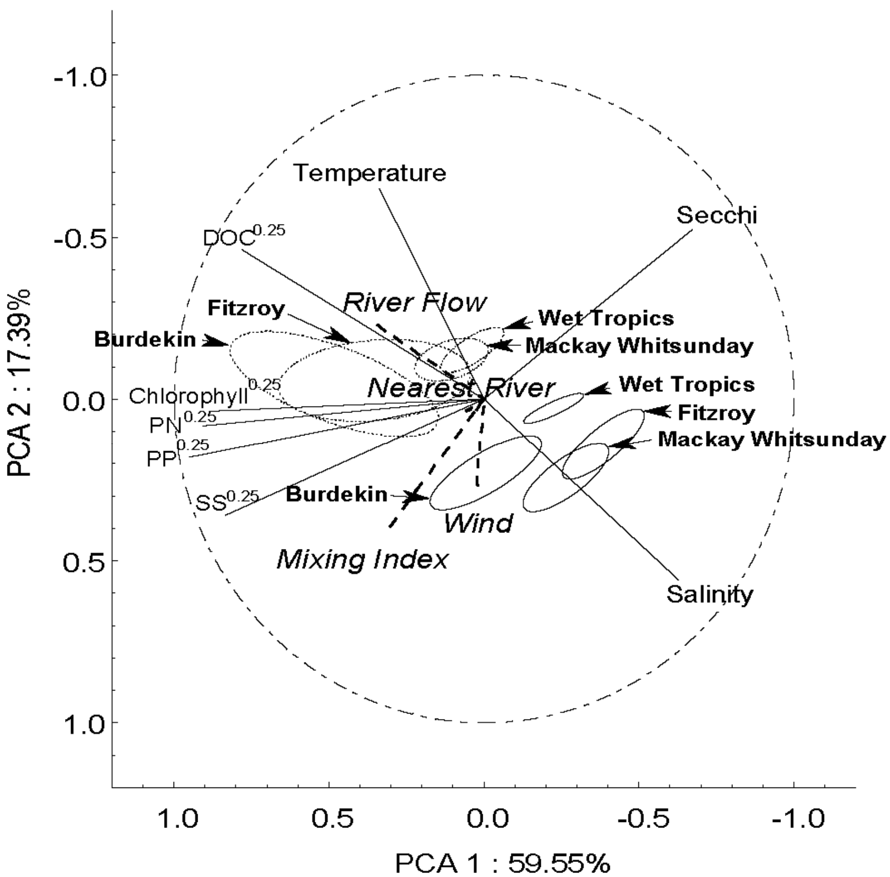


Figure 2.4 Bi plot of results from principal component analysis on water-quality parameters measured at various sites along the GBR coast between May 2005 and April 2007. Ellipses encompass 95% confident regions for the bivariate mean of coastal stations sampled in each NRM region. Dashed ellipses represent wet season sampling (November to April) and solid ellipses dry season sampling (May to October). Unit circle denotes the range of the Pearson correlation coefficient.

The long-term time series of water quality parameters sampled since 1989 along the 'AIMS Cairns Coastal Transect' (Figure 2.5 for sampling locations) was continued and all data were reanalysed. All parameters, except chlorophyll *a*, showed significant long-term patterns (Figure 2.6, Table 2.9). Long-term trends were non-linear with the exception of particulate phosphorus (PP), which showed a linear trend of declining values over time. Dissolved organic nitrogen (DON) and dissolved organic phosphorus (DOP) increased in the mid to late1990s, peaked around 2003 and then declined. Suspended solids (SS) 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. In addition to the long-term trends, some variables had recurring seasonal trends (Table 2.9, 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.

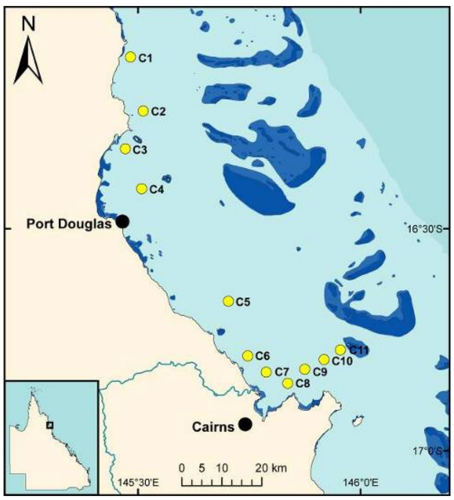


Figure 2.5 Locations of coastal stations in the Cairns region that have been repeatedly sampled by the Australian Institute of Marine Science from 1989-2008.

Table 2.9 Analyses of variance assessing the significance of trends over time, by years and months.

Response Variable	Source	df	F	Pr (>F)	Deviance Explained %
DON	Years	5	4.099	0.004	46.3
	Months	3	1.913	0.136	
	Residuals	37			
DOP	Years	4	7.5	<0.001	54
	Months	3	1.715	0.173	
	Residuals	38			
PN	Years	5	5.584	<0.001	57.5
	Months	3	1.943	0.132	
	Residuals	37			
PP	Years	1	4.421	0.028	24.5
	Months	3	1.357	0.268	
	Residuals	40			
SS	Years	2	5.026	0.008	46.8
	Months	3	3.719	0.016	
	Residuals	35			
Chl	Years	5	1.986	0.098	45.3
	Months	3	4.134	0.009	
	Residuals	37			

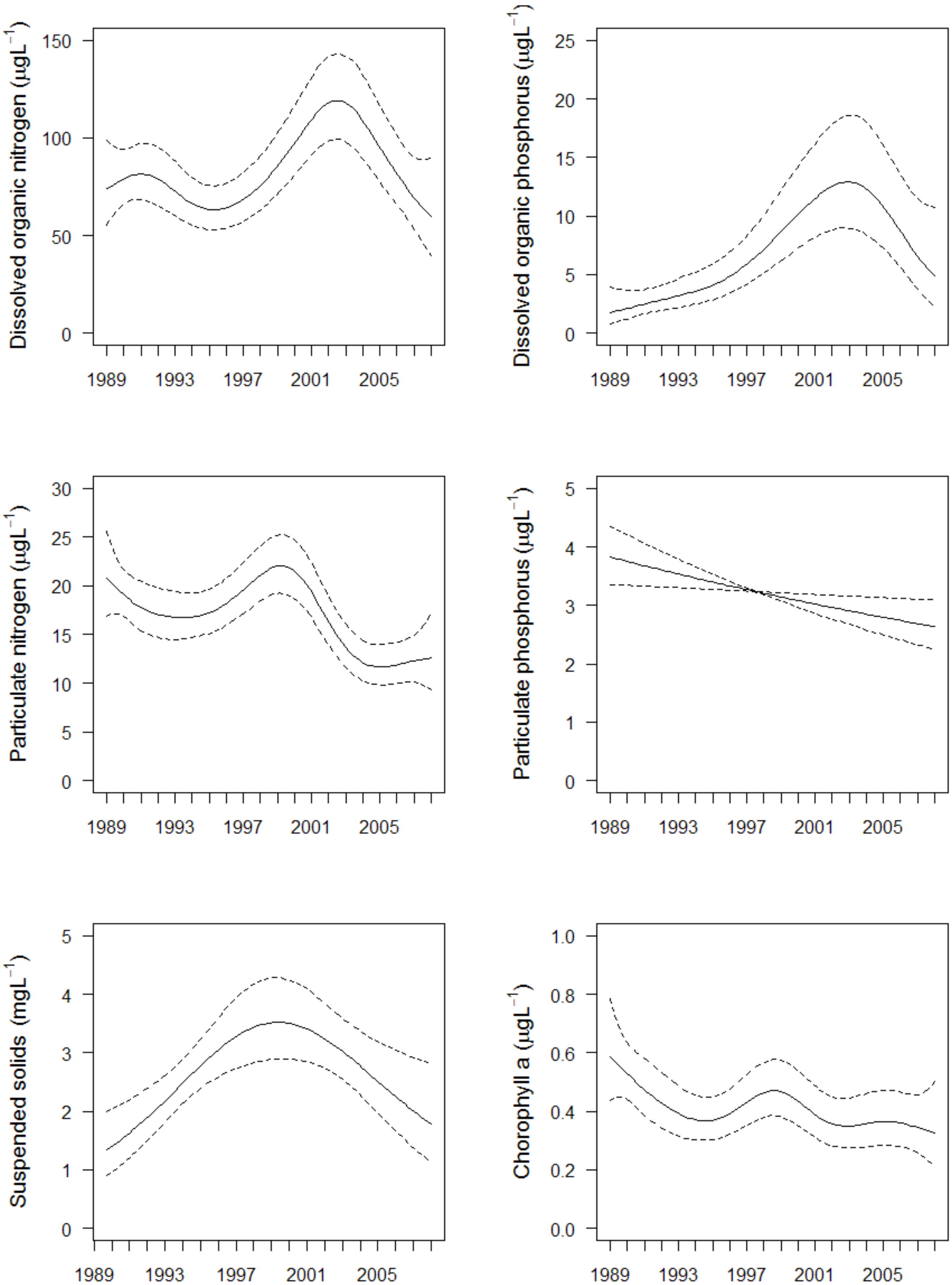


Figure 2.6 Smooth trends over sampling years from 1989 to2008 (partial effects) for the water quality parameters dissolved organic nitrogen (µg L^{-1}), dissolved organic phosphorus (µg L^{-1}), particulate nitrogen (µg L^{-1}), particulate phosphorus (µg L^{-1}), suspended solids (mg L^{-1}) and chlorophyll a (µg L^{-1}).

Coastal and Lagoon Chlorophyll *a* Concentrations

(Schedule 1, Tasks 3.3, 3.4)

METHODS

[Note: detailed documentation of methods was provided to GBRMPA in a separate report in October 2005: *Water Quality and Ecosystem Monitoring Programs - Reef Water Quality Protection Plan: Methods and Quality Assurance/Quality Control Procedures*. (CRC Reef Consortium 2005)]

Community sampling network

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 were established, commencing in July 2006 (Table 2.10). In 2005/06, community and other interest groups were engaged to carry out collection and initial preparation of water samples at selected coastal locations, in collaboration with GBRMPA (see Table 2.11 for details). Sampling of the transect and coastal stations established in 2006 has continued at most of the sites during 2007/08, however at a number of sites very irregularly (see Tables 2.10, 2.11 and Results section for details).

In 2007/08 GBRMPA had a stronger role in communicating and liaising with the sampler organisations (tourism operators and community groups), including arranging training sessions, and also had responsibility for transporting samples to AIMS through the Community Partnerships Program. AIMS contributed to the technical aspects of the program, as required, including provision of updated manuals, sampling kits and training sessions.

Sample collection, preparation and analyses

A surface water sample is supposed to be collected at each site every month. Replicate samples are to be collected every 3 months, for quality control purposes. Each sample is subsampled and filtered onto 2 replicate GF/F filters and stored at -18°C until analysis (refer to methods for Marine Water Quality methods, 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*, and information about the weather, wind and tides, and, at the transect sites also Secchi depth and water depth (depth sounder).

Table 2.10 Details of the Long-term chlorophyll monitoring: cross-shelf network sampling in 2007/08. *denotes transect in addition to Contract requirements.

NRM Region	Transect name	No of sites	Sampler	Sampling details
Cape York	Cooktown-Osprey	5	Undersea Explorer	Continued monthly sampling at most sites, samples only received and analysed to October 2007.
	Port Douglas	7	Undersea Explorer	Continued monthly sampling at most sites, samples only received and analysed to September 2007.
Wet Tropics	Wet Tropics	3	Fitzroy Island resort	Continued monthly sampling since January 2007 of the Fitzroy Island site. Sampling of offshore sites only once each (Apr 07, Oct 07). All Dec 07 -Mar 08 samples defrosted during transfer to AIMS and not analysed.
Burdekin	Townsville*	2	Sunferries	Only one sample this year (May 07), sampling on hold for operational reasons, recommenced in May 08.
Mackay Whitsunday	Whitsunday	3	FantaSea	Regular monthly sampling recommenced in May 2007, samples analysed including April 2008. Change of offshore site from Hardy to Line Reef
Fitzroy	Keppel Bay	1	Freedom Fast Cats	Operator discontinued sampling in early 2007.

Table 2.11 Details of the coastal chlorophyll monitoring carried out by community groups in 2007/08.

NRM Region	Location	Community Group	Sampling details
Cape York	Cooktown	Cook Shire Council	Discontinued in Apr 07, sampling staff left, GBRMPA to contact Council re continuation.
Wet Tropics	Port Douglas	Undersea Explorer	Continued as part of Port-Douglas transect (Table 2.10).
	Mission Beach, Clump Point	FNQ NRM	Discontinued in Apr 07, GBRMPA to contact sampler re continuation.
	Dunk Island*	Dunk Island Resort	Discontinued in Mar 07, GBRMPA to contact sampler re continuation.
Burdekin	Magnetic island	GBRMPA	GBRMPA assumed responsibility for sampling in May 2007 due to proximity to passive sampler maintained by GBRMPA; no samples for Oct, Nov and Dec 2007, samples received and analysed to Mar 08.
Mackay Whitsunday	Shute Harbour	MWHW	Regular monthly sampling, analysis complete to Apr 08.
	Mackay Marina	MWHW	Regular monthly sampling, analysis complete to Apr 08.
Fitzroy	Rosslyn Bay	Cap Reef	Regular monthly sampling, samples only received and analysed to December 2007.
	Gladstone, Tannum-Boyne coast (6 sites)	Tannum Sands Coastcare	Regular monthly sampling, samples only received and analysed to January 2007.
Burnett Mary	Burnett coast (5 sites)	Woongarra Marine Park Monitoring & Education Project	Regular monthly sampling, analysis complete to Apr 08.
	Hervey Bay	Queensland Sea Scallops	Monthly sampling from April 2007, samples only received and analysed to December 2007.

Data analyses

To present the spatial patterns of chlorophyll concentrations in Great Barrier Reef waters we aggregated the data from the transect and coastal monitoring and the biannual lagoon water sampling stations over the sampling periods in 2005/06, 2006/07 and 2007/08 for each NRM region. Data were averaged over replicates and duplicates and presented as regional medians and quartile ranges. In Appendix 1, medians, means and standard deviations for each sampling location are tabulated and compared to the GBRMPA Draft Water Quality Guideline (GBRMPA 2008).

RESULTS

Sampling in 2007/08 continued at most of the transect and coastal locations that were established in 2006. However, for a large number of locations, we have neither received samples, nor were we able to get in contact with the samplers to find out whether they were still collecting or whether they needed any assistance. The best sampled locations and most reliable samplers continued to be the coastal sites at Shute Harbour and Mackay Marina, sampled by Mackay Whitsundays Healthy Waterways staff, Rosslyn Bay Marina, sampled by CapReef and the five coastal sites in the Burnett Mary NRM Region sampled by the Woongarra Marine Park Monitoring & Education Project (Table 2.11). Two cross-shelf transects were reliably sampled in 2007/08. The Port Douglas/Far Northern area has two continuing transects sampled by Undersea Explorer (Table 2.10), however, this year the reliability was more variable than in previous years with regard to regularity of sampling at all locations, transport of samples to AIMS (or GBRMPA) and the return and quality of logsheets. FantaSea Cruises recommenced regular monthly sampling of three stations in the Whitsundays from May 2007 to April 2008. All other locations and samplers had variable levels of reliability.

Maintaining the transect and coastal stations continued to be very time-consuming, for both AIMS and GBRMPA. Ongoing components of the community engagement are trouble-shooting via telephone and the provision of hands-on training in sample collection and initial sample preparation (filtration before freezer storage) for both new and existing samplers. Regular contact with sampling organisations and individuals continues to be difficult (mainly due to people being not available/contactable or the departure of nominated contact persons without informing us) and requires significant resources of both AIMS and GBRMPA.

AIMS and GBRMPA agreed in mid 2007 to urgently review the chlorophyll sampling network and to discontinue the involvement of unreliable samplers/organisations. The review was also supposed to discuss changes to the sampling process and how to implement them. For example, i) the locations of the transect stations were to be reviewed (should be away from reefs) and actual geographical positions should be recorded by the samplers, and ii) Secchi-discs readings were to be included in the sampling of the coastal sites. GBRMPA had not met with AIMS to carry out the review and the planned changes were not implemented in 2007/08.

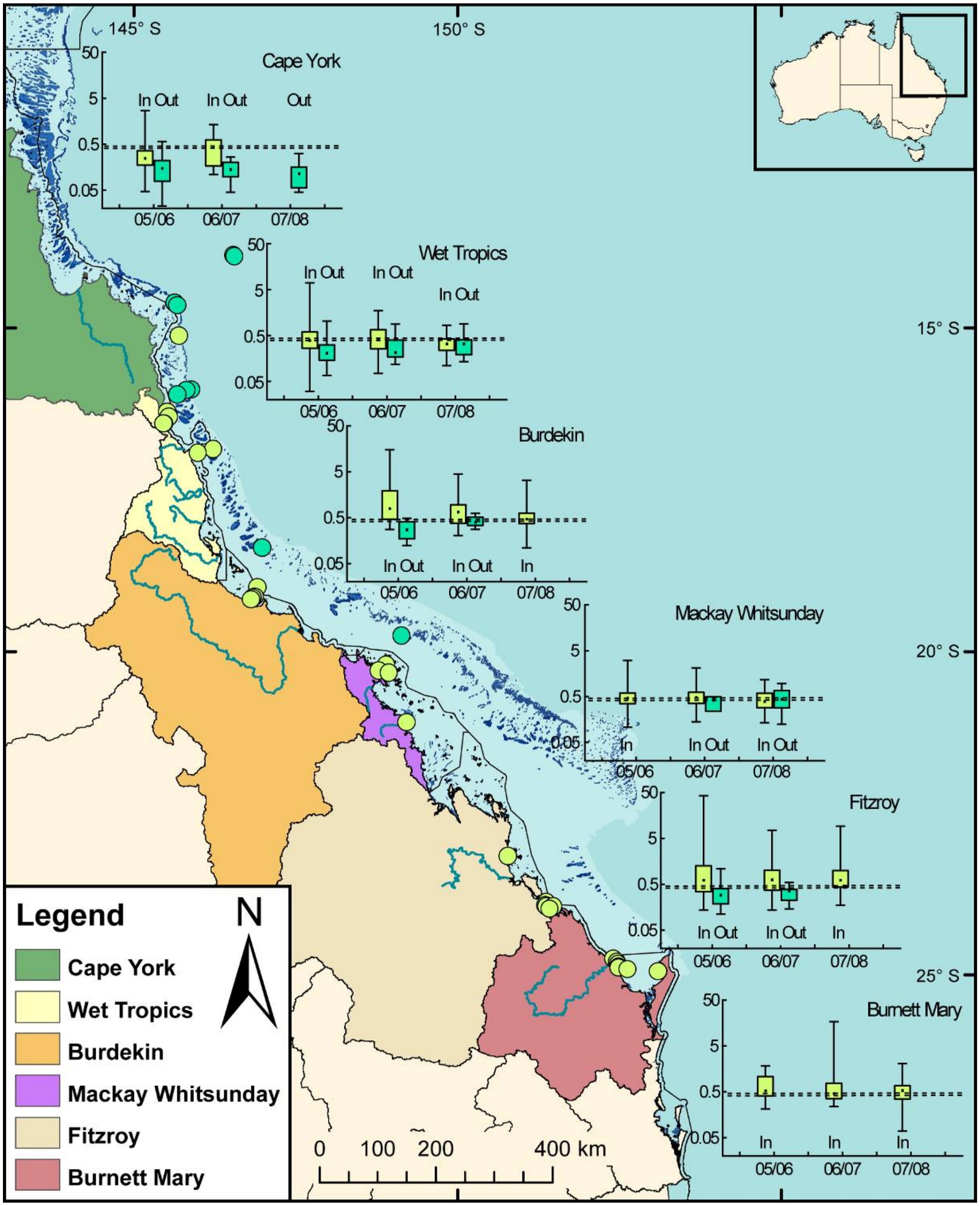


Figure 2.7 Chlorophyll community sampling locations sampled in 2007/08 and a summary of chlorophyll values measured in waters adjacent to coastal NRM regions for 2005/06, 2006/07 and 2007/08 (each for sampling periods 01 May to 30 April). 'In'=' Inner' stations in water less than 20 m deep (lime green symbols; equivalent to 'coastal' and 'inshore' stations in GBRMPA (2008)), 'out'= 'outer' stations in water deeper than 20 m (turquoise symbols; equivalent to 'offshore' stations in GBRMPA (2008)). Square symbols= median, boxes=quartiles, whiskers=maximum and minimum values. Horizontal lines represent the chlorophyll trigger values in the Draft Water Quality Guideline for the Great Barrier Reef Marine Park (GBRMPA 2008; 0.45 µg L^{-1} for coastal, 0.4 µg L^{-1} for inshore and offshore waters). Note the logarithmic scale.

The scientific value of the data from chlorophyll monitoring network decreased since the 2006 change-over from the network that was predominantly serviced by QPWS, mainly because of the reduced number of collected samples and the sometimes doubtful quality. For the representation of annual summary data (Figure 2.7) we combined the community data with the data sampled by the biannual inshore water quality monitoring (see above) to enhance the dataset as much as possible.

In all regions, annual median chlorophyll values were higher in the coastal and inshore zones ('inner'; Figure 2.7) compared to offshore locations ('outer'). Coastal and inshore values in the Cape York, Wet Tropics and Mackay Whitsunday NRM region are generally lower than those in other regions. Regional annual median values over the three monitoring years were close to or below the trigger value of 0.45 µg L-1 (coastal zone) of the Draft Marine Water Quality Guideline for the Great Barrier Reef Marine Park (GBRMPA 2008). Regional annual median values over the three monitoring years for offshore sites were also close to or below the trigger value of 0.40 µg L-1 (offshore zone) of the GBRMPA Guideline, with lowest values adjacent to the Cape York.

Detailed seasonal values for chlorophyll for all locations sampled in 2007/08 are presented in Table A1-2.1 (Appendix 1). The recording of temperature and Secchi depth information was incomplete and these data are only included in the data delivery CD and not presented as data tables.
Mean seasonal chlorophyll *a* values from offshore locations ('outer' stations of the chlorophyll transects, defined as stations in water deeper than 20m) were mostly below the GBRMPA Guideline (Table A1-2.1), except for three locations during the dry season (Inside Agincourt 4 Reef, Rudder Reef, John Brewer Reef). In contrast, seasonal means at a number of coastal and inshore chlorophyll sampling locations exceeded the GBRMPA Guideline, especially in the Fitzroy and Burnett Mary NRM regions (Table A1-2.1.

The spatial patterns of chlorophyll concentrations from the now three years of sampling under Reef Plan MMP confirm the well-known pattern of GBR chlorophyll concentrations, with a strong cross-shelf decrease of chlorophyll with increasing distance from the coast for all regions except the Far Northern region (equivalent to the Cape York NRM region) and a general southward increase of chlorophyll concentrations, both inshore and offshore (Figure 2.8; also see Brodie *et al.* 2007, De'ath and Fabricius 2008).

An analysis of temporal trends was not undertaken because we assume the spatially much reduced current sampling network will not improve the power of the past analysis of long-term trends. Chlorophyll concentrations from the GBR Long-term chlorophyll monitoring program (sampled 1992 to 2006) showed fluctuations over time, but no net increasing or decreasing trends (Brodie *et al.* 2007, CRC Consortium 2006).

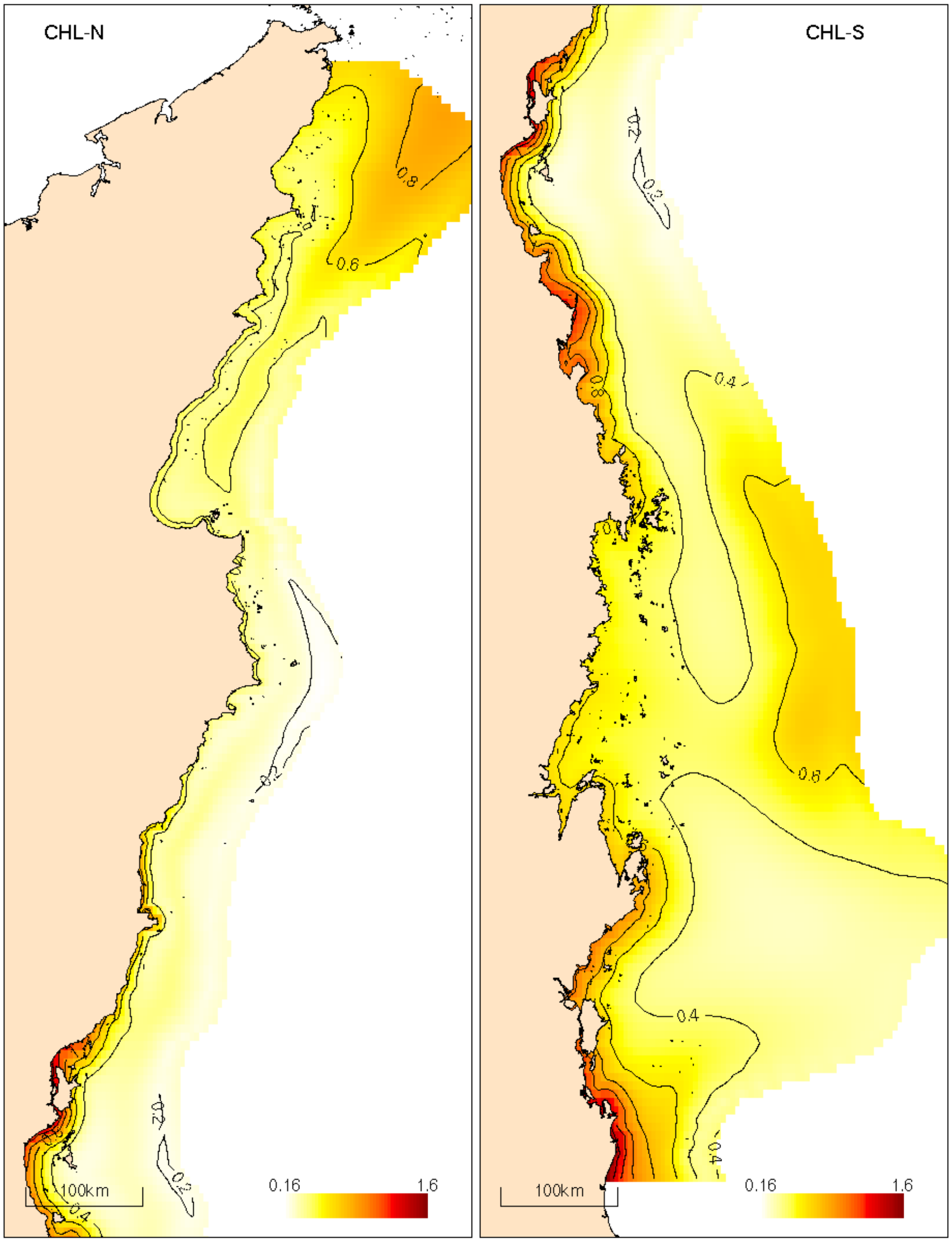


Figure 2.8 Estimated spatial distribution of chlorophyll a concentrations (µg L^{-1}) in the Great Barrier Reef Lagoon based on data from the Long-term chlorophyll monitoring program sampled 1992 to 2006 (reproduced from De'ath and Fabricius 2008).

Autonomous Environmental Loggers

(Schedule 1, Task 3.6)

METHODS

[Note: detailed documentation of methods was provided to GBRMPA in a separate report in October 2005: *Water Quality and Ecosystem Monitoring Programs - Reef Water Quality Protection Plan: Methods and Quality Assurance/Quality Control Procedures*; CRC Reef Consortium 2005.]

During test deployments of the WET Labs Eco FLNTU Combination Fluorometer and Turbidity Sensors (Wet Labs Inc., Philomath, Oregon) over the first two years of the Reef Plan MMP, the deployment, calibration and data management procedures were refined and in 2007/08 the instruments were applied for routine water quality measurements under Reef Plan MMP.

The Eco FLNTU Combination instruments 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. Fluoresced red light (683 nm) is received by a detector 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. The red fluorescence emitted is detected by a silicon photodiode. 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.

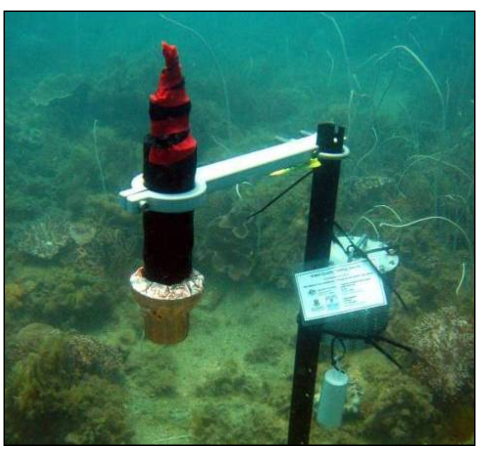


Figure 2.9 FLNTUSB logger deployed at Pelican Island in the Fitzroy NRM Region in October 2007.
Note the co-deployed passive sampler for pesticide monitoring.

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 4000NTU Formazin standard (for turbidity) 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 (µg 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 (Whisky©-TV, Kisters). After removal of spikes and other unreliable data, gaps in the record are filled by linear interpolation.

Field deployments

The 25 new FLNTUSB loggers purchased by the GBRMPA were delivered to AIMS in October and November 2007. Together with the three loggers purchased in 2006 for initial testing, we now have 28 loggers available (two for each station), allowing change-over of fully serviced instruments (no battery exchanges or downloads in the field) and appropriate redundancy. The instruments were deployed at all 14 water quality monitoring sites in October 2007, as close as possible to the inshore reef surveys sites at 5 m depth (LAT), and changed-over every 3-5 months (Table 2.12 for details). To decrease fouling of the instrument, the loggers were wrapped with plastic and electrical tape and the lower part of the instrument additionally with copper tape. Underwater, the instruments were attached with a custom-made clamp to a star picket with the measurement window pointing downward (Figure 2.9).

For validation of the instrument data, water samples were collected at each deployment/ retrieval for analysis of chlorophyll and suspended solids concentrations using standard laboratory techniques (as above for inshore lagoon water monitoring).

Table 2.12 Locations selected for inshore water quality monitoring by autonomous instruments (Wetlabs FLNTUSB SB) and deployment and change-over times.

NRM Region	Water quality monitoring locations	FLNTUSB deployments			
Wet Tropics	Snapper Island North	Oct 07		Mar 08	
	Fitzroy Island West	Oct 07*	Dec 07	Mar 08	
	High Island West	Oct 07	Dec 07	Mar 08	
	Frankland Group West	Oct 07	Dec 07	Mar 08	
	Dunk Island North	Oct 07	Dec 07	Mar 08	
Burdekin	Pelorus & Orpheus Is West	Oct 07	Dec 07	Mar 08	
	Pandora Reef	Oct 07	Dec 07#	Mar 08	
	Geoffrey Bay	Oct 07*	Dec 07**	Mar 08	
Mackay Whitsunday	Double Cone Island	Oct 07		Feb 08**	Apr 08
	Daydream Island	Oct 07		Feb 08	
	Pine Island	Oct 07		Feb 08	
Fitzroy	Barren Island	Oct 07		Feb 08	
	Pelican Island	Oct 07		Apr 08	
	Humpy & Halfway Island	Oct 07		Feb 08	

* Data records recovered from loggers shortened due to fouling/instrument problems, instrument returned to manufacturer April 2008 for service.

** Logger calibration problems, instrument returned to manufacturer April 2008 for service

Logger failed to download, was returned to manufacturer April 2008, unserviceable (data lost), replaced under warranty.

Out of 22 retrieval and download occasions only three had issues that resulted in loss of data (details in Table 2.12). The three existing instruments were returned to the manufacturer for service and recalibration to match the measurement range of the newly purchased instruments. Seven of the new instruments were also returned to the manufacturer for service/upgrade in May 2008 because of various issues noted after the first two deployments (calibration problems, signs of abrasion on the copper face plate, etc.). One instrument was unserviceable and replaced under warranty.

RESULTS

Time-series of chlorophyll concentration and turbidity

Data time series were obtained for all 14 deployment locations, with some data gaps (see above and Table 2.12). Time-series are presented as daily means (Figures 2.10 to 2.15), calculated from the readings obtained every 10 minutes. In addition to the instrument readings, the graphs include relevant environmental data (daily discharge volume of the closest river, provided by QDNRW, and averaged daily wind speed data from the nearest weather station of the Bureau of Meteorology, calculated from twice-daily readings available at URL http://www.bom.gov.au/climate/dwo. To bring the time series data into context, we included the seasonally adjusted chlorophyll Guideline trigger values (GBRMPA 2008). For turbidity we applied a suggested turbidity 'threshold' of 5 NTU, beyond which corals may be severely light-limited (based on experiments with the coral species *Pocillopora damicornis* and field assessments; Cooper *et al.* 2007 and 2008). This threshold was deduced from turbidity and light measurements at 2 m depth (LAT), hence, applying it to our logger data from 5m depth (LAT) gives a conservative estimate of turbidity-related stress because the light reduction would be more pronounced at this deeper depth.

The times series obtained using FLNTUSB loggers delivered high-frequency, location-specific data records. In the future, these will be invaluable to interpret patterns and change of coral reef communities at these locations. The results from the loggers largely confirmed our qualitative assessments of water quality based on observations from diving at these locations.

Out of the 14 monitoring locations, 10 showed chlorophyll values above the GBRMPA threshold, 8 of these are south of the Palm Island Group, which confirms again the well-known southward increase of chlorophyll concentrations. Only one location had generally very turbid water, Pelican Island in the Fitzroy Region, and during the summer floods the suggested photo-physiology threshold of 5 NTU was continuously exceeded for 30 days. Three locations (Snapper and Dunk Island in the Wet Tropics and Geoffrey Bay in the Burdekin region) were regularly turbid with values around 2 NTU and high values (>5 NTU) for >10% of the record. All other locations had low mean turbidity around or below 1 NTU and only rare high turbidity spikes.

In three regions, decreasing mean chlorophyll and turbidity values agree well with increasing distance of locations from the closest river mouth; in the Wet Tropics: Dunk, High and Russell islands (high to low values), in the Burdekin Region: Geoffrey Bay, Pandora Reef, Pelorus Island; in the Fitzroy Region: Pelican, Humpy and Barren islands. In the Mackay Whitsunday Region the location closest to the mouth of the Pioneer River is Pine Island, which showed the highest chlorophyll and turbidity values, but the two locations further away from the river (but both relatively close to the coast) had relatively similar turbidity values. Details of the time series from each of the 14 deployment locations are described in detail in the following section.

Five reef locations in the Wet Tropics NRM Region had instruments deployed.
Snapper Island, the northernmost location of the Reef Plan MMP inshore water quality network, had an extremely spiky record, especially for turbidity (Figure 2.10). The overall mean chlorophyll concentration was 0.51 µg L^{-1}, which was above the GBRMPA Guideline value. Mean turbidity was ~2 NTU, but frequent spikes were above this mean with a highest daily value of 18 NTU. 23% of the daily means in the record exceeded the GBRMPA chlorophyll trigger values (Table 2.13) and 10% of values exceeded the suggested 5 NTU limit for coral photo-physiological stress. A 10 d period of high turbidity readings during March 2008 coincided with a flood event of the Daintree River; high chlorophyll values follow the turbidity readings with a lag of a few days.

The mean chlorophyll concentration at Fitzroy Island was 0.42 µg L^{-1} (Table 2.13). Mean turbidity was ~0.9 NTU, with two spikes in February reaching a maximum value of 8 NTU and elevated turbidity during the March flood of the Russell-Mulgrave River (Figure 2.10). 21% of the daily means in the record exceeded the GBRMPA chlorophyll trigger values and only 1% of values exceeded the suggested 5 NTU limit for coral photo-physiological stress (Table 2.13).

Russell Island, in the Frankland Islands Group had the lowest chlorophyll and turbidity levels in the Wet Tropics Region (Figure 2.11). The mean chlorophyll concentration was 0.28 µg L^{-1} (Table 2.13). Mean turbidity was ~0.5 NTU, with elevated turbidity during the March flood of the Johnstone River but a maximum value of only ~2 NTU (Figure 2.10). Only 3% of the daily means in the record exceeded the GBRMPA chlorophyll trigger values and none exceeded the suggested 5 NTU limit for coral photo-physiological stress (Table 2.13).

High Island had a mean chlorophyll concentration of 0.37 µg L^{-1} and a mean turbidity of 0.9 NTU (Table 2.13). Maximum turbidity was ~7 NTU, reached during a period of elevated turbidity during the March flood of the Johnstone River (Figure 2.11). 12% of the daily means in the record exceeded the GBRMPA chlorophyll trigger values and only 1% exceeded the suggested 5 NTU limit for coral photo-physiological stress (Table 2.13).

Dunk Island chlorophyll and turbidity levels and variability over time were comparable to Snapper Island. Dunk Island had a mean chlorophyll concentration of 0.48 µg L^{-1}, which was above the GBRMPA threshold, and a mean turbidity of 2.3 NTU (Table 2.13). Maximum turbidity was 18 NTU, reached during a period of elevated turbidity during the March flood of the Tully River (Figure 2.12). 17% of the daily means in the record exceeded the GBRMPA chlorophyll trigger values and 15% exceeded the suggested 5 NTU limit for coral photo-physiological stress (Table 2.13).

In the Burdekin NRM Region, three reef locations had instruments deployed.
Due to instrument problems, data for Pelorus Island were only retrieved from one deployment from October to December 2007 (Figure 2.12). The overall mean chlorophyll concentration in that record was 0.33 µg L^{-1}. Mean turbidity was 0.5 NTU, the lowest in the Burdekin Region, with a maximum daily value of 0.9 NTU. 16% of the daily means in the record exceeded the GBRMPA chlorophyll trigger values and none exceeded the suggested 5 NTU limit for coral photo-physiological stress (Table 2.13).

Table 2.13 Summary of chlorophyll (µg L^{-1}) and 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, SE= standard error. "Above trigger value" refers to the percentage of days with mean values above the chlorophyll trigger values from the GBRMPA Draft Water Quality Guideline for the Great Barrier Reef Marine Park (GBRMPA 2008) or the suggested turbidity threshold of 5 NTU (Cooper *et al.* 2008).

			Chlorophyll			Turbidity		
NRM Region	Location	N (d)	Mea	SE	Above trigger value (%)	Mea n	SE	Above trigger value (%)
Wet Tropics	Snapper Island	169	0.51	0.0	23	2.11	0.2	10
	Fitzroy Island	149	0.42	0.0 2	21	0.85	0.0 1	1
	Russell Island*	170	0.28	0.0 1	3	0.45	0.0 7	0
	High Island	169	0.37	0.0 1	12	0.91	0.0 2	1
	Dunk Island	145	0.48	0.0 1	17	2.32	0.2 7	15
Burdekin	Pelorus Island*	68	0.33	0.0 2	16	0.53	0.0 5	0
	Pandora Reef*	169	0.53	0.0 1	48	1.11	0.0 2	2
	Geoffrey Bay	146	0.58	0.0 2	46	2.72	0.3 8	14
Mackay Whitsunday	Double Cone Island	133	0.69	2 0.0	54	1.28	0.1	4
	Daydream Island	130	0.48	0.0 6	25	1.27	0.0	2
	Pine Island	134	0.73	0.0 1	69	1.67	0.1 9	4
Fitzroy	Barren Island*	146	0.5	0.0 1	44	0.43	0.0	0
	Humpy Island	146	0.56	0.0 1	35	1.04	0.1 4	2
	Pelican Island	183	0.76	0.0 2	60	7.3	0.6	46

*station in inshore zone, all other stations in coastal zone, 4 as defined in GBRMPA (2008)

Pandora Reef had a mean chlorophyll concentration of 0.53 µg L^{-1}, which was above the GBRMPA threshold, and a mean turbidity of ~1 NTU (Table 2.13). Maximum turbidity was ~6 NTU, briefly reached twice during October and November. Turbidity was more variable and slightly elevated from late December to end of March. Chlorophyll was above the GBRMPA chlorophyll trigger value from late January to late March, coinciding with major flooding of the Burdekin River (Figure 2.13). 48% of the daily means in the record exceeded the GBRMPA chlorophyll trigger values and only 2% exceeded the suggested 5 NTU limit for coral photo-physiological stress (Table 2.13).

Geoffrey Bay Reef had a mean chlorophyll concentration of 0.58 µg L^{-1}, which was above the GBRMPA threshold, and a mean turbidity of ~3 NTU, the highest in the Burdekin Region (Table 2.13). Turbidity was more variable and elevated from late December to late March with a maximum value of ~24 NTU (Figure 2.13). Chlorophyll was above the GBRMPA chlorophyll trigger value from early February to mid March, coinciding with the second major flood peak of the Burdekin River (Figure 2.13). 46% of the daily means in the record exceeded the GBRMPA chlorophyll trigger values and14% exceeded the suggested 5 NTU limit for coral photo-physiological stress (Table 2.13).

Three reef locations in the Mackay Whitsunday NRM Region had instruments deployed.
Double Cone Island had a mean chlorophyll concentration of 0.69 µg L^{-1}, which was above the GBRMPA threshold, and a mean turbidity of ~1.3 NTU (Table 2.13). Turbidity and chlorophyll concentrations were elevated from mid December to early January (Figure 2.14), for no obvious reason. Maximum turbidity was ~6 NTU. Chlorophyll was above the GBRMPA chlorophyll trigger

value from mid January to mid February, coinciding with the two major flood peak of the Pioneer River (Figure 2.14). 54% of the daily means in the record exceeded the GBRMPA chlorophyll trigger values and only 4% exceeded the suggested 5 NTU limit for coral photo-physiological stress (Table 2.13).

Daydream Island had a mean chlorophyll concentration of 0.48 µg L^{-1}, which was just above the GBRMPA threshold and the lowest value in the Region, and a mean turbidity of ~1.3 NTU (Table 2.13). Maximum turbidity was ~8 NTU, reached briefly mid February, coinciding with the second major flood peak of the Pioneer River (Figure 2.14). Chlorophyll was above the GBRMPA chlorophyll trigger value for most of October but show very little response to the flood. 25% of the daily means in the record exceeded the GBRMPA chlorophyll trigger values and only 2% exceeded the suggested 5 NTU limit for coral photo-physiological stress (Table 2.13).

Pine Island had a mean chlorophyll concentration of 0.73 µg L^{-1}, which was above the GBRMPA threshold, and a mean turbidity of ~1.7 NTU, both the highest values in this Region (Table 2.13). Chlorophyll was above the GBRMPA chlorophyll trigger value for most of the record with 91% of the daily means exceeding this value. Maximum turbidity was ~7 NTU and was variable and slightly elevated from late December to mid February, the latter part coinciding with the flood of the Pioneer River (Figure 2.14). However, only 4% of daily means exceeded the suggested 5 NTU limit for coral photo-physiological stress (Table 2.13).

Three reef locations in the Fitzroy NRM Region had instruments deployed.
Barren Island had a mean chlorophyll concentration of 0.5 µg L^{-1}, which was above the GBRMPA threshold, and a mean turbidity of ~0.4 NTU, both the lowest values in this Region (Table 2.13). Turbidity was slightly elevated and more variable from late December to late February with a maximum of ~3 NTU (Figure 2.15). Chlorophyll was highest after the second flood peak of the Fitzroy River mid to late February (Figure 2.15). 44% of the daily means in the record exceeded the GBRMPA chlorophyll trigger values but none exceeded the suggested 5 NTU limit for coral photo-physiological stress (Table 2.13).

Humpy Island had a mean chlorophyll concentration of 0.56 µg L^{-1}, which was above the GBRMPA threshold, and a mean turbidity of ~1 NTU (Table 2.13). Chlorophyll was above the GBRMPA chlorophyll trigger value for most of October and in mid February, coinciding with the second major flood peak of the Fitzroy River, during which also the maximum turbidity of ~6.5 NTU was briefly reached (Figure 2.15). 35% of the daily means in the record exceeded the GBRMPA chlorophyll trigger values and only 2% exceeded the suggested 5 NTU limit for coral photo-physiological stress (Table 2.13).

Pelican Island had a mean chlorophyll concentration of 0.76 µg L^{-1}, which was above the GBRMPA threshold, and a mean turbidity of ~7.3 NTU, both the highest values in this Region and of all 14 locations (Table 2.13). Daily means of chlorophyll were above the GBRMPA chlorophyll trigger value on 60% of the days, during the flood event for 77 days in a row. Maximum turbidity was ~37 NTU and values were very variable for most of the record with more elevated values from late December to late March, encompassing the major flood of the Fitzroy River (Figure 2.15). 46% of daily means exceeded the suggested 5 NTU limit for coral photo-physiological stress, with 30 days above this threshold during the flood event (Table 2.13).

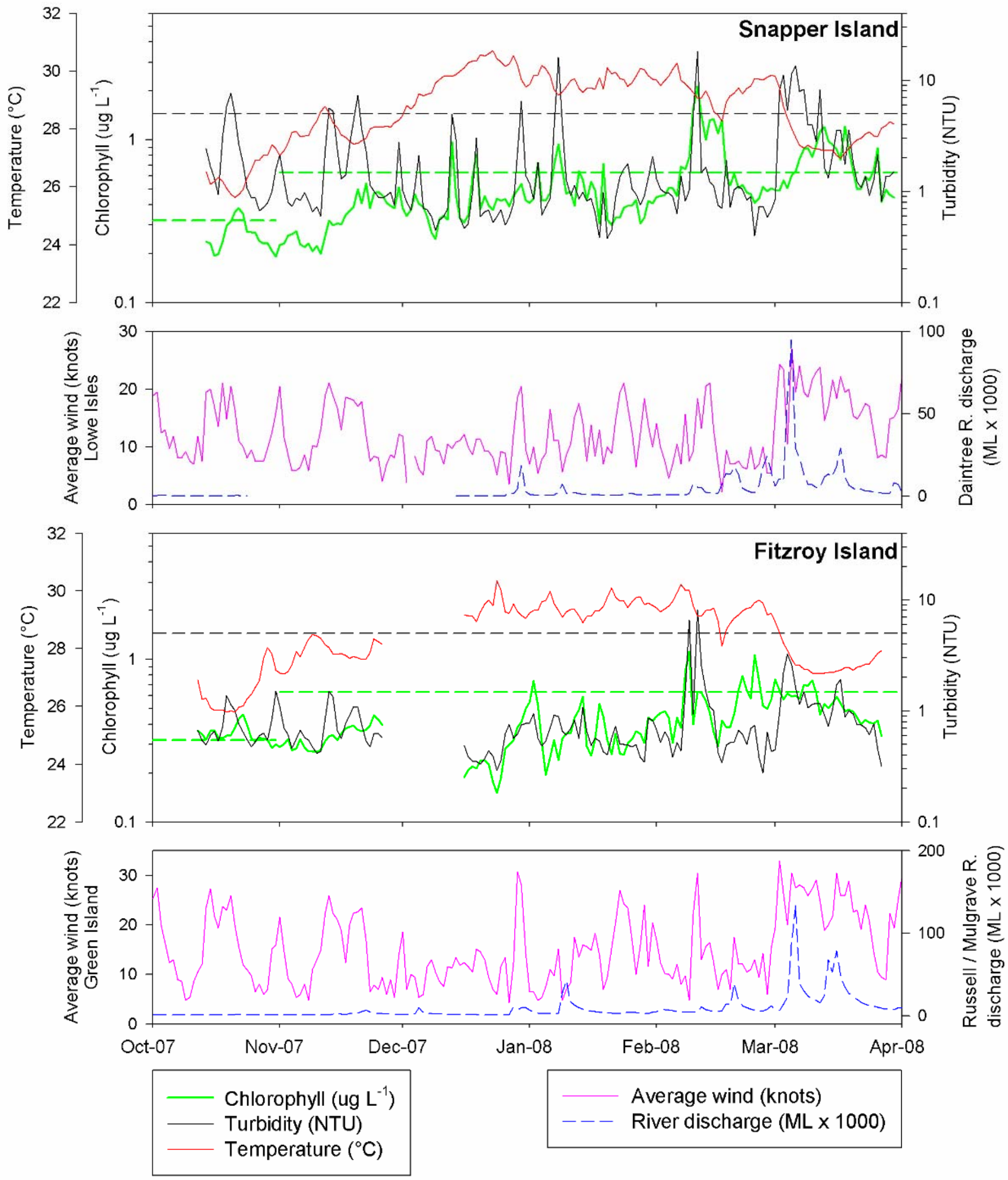


Figure 2.10 Time series of chlorophyll (µg L-1, green line) turbidity (NTU, black line) and temperature (ºC, red line) from field deployments of WET Labs Eco FLNTUSB Combination Fluorometer and Turbidity Sensors at Snapper and Fitzroy islands in the Wet Tropics NRM Region. Additional panels represent daily mean wind speeds from weather stations closest to the deployment locations (knots, pink solid line) and discharge volumes from the closest river (ML x 1000, blue dashed line). Green horizontal dashed lines represent the chlorophyll trigger values in the GBRMPA Draft Water Quality Guideline for the Great Barrier Reef Marine Park (GBRMPA 2008), black dashed lines represent the suggested turbidity 'threshold' of 5 NTU, beyond which corals may be severely light-limited (Cooper *et al.* 2008).

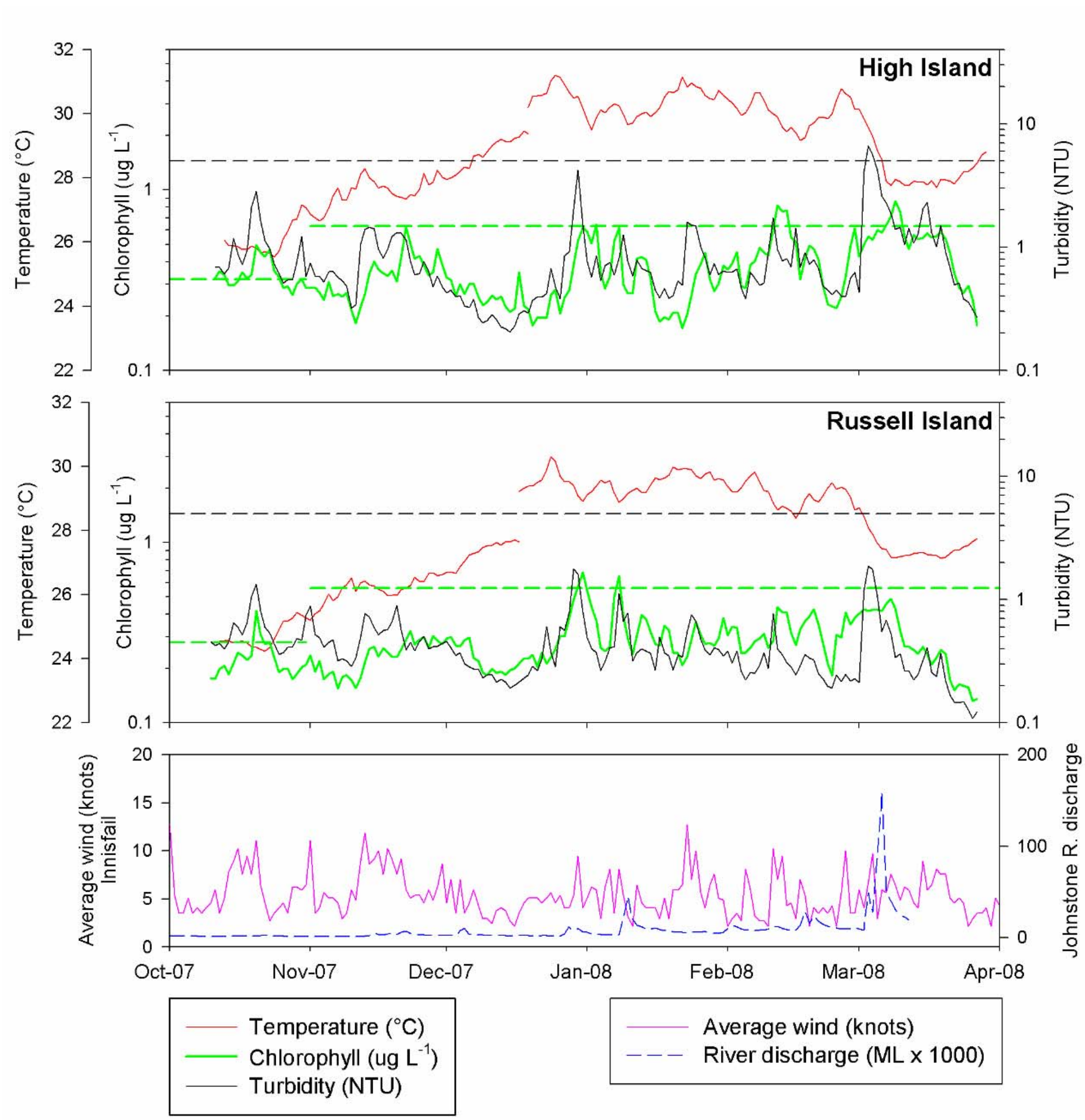


Figure 2.11 Time series of chlorophyll (µg L^{-1}, green line) turbidity (NTU, black line) and temperature (ºC, red line) from field deployments of WET Labs Eco FLNTUSB Combination Fluorometer and Turbidity Sensors at High and Russell islands in the Wet Tropics NRM Region. All other details as in Figure 2.10.

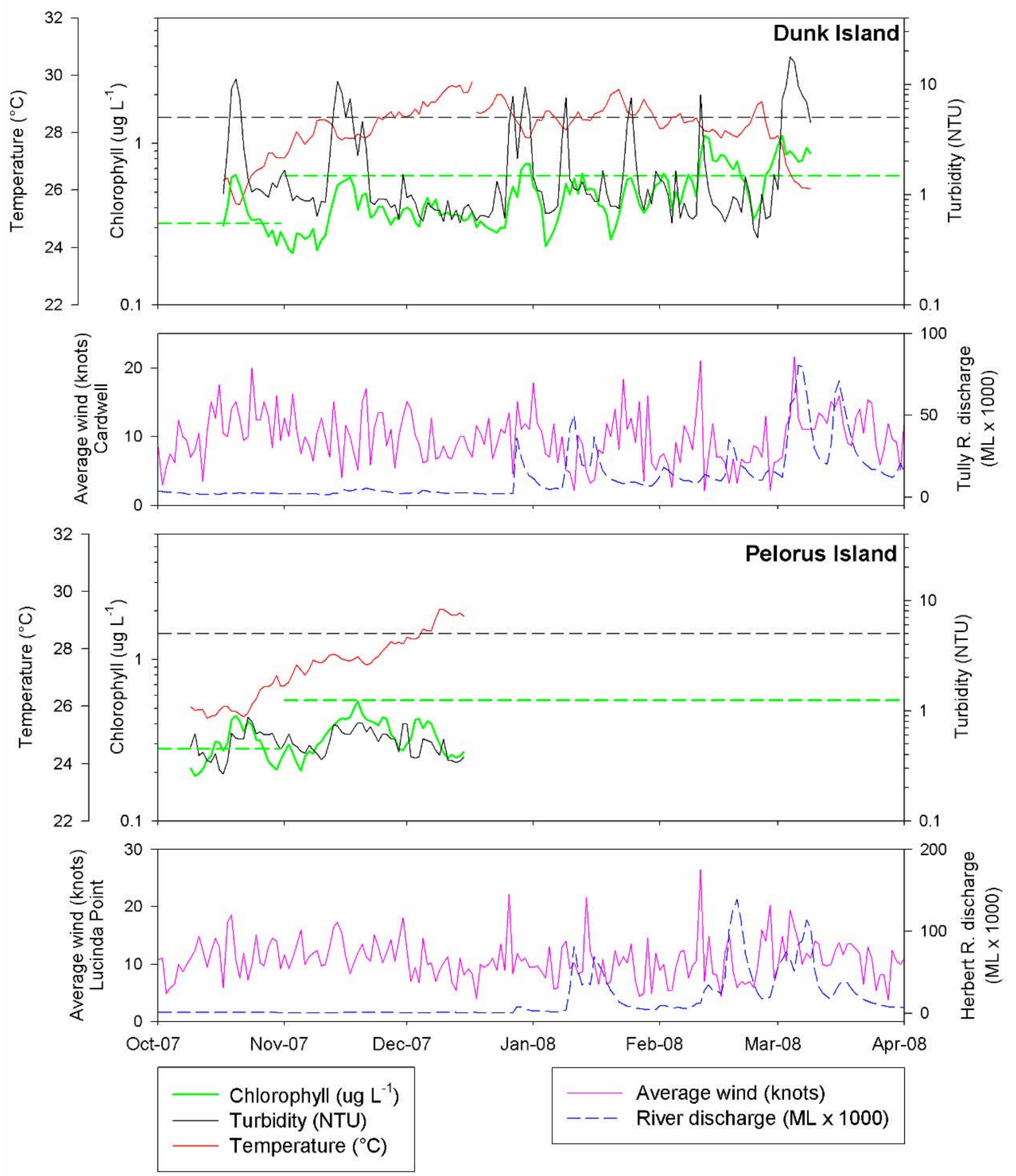


Figure 2.12 Time series of chlorophyll (µg L^{-1}, green line) turbidity (NTU, black line) and temperature (ºC, red line) from field deployments of WET Labs Eco FLNTUSB Combination Fluorometer and Turbidity Sensors at Dunk Island in the Wet Tropics NRM Region and Pelorus Island in the Burdekin NRM Region. All other details as in Figure 2.10.

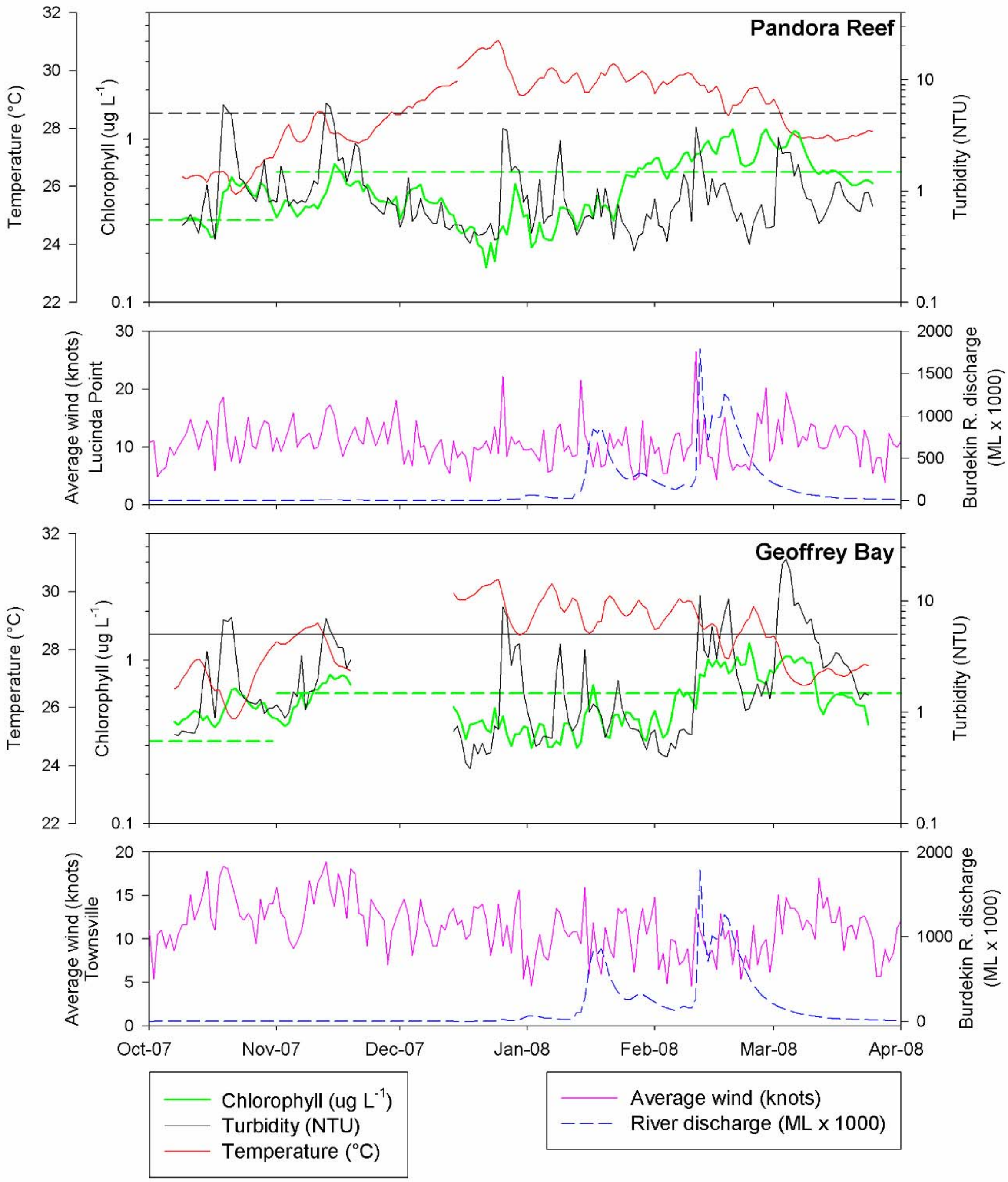


Figure 2.13 Time series of chlorophyll (µg L^{-1}, green line) turbidity (NTU, black line) and temperature (ºC, red line) from field deployments of WET Labs Eco FLNTUSB Combination Fluorometer and Turbidity Sensors at Pandora Reef and Geoffrey Bay Reef in the Burdekin NRM Region. All other details as in Figure 2.10.

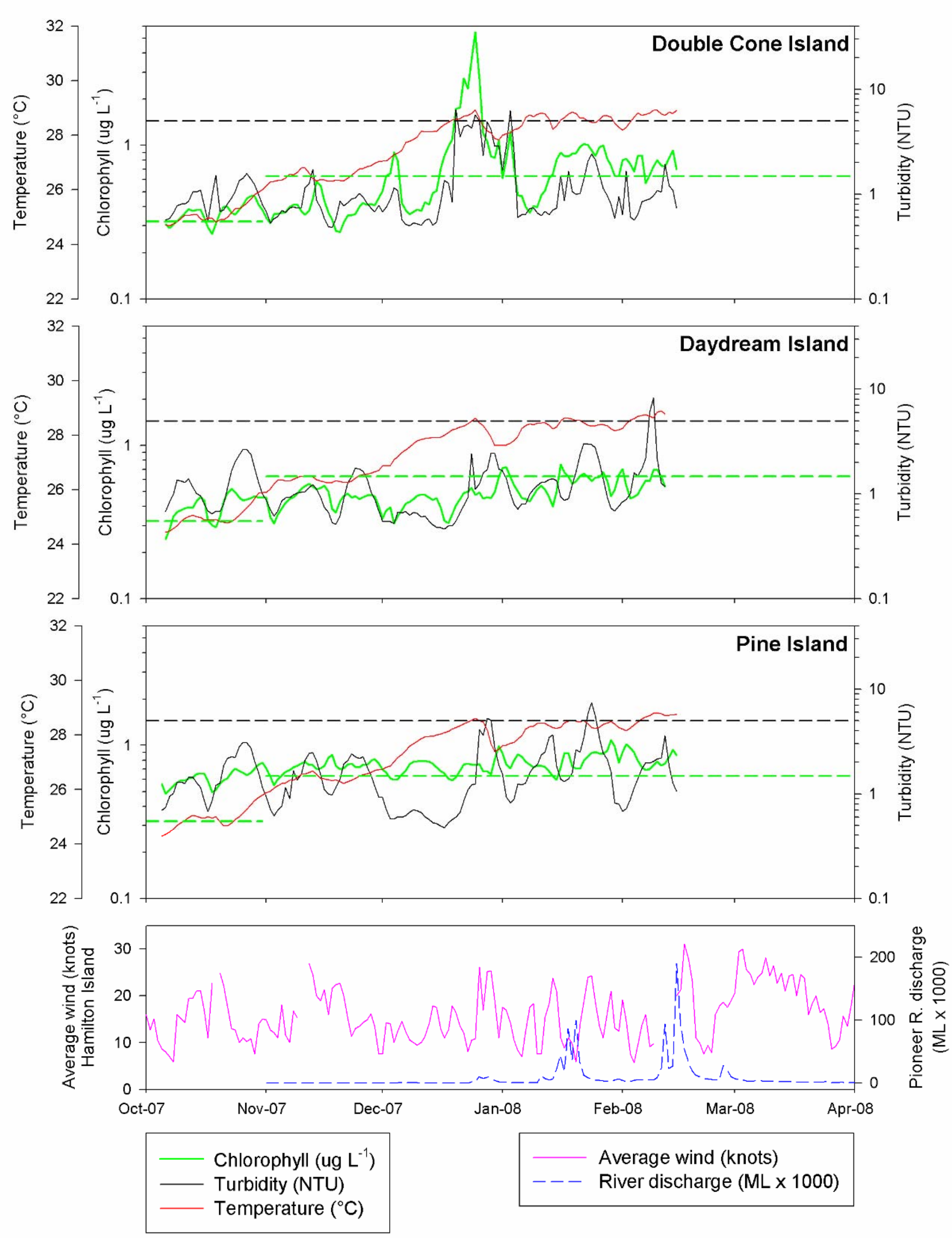


Figure 2.14 Time series of chlorophyll (µg L^{-1}, green line) turbidity (NTU, black line) and temperature (ºC, red line) from field deployments of WET Labs Eco FLNTUSB Combination Fluorometer and Turbidity Sensors at Double Cone, Daydream and Pine islands in the Mackay Whitsunday NRM Region. All other details as in Figure 2.10.

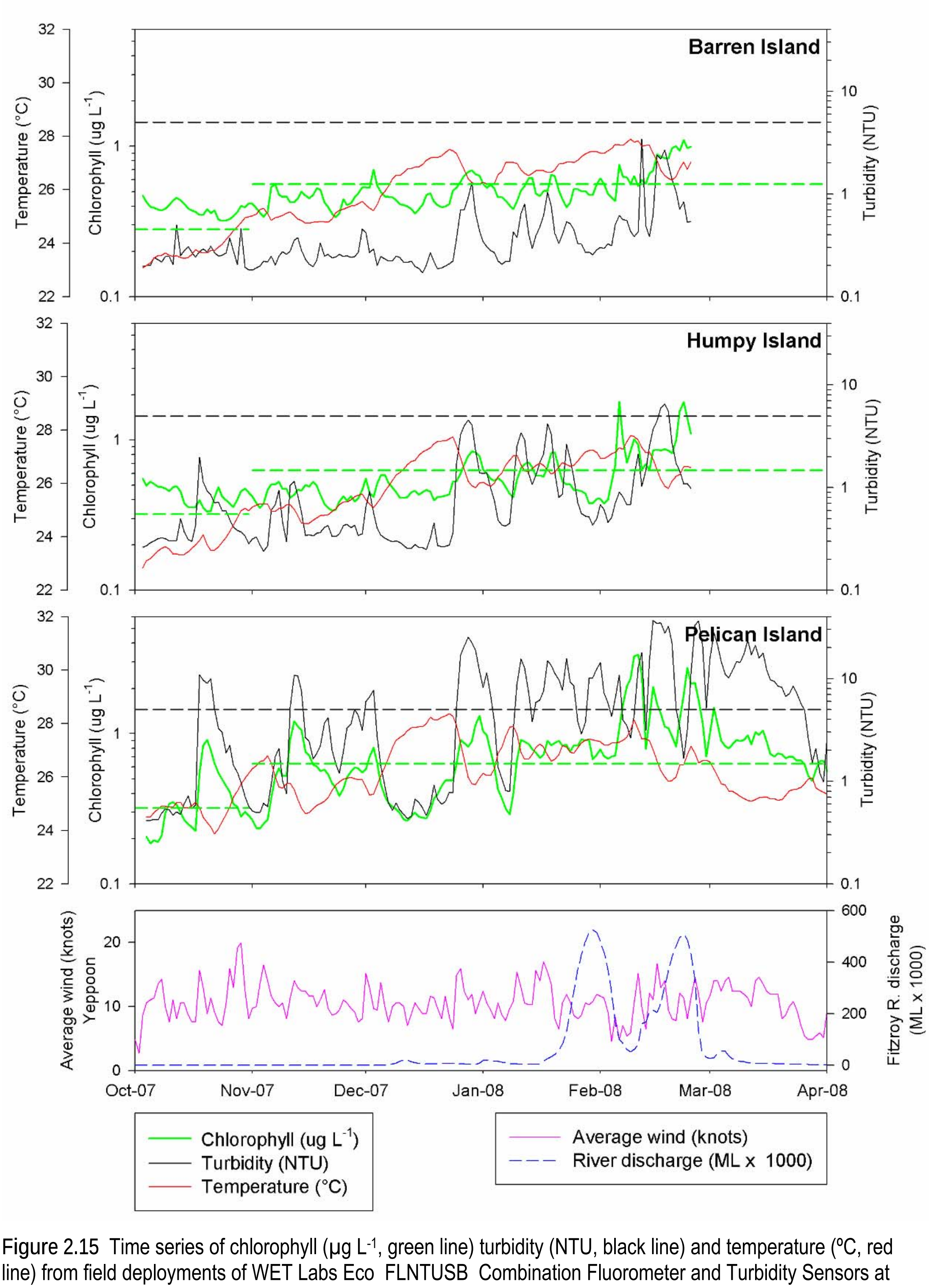


Figure 2.15 Time series of chlorophyll (µg L^{-1}, green line) turbidity (NTU, black line) and temperature (ºC, red line) from field deployments of WET Labs Eco FLNTUSB Combination Fluorometer and Turbidity Sensors at Barren, Humpy and Pelican islands in the Fitzroy NRM Region. All other details as in Figure 2.10.

Validation of 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 2.16) showed 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 10% higher values than the 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. The impact 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 [FLNTUSB Turbidity (NTU) = 0.75 x TSS (mgL^{-1})] can be used for conversion between these two variables. Applying this equation to convert the Draft GBRMPA Guideline trigger value for suspended solids (2 mg L^{-1}) yields a turbidity trigger value of 1.5 NTU for coastal sites. This converted trigger value is exceeded at four locations (compare Table 2.13), Snapper and Dunk islands (Wet Tropics Region), Geoffrey Bay (Burdekin Region) and Pelican Island (Fitzroy Region), all recognised as relatively turbid reefs.

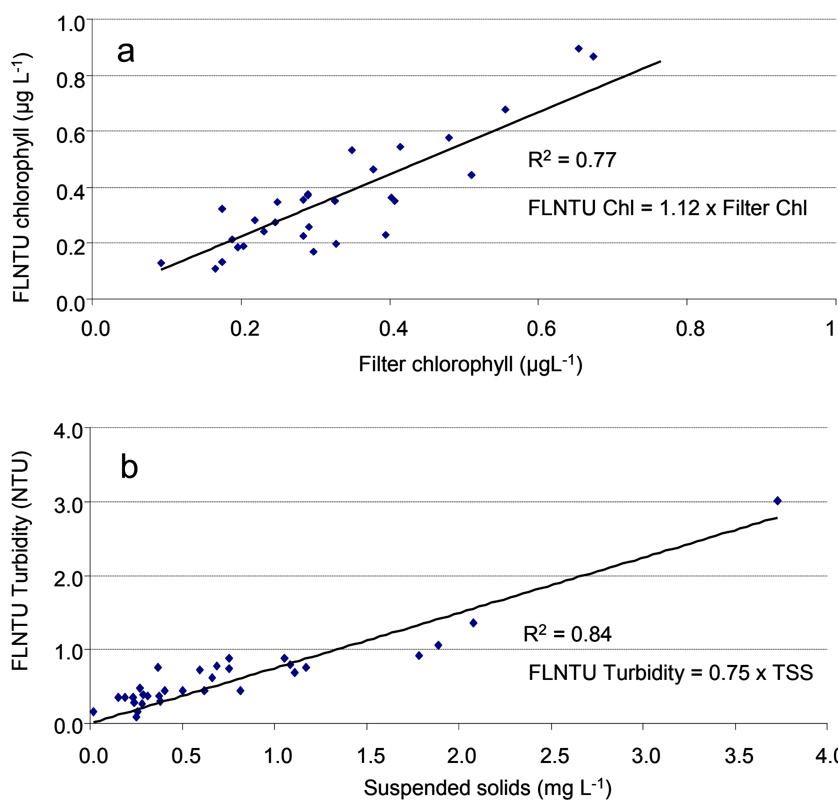


Figure 2.16 Match-up of instrument readings of a) chlorophyll a (µg L^{-1}) and b) turbidity (NTU) from field deployments of WET Labs Eco FLNTUSB Combination Fluorometer and Turbidity Sensors with values from standard laboratory analysis of concurrently collected water samples.

Temperature Monitoring

(Schedule 1, Task 3.7)

METHODS

[Note: detailed documentation of methods was provided to GBRMPA in a separate report in October 2005: *Water Quality and Ecosystem Monitoring Programs - Reef Water Quality Protection Plan: Methods and Quality Assurance/Quality Control Procedures.* (CRC Reef Consortium 2005)]

Data loggers (Odyssey, Dataflow Systems NZ) instantaneously record sea temperatures every 30 minutes, log data 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.

Reef Plan sea temperature monitoring network

Autonomous temperature loggers are now continuously deployed at all 27 inshore reef locations specified in the Contract (Table 2.14). This instrument network includes two sites of the AIMS Long-term Temperature Monitoring Program (SeaTemps), funded by various sources, at locations very close to the Reef Plan MMP coral survey sites and new locations established under Reef Plan MMP between 2005 and 2007. At most sites two temperature loggers have been deployed, at 2m and 5m depth, to correspond with the inshore coral monitoring carried out at these depths and provide redundancy in case of possible losses of loggers or data. A change-over schedule for each location is in place and is dictated by operational practicalities.

Temperature data from the ongoing AIMS Long-term Temperature Monitoring Program which has been operational since 1992, continue to be reported in summary form (average daily, weekly and monthly temperatures) through an interactive webpage that allows data visualisation and download at http://adc.aims.gov.au:9555/seatemp/do/index.do. This site is intermittently updated when new data become available from retrieved loggers.

Data analysis

Data are calculated as 24 hour averages and reported as regional daily averages from 01 May 2004 to 30 April 2007, using all available data from the Reef Plan MMP temperature monitoring network augmented for the earlier years by relevant data from the AIMS Long-term Temperature Monitoring Program.

As a reference, a regional 10-year average was calculated from daily average temperature values from the existing AIMS Long-term Temperature Monitoring Program (including some of the temperature loggers deployed under reef Plan MMP since 2005). The following loggers were used for the long-term averages: For the Wet Tropics Region: Coconut Beach, Black Rocks, Fitzroy Is., Low Isles, Frankland Is. and High Is.; for the Burdekin Region: Middle Reef, Geoffrey Bay, Nelly Bay, Cattle Bay, NE Reef, Pandora Rf., Havannah Is., Lady Elliot Rf. and Pelorus Is.; for the Mackay Whitsunday Region: Daydream Is., Dent Is., Seaforth Is., Shute Is., Hook Is. and Hayman Is., and for the Fitzroy Region: Halfway Is., Nth Keppel Is., Halftide Rocks, Barren Is., Peak Is., and Pelican Is..

Table 2.14 Location of temperature loggers for monitoring of sea temperatures.

NRM Region	Primary Catchment	Coral monitoring locations	Reef Plan MMP loggers	Existing AIMS loggers
Wet Tropics	Daintree	Daintree Reefs		√ (Coconut Bch. Rf.)
		Snapper Island	√	
	Russell-Mulgrave, Johnstone	Fitzroy Island	√	
		High Island	√	
		Frankland Group	√	
	Tully	North Barnard Group	√	
		King Reef	√	
		Dunk Island	√	
Burdekin	Herbert	Orpheus Island		√
		Lady Elliot Reef	√	
	Burdekin	Pandora Reef	√	
		Havannah Island	√	
		Middle Reef[2]		√
		Geoffrey Bay		√
Mackay Whitsunday	Proserpine	Double Cone Island	√	
		Daydream Island		√
		Shute & Tancred Island	√	
		Pine Island	√	
		Hook Island	√	
		Dent Island	√	
		Seaforth Island	√	
Fitzroy	Fitzroy	Peak Island	√	
		Barren Island	√	
		Pelican Island	√	
		Humpy & Halfway Island	√	
		Middle Island		√ (Halftide Rocks)
		North Keppel Island	√	

RESULTS

The temperature logger network is now complete (as of July 2007) and covers all Reef Plan MMP sites. Temperature data are reported for the period of May 2004 to April 2007 (Figure 2.17), spanning the three wet and dry seasons before the period when surveys of inshore coral reefs under Reef Plan MMP were undertaken (see Chapter 3).

Temperatures follow a typical seasonal pattern with lowest temperatures occurring during the winter months (June, July, August) and highest temperatures during the summer months (December, January, February). A latitudinal pattern is also obvious with decreasing average values from north to south (Figure 2.17). During the 2005/06 wet season, water temperatures in all regions were higher than the 10-year average. The wet season 2006/07 was similar to the 10-year average, with temperatures even slightly below average in the Fitzroy Region. There was no bleaching-related mortality observed in the inshore coral reef surveys in 2007 (see Chapter 3 for more information).

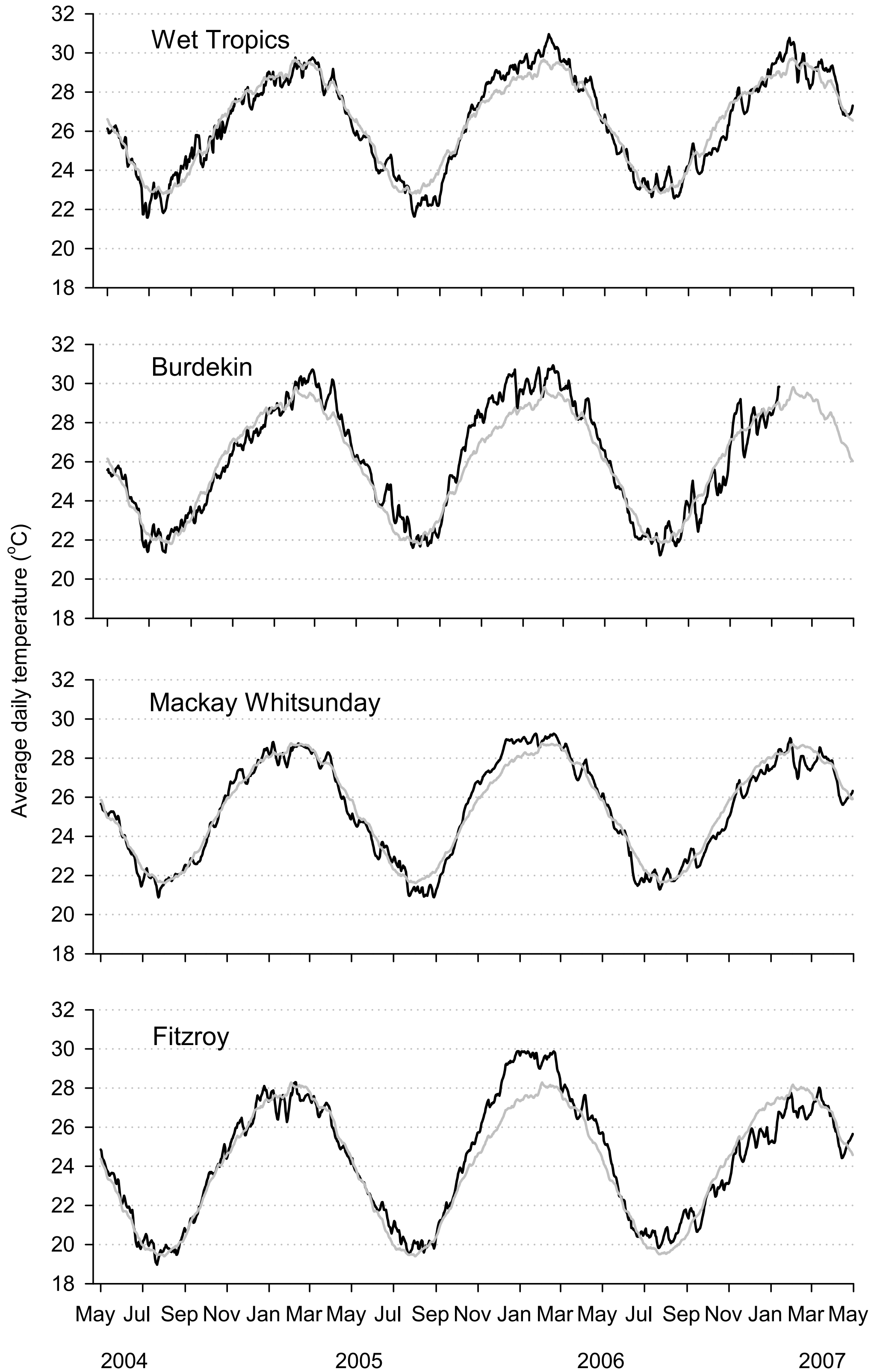


Figure 2.17 Average daily seawater temperatures measured with temperature loggers at reef locations in five NRM regions. Black lines are actual data for the years plotted, grey lines are a 10-year average.

Discussion

As in the previous two years of Reef Plan monitoring, the concentrations of water quality parameters measured in the Great Barrier Reef inshore lagoon in 2007/08 were in the expected range, based on published accounts of water quality in coastal and inshore waters of the GBR (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.). Elevated nutrient concentrations in inshore waters usually indicate nutrient release from wind-forced re-suspension of coastal sediments (Walker 1982; Ullman and Sandstrom 1987) and/or nutrient input from rivers (Devlin *et al.* 2001; Devlin and Brodie 2005).

Analysis of the lagoon water quality data showed no distinct wet-season regional-scale differences along the coast between the Daintree River (16°S) and Keppel Bay (23°S). The absence of clear differences is primarily due to the variability in concentrations among stations within all regions along the coast, for example caused by the presence of flood plumes. Our current understanding of physical transport and mixing within the GBR system is that inshore waters can be trapped for extended periods of time in the coastal zone until they are transported out of the GBR lagoon, primarily to the north and south (Luick *et al.* 2007, Wang *et al.* 2007). Cross-shelf mixing is strongest on the outer shelf. Because of this widespread transport, the 'natural' water quality parameters measured in this part of the Programme are of limited use as tracers for inputs from particular catchments. However, the monitoring results do indicate that runoff from the GBR catchment rivers may influence a wider inshore area than previously assumed.

In contrast, there were statistically discernable differences in dry season water quality characteristics between NRM regions. These differences are likely related to lesser within-region variability, the more sustained flow of rivers in the Wet Tropics region, and spatial or temporal differences in the re-suspension of sediments and nutrients by wind waves or tides. Some of these factors are local or regional in effect and often short-lived. The current semi-annual sampling campaigns cannot provide a useful resolution of the frequency and magnitude of short-lived disturbance events on water quality at scales relevant for coral reef communities, for which they are recognised as driving factors (Fabricius 2005). In the future, the resolution of water quality monitoring will be much improved by the data from the now routinely applied automated instrumentation for local high-frequency monitoring of temperature, chlorophyll and turbidity at the 14 'core' coral monitoring sites (see below).

In the wet season 2007/08, the Barron, Pioneer and especially the Burdekin and Fitzroy rivers exceeded their long-term discharge averages, whereas the Normanby, Tully and Herbert Rivers were close to average. The Johnstone and O'Connell rivers were below average, and the Burnett River again much below its long-term average, similar to the last three dry years in this catchment. The Burdekin flood in 2007/08 was ranked 3rd largest in the river discharge record going back to 1951, while the Fitzroy flood was the 5th largest since 1964 and the most significant event since the 1990/91 flood, which is still the largest on record (information from www.nrw.qld.gov.au/watershed/precomp; accessed 23/06/2008). In the wet season, water quality conditions in the coastal and inshore waters of the GBR can change abruptly and nutrient levels increase dramatically for short periods following river floods and strong wind events. This was particularly apparent in the 2007/08 wet season sampling of the coastal and inshore waters bordering all four monitored NRM regions, but especially in the Fitzroy Region. Inshore waters were characterized by elevated concentrations of most variables (DIN, PN, PP, DOC, POC, chlorophyll, SS, Si) and reduced salinity. A well-developed plume of highly turbid water was encountered in Keppel Bay during sampling at the height of the flood in late February 2008, and the highest values of all water quality parameters were measured at Pelican Island, the innermost location in Keppel Bay, close to the mouth of the Fitzroy River. A repeat visit of this site in early April showed lower but still elevated levels of most water quality parameters, confirming typical time trajectories of flood plumes over several weeks through dilution and dispersal (Devlin et al 2001, Devlin and Brodie 2005).

Nutrients exported into Great Barrier Reef lagoon waters during flood events are generally taken up rapidly by pelagic and benthic algal and microbial communities (Alongi and McKinnon 2005), fuelling short-lived phytoplankton blooms and transient events of higher level organic production (Furnas *et al.* 2005). Data from the Reef Plan MMP lagoon water quality and chlorophyll monitoring tasks showed elevated chlorophyll *a* values during the wet seasons of all three monitoring years.

Surface chlorophyll *a* concentrations in Great Barrier Reef waters have been measured since 1992 as part of a number of long-term monitoring programs (e.g. De'ath, 2005; Brodie *et al.* 2007). The Reef Plan MMP continued sampling of a number of stations along cross-shelf transects and at the coast. The sampling under Reef Plan MMP has confirmed the general spatial patterns of chlorophyll concentration found in the long-term datasets (Brodie *et al.* 2007, De'ath and Fabricius 2008) with a southward increase in mean chlorophyll *a* concentration, especially in the coastal zone (Figure 2.7). No significant cross-shelf gradient is found in chlorophyll concentrations in the Cape York region, while all sectors further south have significantly higher chlorophyll values inshore than offshore. The lack of a cross-shelf gradient in the North most likely reflects the smaller terrestrial nutrient inputs in this sector and perhaps, a greater degree of cross-shelf mixing (Brodie *et al.* 2007). The community chlorophyll sampling network needs urgent review by GBRMPA, AIMS and other interested parties to redefine the objectives of this sampling and to improve the operational problems that have arisen (unreliable sampling at a number of sites due to operational constraints by industry and community partners). The reduced spatial coverage means the current dataset is unsuitable for a continuation of the previous long-term trend analyses (De'ath 2005, CRC Reef Consortium 2006, Brodie *et al.* 2007), which were based on ongoing monitoring in the same locations. A realistic future objective could be to continue the community/industry monitoring to provide monthly validation data for monitoring of chlorophyll concentrations by remote sensing. To do, this however, the design needs to be modified, e.g. sampling needs to occur away from reefs and coastline and more precise geographic locations need to be reported.

The longest and most detailed time series of a suite of "robust" water quality parameters in the Great Barrier Reef (DON, DOP, PN, PP, SS and chlorophyll) has been measured by AIMS in coastal waters at 11 stations between Cape Tribulation and Cairns since 1989; this sampling was continued under Reef Plan MMP in 2007/08. All parameters, except chlorophyll *a*, showed significant long-term patterns, generally decreasing since the early 2000s (Figure 2.6). Apart from particulate phosphorus levels of all variables fluctuated over years. The results of the trend analysis changed compared to previous analysis of this data (De'ath 2005, CRC Consortium 2006, Schaffelke *et al.* 2007) and significant temporal trends can now be discerned, which illustrates that it is necessary to take a long-term view in assessing long-term changes in water quality variables. The Barron River, which is the river most likely influencing the Cairns water quality transect stations, had significant flood events at the beginning of the time series in 1991 and in the wet seasons of 1999 and 2000. It is tempting to interpret the fluctuations in the PN, chlorophyll and, to some extent, SS data as a flood response, despite the long period (several years) of the fluctuations. In contrast, levels of DON and DOP peaked around 2003, which had no significant floods in the years before and after. A further analysis of the Cairns transect data considering river flow and perhaps weather data might indicate how long flood effects continue to be discernible in coastal waters and whether lag-phases of several years are probable.

2007/08 was the first year where we routinely deployed autonomous data logging instruments (WetLabs Eco FLNTUSB) at the 14 'core' reef locations to monitor chlorophyll and turbidity under Reef Plan MMP. In the previous years only temperature had been monitored by instruments on all survey reefs under Reef Plan MMP. This instrumental monitoring provides the capacity to measure key water quality parameters in close proximity (ca. 1 m) to corals and benthic communities on coastal reefs and to record short-term variability in water quality associated with flood plumes and wind-driven resuspension events. While in the future, satellite ocean colour remote sensing will allow the monitoring of large-scale water quality patterns, autonomous instruments will be of ongoing significance because they have the benefit of obtaining high-frequency data series at one location of particular interest, e.g. a reef or seagrass bed where long-term monitoring of biological status is undertaken.

Time series data were obtained for all 14 deployment locations and the results largely confirmed our qualitative assessments of water quality based on observations from diving at these locations. 10 monitoring locations had chlorophyll values above the trigger value from the Draft Water Quality Guideline for the Great Barrier Reef Marine Park (GBRMPA 2008); 8 of these are south of the Palm Island Group, which confirms again the southward increase of GBR chlorophyll concentrations. Only one location had generally very turbid water, Pelican Island in the Fitzroy Region, and during the summer floods the suggested photo-physiology stress threshold of 5 NTU (Cooper et al. 2008) was continuously exceeded for 30 days. Three locations (Snapper and Dunk Island in the Wet Tropics and Geoffrey Bay in the Burdekin region) were regularly turbid with high values (>5 NTU) for >10% of the record. All other locations had low mean turbidity around or below 1 NTU and only rare high turbidity spikes.

In three regions, decreasing mean chlorophyll and turbidity values agree well with increasing distance of locations from the closest river mouth; in the Wet Tropics: Dunk, High and Russell islands (high to low values), in the Burdekin Region: Geoffrey Bay, Pandora Reef, Pelorus Island; in the Fitzroy Region: Pelican, Humpy and Barren islands. In the Mackay Whitsunday Region the location closest to the mouth of the Pioneer River is Pine Island, which showed the highest chlorophyll and turbidity values, while the two locations further away from the river (but both relatively close to the coast) had similar turbidity values.

At this stage, chlorophyll, turbidity and temperature monitoring data have been only analysed to present the time series and provide preliminary data exploration and summary statistics. In the near future, these data will become more important in the future of the Reef Plan MMP, when they will serve as a correlative environmental variable for analysis of spatial differences in coral reef community structure (proposed as an additional project, co- funded by GBRMPA and AIMS).

Comparing the Reef Plan MMP water quality data to the Draft Water Quality Guideline for the Great Barrier Reef Marine Park (GBRMPA 2008) provided important context to interpret the information. Seasonal and annual means, averaged over all stations and three years of sampling, exceeded the trigger values for chlorophyll *a*, suspended solids and Secchi depth (Table 2.8). Also, the annual and wet season means for particulate phosphorus exceeded the trigger value. On a regional basis, the 2007/08 chlorophyll annual and seasonal means were mainly exceeded in the Burdekin, Mackay Whitsunday and Fitzroy regions, the latter 2 regions exceeded trigger values predominantly in the wet season, based on data from both manual water sampling and the autonomous instruments. The Secchi depth trigger value was exceeded by more than half the locations across all 4 regions in both dry and wet season of 2007/08. Trigger values of suspended solids and particulate phosphorus were exceeded in the 2007/08 wet season in the Fitzroy Region, due to the major flood event during which the inshore sampling was carried out. Other water quality variables had values that exceeded trigger values only at single locations or during one season, often explained by flood influences. Our data suggest that high chlorophyll concentrations and turbidity levels are the main water quality issues in the GBR. The continued instrumental monitoring of these two parameters will deliver important information to determine the trajectories into the future 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.

There are very few data available from long-term and broad-scale water quality monitoring programs in other coral reef systems to compare with GBR water quality data. Comparing our 3 year averages over all stations and data from water quality instruments to data from a tropical water quality long-term monitoring program in the Florida Keys (Lirman and Fong 2007) show that inshore GBR water column dissolved inorganic nitrogen (DIN) concentrations are generally lower than values observed in Florida while chlorophyll and phosphate concentrations and turbidity are higher. Ratios of DIN to phosphate indicate high concentrations of bioavailable dissolved phosphorus relative to dissolved nitrogen, compared to other parts of the world, especially during the dry season. However, nitrogen input during flood events is a significant water quality issue, because it supports high levels of phytoplankton production (Furnas 2005), leading to high chlorophyll levels. To date, it is unclear what the consequences of high phosphate availability are, but it is possible that certain types of phytoplankton (e.g. N-fixing cyanobacteria) may benefit from these conditions.

3. Inshore Coral Reef Monitoring

(Schedule 1, Tasks 3.8 to 3.12)

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 Plan MMP estimate cover of various coral taxa and also collect information of size-distribution of colonies as evidence for the extent of past and 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 (a water quality bioindicator in the testing phase, Uthicke and Nobes 2008) were new components of the coral reef monitoring, to provide additional information about the environmental conditions at the individual survey reefs.

The key aims of the inshore coral reef monitoring are to provide:

- Annual time series of community status for inshore reefs as a basis for detecting changes related to water quality and other disturbances;
- Information about ongoing coral recruitment on Great Barrier Reef inshore reefs as a measure for reef resilience;
- Information about sediment quality and assemblage composition of benthic foraminifera as indicators for water quality and environmental conditions at inshore reefs.

This report presents data from the third annual survey of coral reef sites under Reef Plan MMP (undertaken in the period from May 2007 to Feb 2008; hereafter called "2007") and provides analyses of differences in the suite of community variables compared to results from the first two surveys (undertaken in the period from April 2005 to January 2006; hereafter "2005" and May 2006 to Feb 2007; hereafter called "2006"). Also presented are analyses of the correspondence between various aspects of the benthic communities and estimates of sediment quality (grain size and carbon and nitrogen composition) on the survey reefs. This is the first step toward more comprehensive analysis of the relationship between community characteristics with their surrounding local environment which are planned to be undertaken in 2009 (proposal currently under consideration by GBRMPA).

Sampling locations

Sampling locations were prescribed in the Contract and were chosen to represent reefs along a wide area of the coastline (and four Regional NRM regions, Figure 3.1), and to represent gradients downstream from the major rivers flowing into the Great Barrier Reef lagoon (Table 3.1). Sites at all survey locations were permanently marked in 2005 and resurveyed in 2006. In 2007, three sites in each of the four NRM regions were designated 'core reefs'. At these core reefs the full suite of coral reef benthos surveys are undertaken annually along with the deployment of autonomous turbidity, chlorophyll and temperature samplers. Passive samplers for toxicants are deployed to core reefs during the coral spawning period. The remaining reefs in each region are designated 'cycle reefs' where benthic surveys are undertaken biannually. Settlement of coral spat to tiles is not undertaken at cycle reefs. Surveys at three reefs along the Daintree coast have been discontinued due to logistical and safety concerns (increasing frequency crocodile sightings in the area). The northern and southern faces of Snapper Island are surveyed annually as they are the most northern location and represent the continuation of a long time series (since 1995). Snapper Island North is also the location of an autonomous sampler.

Two replicate sites are surveyed at each survey location. Ideally each site consists of a set of five 20 m transects, separated by 5m, laid along depth contours on the reef slope at each of two depths: 2 and 5m below Lowest Astronomical Tide (LAT). At Middle Reef and one site at Middle Island there were no coral communities at or deeper than 5 m below LAT so no surveys of reef communities were possible at this depth. The five transects were permanently marked and GPS waypoints are recorded. The start points are marked with star-pickets and transects were laid out following the depth contour as precisely as possible. Compass bearings for each change in transect direction aid in tracking the path along the depth contour between star-pickets. In 2007, site marking was augmented with the placing of additional stakes of 10mm reinforcing rod at the mid point and end of each transect surveyed.

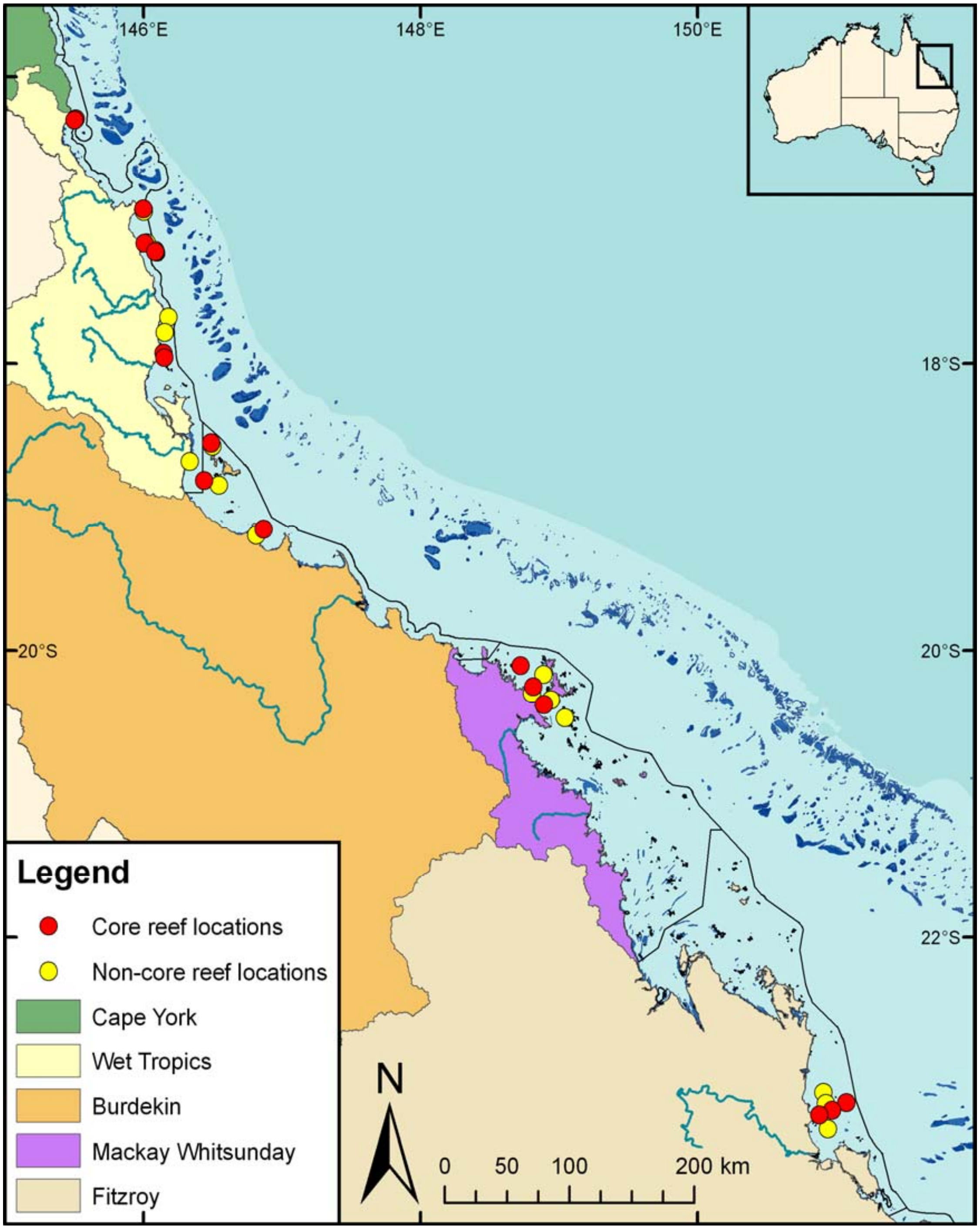


Figure 3.1 Sampling locations under the Reef Plan MMP inshore marine water quality and coral monitoring tasks. Core reef locations have annual coral reef benthos surveys, coral settlement assessments, autonomous water quality instruments (temperature, chlorophyll and turbidity) and regular water sampling. Non-core reef locations have benthos surveys every two years, no water quality assessments. Exceptions are Snapper Is (water quality instruments, regular water sampling, coral annual surveys, but no coral settlement) and Dunk Is (water quality instruments, regular water sampling, but coral surveys every other year). See Table 3.1 for the list of surveys completed in 2007.

Table 3.1 Inshore coral reef monitoring completed during the period May 2007 and February 2008. Sampling additional to contractual requirements indicated by grey ticks (✓).

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	✓	✓
		Fitzroy Island East	✓	✓
		High Island West	✓	✓
		High Island East	✓	✓
		Frankland Group West	✓	✓
		Frankland Group East	✓	✓
	Tully	North Barnard Group	✓	
		Dunk Island North	✓	
Burdekin	Herbert	Pelorus and Orpheus Island West	✓	✓
	Burdekin	Pandora Reef	✓	✓
		Havannah Island	✓	
		Middle Reef[2]	✓	
		Geoffrey Bay	✓	✓
Mackay Whitsunday	Proserpine	Double Cone Island	✓	✓
		Daydream Island	✓	✓
		Pine Island	✓	✓
		Dent Island	✓	
		Seaforth Island	✓	
Fitzroy	Fitzroy	Barren Island	✓	✓
		Pelican Island	✓	✓
		Humpy & Halfway Island	✓	✓
		North Keppel Island	✓	

Note:

[2] indicates locations where surveys were only at 2m.

Sediment quality

METHODS

Sediment samples were collected from all reefs visited during 2007 (Table 3.1) for analysis of grain size the proportion of inorganic carbon, organic carbon and total nitrogen. At each 5m deep site six 1cm deep cores were collected haphazardly along the length of the site from available deposits. Grain size fractions were estimated by dry sieving larger fractions (>1.4mm) and MALVERN laser analysis of smaller fractions (<1.4mm). Total carbon (carbonate carbon + organic carbon) and Nitrogen was determined by combustion of dried and ground samples, on a LECO Truspec C/N Analyser. Organic carbon was measured using a Shimadzu TOC-V Analyser with 5000A Solid Sample Module after acidification of the sediment with 2M hydrochloric acid. Inorganic (carbonate) carbon was then calculated as the difference between the total carbon and organic carbon (total carbon – organic carbon).

RESULTS

Sediment samples collected from each of the benthic community monitoring sites are analysed for grain size distribution and nitrogen, organic carbon and total carbon. Inorganic carbon is calculated as the total carbon minus organic carbon. This section provides a brief over view of this data (complete results in Appendix Table A1-3.1).

There where two main results from the sediment quality analysis. Firstly, that the sediment variables of interest for understanding of benthic communities were highly correlated. The content of nitrogen in the sediment is positively correlated to the proportion of fine grain sizes (<0.031mm) in the sample (Figure 3.2a) and both these variables were negatively correlated to the inorganic carbon content (Figure 3.2 b and c). Secondly, the sediment composition in the Mackay Whitsunday region was substantially different to the other regions with very high concentrations of sediment nitrogen, a high proportion of fine grain sizes and relatively low content of inorganic carbon (Figure 3.3).

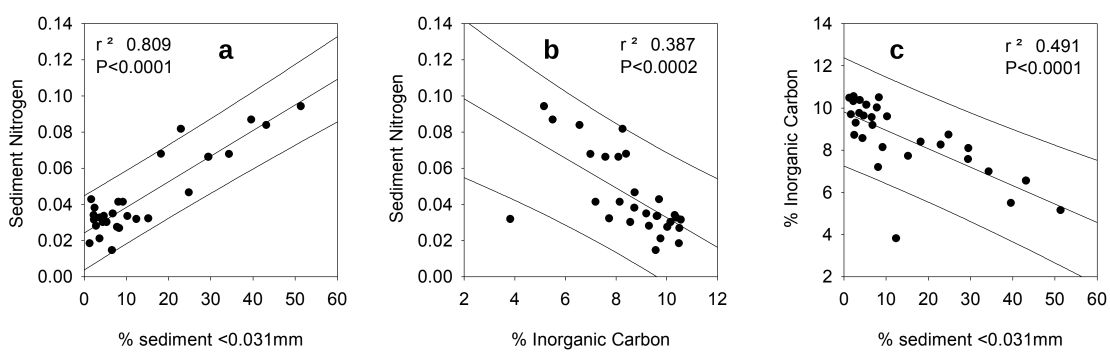


Figure 3.2. Relationships between ecologically relevant measures of sediment quality; a) nitrogen content and proportion of fine grain sizes (<0.031mm), b) nitrogen and inorganic carbon content, c),inorganic carbon content and proportion of fine grain sizes (<0.031mm).

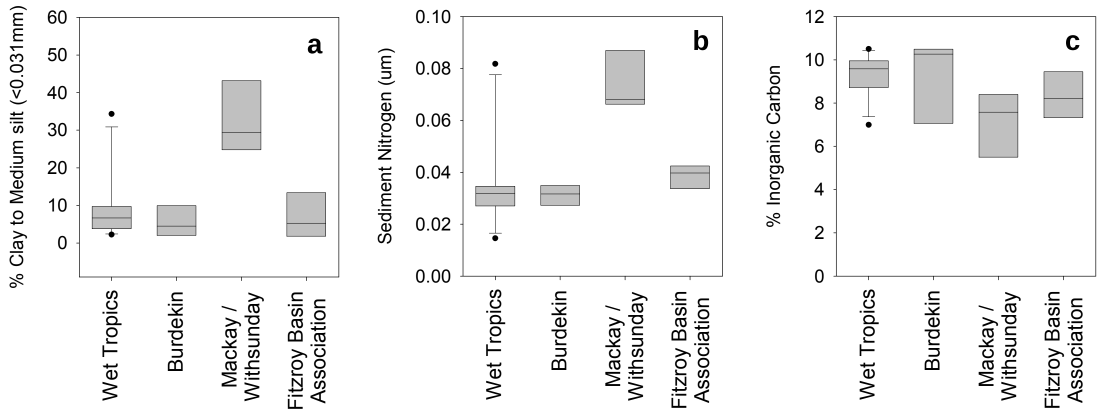


Figure 3.3. Regional variation in estimates of ecologically relevant measures of sediment quality. In each plot boxes represent the median (line within box) and range of sediment variable estimates. The exception is for the Wet Tropic region where more reefs sampled and the grey box represents the 25th and 75th percentiles of the range of samples, and the "whiskers" the 10th and 90th percentiles of the range, points out side the whiskers are extreme values. Plot show regional distribution of a) proportion of fine grain sizes (<0.031mm), b) nitrogen content and c) inorganic carbon content.

Coral reef Communities

METHODS

[Note: detailed documentation of methods was provided to GBRMPA in a separate report in October 2005: *Water Quality and Ecosystem Monitoring Programs - Reef Water Quality Protection Plan: Methods and Quality Assurance/Quality Control Procedures*.]. These methods are outlined below along with descriptions of the changes incorporated in this third annual survey as a result of a project review.

Transect sampling

Four types of data were collected along each transect on locations listed in Table 3.1:

1. *Benthic cover*: Cover of benthic organisms was estimated from five 20m photo point intercept transects. Along these transects still digital photographs were taken at 50cm intervals. Thirty two of the resulting images were selected at random and the organisms beneath 5 fixed points on each image identified to highest possible taxonomic resolution (governed by image quality).
2. *Size-frequency of juvenile colonies*: The number of juvenile hard and soft coral colonies were recorded within a 34cm wide (data slate length) belt along each 20m transect. Colonies falling wholly or partly within the belt were identified to genus and classified into the size categories: <2cm, 2cm to <5cm, 5cm to <10cm. This represents a change in methodology from previous samples. In 2005 and 2006 only the first 10m of each transect was searched and additional size classes included. The rationale behind this change was to improve estimates of juvenile colonies by focusing only on these size classes and including a greater area of coverage. The result, however, is that estimates of Juvenile richness are not comparable with data from the shorter transects.
3. *Agents of coral mortality*. All new scars (identified as bare white skeleton) that were encountered along a 2m wide belt centred on the 5 video point transects were scored according to the perceived cause of the mortality. Potential agents of mortality included *Drupella* spp., crown-of-thorns starfish (*Acanthaster planci*), several categories of disease, over growth of colonies by sponge of the Genus *Cliona* and unknown causes. Bleached and physically damaged corals were also recorded as a proportion of the living coral cover.
4. *Coral settlement*. New terracotta tiles (11.5 x 11.5cm) were deployed as settlement plates in mid October 2007, prior to the estimated time of coral spawning on inshore reefs. These tiles were removed in mid December following two expected spawning periods following the October and November full moons and replaced with fresh tiles to capture settlement occurring latter in the summer. This second set of tiles was removed in mid February 2008 in all regions except Fitzroy were strong winds and flooding delayed retrieval until mid March (Table 3.2). Tiles were deployed to base plates left in situ from the previous years sampling. At time of deployment a visual check of the fecundity of selected species of the genus *Acropora* were conducted in an attempt to pinpoint the timing of spawning for these common species. Groups of six tiles were deployed at each reef, one group near the star-pickets marking the start of 1st, 3rd and 5th transects of each site at 5m depth. The base plates to which tiles were attached were left in place for future use. After collection the tiles were bleached, dried and the number and taxonomic

identity (to genus level where possible) of coral recruits was recorded, along with their position on the tile.

Table 3.2 Locations and timing of coral settlement tile deployments.

NRM Region	Catchment	Coral monitoring locations	Coral settlement tile deployment
Wet Tropics	Russell-Mulgrave Johnstone	Fitzroy Is West	12-Oct-07 to 16-Dec-07
			16-Dec-07 to 10-Feb-08
		Fitzroy Is East	12-Oct-07 to 16-Dec-07
			16-Dec-07 to 10-Feb-08
		High Is West	11-Oct-07 to 17-Dec-07
			17-Dec-07 to 11-Feb-08
		High Is East	11-Oct-07 to 17-Dec-07
			17-Dec-07 to 11-Feb-08
		Frankland Is Group East	10-Oct-07 to 15-Dec-07
			15-Dec-07 to 13-Feb-08
		Frankland Is Group West	10-Oct-07 to 15-Dec-07
			15-Dec-07 to 13-Feb-08
Burdekin	Burdekin	Geoffrey Bay	07-Oct-07 to 14-Dec-07
			14-Dec-07 to 08-Feb-08
		Pandora Rf	09-Oct-07 to 15-Dec-07
			15-Dec-07 to 09-Feb-08
		Orpheus Is & Pelorus Is West	09-Oct-07 to 15-Dec-07
			15-Dec-07 to 09-Feb-08
Mackay Whitsunday	Proserpine	Double Cone Is	06-Oct-07 to 12-Dec-07
			12-Dec-07 to 15-Feb-08
		Daydream Is	06-Oct-07 to 13-Dec-07
			13-Dec-07 to 14-Feb-08
		Pine Is	05-Oct-07 to 13-Dec-07
			13-Dec-07 to 14-Feb-08
Fitzroy	Fitzroy	Pelican Is	04-Oct-07 to 11-Dec-07
			11-Dec-07 to 03-Apr-2008
		Humpy Is & Halfway Is	03-Oct-07 to 11-Dec-07
			11-Dec-07 to 03-Apr-2008
		Barren Is	03-Oct-07 to 11-Dec-07
			11-Dec-07 to 25-Feb-2008

Data analysis

<u>Data manipulations prior to analysis</u>

For the univariate analysis of the cover of hard coral, soft coral and macroalgae and the density of juvenile colonies it was necessary to fourth-root transform the data. The numbers of recruits on settlement tiles required natural log transformation. Estimates of the overall richness of genera and the richness of genera represented by juvenile colonies did not require transformation prior to analysis.

Two analyses of the density of juvenile colonies were performed. The first was simply the density per m^2 of transect searched. The second standardised the number of colonies recorded to the area of substratum considered 'available' to settling hard coral larvae. Available substratum was taken as the proportion of the substratum that was classified as "Algae" or "Rubble" in the point-intercept analysis. Substratum occupied by living corals, other organisms (such as sponges) or consisting of soft sediments (sand and silt), were not considered as being available to coral settlement.

Univariate analyses

Because the rivers draining into the GBR lagoon are so diverse in size and flow pattern, we analysed survey location by closest major catchment. This divides the Wet Tropics NRM reefs into three sub-regions associated with the catchments indicated in Table 3.1, each other NRM region has reefs associated with a single major catchment only. Variation in univariate summary variables (cover hard coral, soft coral and macroalgae and the density of juvenile colonies, overall richness of genera, richness of genera represented by juvenile colonies and the number of coral recruits found on settlement tiles) was analysed using linear mixed-effects models. Fixed effects were Catchment, Reef (nested within Catchment), Depth and Year; random effects were Site (nested within Reef) and the interactions with other fixed factors and the mean square error (Figure 3.4). Prior to analysis, data were averaged over transects, therefore this term does not appear in subsequent analyses.

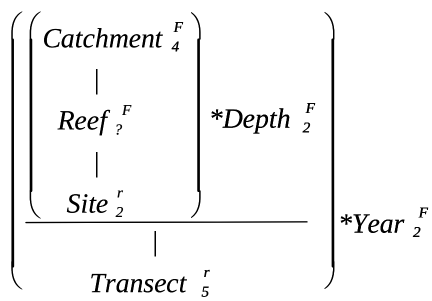


Figure 3.4. Schematic representation of the sampling design. Terms linked by an asterisk are crossed; the hierarchy of nested terms is linked by a bar. The superscript F indicates a fixed effect and superscript r indicates a random effect; subscripts represent the number of levels of the factor terms.

Initial analyses compared estimates from 2006 to those observed in 2007 to highlight any recent changes in communities. A second analysis then compares data from 2005 to 2007 to explore changes occurring over the two year period. Gradual increase in cover due to growth for example might be expected to be more evident in comparisons over longer time periods than the almost instantaneous changes associated with some disturbance events. Catchment means are deemed significantly different if 95% confidence limits do not overlap.

To explore relationships between individual benthic community attributes and sediment data, linear models were fitted that included three estimates of sediment "quality" (Table 3.3) along with a spatial term Region. Backward-elimination of the three sediment variables and Regions was used to identify factors that were associated with differences in each of the benthic community attributes. To further explore and help visualise relationships between the benthic communities and sediments linear models were fitted separately to each combination of benthos and sediment variable retained by the reduced models resulting from backward-elimination. When the term Region was retained in the reduced model separate linear models were fitted for each region. Data for these analyses were averaged over 2006 and 2007 estimates for both benthos and sediment variables and included estimates from 5m depth only.

Table 3.3 Sediment variables used in univariate and multivariate analyses of spatial pattern of coral reef benthos

Sediment variable	Used as an indicator for
Grain size (proportion <0.031 mm	The fraction of fine sediments can be considered a proxy for the hydrodynamic setting of a site.
Nitrogen content of sediment	The nitrogen content of the sediment is a measure of the nutrient content.
Inorganic Carbon (% of sample)	The proportion of inorganic carbon indicates the source of the sediment. Values approaching 12% indicate reef derived sediments. Lower the values indicate increasing terrigenous content.

In addition to the sediment variables in Table 3.3 the numbers of coral spat settling onto terracotta tiles was also compared to estimates of broodstock availability. Three main genera of corals settle onto tiles *Acropora*, *Porites* and *Pocillopora*. For each of these two broodstock estimates were included, the mean cover of the genus at the reef and also the regional mean cover as averaged over all reefs with the region (or for the Wet Tropics the Johnstone Russell-Mulgrave sub-region). For the genus *Acropora* two addition reef level estimates of broodstock were included, the cover of *Acropora* with a branching life form, and the cover of *Acropora* with a non-branching life form.

Multivariate analyses

In multivariate analyses community data for hard and soft coral cover by genus and juvenile hard coral counts by genus were related to sediment quality variables (Table 3.3) and regional locations. These analyses were based on principal component and redundancy analysis. As for the univariate exploratory analyses community data for these analyses was averaged over 2006 and 2007 and from 5m depth only.

To compare the consistency of spatial differences in coral communities between years, principal component ordinations of coral community data were compared using procrustes analysis (Peres-Neto and Jackson 2001). The procrustes analysis takes the ordination from one sample and then stretches and rotates an ordination from a second sample to fit the first. The degree of stretching required can be interpreted as the relative difference between the two communities. The probability that two samples would produce ordinations as similar as those observed were estimated using randomisations of observations within one sample while keeping observations in their original order in the other and recalculating the degree of stretching required. This process is repeated 1000 times to provide a distribution of stretching estimates against which that obtained from the true data can be compared. Comparisons between soft coral communities from 2005 to 2006 and 2007 were not appropriate as taxonomic resolution to genus was inconsistent in 2005 as a result of image quality produced by the video sampling technique used in that year.

RESULTS

Results are presented in three sections. In the first section the results of temporal analyses of the various community attributes are presented at the spatial scale of catchments. The aim of this is to highlight the major changes or stability of the benthic communities observed between years. Spatial differences among catchments are also discussed. The second section presents statistical exploration of relationships between "sediment quality" and coral reef communities. In the third section, temporal changes are presented for each reefs within each NRM region to fulfil contract requirements for regional reporting. In both the first and third sections, the focus is on changes that have occurred in various estimates of community attributes between the first, second and third years of sampling under Reef Plan MMP.

It is important to note that results presented from 2005 and 2006 surveys only include estimates from those reefs included in the 2007 survey (Table 3.1) and means may differ to those reported previously based on the full set of reefs surveyed in previous years (CRC Consortium 2006 and Schaffelke *et al.* 2007). Also from 2006 onwards, the technique to assess benthic cover and richness along the permanent transect was changed from using video to still photographs. The better resolution of still photographs allows for improved recognition and identification of benthic organisms, especially of macroalgae. Macroalgal data from 2005 are, hence, not easily comparable to those from later surveys years.

Summary of temporal changes in benthic coral reef communities

No major disturbances affected benthic coral reef communities in the period between surveys in 2006 and 2007. The most obvious changes occurring during this period represent flow-on effects from two major disturbances that impacted some reefs prior to the 2006 survey. In the Wet Tropics NRM Region, surveys in 2006 documented substantial reductions to the cover of hard corals, soft corals and macroalgae on several reefs due to the passage of Tropical Cyclone Larry. In 2007, the impacted reefs that were resurveyed indicated little recovery of the coral communities and an increase in the cover of macroalgae, which colonised space made available by the reductions in coral cover. In the Fitzroy NRM region surveys in 2006 documented substantial decline in the cover of hard corals on several reefs and a increase in the cover of macroalgae (largely due to an increase in *Lobophora* sp.) following a coral bleaching event in early 2006. In 2007, average coral cover on these impacted reefs increased indicating some recovery from the bleaching events. The cover of macroalgae, however, was still very high compared to pre-disturbance covers. Analyses of community composition of both hard corals and soft corals showed relatively little change between 2006 and 2007 compared to that observed between 2005 and 2006.

<u>Cover of hard corals</u>

There was an overall increase in hard coral cover form 31% in 2006 to 33% in 2007 (Table A1-3.2). This result reflects small increases in cover in all regions and sub regions with the exception of the Tully Herbert sub-region. These small but consistent increases in cover reflected the lack of disturbance events in the period between the 2006 and 2007 surveys. Cover in 2007 was, however, still significantly lower overall than observed in 2005 as increased cover to 2007 did not match the reductions from 2005 to 2006 resulting from the major disturbances of Tropical Cyclone Larry on some reefs in the Wet Tropics region and coral bleaching in the Fitzroy region (Figure 3.5). Further, while the majority of reefs that were not disturbed in 2006 had increased cover between 2006 and 2007 this was not the case for the majority of reefs impacted by either Cyclone Larry or coral bleaching. On these impacted reefs hard coral cover typically further declined indicating continuing impacts past the 2006 surveys (see following regional summaries). The Daintree sub-region is the only region to show a marked increase in the cover of hard corals between the 2005 and 2007 surveys, with average cover rising from 32% to 47% (Figure 3.5). Coral communities on individual reefs and depths in other regions also showed substantial increases (see regional summaries, below). Reefs in the Burdekin region and Tully Herbert sub-region in 2007 had significantly lower cover of hard corals than other regions (Figure 3.5 dark grey bars. In the Burdekin region cover has been consistently low over the period 2005-2007. The lower cover on reefs on the Tully Herbert sub-region is the result of disturbance caused by Tropical Cyclone Larry with cover in this catchment in 2005 not substantially different to catchments other than the Burdekin.

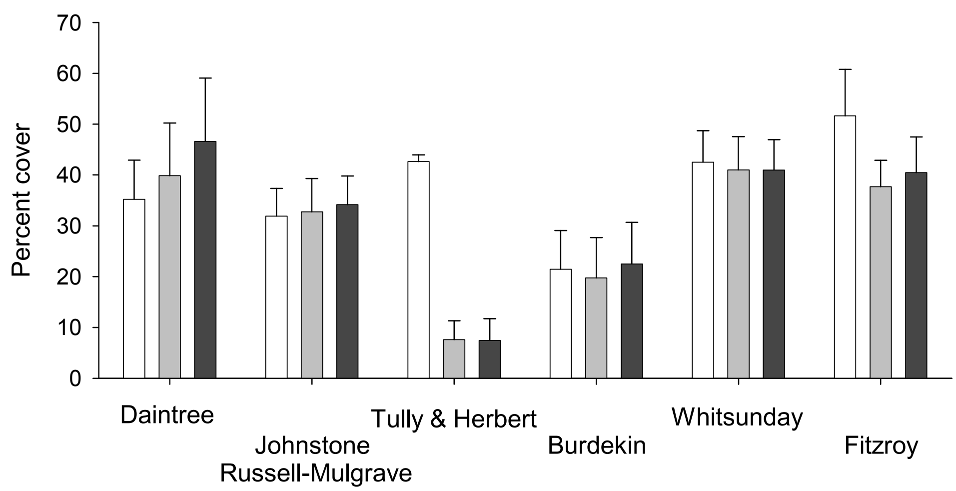


Figure 3.5. Average cover of hard coral on reefs for each NRM region / sub-region (+/- standard error). For each region the first (clear) bar represents data from 2005, the second (pale grey) bar represents data from 2006 and the third (dark grey) bar 2007 data.

<u>Cover of soft corals</u>

There was neither an overall difference in the cover of soft corals between surveys in 2006 and 2007 nor between 2005 and 2007 (Table A1-3.2). The lack of an overall difference in cover between visits however masks the differing trajectories of soft coral cover among regions. In contrast to slight increases in cover observed between 2005 and 2007 in most regions, there was a substantial decline in the Tully Herbert sub-region which had significantly lower cover than elsewhere (Figure 3.6 dark grey bars). Soft coral cover in Tully Herbert sub-region was reduced from 6.5% in 2005 to 0.3% in 2006, following the passage of Cyclone Larry; there was negligible recovery, the mean cover in 2007 was 0.5%.

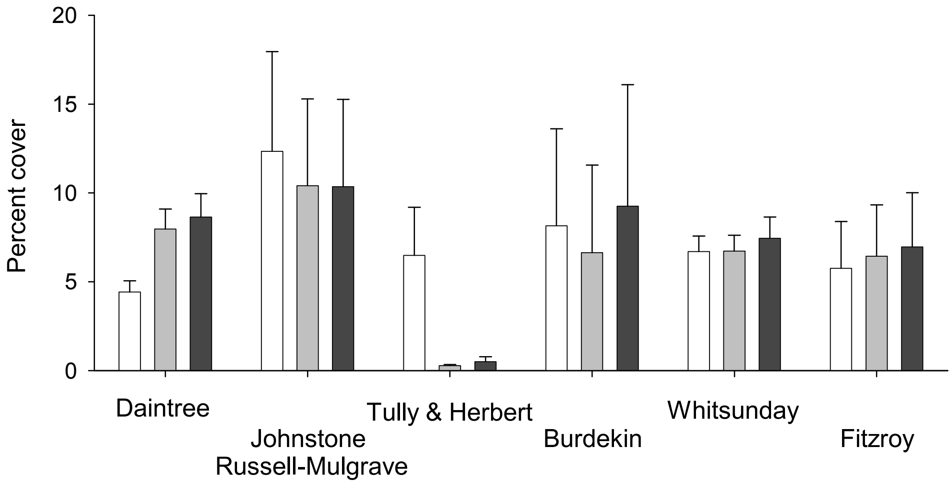


Figure 3.6. Average cover of soft coral on reefs for each NRM region / sub-region (+/- standard error). For each region the first (clear) bar represents data from 2005, the second (pale grey) bar represents data from 2006 and the third (dark grey) bar 2007 data.

<u>Cover of macroalgae</u>

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 has increased in each consecutive survey from 9% in 2005 through 11% in 2006 to 13% in 2007 (Tabl A1-3.2). Much of these increases were attributable to rapid colonisation of space at relatively few sites following disturbance events. The most dramatic of these were the three reefs in the Fitzroy region where coral cover was reduced as a result of coral bleaching in early 2006 and macroalgae (primarily of the genus *Lobophora*) rapidly colonised the newly available substrate (Figure 3.7). On these reefs the cover of macroalgae continued to increase through to 2007 (see regional summary, below). In the Tully Herbert and to a lesser extent the Johnstone / Russell - Mulgrave sub-regions macroalgae increased between 2006 and 2007 following disturbance associated with Cyclone Larry. Elsewhere the cover of macroalgae was either consistently low or variable with no clear temporal trends.

In 2007, the cover of macroalgae varied among regions. Cover on reefs associated with the Burdekin and Fitzroy regions was higher than that observed in the Daintree and Johnstone sub-regions or Mackay Whitsunday region. Macroalgae cover was also significantly higher on reefs associated with the Tully Herbert sub-region than those associated with the Daintree sub-region (Figure 3.7. dark grey bars). The relatively high cover on reefs associated with the Burdekin region has been consistent from 2005 to 2007.

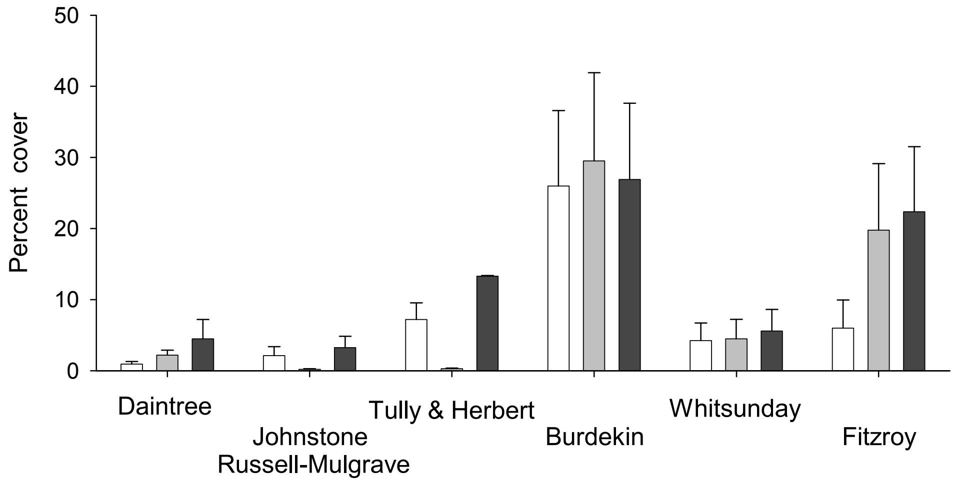


Figure 3.7. Average cover of macroalgae on reefs for each NRM region / sub-region (+/- standard error). For each region the first (clear) bar represents data from 2005, the second (pale grey) bar represents data from 2006 and the third (dark grey) bar 2007 data.

<u>Density and count of juvenile colonies</u>

We compare the number of coral juveniles in two ways. As space to settle and grow can become a limiting factor for corals it is inappropriate to directly compare the number of juveniles counted within an area between reefs with different levels of total coral cover. We control for the possible effects of available space by comparing the density of juvenile colonies per unit area of space considered "available" to coral recruits. This comparison, however, becomes problematic if a reef has been recently disturbed as the estimate of available substratum will be very high but there will have been insufficient time for corals to have recruited and grown into observable juveniles. In such situations it is useful to also consider the number of recruits observed. As the transect area was doubled in 2007 from that used in earlier surveys, counts of juveniles are standardised to the number observed per square metre of transect.

The overall average number of juvenile colonies per square metre of available substrate did not differ between 2006 and 2007 (Figure 3.8a Table A1-3.2). Comparing the density of coral recruits between 2006 and 2007 within each region and sub-region separately indicated that while most conformed to the overall trend of "no change" an increase from 6 to 11 juvenile colonies per square metre of available substrate was noted in the Daintree sub-region (Figure 3.8a).

A comparison between the densities of juvenile corals observed in 2007 to those recorded in 2005 showed that reductions attributable to Tropical Cyclone Larry in 2006 to some reefs in the Johnstone Russell - Mulgrave and Herbert Tully sub-regions were still evident with substantially lower densities of juvenile colonies in 2007 (Figure 3.8a). Considering the numbers of juvenile colonies irrespective of the available substrate indicates that lower density of juvenile colonies in the cyclone impacted sub-regions predominantly reflects fewer juveniles rather than simply and increase in the area of available for substrate recruitment (Figure 3.8b). It is not surprising that on impacted reefs numbers of recruit-sized colonies are still lower than those observed prior to disturbance on impacted reefs as there has been insufficient time for new recruits to have settled and grown to a size visible in the dive surveys.

Analysis of the number of juveniles per square metre of transect provides similar results to the analysis that accounts for the area of available substratum with no overall differences in abundance between 2006 and 2007 but significantly lower abundance in 2007 than in 2005 (Table A1-3.2), which was driven by reductions on cyclone-impacted reefs. The average numbers of juvenile colonies have remained reasonably stable over the three years of sampling in the Fitzroy, Mackay Whitsunday and Burdekin regions (Figure 3.8b).

A comparison among regions in 2007 showed that the average number of juvenile colonies, corrected for available substratum was significantly lower on reefs in the Fitzroy region than those in the Daintree, Johnstone Russell-Mulgrave sub-regions or Mackay Whitsunday regions (Figure 3.8a. dark grey bars,). Similarly, the number of juvenile sized colonies per square metre of transect (uncorrected for available space) was significantly lower in the Fitzroy region than either the Herbert Tully and Johnstone Russell-Mulgrave sub-regions or the Mackay Whitsunday region (Figure 3.8b dark grey bars). To some degree the low numbers of juveniles recorded on Fitzroy region reefs may be an artefact of the fact that a high proportion of available space represents a single microhabitat, namely the algal-covered lower branches within branching *Acropora* thickets. This microhabitat is not common elsewhere and may not be as appealing to coral settlement as other microhabitats.

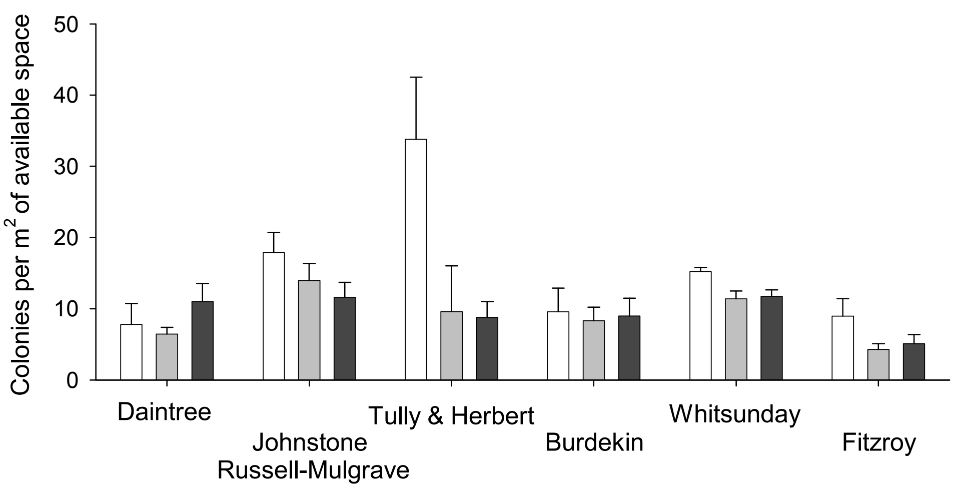


Figure 3.8a. Average density of hard coral colonies < 10cm in diameter per square metre of available substratum on reefs for each NRM region / sub-region (+/- standard error). For each region the first (clear) bar represents data from 2005, the second (pale grey) bar represents data from 2006 and the third (dark grey) bar 2007 data. Note that data from 2005 are not directly comparable to later years due to a change in methodology.

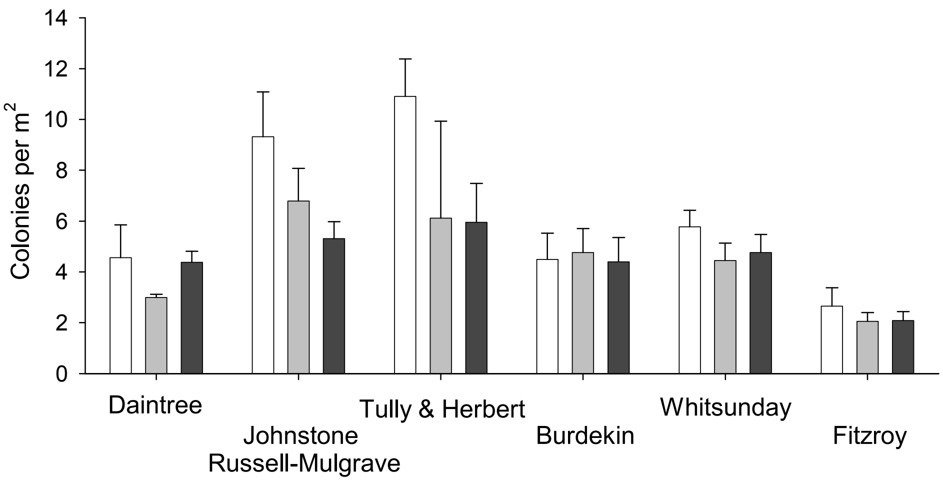


Figure 3.8b. Average number of hard coral colonies < 10cm in diameter on reefs for each NRM region / sub-region (+/- standard error). For each region the first (clear) bar represents data from 2005, the second (pale grey) bar represents data from 2006 and the third (dark grey) bar 2007 data. Note that data from 2005 are not directly comparable to later years due to a change in methodology.

Richness of hard coral genera

There was no overall difference in the average richness of hard coral genera between 2006 and 2007 or 2005 and 2007. However, there was some variability between years in some regions (Table A1-3.2). Changes in richness between 2006 and 2007 were marginal with slight increases in the Burdekin region and Daintree sub-region and slight declines in the Fitzroy region and Tully Herbert sub-region (Figure 3.9). Between 2005 and 2007, changes in richness were more evident in the Tully Herbert sub-region where the average number of genera per site declined from 16 to 10. It is likely that this ongoing reduction represents the continued impact of Cyclone Larry. In contrast the average richness in the adjacent Johnstone Russell-Mulgrave sub-region, where only one of the six reefs was substantially impacted by Cyclone Larry, has increased from 12 to 14 genera per site over the same period.

For the reefs resurveyed in 2007, the richness of hard coral genera was significantly lower in the Fitzroy region than in all other regions and sub-regions, with the exception of the Tully Herbert sub-region (Figure 3.9 dark grey bars). The relatively low richness in the Fitzroy region has been a consistent pattern over the period 2005-2007 and most likely reflects a latitudinal decline in richness toward the southern GBR. The relatively low richness for the Tully Herbert sub-region in 2007 is a result of disturbance, as discussed above. The richness of hard coral genera did not differ significantly between the remaining regions and sub-regions in 2007. Hard coral richness data for 2007 are included as Table A1-3.3.

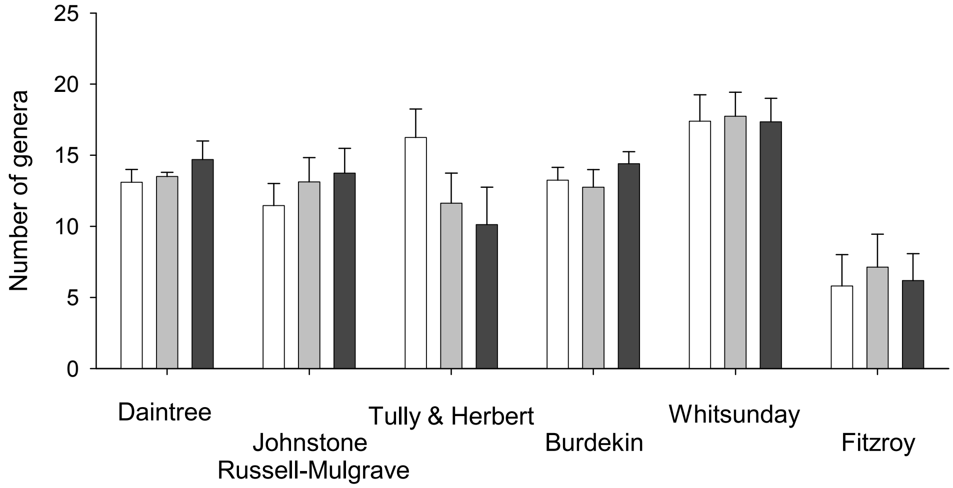


Figure 3.9. Average number of hard coral genera per site per depth on reefs for each NRM region / sub-region (+/- standard error). For each region the first (clear) bar represents data from 2005, the second (pale grey) bar represents data from 2006 and the third (dark grey) bar 2007 data.

<u>Richness of juvenile (<10cm) hard coral colonies</u>

Estimates of the richness of juvenile corals from 2007 are not directly comparable to those from previous years due to the increased survey. 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 in 2007 in all regions compared to 2005 and 2006 estimates cannot be interpreted (Figure 3.10). The decline in richness in 2007 in the Tully Herbert sub-region compared to 2005, however, may be a real decline due to the impact of Cyclone Larry in 2006.

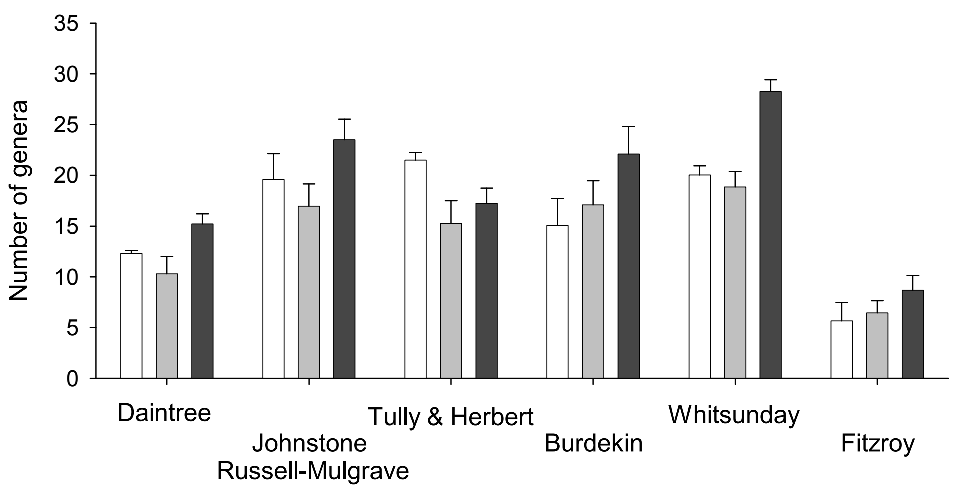


Figure 3.10. Average number of hard coral genera represented by colonies < 10cm in diameter per site per depth on reefs in each NRM region / sub-region (+/- standard error). For each region the first (clear) bar represents data from 2005, the second (pale grey) bar represents data from 2006 and the third (dark grey) bar 2007 data. Note that data from 2005 are not directly comparable to later years due to a change in methodology.

In 2007, richness of juvenile hard coral genera is significantly lower in the Fitzroy region than all in other regions and sub-regions, similar to the richness of adult hard corals. In contrast, the richness on reefs associated in the Mackay Whitsunday region is significantly higher than all other regions and sub- regions (Figure 3.10 dark grey bars, Table A1-3.2).

The number of recruits to tiles

Coral settlement sampling was expanded in 2007 to include three reefs in the Burdekin region. All reefs at which coral settlement was assessed in 2006 were again sampled in 2007, however, tiles were only deployed at 5m below datum. Coral settlement was estimated from six reefs adjacent to the Johnstone Russell-Mulgrave sub-region, including three reefs in addition to contract requirements. The primary reason for this additional sampling effort was to maintain a finer spatial scale of sampling in this catchment and allow the comparison between windward and leeward locations.

Comparison among regions for settlement in 2007 shows that, on average, settlement in the Wet Tropics was more than three times higher than in the Mackay Whitsunday region and 4 to 5 times higher than the Burdekin and Fitzroy regions (Figure 3.11, Table A1-3.4). However, there was significant variation in the settlement recorded among the reefs within most regions (Tables A1-3.2) see also regional summaries below). The exception to this was the Burdekin region where recruitment was very similar on all three reefs (see regional summary below).

It should also be noted that low estimates of settlement in the Fitzroy region may have resulted, at least in part, to spawning irregularity. In this region coral spawning following the November moon occurred as much as seven days later than expected (Alison Jones pers. comm.). This delay was likely caused by unseasonably overcast and rough conditions over a prolonged period leading up to, and over, the expected spawning date. This delay would have resulted in a mismatch between peak settlement and the timing of tile deployments, hence underestimation of overall settlement.

Temporal comparisons between regions sampled in 2006 and 2007 showed that settlement was significantly higher in 2007 (Table A1-3.2). This overall increase was driven by a significant increase in the Wet Tropics and a lesser increase in the Mackay Whitsunday region (Figure 3.11). These increases contrasted the observed decline in the Fitzroy region (Figure 3.11). Differences in settlement between 2006 and 2007 varied among the reefs within regions, however note, all six reefs sampled in the Wet Tropics region showed higher settlement in 2007 than observed in 2006 (see regional summaries below).

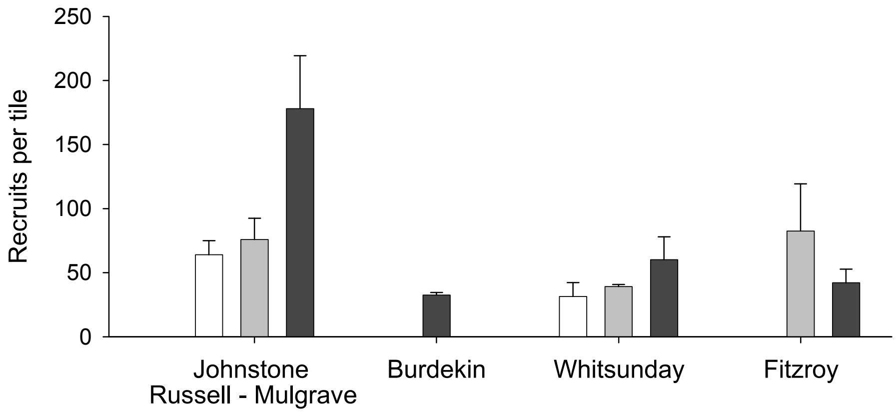


Figure 3.11. Average number of hard coral recruits per tile on reefs in each NRM region/sub-region (+/- standard error). Estimates are for 5m depth tile deployments only. Colour of bars represent sampling years within each region data from the 2005/2006 summer are represented by clear, the 2006/2007 summer pale grey and the 2007/2008 summer dark grey.

Variation in benthic community composition between sampling years

Consistent with the above reported univariate community attributes there was little change in the genus-level composition of hard and soft coral communities over the period 2006 and 2007, which was a period with no major disturbances. Results from procrustes analysis indicate that ordinations of communities observed in 2006 were highly correlated to those observed in 2007 (correlation in symmetric procrustes rotations =0.982 for hard corals and 0.912 for soft corals, Figure 3.12 a and c). In contrast, ordinations from 2005 and 2006 were less correlated (Correlation = 0.795, Figure 12b). This highlights the influence of disturbance on community composition which is important to consider when comparing among communities and when attributing differences in community composition to environmental variables. That community composition changes as a result of disturbance will almost certainly obscure relationships between community composition and environmental factors. Soft coral communities from 2005 are not compared to 2006 as taxonomic resolution differed between samples (see methods section, above).

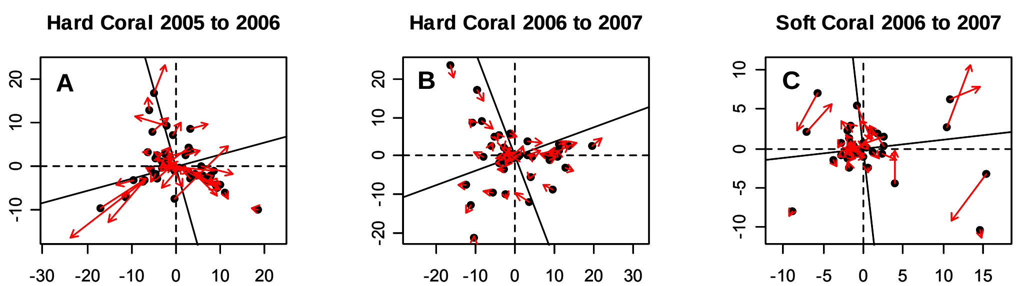


Figure 3.12. Results from Procrustes analysis. Each plots represent the overlay of ordinations of community data from the same sites in different years. The black dots represent the ordination from one year with the red arrows pointing to the position of the same site the ordination from a following year, after rotation and stretching. The relative length of the arrows can be interpreted as representing the relative similarity in community composition. Longer arrows indicate greater change in community composition between years.

Relationship between benthic communities and sediment quality

Variation in benthic community attributes was assessed against estimates of sediment quality by separately modelling each combination of benthic community attribute and sediment quality variable. Separate model for each sediment quality variable were necessary due to the highly correlated nature of these variables (Figure 3.2).

Relationship between univariate community attributes and sediment quality

Very few of the univariate benthic community attributes explored showed evidence of a relationship to sediment quality variables (Table 3.4). Cover and richness of hard corals were the exceptions. Hard coral cover showed a relationship to all three sediment variables with the variance in cover explained by the sediments ranging from 20% for the proportion of sediment with grain-size classified as clay through to medium silt (<0.031mm) through to 26% for the nitrogen content of the sediments (Table 3.4). Hard coral cover was generally higher on reefs with high sediment nitrogen content and higher proportions of finer grained sediments (Figure 3.13a, and c). Conversely, hard coral cover was lower on reefs with higher inorganic carbon content typical of reef derived sediments (Figure 3.13b). The number of hard coral genera recorded per site (richness) was also higher at reefs with higher proportions of finer grained sediments (Figure 3.13d).

Table 3.4. Linear regression results from models that separately regress each sediment quality variable with each coral reef benthic community attribute. For each analysis the variance explained is the proportion of the variation in the benthic attribute by the sediment quality variable (model R-squared). Pr(>|t|) is the probability that no relationship exists between the benthic attributer and sediment variable.

Coral reef benthic community attribute	Sediment N		Grain-size		Inorganic C	
	variance explained %	Pr(>|t|)	variance explained %	Pr(>|t|)	variance explained %	Pr(>|t|)
Hard coral cover	26.4	0.004	19.9	0.022	20.7	0.013
Soft coral cover	0.5	0.700	0.2	0.806	9.2	0.111
Macroalgae cover	1.2	0.572	5.9	0.248	0.3	0.785
Hard coral richness	0.9	0.622	10.7	0.083	3.8	0.311
Soft coral richness	0.5	0.703	8.2	0.131	0.0	0.978
Juvenile HC richness	2.2	0.443	9.1	0.111	0.2	0.819
Juvenile SC richness	4.5	0.271	4.1	0.292	5.2	0.232
Juvenile HC density	2.4	0.418	8.0	0.137	4.3	0.282

As sediment variables vary between regions (Figure 3.3) it is possible some variation in benthic community attributes is the result of spatial co-variation of the sediments and benthic attributes and not the just the sediment variable. In a second set of analysis we include region as additional factor in the linear models reported in Table 3.4. The results of these models were to again highlight the relationships between hard coral cover and each sediment quality variable, the strength of these relationships was, however, reduced. The probability estimates for each sediment variable against hard coral cover were; P=0.01 for sediment nitrogen, P=0.05 for proportion of fine grained particles, and P=0.043 for inorganic carbon content. Including region in the model removed the relationship between hard coral richness and grain-size to become non-significant (P=0.636) and indicated relationships between the cover of soft coral and sediment nitrogen and inorganic carbon content, with cover higher at lower values of sediment nitrogen (P=0.042) and higher levels of inorganic carbon (P=0.011). Juvenile soft coral richness was also higher when inorganic carbon content was higher (P=0.013).

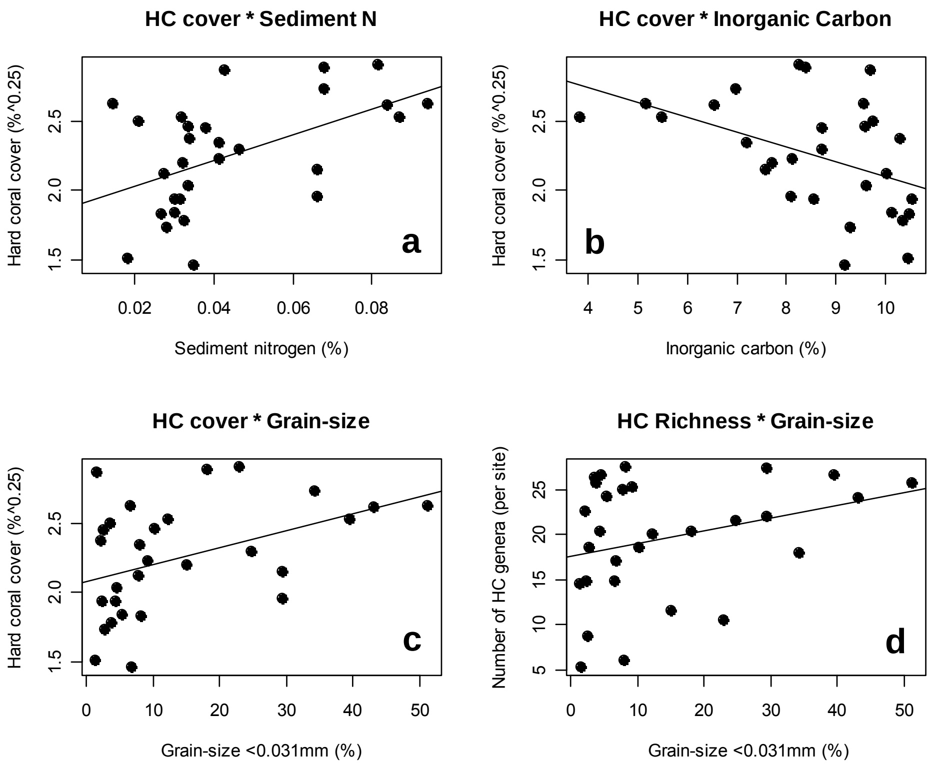


Figure 3.13. Significant results form Pair-wise comparisons of the benthic attributes and sediment quality variables. Combinations of benthic community attribute and sediment quality variables are included if the regression was significant at P<0.1 (Table 3.4).

<u>Relationship between coral settlement sediment and availability of broodstock</u>

Settlement of coral larvae is an important step in the recovery and maintenance of coral communities and signifies the culmination of successful sexual reproduction and larval survival. In addition to environmental factors that may limit larvae reaching settlement competency, settlement may fail due to a lack of supply. For this reason we included estimates of both reef level and regional broodstock (as described in the methods section) along with sediment variables in linear models to explore relationships between environmental factors and coral settlement. Backward elimination of sediment quality (Table 3.3) and broodstock variables against *Acropora* settlement produced a reduced model that indicated sediment nitrogen and the cover of non-branching *Acropora* improved the model fit. Of these, however, only sediment nitrogen was significant (P=0.035) with lower numbers of settlers at higher levels of sediment nitrogen (Figure 3.14). For *Porites* the reduced model following backward elimination of sediment and broodstock variables indicated that the proportion of fine grain sizes and the inorganic carbon content of the sediments as well as regional cover of *Porites* all improved the models fit to observed settlement. Investigating each of these variables in separate linear models showed that only regional cover of *Porites* had a statistically significant relationship (P<0.001) to the numbers of spat recorded on tiles; intuitively settlement was higher when regional cover was higher (Figure 3.14). All three measures of sediment quality and the reef level cover of *Pocillopora* were retained in the reduced model for *Pocillopora* settlement. Individually none of these variables bore a statistically significant (P<0.05) linear relationship to *Pocillopora* settlement.

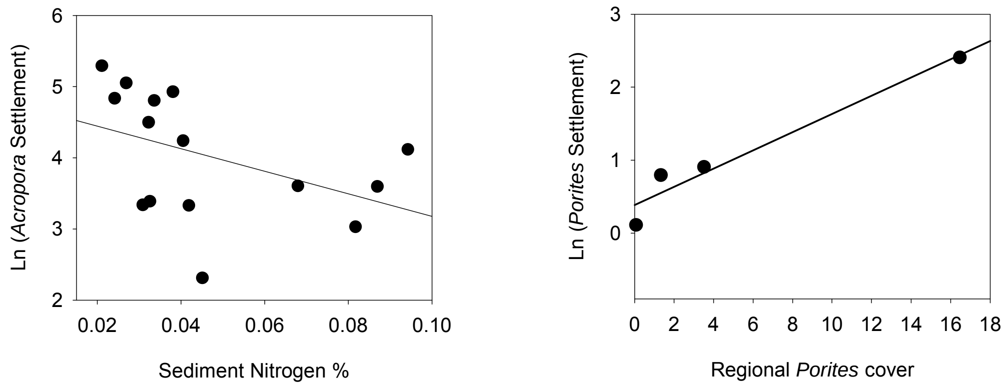


Figure 3.14. Relationship between sediment nitrogen content and *Acropora* settlement (left), and regional *Porites* cover and *Porites* settlement (right). Fitted lines are indicative only as they do not include the influence of additional explanatory variables retained by model selection.

Variation in composition of coral communities related to sediment quality

In addition to variation in the various community attributes among reefs there was also substantial variation in the taxonomic composition of coral reef communities. These patterns have been reported previously (CRC Reef Consortium 2006). Of interest is the role of environmental variables contributing to this variation. Data from 2005 showed a significant relationship between community structure of hard coral communities and a Water Quality Index constructed as the average z-scores of a variety of water quality parameters. This Water Quality Index explained 6.3% of the variation observed in hard coral communities (Schaffelke *et al.* 2007). While the relationship between the composition of soft coral communities and the Water Quality Index was not significant, the variation in the Water Quality Index did explain 5% of the variability in soft coral communities. This preliminary analysis used only limited water quality samples. A more comprehensive analysis is possible now that three years of water quality and coral community data are available. This is planned as an extra project currently being negotiated with GBRMPA.

During 2006, sediment samples were collected at 5m depths of 27 reef sites and were analysed to estimate the distribution of grain size and the content of organic carbon, inorganic carbon and total nitrogen. A preliminary analysis showed that the resulting 11 grain size and three sediment chemical composition variables explain a high degree of variability in the hard coral (44.3%) and soft coral (35.5 %) communities (Schaffelke *et al.* 2007). The grain size of the sediments is considered a proxy for both the hydrodynamic setting of the study reefs (e.g. the degree to which suspended sediment and organic matter remain at the sites) and for inputs of nutrient and suspended sediment from land runoff.

In the following analyses we use only the three sediment quality variables listed in Table 3.3. Each of these sediment variables varies among regions (Figure 3.3) so that spatial variation cannot be fully separated from sediment quality. To further explore this we conducted two sets of analyses. In the first, spatial variation in community composition was removed prior to redundancy analysis to determine the variation attributable to sediment quality independent of regional differences. For hard coral communities the proportion of fine grained sediments and the inorganic carbon content of the sediments both independently explained a significant amount of the variation in community composition while for juvenile hard corals (see Table A-3.5 for 2007 data) the sediment nitrogen content was the only variable to explain a significant amount of variation community composition (Table 3.5). None of the sediment variables explained significant portion soft coral community composition (Table 3.5).

It is possible that regional variation in coral community composition is the result of differences in sediment quality and as such removing regional differences prior to redundancy analysis may underestimate the relationship between sediment quality and community composition. The second multivariate analysis explores variation in coral community composition directly to sediment quality variables. By not removing regional variation in communities, the sediment variables explained a higher proportion of the variation observed in the coral community composition (Table 3.5 columns 4 and 6). For all four coral communities investigated the variation explained by including all sediment variables was higher than the sum of the variables analysed independently suggesting interactions between the variables may be important (Table 3.5 rows "Combined"). For soft corals the combination of sediment nitrogen and inorganic carbon content and the proportion of fine particles explain a significant amount of variation in community composition when independently the sediment variables are not significant in terms of community composition (Table 3.5 rows 12 and 16). Results from the more extreme models that do not account for regional differences show that relationships between coral genera and sediment variables are broadly consistent between juvenile communities and adult colonies (Figures 15 and 16), the later are typically driving variation in community estimates derived from observations of cover.

Table 3.5. Redundancy analysis of adult and juvenile hard and soft coral community composition (genus –level): The amount of variance explained by sediment quality parameters when regional variation in communities is removed (partial redundancy analysis (columns 3 and 4) and when water quality parameters are included without accounting for regional variation in communities (columns 5 and 6). P values are from permutation tests. Variation accounted for by all three sediment quality variables and the full model permuted P are listed as "Combined".

Variables		Regional variation removed			Regional variation ignored	
Community	Environmental	P	Variance %		P	Variance %
Hard Coral	Sediment N	0.094	4.8		0.054	6.3
	Grain size	0.043	5.4		0.011	8.3
	Inorganic C	0.013	6.9		0.008	8.5
	Combined	0.018	13.85		0.001	18.37
Juvenile Hard Coral	Sediment N	0.036	6.9		0.029	8.9
	Grain size	0.205	4.4		0.040	8.7
	Inorganic C	0.310	3.9		0.095	6.7
	Combined	0.048	15.02		0.002	26.3
Soft Coral	Sediment N	0.307	3.7		0.239	4.3
	Grain size	0.931	1.4		0.107	5.8
	Inorganic C	0.195	4.5		0.277	4.3
	Combined	0.262	11.41		0.041	17.26
Juvenile Soft Coral	Sediment N	0.848	1.4		0.297	4.2
	Grain size	0.497	2.5		0.097	6.4
	Inorganic C	0.061	6.0		0.121	5.9
	Combined	0.228	10.54		0.046	17.39

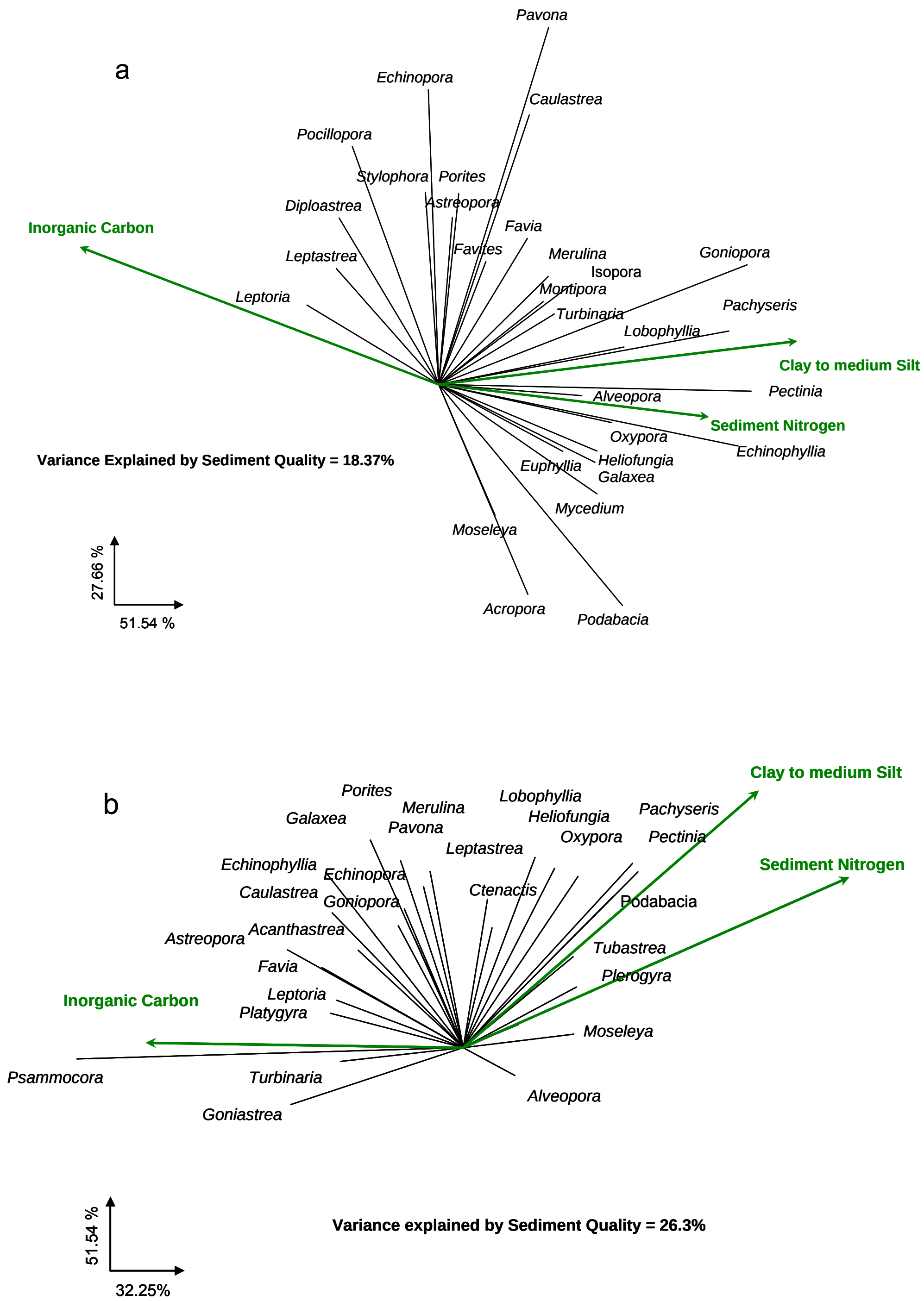


Figure 3.15. Redundancy analysis biplots showing the relationship between grain size, carbon and nitrogen composition of reef sediments and hard coral community composition (genus-level) of a) adult colonies expressed as cover, and b) juvenile colonies. Regional differences among communities were not removed as they are confounded with sediment variables. Vectors indicate the dimension of the greatest variation in values of sediment variables (thick green arrows) or relative abundance of a coral genus (thinner black lines). Genera whose vectors align most closely with the vector for a sediment variable co- vary most with that variable; vectors in opposing directions indicate negative associations; vectors at right angles indicate little or no association. Note that genera that varied little in the plotted dimensions (very short vectors) were removed for clarity.

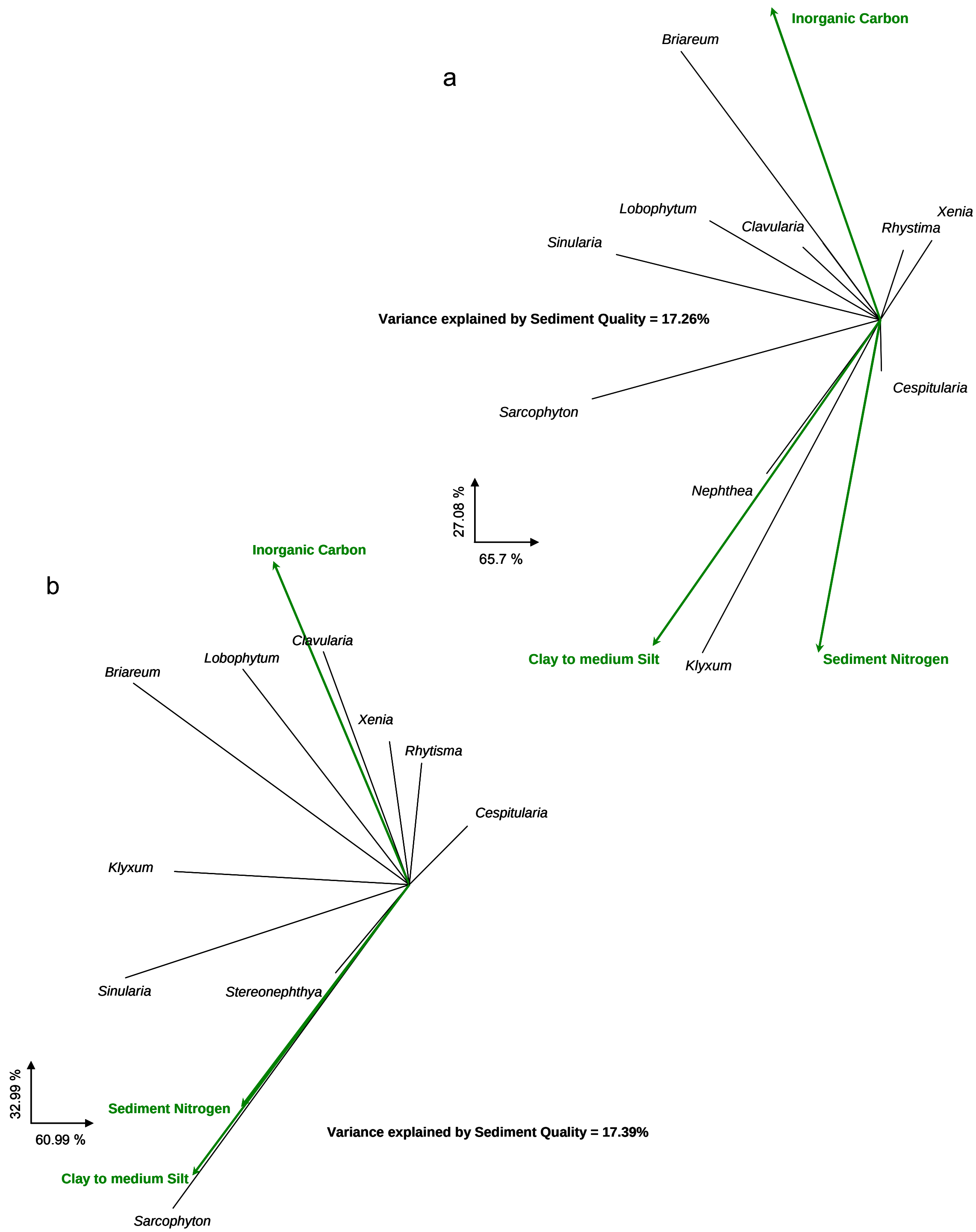


Figure 3.16. Redundancy analysis biplots showing the relationship between grain size, carbon and nitrogen composition of reef sediments and soft coral community composition (genus-level) of a) adult colonies expressed as cover, and b) juvenile colonies. Regional differences among communities were not removed as they are confounded with sediment variables. Vectors indicate the dimension of the greatest variation in values of sediment variables (thick green arrows) or relative abundance of a coral genus (thinner black lines). Genera whose vectors align most closely with the vector of a sediment variable co-vary most with that variable; vectors in opposing directions indicate negative associations; vectors at right angles indicate little or no association. Note that genera that varied little in the plotted dimensions (very short vectors) were removed for clarity.

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

Wet Tropics NRM region: Barron-Daintree sub-region

Sampling effort in this sub-region was reduced from five reefs in 2005 and 2006 to two reefs in 2007 as a result of agreed changes to the sampling design of the coral reef component of the Reef Plan MMP. Monitoring of Daintree South, Daintree Central, and Daintree North were discontinued Results from 2007 surveys of Snapper Island North and Snapper Island South are included in this report.

Snapper Island reefs have been monitored by Sea Research since 1995. This historical data show that while these reefs experienced several disturbances (Table A1-3.3) they showed resilience with coral cover tending to increase in inter-disturbance periods (Ayling and Ayling 2005). 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 a 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 2007 there have been no further disturbances to these reefs and the benthic communities at both depths of both reefs showed increases in the cover of hard and soft corals (Figure 3.17). While the cover of macroalgae has also increased slightly on these reefs the cover in 2007 is still below the average over all reefs surveyed. In conjunction with increased cover the richness of hard coral genera has also increased at both depths of both reefs.

The number of juvenile corals per square metre averaged across all size classes was slightly higher in 2007 than 2006 at both depths of both reefs (Figure 3.18). At Snapper North, however, these numbers were slightly below those observed in 2005. Correcting for the substantial increase in coral cover indicates that the density of juvenile hard corals per area of substrate available for settlement was marginally higher in 2007 than 2005. The high coral cover, and as such reduced area of substrate available to coral recruitment, should also be taken into account when viewing the below overall average density of juvenile corals at the 5m sites of these reefs (Figure 3.18).

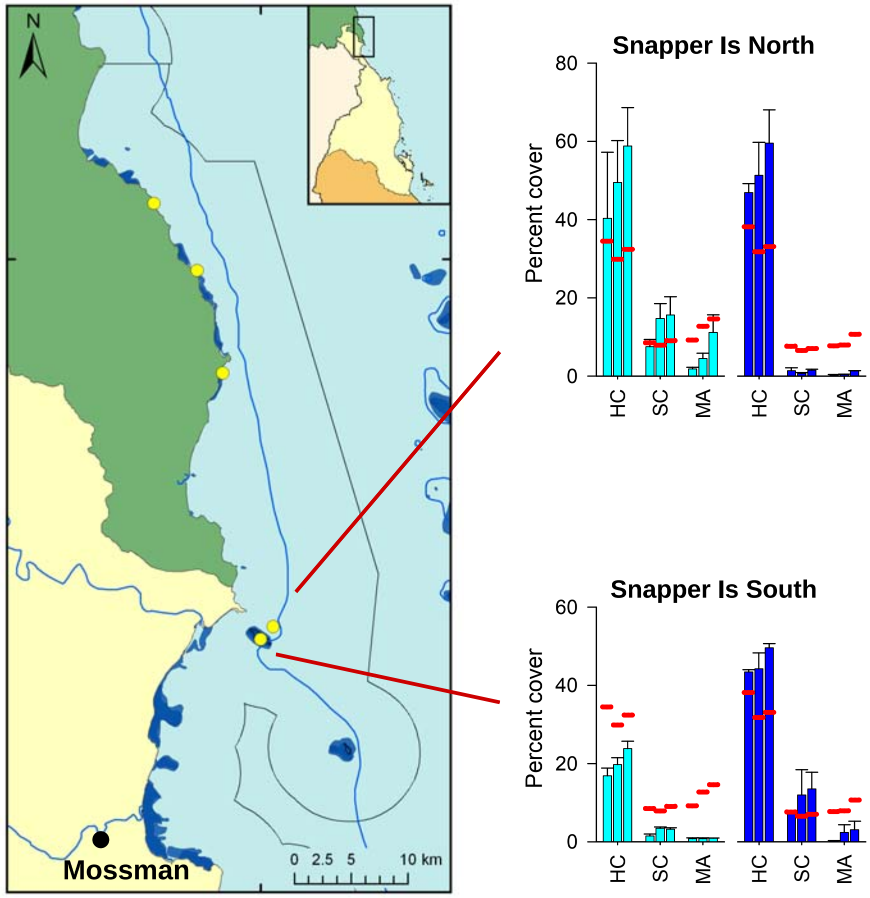


Figure 3.17. Percent cover estimates of major benthic groups, hard coral (HC), soft coral (SC) and macroalgae (MA) on reefs in the Barron Daintree sub-region of Wet Tropics NRM region. Pale blue bars represent values for 2m depth and dark blue bars for 5m depth. Average values for each group and depth from all reefs and NRM regions combined are indicated by red lines. For each benthic group the three bars represent, from left to right, data from 2005, 2006 and 2007.

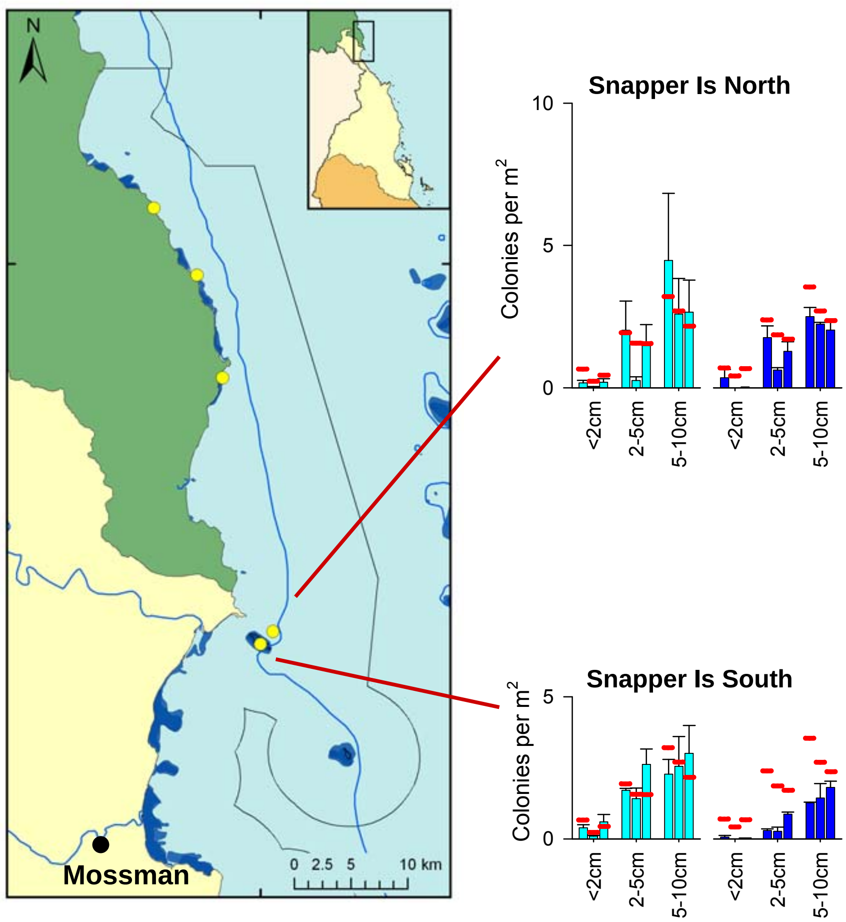


Figure 3.18. Abundance of juvenile hard coral colonies by size class for reefs in the Barron Daintree sub-region of the Wet Tropics NRM region. Pale blue bars represent values for 2m depth and dark blue bars for 5m depth. Average values for each size class and depth from all reefs and NRM regions combined are indicated by red lines. For each size class the three bars represent, from left to right, data from 2005, 2006 and 2007.

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

Of the reefs surveyed in this sub-region 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 Plan MMP have documented four major disturbances that have resulted in 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 (TableA1-3.3). In 1998 coral bleaching affected all coral communities on the target reefs in this NRM region. The eastern reefs of the Frankland Group suffered the greatest coral mortality 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.* 2001), 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. 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.

Comparing pilot surveys in 2004 (Sweatman *et al.* 2007) and Reef Plan MMP surveys in 2005 indicates a period of recovery of hard corals at both the Frankland Group and High Island. This was especially evident on eastern reefs where hard coral cover increased notably and especially at 2m were there was a high component of the fast growing *Acropora* genus. There was also a general increase in the density of juvenile colonies over this period indicating continued recruitment. The western reef of the Frankland Group was an exception to this pattern with little change in hard coral cover.

Between 2005 and 2006 Cyclone Larry passed to the south of this sub-region. The main impact was a substantial reduction in the cover of hard corals at site 1 of the Frankland Group East and some toppling of large *Porites* that resulted in a decline in cover at High Is West. In 2007 there had been no evidence of recovery from the cyclone with cover very similar or even declining further on the impacted reefs (Figure 3.19). At Frankland East the cover of macroalgae in 2007 had increased at 2m colonising some of the space made available by the reduction in coral cover. In contrast, reefs not impacted by Cyclone Larry have shown marked increases in the cover of hard corals due mostly to increasing cover of the genus *Acropora*. The exception to this generalisation is the western reef of the Frankland group where coral has remained relatively stable. There was a slight decline in coral cover between 2006 and 2007 at 5m were a small increase in the cover of macroalgae has reduced the estimate of coral cover. The community here however still maintains a very high cover of the genus *Porites* with cover in 2007 very similar to that observed in 2005. Even considering the slight increases in macroalgae cover observed on reefs in the Frankland Group this component of the benthic community remains regionally low. The cover of soft corals has remained stable over the period 2005 to 2007 with the exception of sites at Fitzroy West where slight declines contrast increases in hard coral cover.

The density corals juveniles (<10cm in diameter) has declined annually from 2005 to 2007 (Figure 3.8b). Accounting for increases in coral cover and hence the proportion of the survey sites available to corals to settle and grow does not fully explain the decline in the density of juveniles observed (see Figure 3.8a). For most reefs however density of juvenile colonies in 2007 were still at or above the average density observed over all reefs surveyed (Figure 3.20). The only coral community to have substantially lower than average numbers of juvenile colonies was at 5m at Frankland Group West where coral cover was very high at 66% and hence the limited space available for recruitment largely explains the low values observed in this instance.

Regionally, settlement to tiles has increased each year between and 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 consistent to all reefs (Figure 3.21). Of particular interest is the substantial increase in settlement at Frankland Island Group Front a site that recorded low settlement in 2006 following disturbance associated with

Cyclone Larry. During the deployment of tiles in 2006 it was noted that a bloom of blue-green algae was occurring at this site this had largely disappeared during the 2007 tile deployments. It is feasible that this bloom represented a short-term deterrent to coral larvae searching for a settlement substrate. 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.

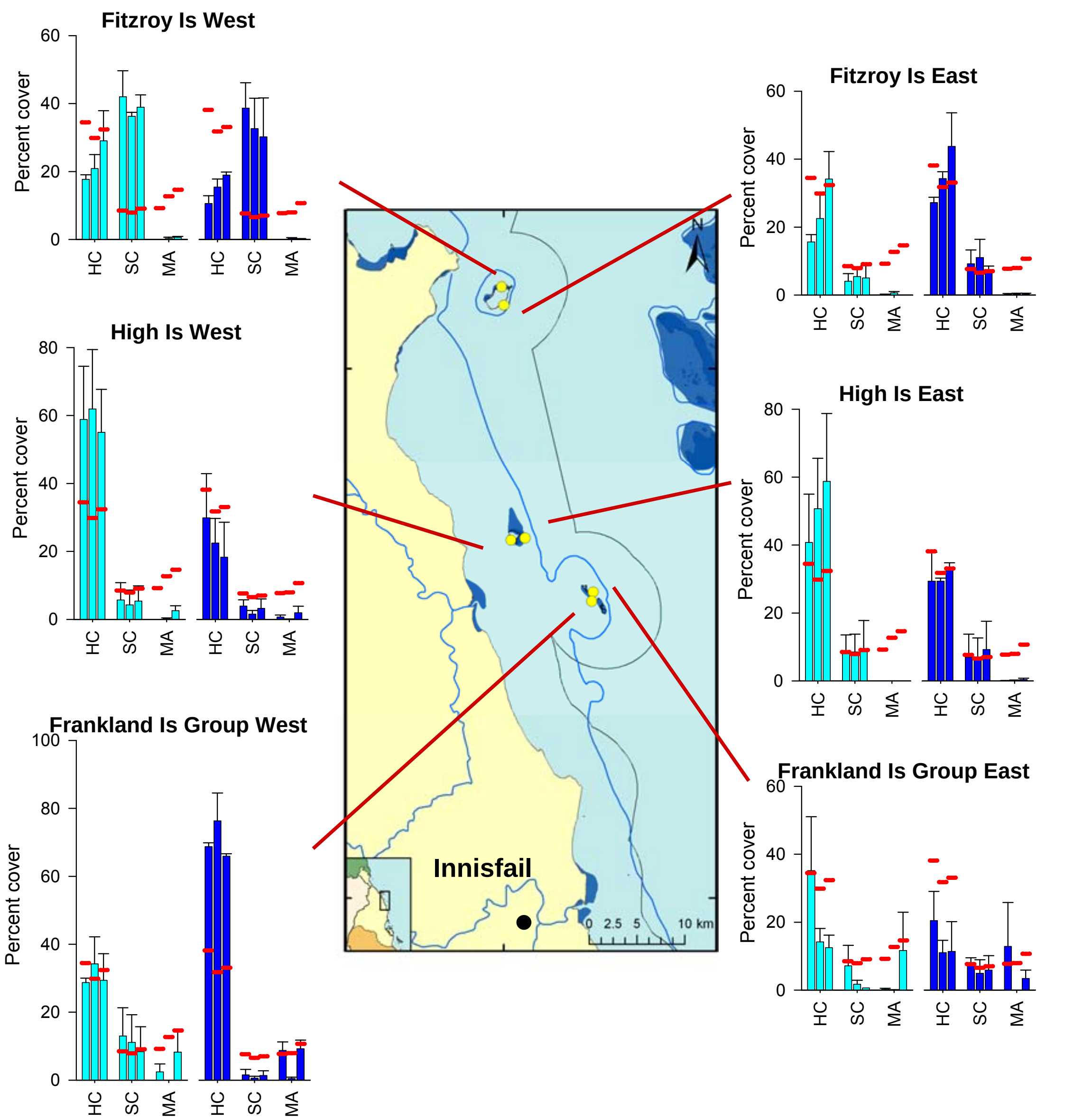


Figure 3.19. Percent cover estimates of major benthic groups, hard coral (HC), soft coral (SC) and macroalgae (MA) on reefs in the Johnstone Russell-Mulgrave sub-region of the Wet Tropics NRM region. Pale blue bars represent values for 2m depth and dark blue bars for 5m depth. Average values for each group and depth from all reefs and NRM regions combined are indicated by red lines. For each benthic group the three bars represent, from left to right, data from 2005, 2006 and 2007.

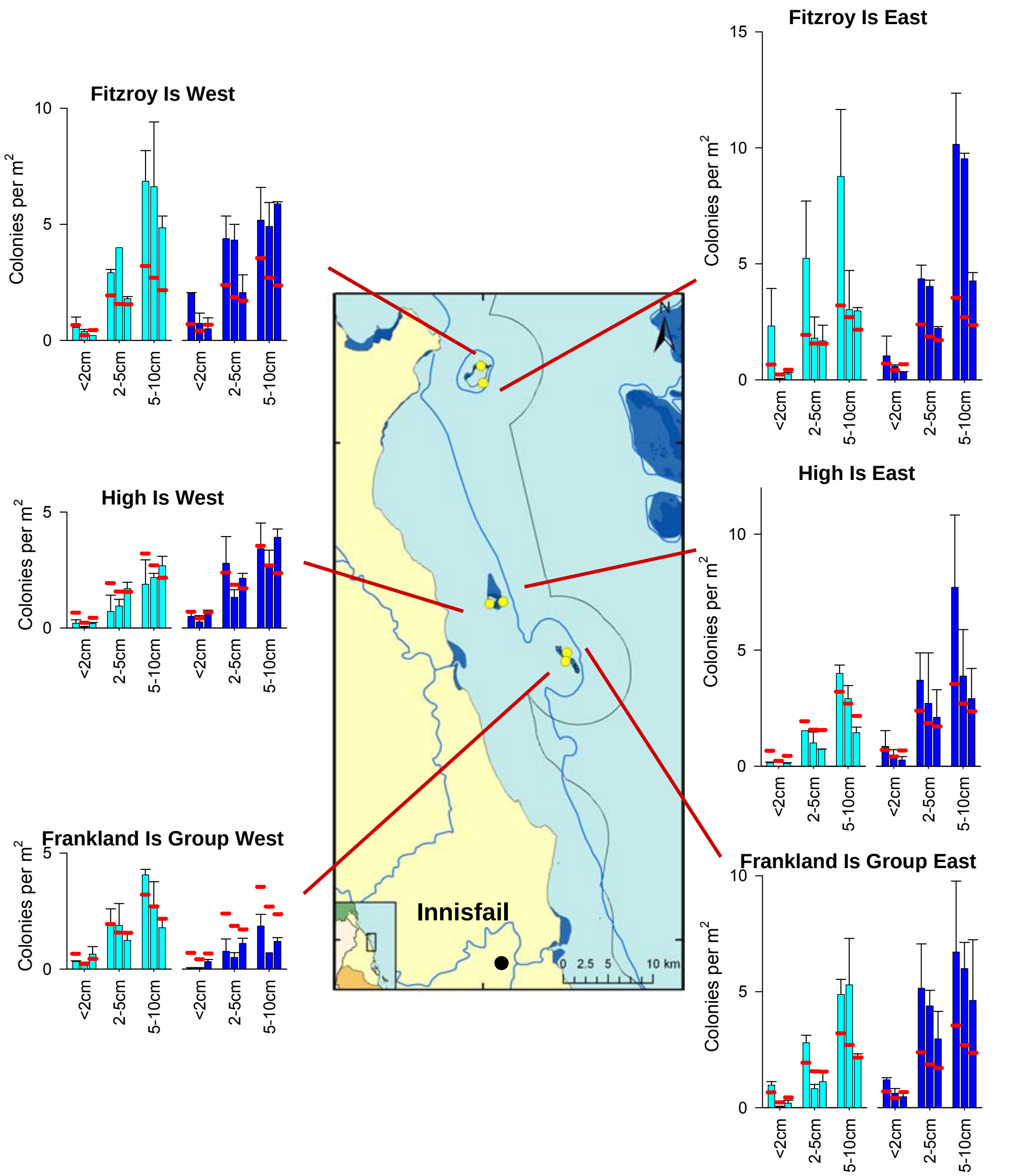


Figure 3.20. Abundance of juvenile hard coral colonies by size class for reefs in the Johnstone Russell-Mulgrave sub-region of the Wet Tropics NRM region. Pale blue bars represent values for 2m depth and dark blue bars for 5m depth. Average values for each size class and depth from all reefs and NRM regions combined are indicated by red lines. For each size class the three bars represent, from left to right, data from 2005, 2006 and 2007.

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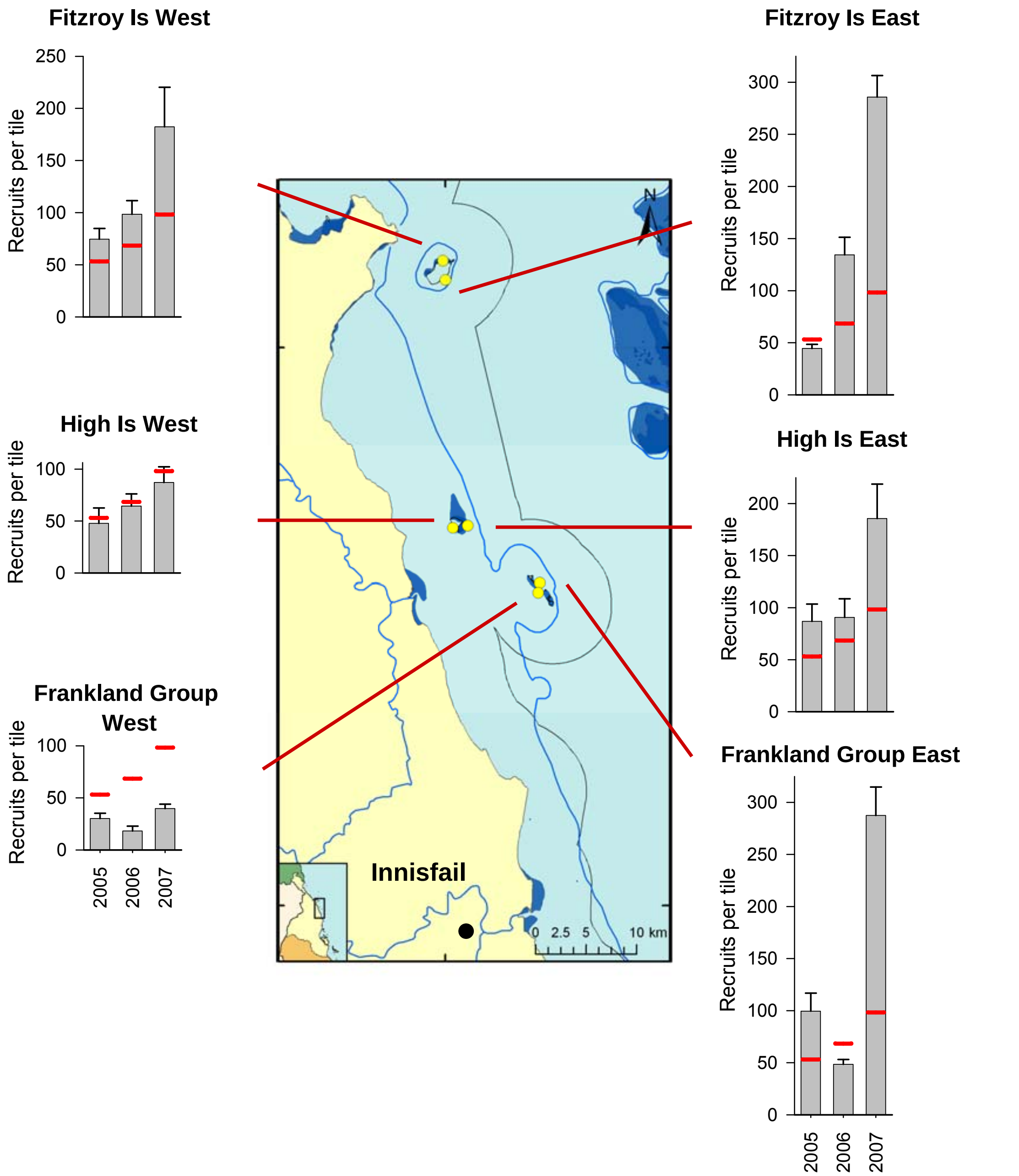

Figure 3.21. Average number of coral recruits per tile on reefs in the Johnstone Russell-Mulgrave sub-region of the Wet Tropics NRM region. Data are from 5m tile deployments. Average values from all reefs and NRM regions sampled in each year are indicated by red lines. It should be noted that comparison of over all means (red lines) over time is not possible as the regions sampled vary among years (2005 includes reefs from the Wet Tropics and Mackay Whitsunday NRM regions, in 2006 sampling also included reefs from the Fitzroy NRM region and then 2007 included these and also reefs from the Burdekin NRM region).

Wet Tropics NRM region: Herbert Tully sub-region

The past dynamics of the reefs in this region are largely unknown as no quantitative monitoring has been undertaken prior to Reef Plan 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 A1-3.3) thought 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 A1-3.3). Similar reductions in hard coral cover (43%) to those observed by Ayling and Ayling (2005) at the Frankland Island Group in 1998 are quite possible.

There is little available information describing coral communities of either the North Barnard Group or Dunk Island North sites surveyed by Reef Plan MMP are very close to but not exactly the same as those surveyed in 2004 using a similar suite of methods (Sweatman *et al.* 2007). Comparison between these 2004 data and data collected in 2005 indicate little change in the coral communities over the intervening year with high coral covers and high densities of juvenile colonies at both reefs. In March 2006 Cyclone Larry severely impacted both the North Barnard Group and Dunk Island North reefs resulting in a substantial reduction in the cover of hard and soft corals and also macroalgae (Figure 3.22). In 2007 there had been negligible change in the covers of either hard or soft corals but macroalgae cover had increased at both depths on both depths (Figure 3.22).

Prior to Cyclone Larry the density of juvenile corals was at or above average for reefs included in the Reef Plan MMP with the densities at both 2m and 5m very high at North Barnard Group sites in particular. The density of juvenile colonies was markedly reduced by the cyclone and The North Barnard Group sites and to a lesser degree at 5m at Dunk Island North. In 2007 a high number of very small recruits were recorded at 5m at North Barnard Group sites which may indicate the beginning of a recovery cycle. The density of juvenile hard coral colonies at Dunk Island North were not as severely impacted as at North Barnard Group and though declined from 2006 to 2007 were still at or above the average for all reefs included in the 2007 survey (Figure 3.23).

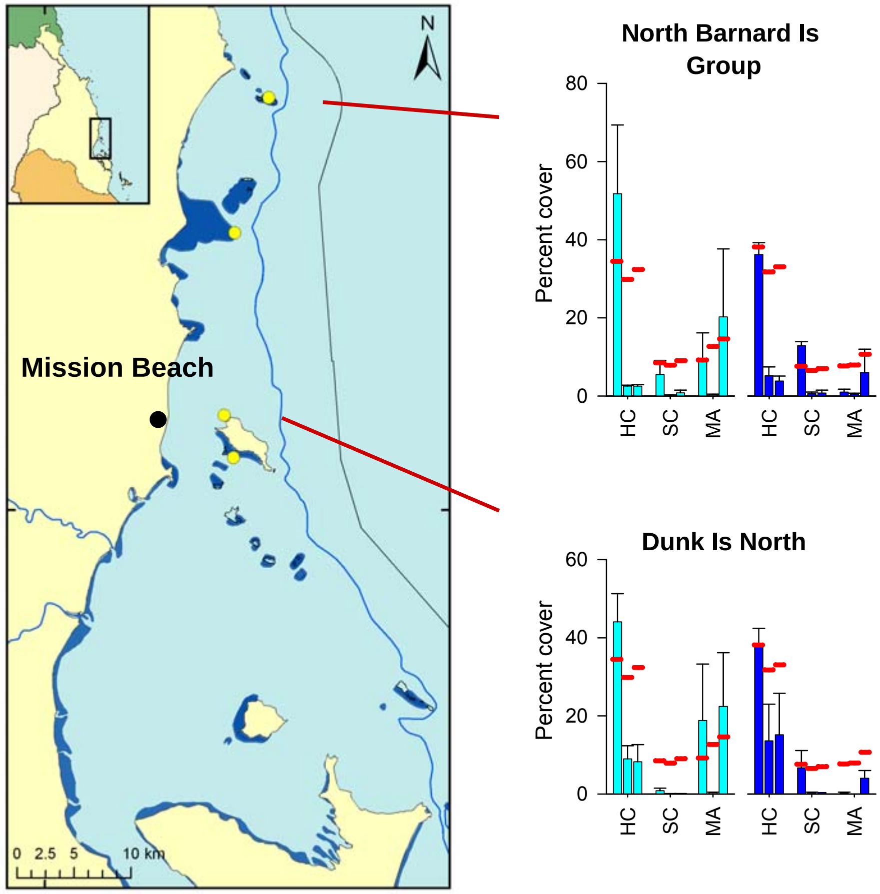

Figure 3.22. Percent cover estimates of major benthic groups, hard coral (HC), soft coral (SC) and macroalgae (MA) on reefs in the Herbert Tully sub-region of Wet Tropics NRM region. Pale blue bars represent values for 2m depth and dark blue bars for 5m depth. Average values for each group and depth from all reefs and NRM regions combined are indicated by red lines. For each benthic group the three bars represent, from left to right, data from 2005, 2006 and 2007.

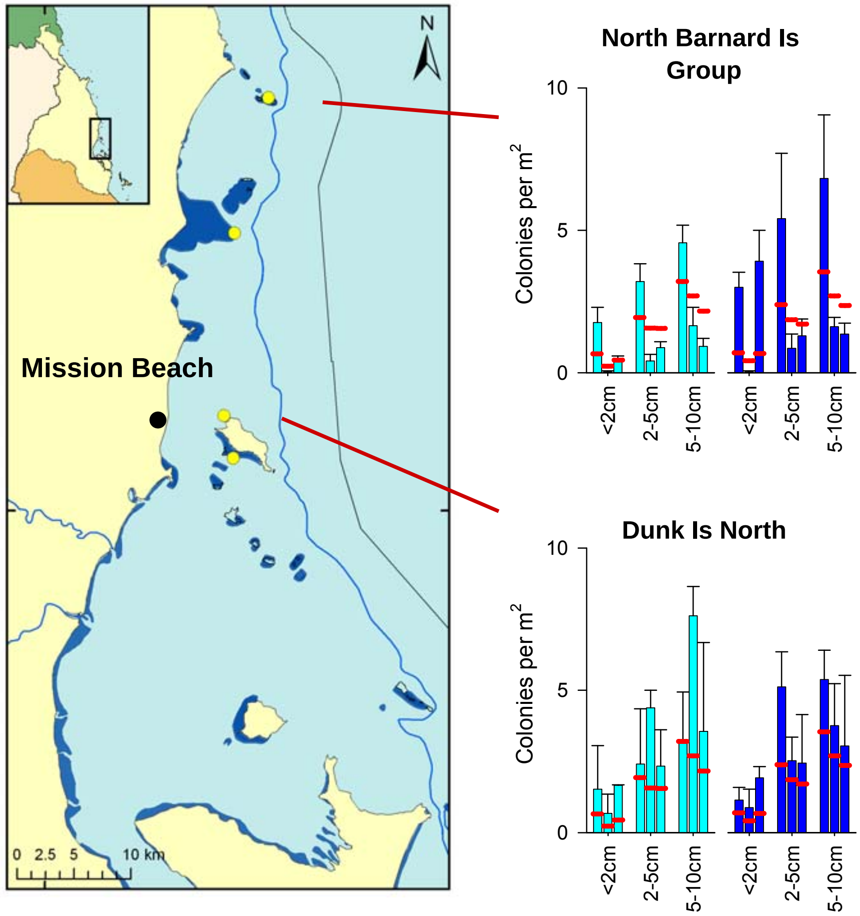

Figure 3.23. Abundance of juvenile hard coral colonies by size class for reefs in the Herbert Tully sub-region of Wet Tropics NRM region. Pale blue bars represent values for 2m depth and dark blue bars for 5m depth. Average values for each size class and depth from all reefs and NRM regions combined are indicated by red lines. For each size class the three bars represent, from left to right, data from 2005, 2006 and 2007.

Burdekin NRM region

Historical monitoring information about the reefs in this catchment highlights the intense and frequent nature of disturbance to some reefs (Ayling and Ayling 2005, Sweatman *et al.*, 2007, Table A1-3.3). 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 A1-3.3). In 2002 bleaching was less severe than 1998 but still affected the majority of coral communities (Table A1-3.3). 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 a local COTS outbreak at that site 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. However, surveys on Pandora Reef after the major flooding event of 1998 found that around 80% of the corals were bleached to a depth of about 10 metres. This indicates that the effects of the flood plume may have exacerbated the impacts of high temperature during this period (Devantier, Fabricius unpublished). 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 (Figures 3.5 and 5.7). There were no substantial disturbances between surveys in 2005 and 2007, 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 3.24). The most variable benthic group was macroalgae and this should be expected given the seasonal and ephemeral nature of some species. Some of the observed variability in coral cover on these reefs likely reflects changes in the proportion of the coral community obscured at the time of sampling by overhanging macroalgae.

The relatively low density of juvenile colonies (Figure 3.25) coupled with the low cover of hard corals limit the potential for increase in coral cover. The density of juvenile colonies corrected for the proportion of space available for recruitment indicates that the values observed at Pandora Reef and Havannah Island are the lowest recorded for any reef included in this study excepting some reefs that were severely impacted by either bleaching or Cyclone Larry in 2006. Both the high levels of macroalgae present on these reefs and the relatively low supply of larvae (as measure by number of spat settling to tiles, Figure 3.26) are likely to by influencing the low density of juvenile colonies and hence recovery potential of the coral communities in this region.

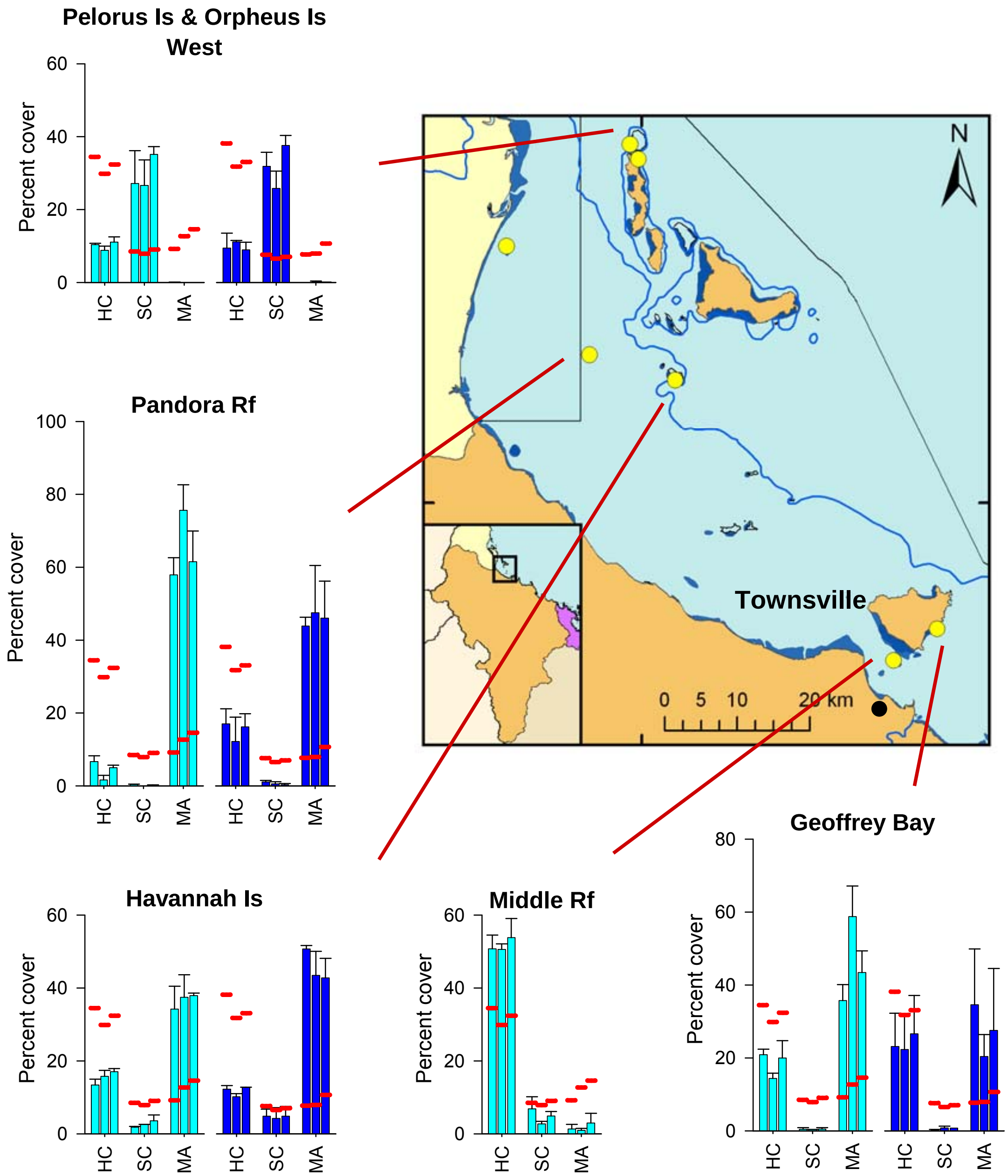

Figure 3.24. Percent cover estimates of major benthic groups, hard coral (HC), soft coral (SC) and macroalgae (MA) on reefs in the Burdekin NRM region. Pale blue bars represent values for 2m depth and dark blue bars for 5m depth. Average values for each group and depth from all reefs and NRM regions combined are indicated by red lines. For each benthic group the three bars represent, from left to right, data from 2005, 2006 and 2007.

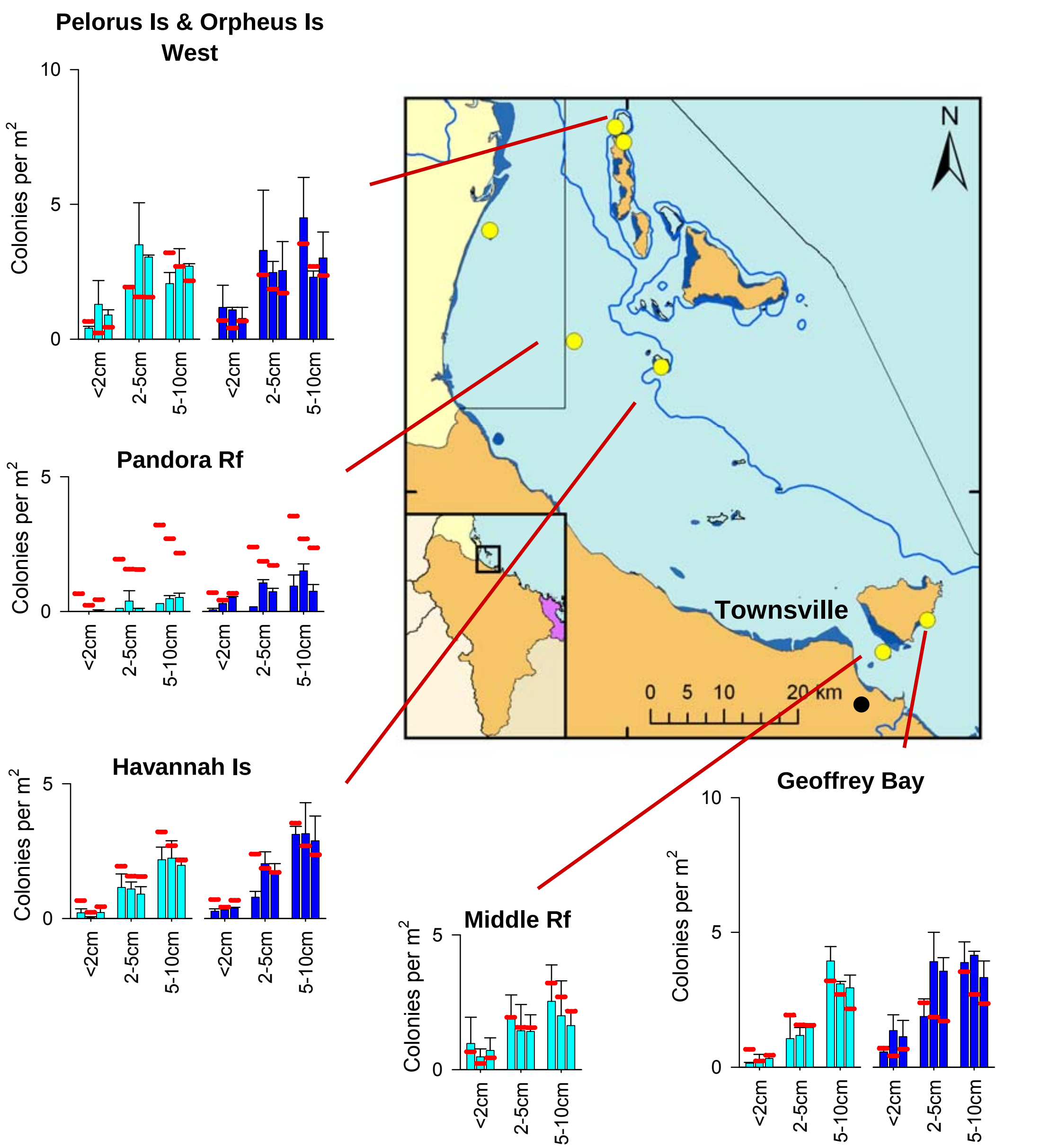

Figure 3.25. Number of juvenile hard coral colonies by size class for reefs in the Burdekin NRM region. Pale blue bars represent values for 2m depth and dark blue bars for 5m depth. Average values for each size class and depth from all reefs and NRM regions combined are indicated by red lines. For each size class the three bars represent, from left to right, data from 2005, 2006 and 2007.

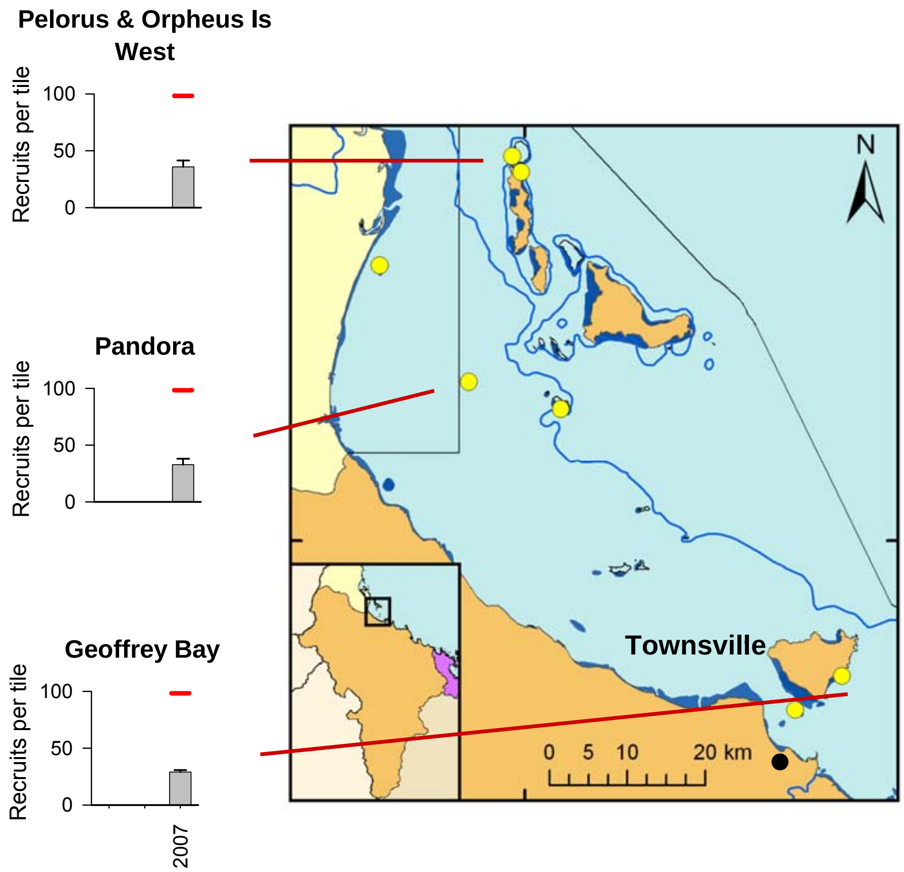

Figure 3.26. Average number of coral recruits per tile on reefs in the Burdekin NRM region. Average values from all reefs and NRM regions sampled in that year are indicated by red lines.

Mackay Whitsunday NRM region

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 target fringing reefs in this region (Table A1-3.3). Between 2005 and 2007 there were no major disturbances to the reefs in this region and this is reflected in largely unchanging regional estimates of the covers of the major benthic groups (Figures 3.5, 3.6 & 3.7). For the 5 reefs surveyed in 2007 the average cover of hard corals has declined from 42.5 % in 2005 to 41% in 2007, the largest decline in cover was at 5m at Dent Island with hard coral declining from 55% to 43% over the two years (Figure 3.27). There were no substantial changes to the cover of either soft corals or macroalgae. The cover of macroalgae in 2007 remained very low at Dent, Double Cone and Daydream Islands and high at 2m depth at both Pine and Seaforth Islands.

Between 2005 and 2006 there was an unexplained decline in the density of juvenile colonies regionally. This decline did not continue through to 2007 with densities very similar between 2006 and 2007 on most reefs (Figure 3.28). The density of juvenile colonies in 2007 was at or slightly below the overall average for reefs surveyed under the Reef Plan MMP. The density of juvenile colonies was lowest at Double Cone Island at 5m. However this is almost certainly due to the lack of substrate available to coral recruits because of the very high coral cover at this site (Figure 3.27).

Settlement of coral recruits to tiles has been reasonably similar over the three reefs and three years of records. The number of spat recorded in 2005 at Double Cone Island was, however, very low in 2005 and regionally high at Daydream Island 2007 (Figure 3.29).

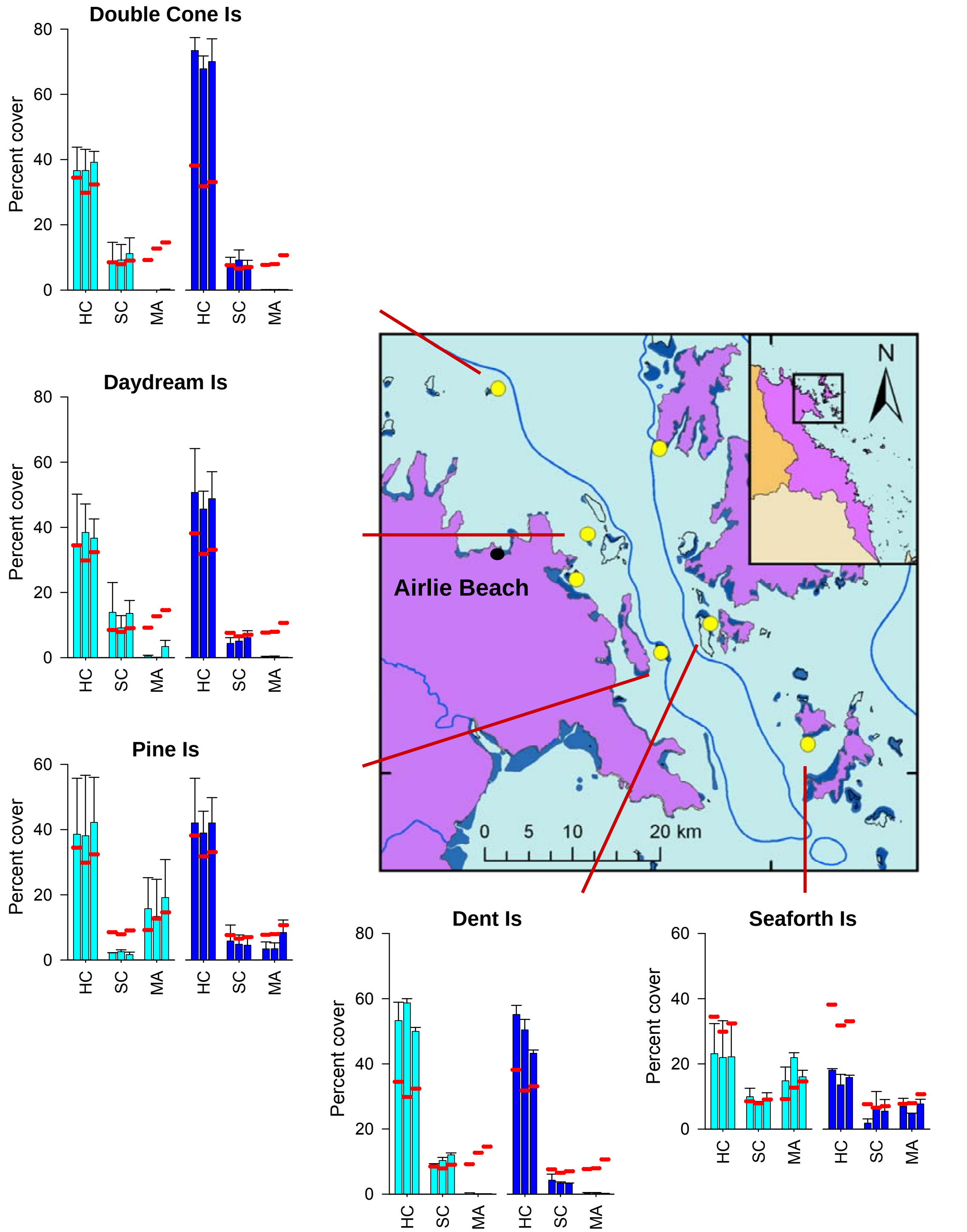

Figure 3.27 Percent cover estimates of major benthic groups, hard coral (HC), soft coral (SC) and macroalgae (MA) on reefs in the Mackay Whitsunday NRM region. Pale blue bars represent values for 2m depth and dark blue bars for 5m depth. Average values for each group and depth from all reefs and NRM regions combined are indicated by red lines. For each benthic group the three bars represent, from left to right, data from 2005, 2006 and 2007.

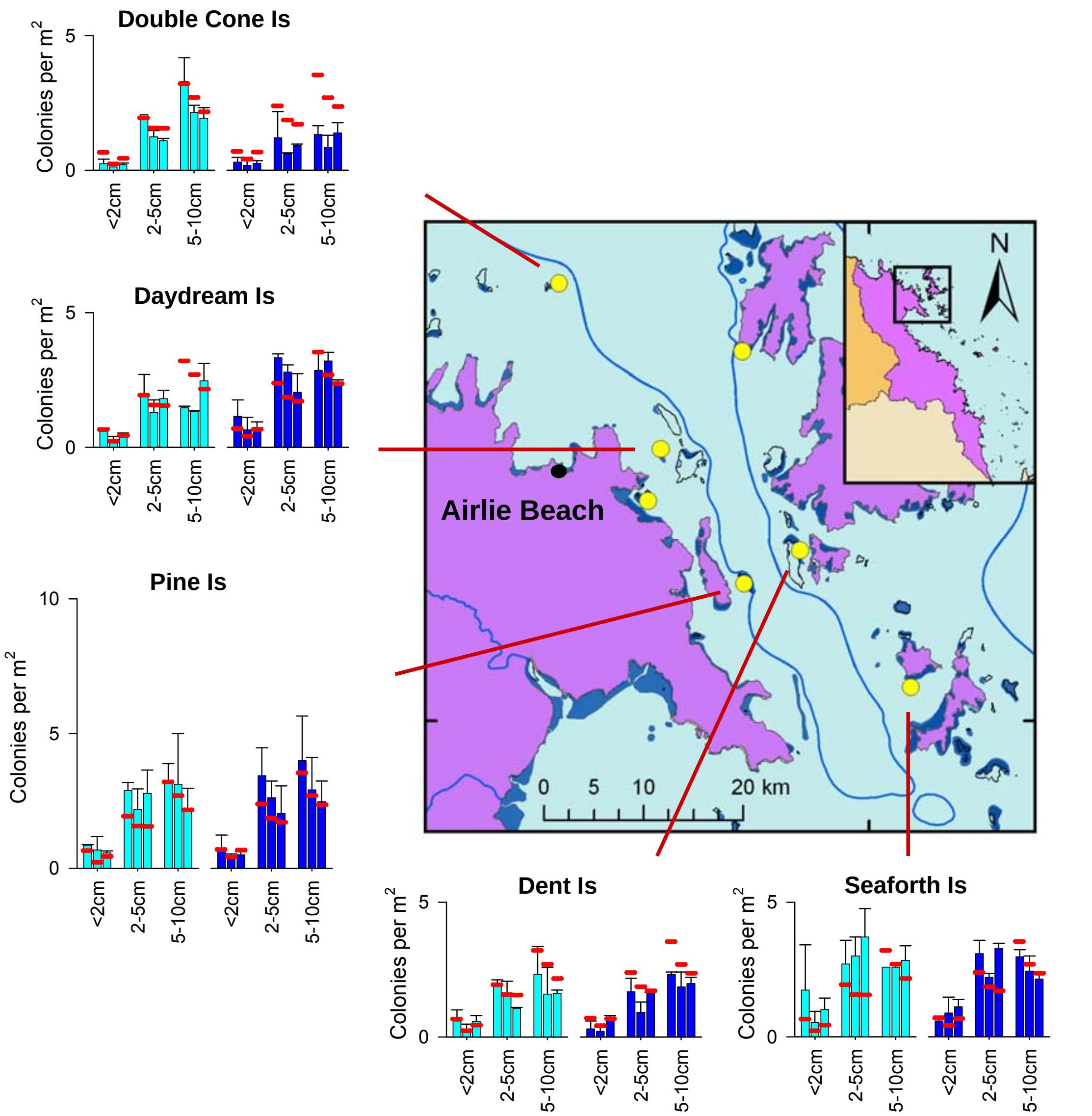

Figure 3.28. Abundance of juvenile hard coral colonies by size class for reefs in the Mackay Whitsunday NRM region. Pale blue bars represent values for 2m depth and dark blue bars for 5m depth. Average values for each size class and depth from all reefs and NRM regions combined are indicated by red lines. For each size class the three bars represent, from left to right, data from 2005, 2006 and 2007.

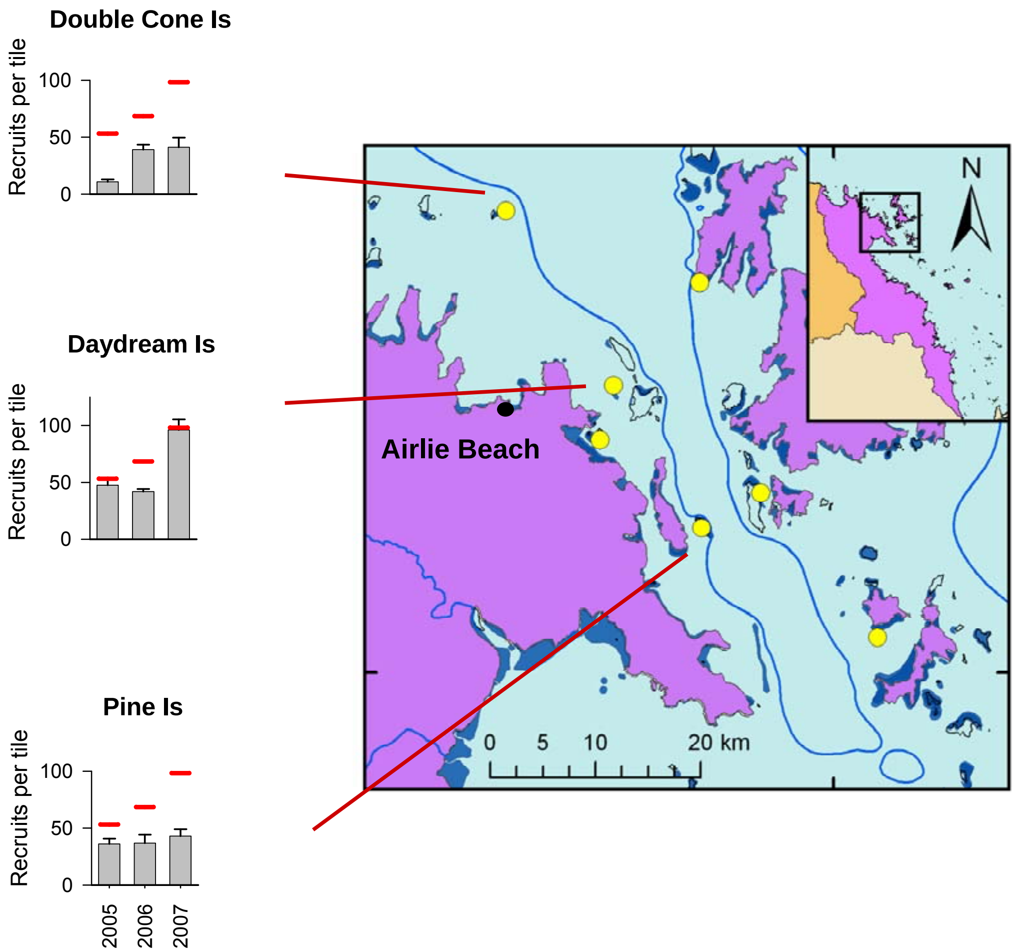

Figure 3.29. Average number of coral recruits per tile on reefs in the Mackay Whitsunday NRM region. Data are from 5m tile deployments. Average values from all reefs and NRM regions sampled in each year are indicated by red lines. It should be noted that comparison of over all means (red lines) over time is not possible as the regions sampled vary among years (2005 includes reefs from the Wet Tropics and Mackay-Whitsunday NRM regions, in 2006 sampling also included reefs from the Fitzroy NRM region and then 2007 included these and also reefs from the Burdekin NRM region).

Fitzroy NRM region

Historical data on benthic communities are available for three of the six reefs selected in this region. Humpy, Halfway and Middle Island 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 Island) or 1996 (Halfway Island) (Sweatman *et al.* 2007)

Between 1991 and 2006, several disturbance events have caused reductions in the coral cover at reefs monitoring 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, Halfway and Middle Island; 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 A1-3.3). Coral cover showed rapid recovery following bleaching in 1998 and 2002 (Sweatman *et al.* 2007).

The propensity for hard coral communities in this region to recover from disturbance was evident in 2007 with coral cover increasing at Barren Island and at 2m at Humpy and Halfway following declines in 2006 due to bleaching (Figure 3.30). These increases contrast continued declines at 5m at Humpy and Halfway Islands and both depths at North Keppel Island where marked increase in the cover of macroalgae (specifically the genus *Lobophora*) may be retarding the recovery of hard corals at least in the short term. The coral community at Pelican Island were not impacted by bleaching in 2006. Here the hard coral community at 2m has shown a substantial increase in cover over between 2005 and 2007 while the deeper community has remained stable (Figure 3.30).

Regionally the density of hard coral recruits is low (Figure 3.31). This along with the rapid increase in cover following disturbances indicates recovery of coral cover is 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) and 2005 surveys (Figure 3.31) indicate that the high numbers of small *Acropora* colonies observed in these surveys are largely responsible for the rapid increase in cover at this location.

In 2006 settlement at Pelican and Halfway/Humpy Islands was similar and well above the all regions average (Figure 3.32). At Barren Island however, the number of recruits was 3-4 times lower than recorded at the two other survey reefs and well below the all region average (Figure 3.32). In 2007 settlement at Barren Island was again lower than at the other two reefs, however, this difference was not as extreme due to the lower settlement recorded at both Pelican and Halfway/Humpy Islands. The strong variability in settlement between years may simply reflect patchiness in larval supply, however, may also be an artefact of an unexpectedly late spawning of corals in this region.

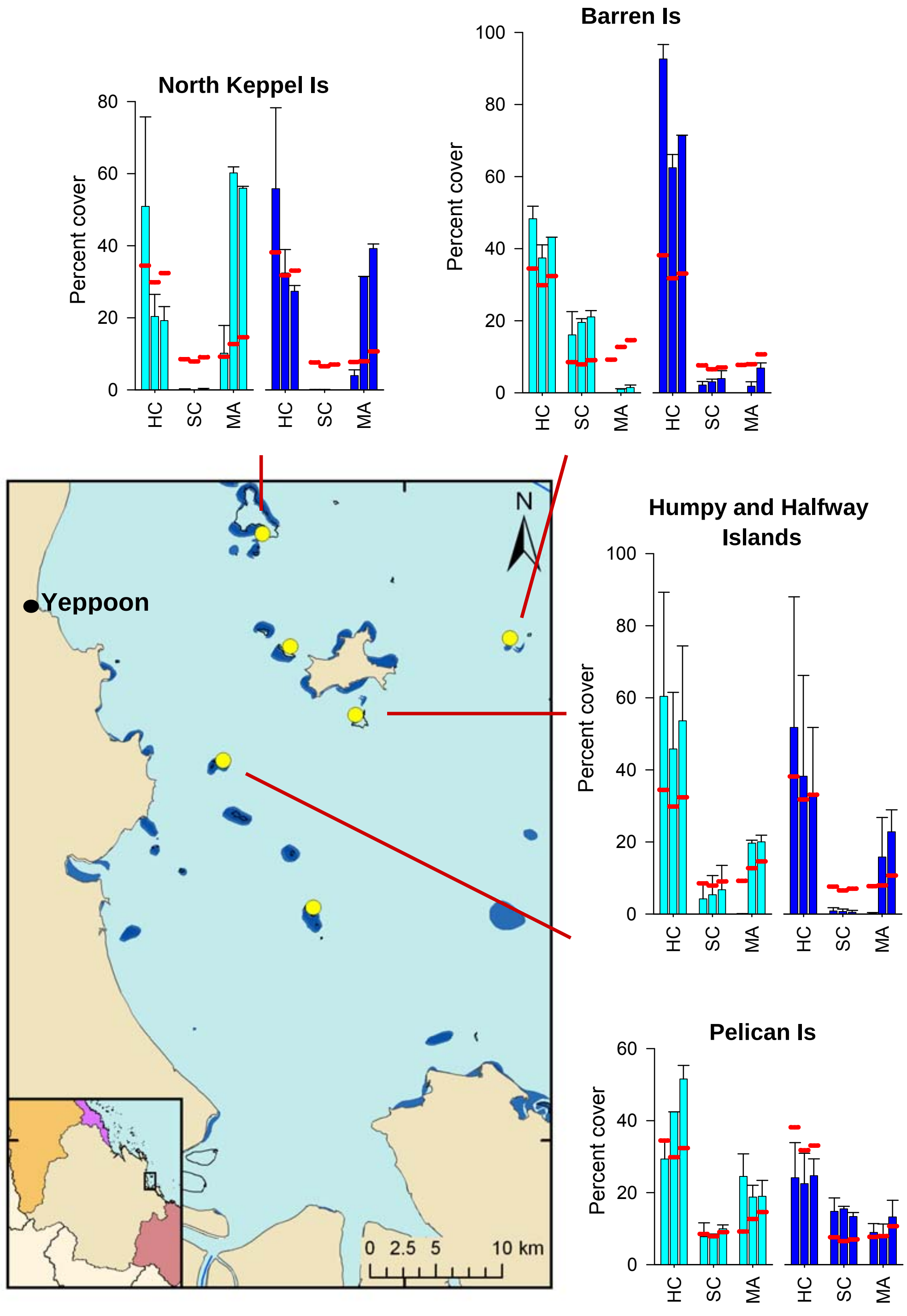

Figure 3.30. Percent cover estimates of major benthic groups, hard coral (HC), soft coral (SC) and macroalgae (MA) on reefs in the Fitzroy region. Pale blue bars represent values for 2m depth and dark blue bars for 5m depth. Average values for each group and depth from all reefs and NRM regions combined are indicated by red lines. For each benthic group the three bars represent, from left to right, data from 2005, 2006 and 2007.

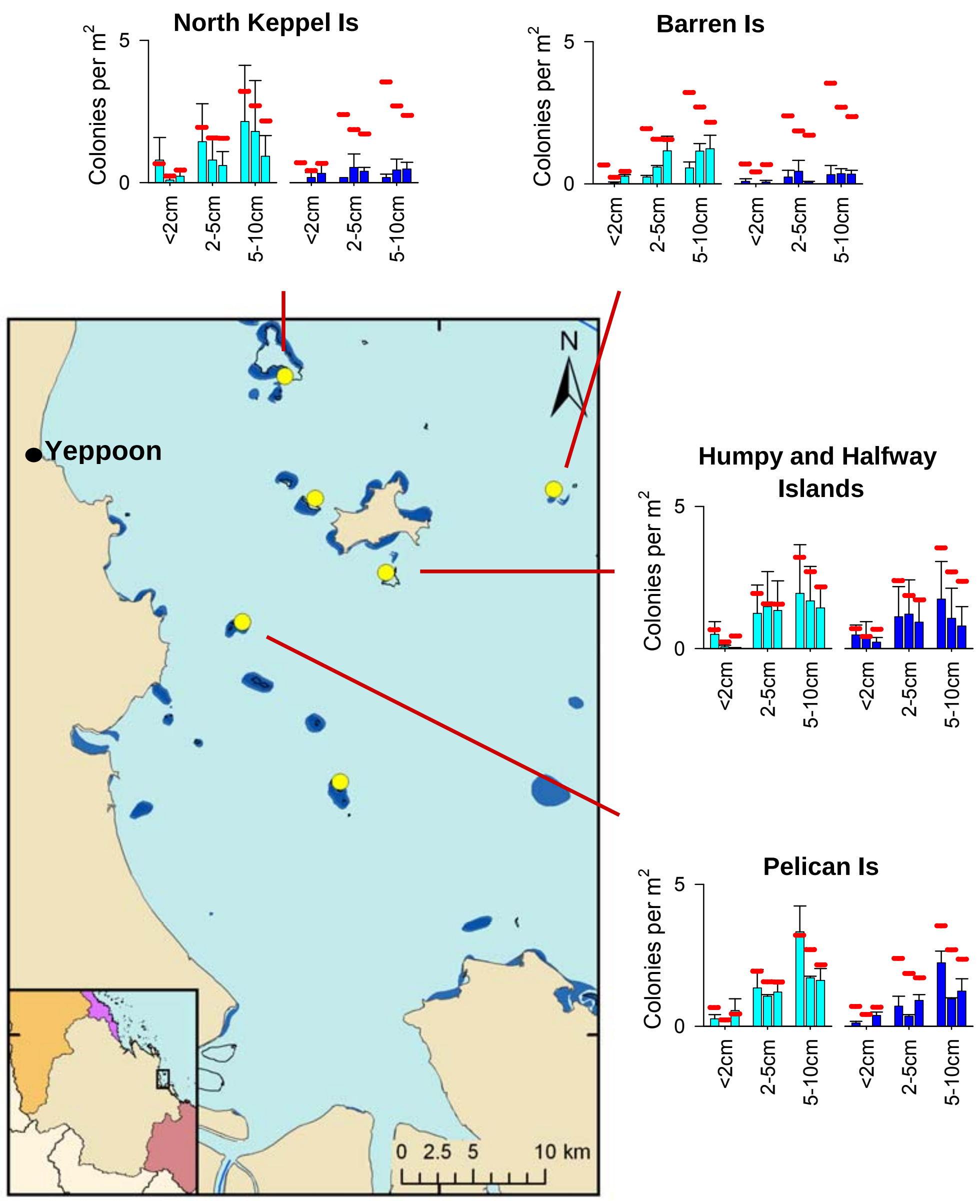

Figure 3.31. Abundance of juvenile hard coral colonies by size class for reefs in the Fitzroy region. Pale blue bars represent values for 2m depth and dark blue bars for 5m depth. Average values for each size class and depth from all reefs and NRM regions combined are indicated by red lines. For each size class the three bars represent, from left to right, data from 2005, 2006 and 2007.

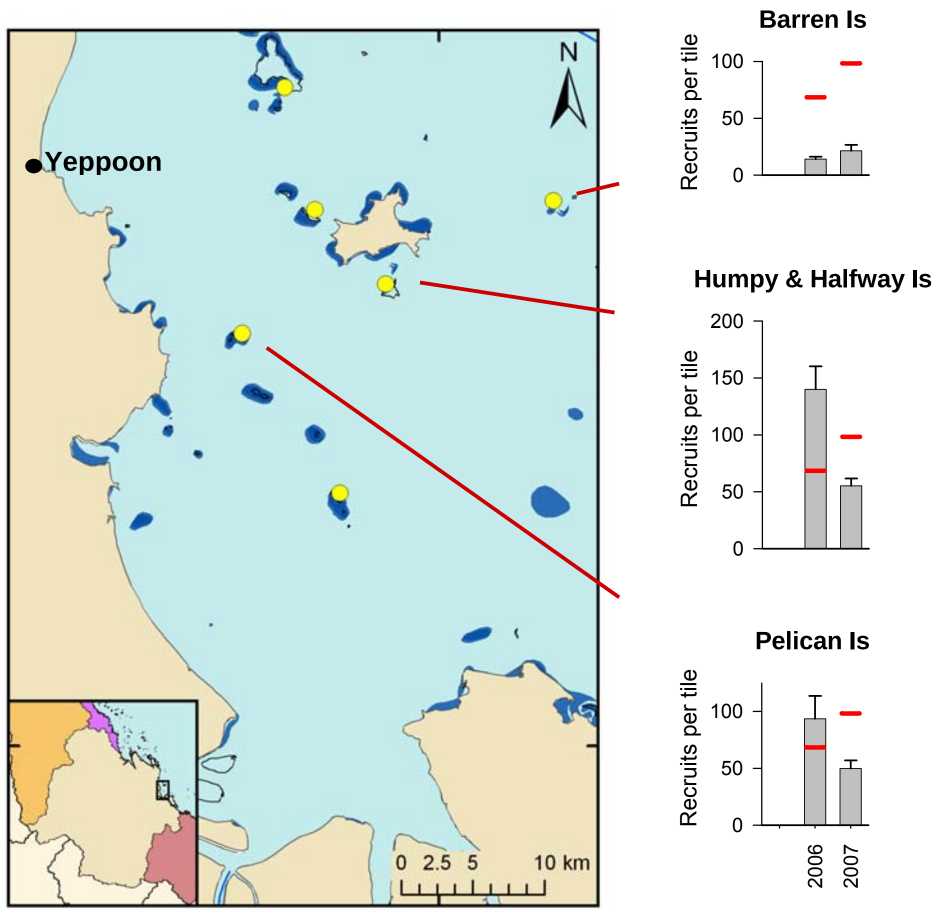

Figure 3.32. Average number of coral recruits per tile on reefs in the Fitzroy Basin Association NRM region. Data are from 5m tile deployments. Average values from all reefs and NRM regions sampled in each year are indicated by red lines. It should be noted that comparison of over all means over time (red lines) is not possible as the regions sampled vary among years (2006 includes reefs from the Wet Tropics, Mackay-Whitsunday and Fitzroy Basin Association NRM regions only while 2007 means include data from these reefs in addition to Burdekin NRM region reefs.

Foraminifera assemblages

Foraminifera are calcareous single celled animals, or protists, abundant in benthic and pelagic marine environments. In shallow water habitats, some benthic foraminifera were found to be sensitive indicators for pollution (e.g. heavy metals, chemicals, sewage or oil; reviewed in Alve 1995). Many large (up to 2cm in diameter) benthic foraminifera in coral reefs harbour symbiotic algae, similar to corals. Symbiont-bearing foraminifera have high calcification rates and contribute around 30% of the carbonate sediments of the GBR (Scoffin and Tudhope 1985, Yamano *et al.* 2000). Foraminiferan-algal symbioses are believed to be advantageous in clean coral reef waters low in dissolved inorganic nutrients and particulate food sources (Hallock 1981), whereas heterotrophic species would tolerate or even benefit from water quality with high turbidity and high availability of inorganic and particulate nutrients. Foraminifera species composition data from sediment samples were summarised into a simple index and used as an indicator of coral reef water quality in Florida and the Caribbean Sea (FORAM index, Hallock 2000; Hallock *et al.* 2003). The FORAM index has been tested on GBR reefs and corresponded well to water quality variables along a gradient in the Whitsunday islands (Uthicke and Nobes 2008).

METHODS

Sample preparation

Sediment samples were collected from all reefs visited during 2007 (Table 3.1) to describe the composition of the foraminiferan assemblages. At each 5m deep site six 1cm deep cores were collected haphazardly along the length of the site from available deposits. Sediments were washed with freshwater over a 63 µm sieve to remove small particles. After drying (>24 h, 60°C), haphazard subsamples of the sediment were taken and all foraminifera picked, until about 200 foraminifera specimens were collected from the sediment. Only intact specimens which showed no sign of ageing were considered. Samples thus defined are a good representation of the present day biocoenosis (Yordanova and Hohenegger 2002), although not all specimens may have been alive during the time of sampling. Species composition of foraminifera was determined in microfossil slides under a dissection microscope.

Data analyses

To measure relatedness of two similarity matrices (i.e., foraminiferan community data from 2005 and 2007) we used Mantel tests (based on Spearman Rank correlations). To investigate differences in community composition between reefs and regions we used Principal Component Analysis (PCA). Regional (inshore reefs in the Wet Tropics, Burdekin, Whitsunday and Fitzroy Region of the GBR) differences in assemblage composition for foraminifera were tested by Analysis on Similarity (ANOSIM). Relative abundance data were fourth root transformed for these tests, and similarity matrices for ANOSIM used Bray Curtis similarities.

The influence of several sediment and water quality parameters on foraminiferan assemblage composition was investigated with redundancy analysis (RDA). Foraminiferan assemblage data were fourth root transformed. Environmental data were z-transformed (mean = 0, SD = 1) prior to analysis to accommodate different measurement units and data were averaged over sampling seasons and years (N=4 water quality, N=2 sediment quality for each reef). Exploratory correlation and principal component analyses indicated that several of the environmental parameters were highly correlated and were pooled before further analysis. The percent contribution of all small sediments and all medium sized sediment were highly correlated, therefore we pooled sediment up to 63µm (clays and silt), those from 63-250µm (very fine and fine sands) and those above 250µm. However, the latter group was omitted from statistical analyses since the three groups were not independent (because their contribution adds up to 100%). Sediment organic carbon and nitrogen values were also pooled. Several water quality parameters related to water clarity (particulate organic carbon, phosphorous and nitrogen; suspended solids, chlorophyll a, dissolved organic carbon, Secchi depth) were pooled by averaging their z-scores (for Secchi data with reversed sign). Initial data analysis using permutation tests indicated that only i) sediment clays and silt, ii) very fine and fine sand, iii) sediment organic carbon and nitrogen, iv) sediment inorganic carbon and v) water column particulates and light explained significant amount of variation of the foraminiferan assemblage. Therefore, only those five parameters were included in the final analysis. For the RDA, the influence of these environmental parameters was assed on the assemblage datasets after removing (partialling out) the effects of 'Region' which were strong in both datasets (see results).

RESULTS

Foraminifera assemblage composition was determined in thirty-one sediment samples from 19 inshore survey reef locations collected in 2007. Most monitoring locations were represented by samples from two sites, these were pooled for subsequent analysis. In total, over 6500 foraminifera from these samples were grouped into 49 foraminiferan taxa (Table 3.6). All larger symbiont-bearing foraminifera were determined to species level, while most small, heterotrophic specimens were determined at least to genus level. Foraminiferan assemblages in all regions were highly diverse, with highest diversity (expressed as species richness or Shannon-Weaver Index) observed in the Burdekin and Whitsunday Regions (Table 3.7). The FORAM index (an accepted Water Quality indicator in Florida and the Caribbean, Hallock *et al.* 2003) varies widely between reefs and assumes values between ca. 2 and nearly 10. Higher indices express a larger proportion of symbiont-bearing taxa, interpreted as indicative of lower nutrient/lower turbidity conditions. Our own work (Uthicke and Nobes 2008) supported that, in principle, this indicator could be used on the GBR, but adaptations taking into consideration the ecology of local species were recommended.

On average, this index only changed little between previous observation in 2005 (carried out as a pilot assessment in addition to Reef Plan MMP contract requirements) and the 2007 data (Table 3.7), and values on the 15 reefs that were sampled in both years were highly correlated (correlation analysis, $R = 0.86$, $p < 0.001$). Removal of data from one reef which declined substantially between 2005 and 2007 (Double Cone Island) from the analysis, improved the correlation further ($R = 0.92$, $p < 0.001$). Regional averages of this index distinctly declined in the Burdekin (ca. 1.5 units) and Whitsunday Regions (ca. 1 unit), whereas data from the Wet Tropics remained relatively stable (Table 3.6, Fitzroy Region data cannot be compared because data are available from only one reef in 2005).

Table 3.6 Foraminifera taxa observed on 19 inshore reef of the GBR in 2007. The type of symbiont is indicated for symbiont-bearing foraminifera, N = no symbionts (heterotrophic species).

Sub Order	Family	Species	Symbionts
Lagenina	Polymorphinidae	*Sigmoidella elegantissima*	N
Miliolina	Alveolinidae	*Alveolinella quoyi*	Diatom
	Hauerinidae	*Hauerina diversa*	N
		Hauerina fragilissima	N
		Hauerina pacifica	N
		Pseudohauerina involuta	N
	Miliolidae	*Discorbinella sp.*	N
		Miliolinella sp.	N
		Planispirinella exigua	N
		Pseudomassolina sp.	N
		Pyrgo spp.	N
		Quinqueloculina spp.	N
		Triloculina spp.	N
		Edentostomina cultrata	N
	Nubeculariidae	*Vertebralina striata*	N
	Soritidae	*Marginopera vertebralis*	Dinoflagellates
		Sorites orbiculus	Dinoflagellates
		Peneroplis antillarum	Red Algae
		Peneroplis pertusus	Red Algae
		Peneroplis planatus	Red Algae
	Spiroloculinidae	*Spiroloculina angulata*	N
		Spiroloculina corrugata	N
		Spiroloculina foveolata	N
		Spiroloculina other	N
Rotaliina	Alfredinidae	*Epistomaroides polystomelloides*	N
	Amphisteginidae	*Amphistegina radiata*	Diatom
		Amphistegina lobifera	Diatom
		Amphistegina lessoni	Diatom
	Bagginidae	*Cancris* sp.	none
	Calcarinidae	*Baculogypsina sphaerulata*	Diatom
		Calcarina hispida	Diatom
		Calcarina mayorii	Diatom
		Calcarina spengleri	Diatom
		Neorotalia calcar	Diatom
	Cibicidae	*Cibicides*	N
	Cymbalporidae	*Cymbalporetta* spp.	N
	Discorbidae	*Rosalina*	N
		Rotorbis	N
	Elphidiidae	*Elphidium* cf. *craticulatum*	Plastids
		Elphidium crispum	Plastids
		Elphidium reticulosum	Plastids
	Eponididae	*Eponides* sp.	None
	Nummunlitidae	*Heterostegina depressa*	Diatoms
		Operculina ammonoides	Diatoms
	Planulinae?	*Planorbulina*	N
	Reussellidae	*Reussella*	N
	Rotaliidae	*Ammonia* sp.	N
		Pararotalia sp.	N
		unknown	N
Textulariina	Textularidae	*Textularia* spp.	N

Table 3.7 Diversity measures (S: number of taxa, H': Shannon-Weaver Index) for Foraminifera and the FORAM Index (FI, Hallock *et al.* 2003) collected in 200) and 2007. Average and standard deviation (SD) are given for each region. Na: data not available. Reef numbers are used in analyses and Figures 3.33 and 3.34.

NRM Region	Reef	Reef No.	S	H'	Foram Index 2005	Foram Index 2007
Wet Tropics	Dunk Island Back	1	30	2.85	6.02	5.29
	Fitzroy Island Back	2	34	2.69	6.64	6.88
	Frankland Islands Back	3	34	2.83	7.54	6.12
	Frankland Islands Front	4	15	1.81	na	8.74
	High Island Back	5	32	2.71	6.02	6.87
	High Island Front	6	8	1.27	9.70	9.84
	North Barnard Islands Front	7	17	1.97	7.88	8.63
			24.29 (10.69)	2.30 (0.62)	7.30 (1.41)	7.48 (1.63)
Burdekin	Geoffrey Bay Front	8	35	2.64	5.76	3.56
	Havannah Island Front	9	26	2.45	8.96	7.10
	Pandora Front	10	30	1.86		8.02
	Pelorus and Orpheus Islands Back	11	44	3.07	8.33	6.19
			33.75 (7.76)	2.51 (0.50)	7.68 (1.70)	6.22 (1.92)
Whitsundays	Daydream Island Back	12	31	2.96	3.21	3.05
	Dent Island Flank	13	28	2.41	2.76	2.03
	Double Cone Island Front	14	39	3.00	7.17	3.29
	Pine Island Back	15	20	2.50	1.92	2.31
	Seaforth Island Front	16	34	2.44	2.51	2.16
			30.40 (7.09)	2.66 (0.29)	3.51 (2.09)	2.57 (0.56)
Fitzroy	Barren Island Back	17	26	2.24	na	7.27
	Humpy and Halfway Islands Back	18	32	2.43	na	6.14
	Pelican Island Flank	19	29	2.53	5.13	4.82
			29.00 (3.00)	2.40 (0.15)	-	6.08 (1.23)

In a community analysis of relative abundances using Principal Component Analysis (PCA) the first and second PCA axis explained > 60% of the observed community variance (Fig. 3.33). The taxa contributing most to these PCA components are mainly symbiont-bearing and those retaining chloroplasts (*Elphidium* spp.). In addition, similar to previous GBR data (Uthicke and Nobes 2008, Uthicke unpublished data) symbiont-bearing species are well separated in the first two dimensions from those which are entirely heterotrophic (Fig. 3.33).

The reefs of the four regions form distinct groups in this analysis and an overall analysis of similarities (ANOSIM) supported significant inter-region differences (Global R: 0.226, p = 0.019). Only the Wet Tropic and Burdekin Regions overlap in the PCA, reefs from the Mackay Whitsunday and Keppel regions are well separated from each other and from the two northern regions.

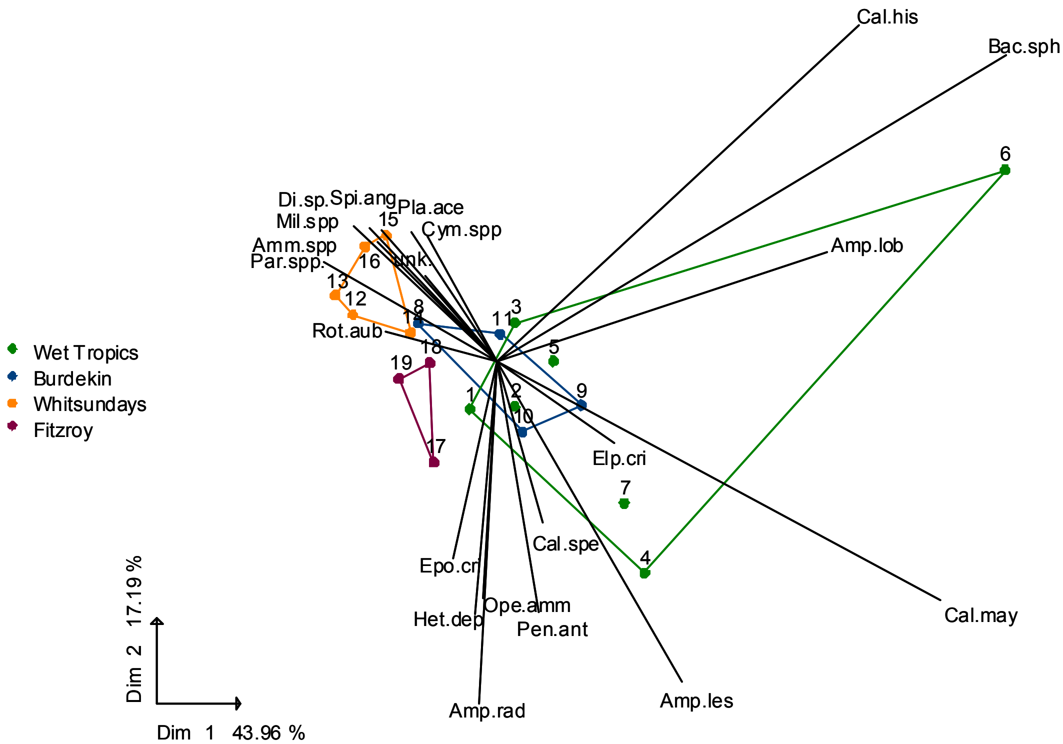

Figure 3.33 A Principal component analysis biplot for foraminferal relative abundances on 19 reef of the GBR. Polygons outline individual regions; only the 40% of the species vectors contributing most to the explained variance are shown. Reefs are indicated using reef numbers as in Tab. 2, species are abbreviated using the first three letters of general and species names (if available, See Tab. 1)

For a redundancy analysis (RDA, Fig. 3.34) we removed the effects of regions and included 5 environmental variables which explained significant amount of variation initial analysis. The variation explained after partialling out the effects of 'Region' was 34.1%, and the environmental parameters included explained an additional 16.9%. The 'Light and Particulates' variable in that analysis roughly points in opposite direction to the amount of inorganic carbon in the sediment. The vectors representing sediments high in organic carbon and nitrogen, and dominated by grain sizes smaller that 250 µm were roughly perpendicular to the light variable.

Heterotrophic foraminifera were associated with high values of 'Particulates' in the water and fine sediments (< 63 and 63-250µm grain size) with high sediment C and N content. In contrast, symbiont-bearing species were associated with low turbidity and high inorganic carbon content in the sediment. Similar to the PCA (see above) heterotrophic and symbiont-bearing foraminifera species were well separated along the first two RDA axes. Thus, light availability for symbiont-bearing foraminifera and food for heterotrophic taxa appear to be the main drivers for foraminiferan community composition.

Individual reefs clearly separated in the RDA and therefore experience different light and nutrient conditions. Several reefs with foraminifera assemblages dominated by autotrophic taxa are located in waters with above average (for inshore reefs) light conditions and with little organic content in the sediments (see above). Most distinct among these are the front reefs of High Island, Frankland Group islands, Pandora Reef and Havannah Island. In contrast, back reef locations on the same reefs are dominated by heterotrophic foraminifera species (leading also to lower FORAM indices, see Table 3.7), have less light available and sediments with higher organic content. Although it is possible that water quality is in general more affected in (usually landwards facing) back reef locations, it is also possible that different sediment regimes in these more sheltered locations favour smaller heterotrophic species. Thus, further work to optimise the FORAM index for use in the GBR need to take the aspect of the sampling location into consideration.

Foraminifera assemblage compositions at the 15 reefs both surveyed in 2005 and 2007 were not significantly different (Mantel test between these 2 years: 0.753, $p < 0.001$).

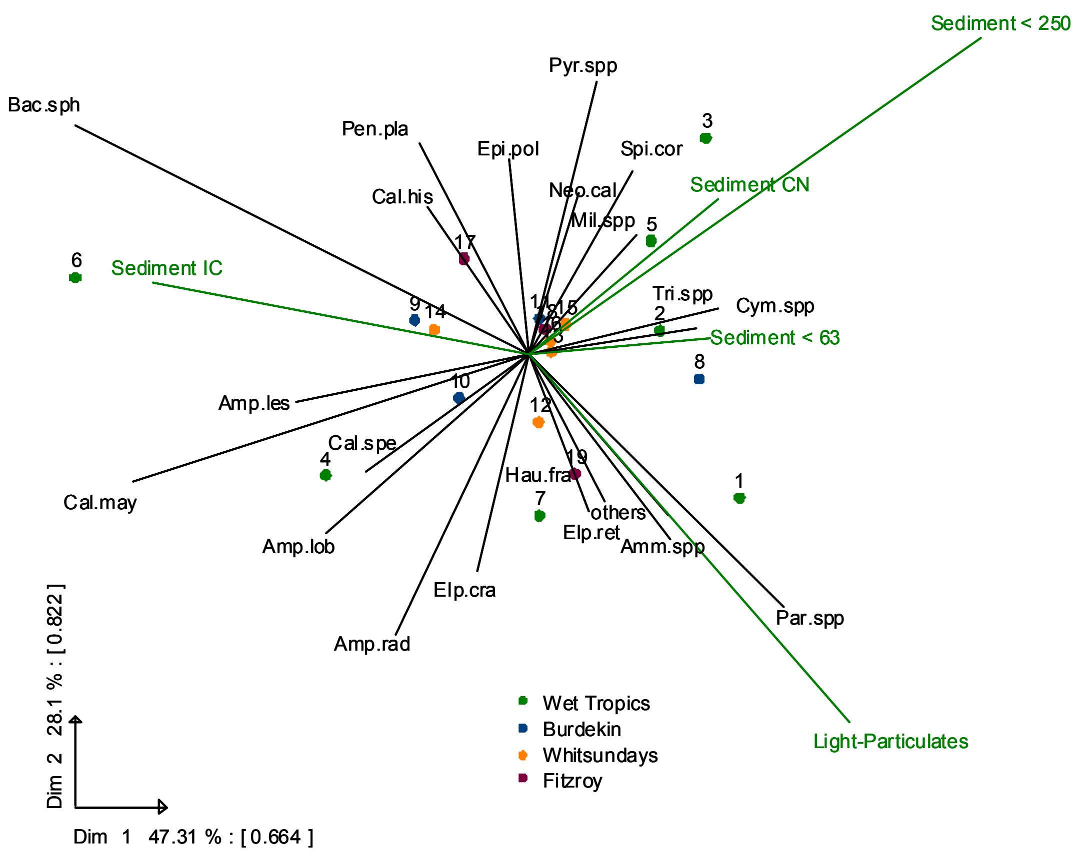

Figure 3.34 Redundancy analysis biplot for foraminferal relative abundances on 19 reef of the GBR. Environmental parameters (green vectors) included are clay and silt size sediments (Sediment < 63); fine and very sine sands (Sediment < 250), Sediment inorganic carbon (Sediment IC), pooled sediment organic carbon and nitrogen (Sediment CN) and a combined variable including water column particulates, secchi depth and dissolved organic carbon (Light-Particulates); only the 40% of the species vectors contribution most to the explained variance are shown. Reefs are indicated using reef numbers as in Tab. 2, species are abbreviated using the first three letters of general and species names (if available, See Tab. 1)

Discussion

In the period 2006 to 2007 no major disturbances impacted any of the monitored reefs and this was reflected in relatively minor changes in the composition and abundance of benthic coral reef communities. Hard coral cover increased overall, when averaged over all survey reefs, however the majority of this increase was due to significant increases in cover at just a few reefs in the Wet Tropics and Fitzroy regions. The fast growing genus Acropora was the dominant community component on these reefs. Cover in communities dominated by other species, and at most reefs in other regions, remained relatively stable. On some reefs, coral cover declined in absence of disturbance; these were Dent Island in the Mackay Whitsunday Region and the landward reefs at High Island and the Frankland Islands Group in the Wet Tropics Region. At the reefs of the Frankland Group we noted red algae of the genera *Laurencia* and *Hypnea* growing thickly among branches of Porites, which may have caused the decline as they over grew the corals.. Hard coral cover also continued to decline (and macroalgal cover to increase) at 5m depth of both North Keppel Island and Humpy/Halfway Island locations in the Fitzroy Region, likely to be an ongoing response to the 2006 local coral bleaching even. Increases in macroalgal cover were recorded in all regions with the exception of the Burdekin where macroalgal cover continued to be at a high level of more than 20%. Soft coral cover was remarkably stable between 2006 and 2007 with the exception of the Burdekin Region, however, these increases were almost entirely due to an increase at just one location (Pelorus Is and Orpheus Is West). The relative stability in absence of disturbance reinforces the importance of disturbance events in shaping coral communities.

The compositions of benthic foraminifera assemblages were also relatively stable between the 2005 and 2007. However, the FORAM index did change on some reefs and also changed on total average in two regions. Whether this is caused by actual changes in environmental conditions or simply represents stochastic variation in communities and differences dues to sampling needs further investigation.

The Reef Plan MMP surveys were specifically designed to include information on recruits (via settlement plate assessments) and juvenile coral colonies (via direct in situ counts), because of the recognised vulnerability of these early life history stages to components of runoff (as reviewed by Fabricius 2005) and also their fundamental importance to the resilience of communities to disturbance. The monitoring data for these two measures of resilience, along with changes in coral cover based assuming that cover will increase unless disturbances occur, suggest that resilience differs between the NRM regions. The Wet Tropics reefs in the Johnstone Russell-Mulgrave sub-region were severely impacted by coral bleaching in 1998 and crown-of-thorns starfish outbreaks in that same period (Sweatman et al. 2005). From 2005 to 2007 most of the monitored Wet Tropics reefs had higher abundances of juvenile corals, increasing coral cover and also high and increasing rates of larval settlement, compared to averages over all reefs, which indicates that these reefs are now recovering and are likely to have been resilient to past disturbances. Reef resilience is less evident in the Burdekin Region where bleaching in 1998 affected most reefs, was more severe and resulted in higher mortality (Sweatman *et al.* 2007). Recovery of these reefs may, hence, take longer (Done *et al.* 2007). On the reefs monitored in the Burdekin Region, settlement of recruits was low, there were fewer juvenile colonies and a negligible increase in hard coral cover. Reefs in the Mackay Whitsunday region had a similar status with moderate, albeit variable, settlement of recruits, generally lower numbers of juvenile colonies and negligible change in coral cover. While coral cover on some reefs in this region was high it is unclear how resilient to disturbance these communities would prove. Reefs in the Fitzroy region have to date been resilient to disturbance, with hard coral cover recovering rapidly following past disturbance events (Sweatman et al 2005). However, this rapid recovery has mainly been the result of the re-growth of surviving fragments of just a few species of *Acropora*. Our data show that the density of juvenile corals is very low on these reefs, even though larval settlement rates are high, which suggests limited recovery potential from disturbances that would cause whole colony mortality over large areas.

The recognised complex relationships between coral communities, their environmental setting and the confounding effects of disturbance make it problematic to identify the causes of any apparent lack of resilience of inshore reefs. There are strong spatial differences between the monitored reef communities and initial data analyses indicate that these differences are related to their environmental setting (CRC Reef Consortium 2006; Sweatman *et al.* 2007, Schaffelke *et al.* 2007). Part of this environmental setting is defined by the geographical (latitudinal) location. Hard corals on the southernmost survey reefs (Fitzroy NRM Region), had low taxonomic richness, in agreement with the documented latitudinal gradient of declining coral biodiversity on GBR reefs (DeVantier *et al.* 2006). Finer scales of variation -neighbouring reefs can have quite different coral communities- is likely to be largely caused by intermittent local disturbance and subsequent recovery. Water quality is more likely to play a regional rather than a local role for shaping coral reef communities as the coastal and inshore water body is generally well-mixed with some water quality gradient apparent along dilution gradients away from river mouths and the mainland coast (Cooper *et al.* 2007). In contrast, sedimentation and associated turbidity can vary on a local reef scale, as they are controlled by local hydrodynamics (wind, tides, and exposure) and the influx of new suspended sediment and organic matter (proximity to river mouths; Wolanski et al 2008).

In our analyses of the relationship between coral reef communities and environmental parameters to date, the most useful proxies for environmental conditions were sediment quality parameters. Sediment nitrogen and organic carbon concentrations are a measure for organic matter and nutrient availability in sediments, inorganic carbon content indicates the proportion of reef-derived versus terrigenous sediments and the grain size distribution is representative of the local hydrodynamics. These three sediment quality measures are logically correlated as fine particles have a very high surface area-to-volume ratio compared to larger grain sizes, which leads to greater biomass of biofilms and adsorption of nutrients (Horowitz 1991) resulting in higher levels of nitrogen and organic carbon. In turbid inshore waters, fine particles settle in calm hydrodynamic settings (reefs protected from prevailing SE winds or in bays), thus reducing the relative component of sediments that are reef-derived. Conversely, in more energetic hydrodynamic settings fine particles are constantly re-suspended and transported leaving only the larger, locally produced, carbonate sediments (Wolanski *et al.* 2005).

Among the variety of benthic coral reef community attributes we monitor, the relative abundances of hard and soft coral genera showed the strongest relationship to sediment quality. Some genera were found predominantly on reefs with a higher proportion of fine sediments and lower proportion of inorganic carbon and could be considered as tolerant to those particular environmental settings. Interestingly, measures such as the cover of soft corals and fleshy macroalgae did not show strong relationships to sediment quality, while the cover and, to a lesser degree, richness of hard corals showed the initially unintuitive tendency for higher values on reefs with higher nutrients, finer grained particles and lower proportions of reef derived sediments. In these silty environments genera such as *Goniopora*, *Porites*, and *Galaxea*, which often have a massive morphology, are more common and are also known to be less susceptible to major disturbances such as coral bleaching (Baird & Marshall 2002) while *Acropora* species (branching morphology, typically fast growing but susceptible to disturbance) exist but are less common.

The assessment of the assemblage composition of benthic foraminifera was for the first time formally included in Reef Plan MMP, to test this candidate bioindicator water quality on a larger spatial scale. The assemblage composition showed distinct regional patterns and these patterns reflected environmental conditions, which are, at least to some extent, related to water quality. The pooled 'light and particulate' water quality variable (PN, PP, POC, DOC, SS, chlorophyll, Secchi depth) was clearly correlated with foraminiferan assemblage composition, most likely by influencing light availability (more autotrophic taxa detected in 'clearer' waters). The concentrations of inorganic carbon and nitrogen in the sediments, which were also significantly correlated with foraminifera assemblage composition (more heterotrophic taxa detected in sediment rich in organic matter), are determined by both, nutrient inputs and hydrodynamic conditions, indicated by the strong correlation of sediment organic composition with small sediment size. Although some changes in the communities may have occurred over the last two years, our analysis show that overall communities are stable, indicating relative stability of water conditions.

In contrast to foraminifera assemblages, we only found limited direct relationship between coral community attributes (such as abundance and richness on genus level) and environmental variables (water quality, CRC Consortium 2006, and sediment quality, this report and Schaffelke *et al.* 2007). This is not surprising for several reasons. Firstly, community summaries aggregate over a wide range of species which will almost certainly have different environmental tolerances. There is extremely limited information about the ecophysiology in coral species and hence the tolerances and responses to various environmental parameters. A more detailed investigation of the composition of individual reef communities in relation their environmental setting maybe more informative. Secondly, our measures of sediment quality vary among regions, hence, possibly confounding environmental relationships with spatially different patterns of abundance. Finally, disturbances have the potential to decouple relationships that do exist by severely altering communities for reasons unrelated to environmental condition. The impact of disturbance events can also vary greatly over small spatial scales (Cheal *et al.* 2002) and differentially among coral species (Baird and Marshall 2002), which adds complexity to disturbance histories for any given community.

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). In addition it is likely that these local and global stressors interact, e.g., nutrient enhancement, pollutant input and climate change (Schmiedeck et al 2007, Carpenter et al. 2008), an issue that is very little understood at present.

In the Great Barrier Reef lagoon, land runoff is the largest quantified external source of sediment and 'new' nutrients (Furnas 2003). However, most of the nutrients used by marine plants and bacteria come from recycling of biomass and other nutrient-containing materials already within the GBR ecosystem (Furnas *et al.* 2005). For the most part, water quality parameters measured in the Reef Plan MMP lagoon monitoring from 2005/06 to 2007/08 are in the ranges historically reported for inshore waters of the Great Barrier Reef (e.g., Schaffelke *et al.* 2003, Furnas 2005, Furnas *et al.* 2005, Cooper *et al.* 2007). The observed seasonal changes also followed historical trends with higher concentrations of most parameters (e.g. chlorophyll *a*, suspended solids and nutrient species) measured during the wet season (ibid.).

Short-term events (flood plumes, resuspension) are recognised as driving factors for the resilience of coastal coral communities (Fabricius 2005). The current design of the lagoon water quality monitoring task based upon semi-annual (planned three times per year from 2008/09 onwards), manual, ship-based sampling is unsuitable to resolve the frequency and magnitude of such short-term events. However, monitoring using autonomous instruments, which was fully implemented as a routine component of Reef Plan MMP in 2007/08, has immensely improved our capacity to measure key water quality parameters in close proximity (ca. 1 m) to corals and benthic communities on coastal reefs and to record short-term variability in water quality associated with flood plumes and wind-driven resuspension events.

The Reef Plan MMP lagoon water quality data were compared with the draft guidelines for water quality trigger values (GBRMPA 2008) for chlorophyll, suspended solids, particulate nutrients and Secchi depth (a proxy for turbidity) to provide context for their interpretation. Seasonal and annual means, averaged over all stations and three years of sampling, exceeded the trigger values for chlorophyll *a*, suspended solids and Secchi depth, as did the annual and wet season means for particulate phosphorus. On a regional basis, chlorophyll annual and seasonal means were mainly exceeded in the Burdekin, Mackay/Whitsunday and Fitzroy regions. 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.

The longest and most detailed time series of a suite of water quality parameters in the Great Barrier Reef has been measured by AIMS at 11 coastal stations between Cape Tribulation and Cairns since 1989; and was continued under Reef Plan MMP in 2007/08. All parameters, except chlorophyll *a*, showed significant long-term patterns, generally decreasing since the early 2000s. We need to further investigate the assumed relationship of these coastal water quality data with Barron River flow (the closest river influencing the sampling stations), weather and land use data. However, the present, almost two decades-long, time series should be continued, especially because another significant flood of the Barron River occurred in 2007/08.

In contrast, we believe that the changes to the monthly chlorophyll monitoring network, have rendered this component less useful to address the longer-term objectives of the Reef Plan MMP (fewer sites, less reliable samplers, different sites to previous long-term dataset diminishing the capacity for long-term trend analysis). The relevance of this monitoring task needs to be urgently discussed and its future resolved.

The third year of monitoring of inshore coral reef communities under Reef Plan MMP has improved our understanding of spatial patterns of community composition and the likely environmental factors shaping these. The results to date strengthened the view that the processes shaping biological communities are complex and are likely to be based on local interactions of various factors ranging from water quality, over climate change to physical disturbance. Hence, it is very important to understand and document the timing and intensity of disturbances and their consequences that are likely to strongly shape the GBR inshore reef communities (e.g. cyclones, climate change, coral-eating crown-of-thorns starfish outbreaks, coral disease).

Some types of disturbance (e.g., outbreaks of the crown-of-thorns starfish, inputs of excess nutrients or pollutants) can be intensified by anthropogenic activities such as coastal development, eutrophication and fishing (Mora 2008, Sandin et al. 2008, Sweatman 2008). These disturbances are now widely recognised as the major factor controlling coral reef health, e.g. by reducing coral recruitment and fish abundance, and increasing incidence of coral disease and abundance of coral competitors. The ability to recover from disturbances is fundamental for the long-term resilience of biological communities and we urgently need to understand the processes involved and time-scales of recovery. The monitoring of reefs that were impacted by Cyclone Larry and coral bleaching (and have pre-disturbance data from the first Reef Plan MMP surveys) has provided a unique opportunity for this under Reef Plan MMP.

Our analyses of the relationship between coral reef communities and environmental parameters focused on sediment quality parameters, as the most useful proxies for environmental conditions. Sediment nitrogen and organic carbon concentrations are a measure for organic matter and nutrient availability in sediments, inorganic carbon content indicates the proportion of reef-derived versus terrigenous sediments and the grain size distribution is representative of the local hydrodynamics. The relative abundances of hard and soft coral genera showed strong relationships to these sediment quality data. Some genera were found predominantly on reefs with a higher proportion of fine sediments and lower proportion of inorganic carbon and could be considered as tolerant to those particular environmental settings. Some of these coral genera are also known to be less susceptible to major disturbances such as coral bleaching (Baird & Marshall 2002). Interestingly, measures such as the cover of soft corals and fleshy macroalgae did not show strong relationships to sediment quality. Interpretation of the observed patterns is difficult since there is extremely limited information about the ecophysiology in coral species and hence the tolerances and responses to various environmental parameters as well as the potential for disturbances to decouple existing relationships by severely altering communities for reasons unrelated to environmental condition. The impact of disturbance events can also vary greatly over small spatial scales (Cheal et al. 2002) and differentially among coral species (Baird and Marshall 2002), which adds complexity to disturbance histories for any given community.

The assemblage composition of foraminifera proved to be a valuable indicators for water quality on GBR reefs. However, further ecological work will be required to further develop a GBR specific FORAM index, with the potential for individual indicator species (e.g. for light conditions or nutrient status). Our analysis showed that overall communities are stable, although some changes in the communities may have occurred over the last two years. However, it is difficult to assess how rapidly communities would change in response to environmental factors as relatively small environmental changes occurred during the present brief study. In the future, it might be a better strategy to continue annual sampling of foraminiferan communities but, initially, only analyse samples from every other year. If changes are detected, then the intervening years could also be analysed.

The overall objective of Reef Plan MMP is to assess temporal change in coral reef communities related to water quality, in order to assess the success of the Reef Plan. After confirmation of spatial patterns in the biological communities and improved understanding of whether and how water quality affects these (a proposal is currently under consideration by GBRMPA to carry out a comprehensive statistical analysis to achieve this) the Programme will move on to the next stage and focus on detecting temporal patterns. For progression to the next phase, we must be confident that the appropriate variables for the detection of temporal patterns are being monitored.

In the future, ocean colour remote sensing will allow the monitoring of large-scale water quality patterns. In addition, autonomous instruments deployed *in situ* will be essential because they record high-frequency data series at individual locations of particular interest, e.g. specific reefs or seagrass beds where long-term monitoring of biological status is undertaken. Ongoing lagoon monitoring by direct water sampling should continue to provide data for high quality validation of the instrument and remote sensing data. Monitors and GBRMPA need to agree on the future of monitoring by manual sampling of those variables that cannot be measured by in situ instruments or satellites (e.g., organic matter, nutrients and pesticides). In addition, continuous improvement is needed e.g. by future inclusion of relevant new ecosystem indicators for changes in water quality (e.g. Fabricius *et al.* 2007), such as the now applied foraminifera assemblage as a water quality bio-indicator.

We would welcome the future development of a framework for integration of all monitoring results obtained under Reef Plan MMP to facilitate and standardise the assessment of ecosystem status, e.g., based on a rating system that also indicates 'data-richness' or confidence in the assessment. An example for such a system is the United States National Estuarine Eutrophication Assessment (NEEA) using an approach based on five 'symptoms' of eutrophication (Bricker *et al.* 2003, 2007). The first steps toward the development of a GBR framework were taken at the Reef Plan MMP synthesis workshop in September 2007. That workshop identified candidate indicators for marine water quality and inshore marine ecosystem health and discussed mechanisms for the assessment of data including approaches for developing spatially appropriate indicator benchmark values and for ranking and reporting regional marine condition. However, we recognise that it will take much more time and effort to develop a widely accepted and workable integration and reporting framework. Another important issue over the past 3 years was the uncertain continuation of Reef Plan MMP (each year required new contract negotiations) and the frequent design changes. While a long-term monitoring program needs to be adaptable and continuously improved, based on data analysis (Field et al. 2007), a certain level of stability is required to allow the gathering of time-series to enable useful data analysis and to prevent the alienation of monitoring providers.

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Appendix 1: Additional Information

Appendix 1 to Chapter 2 - Lagoon water quality Monitoring

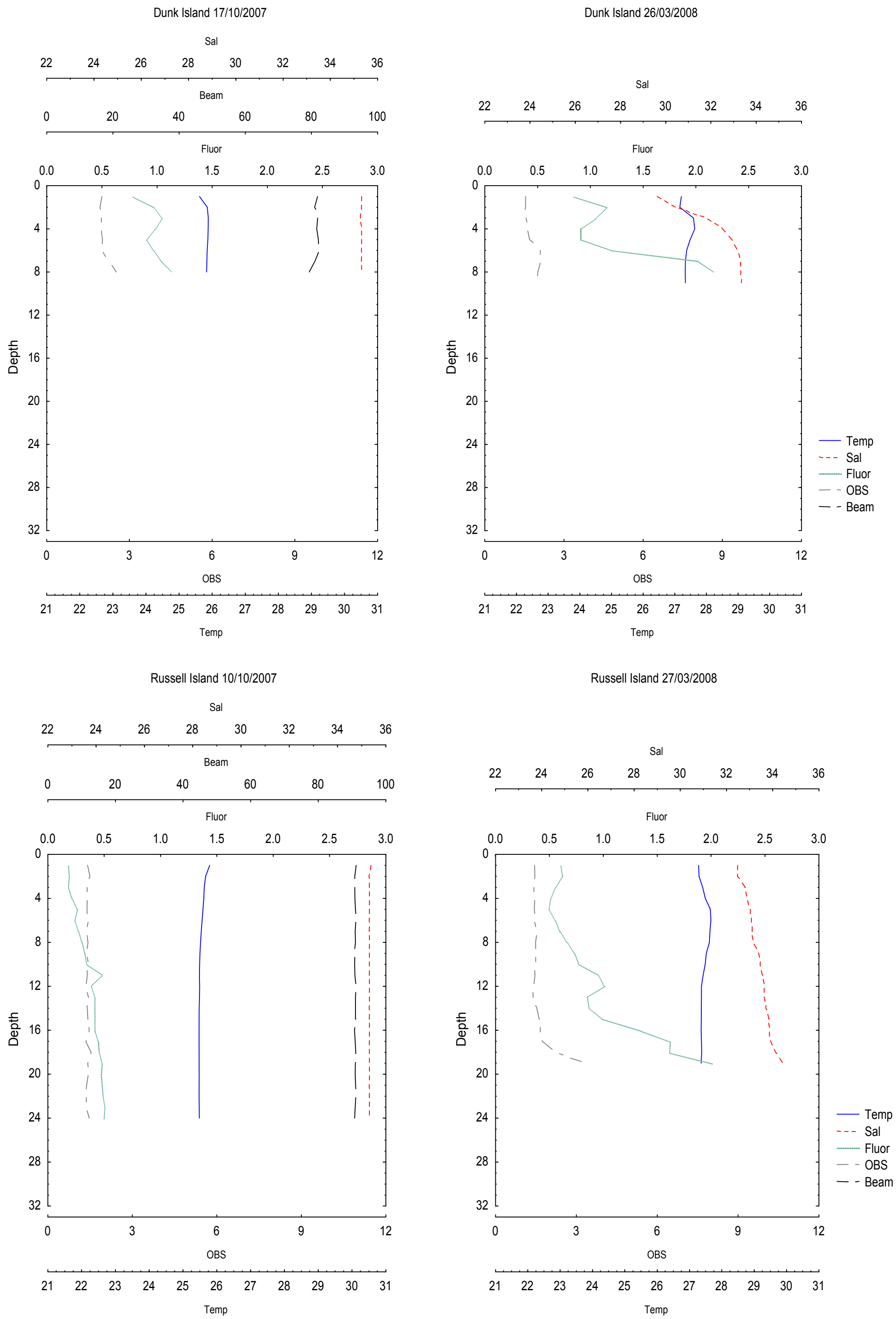

Figure A1-2.1 Depth profiles of temperature (ºC), salinity (PSU), chlorophyll fluorescence (µg L-1) and turbidity (NTU, measured by optical backscatter OBS) at two representative sites in the Wet Tropics NRM Region sampled in the dry season (October 2007) and wet season (March 2008).

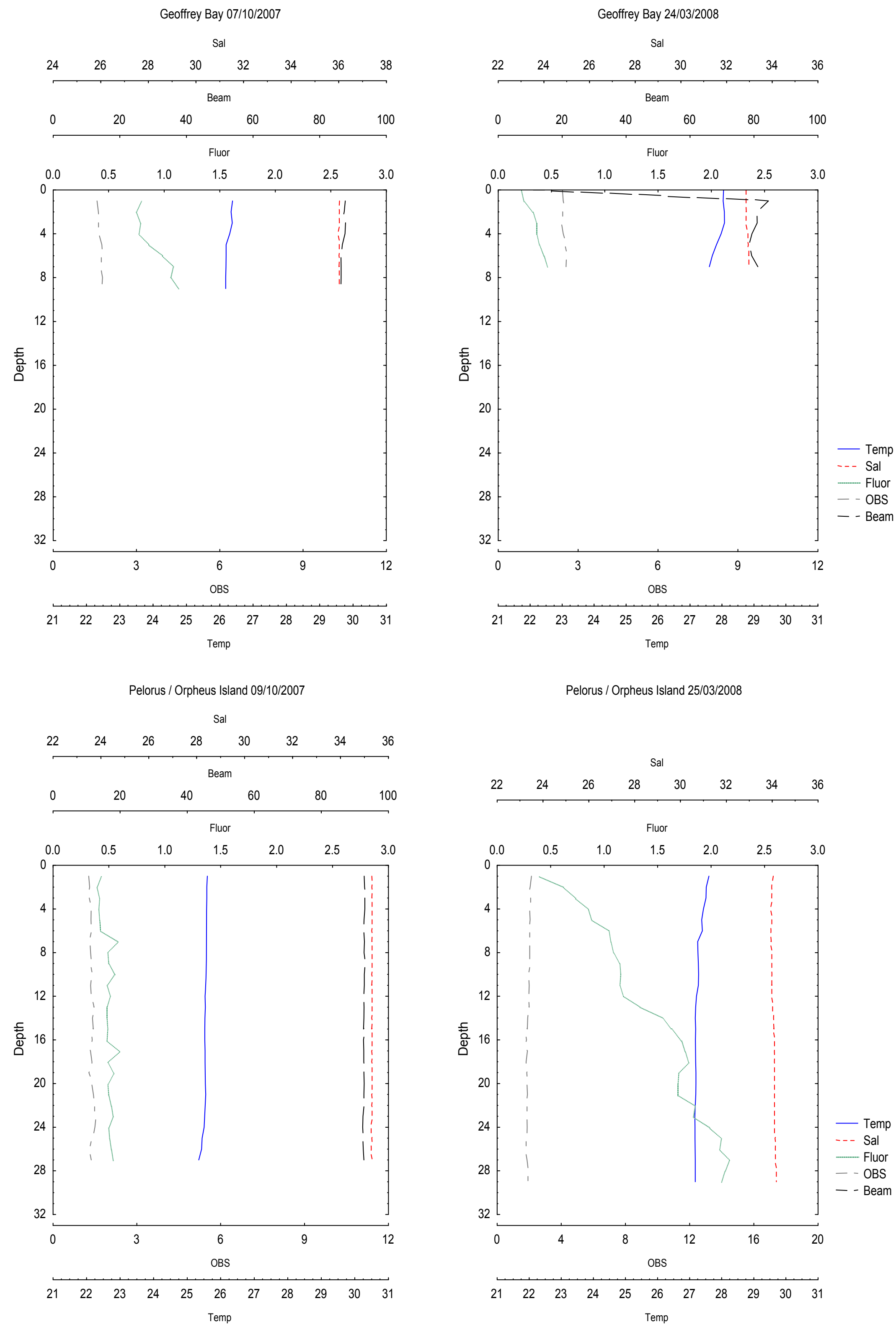

Figure A1-2.2 Depth profiles of temperature (ºC), salinity (PSU), chlorophyll fluorescence (µg L^{-1}) and turbidity (NTU, measured by optical backscatter OBS) at two representative sites in the Burdekin NRM Region sampled in the dry season (October 2007) and wet season (March 2008).

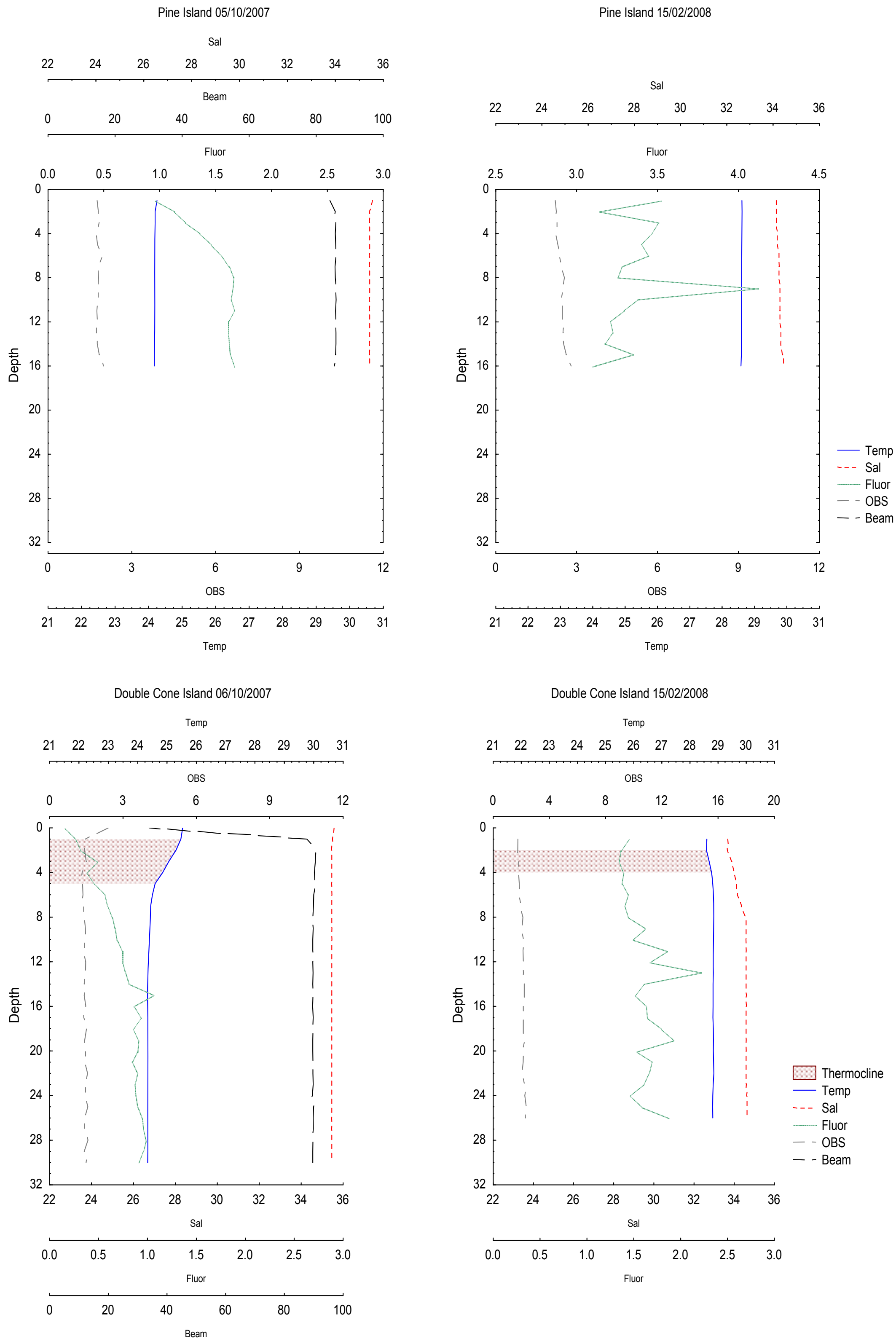

Figure A1-2.3 Depth profiles of temperature (ºC), salinity (PSU), chlorophyll fluorescence (µg L-1) and turbidity (NTU, measured by optical backscatter OBS) at two representative sites in the Mackay Whitsunday NRM Region sampled in the dry season (October 2007) and wet season (February 2008).

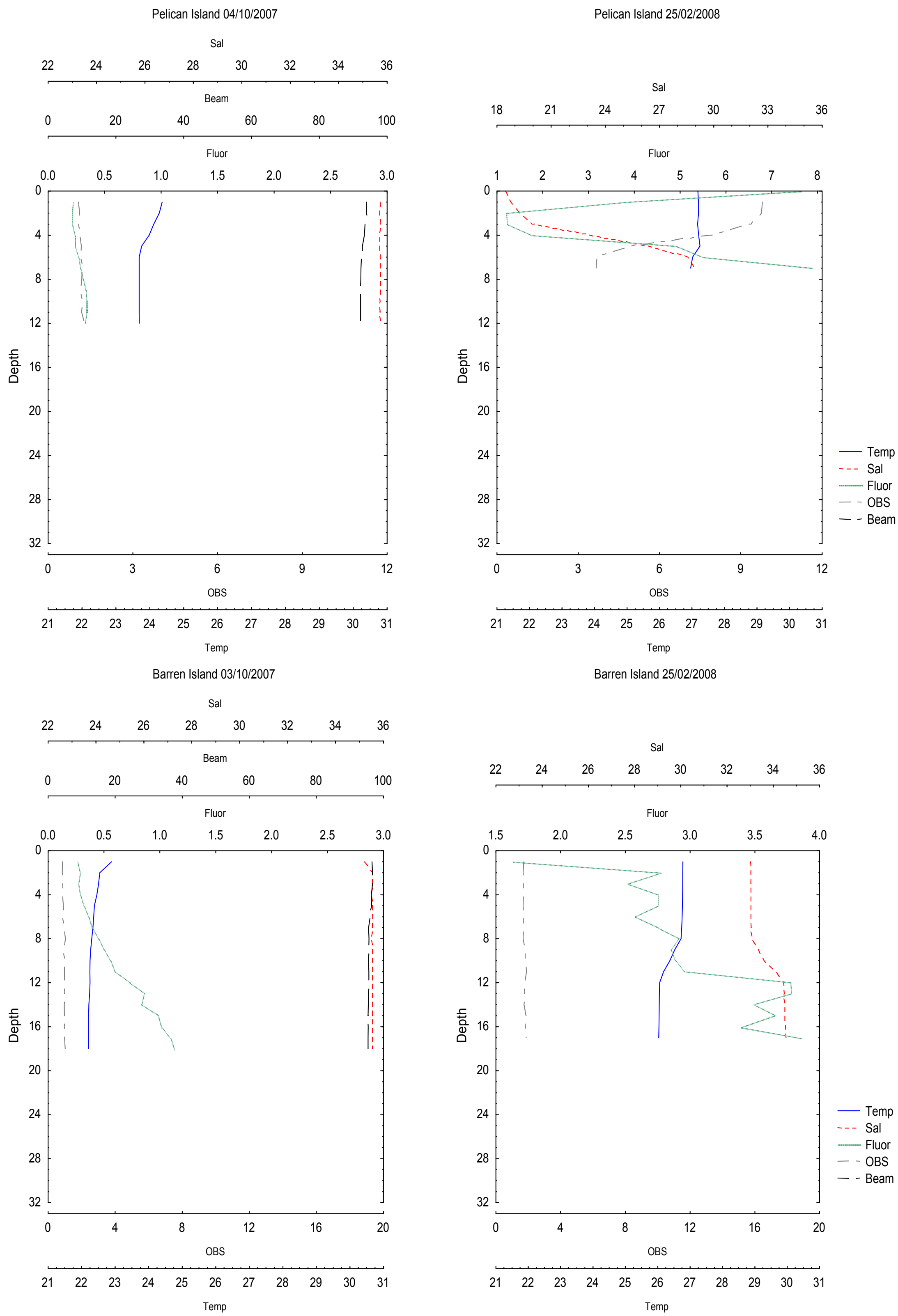

Figure A1-2.4 Depth profiles of temperature (ºC), salinity (PSU), chlorophyll fluorescence (µg L^{-1}) and turbidity (NTU, measured by optical backscatter OBS) at two representative sites in the Fitzroy NRM Region sampled in the dry season (October 2007) and wet season (February 2008).

Table A1-2.1 Chlorophyll monitoring by community groups, cross-shelf transects and coastal stations: summary chlorophyll *a* values (µg L^{-1}) for wet and dry seasons from May 2007 to April 2008. N= number of monthly average values used to calculate seasonal averages. Inner shelf = stations within 20m depth contour, outer shelf = stations outside 20m depth contour. These station designations agree with the designation as 'coastal' and offshore' in the GBRMPA Draft Water Quality Guideline for the Great Barrier Reef Marine Park (GBRMPA 2008). Shading indicates seasonal mean values that exceeded the relevant trigger values from the GBRMPA Draft Water Quality Guideline. See p. 13 for an overview of the trigger values.

		Dry season 2007/08								Wet season 2007/08							
NRM Region	Station name	Inner shelf				Outer shelf				Inner shelf				Outer shelf			
		N	Median	Mean	SD	N	Median	Mean	SD	N	Median	Mean	SD	N	Median	Mean	SD
Cape York	1 mile off Osprey[1]					6	0.115	0.138	0.056								
	Osprey entrance channel[1]					4	0.153	0.146	0.021								
	Codhole[1]					9	0.113	0.063	0.023								
	1 mile outside Codhole[1]					3	0.060	0.050	0.009								
	Harrier Reef[1]					8		0.198	0.075								
Wet Tropics	Outside Agincourt 4 Reef[1]					2		0.170	0.000								
	Inside Agincourt 4 Reef[1]					2	0.220	0.400	0.000								
	Rudder Reef[1]					6	0.188	0.322	0.138								
	Snapper Island[1]	2	0.278	0.128	0.004												
	Low Isles1[1]	8	0.188	0.284	0.111												
	Princes Wharf[1]	2	0.173	0.140	0.007												
	Near Port Douglas[1]	2	0.570	0.560	0.007												
	Moore Rf[2]	1		0.135													
	Fitzroy Island Jetty[2]	7	0.140	0.315	0.153					3	0.440	0.437	0.362				
Burdekin	John Brewer Reef[3]					2		0.315	0.085								
	Townsville Shipping Channel[3]	2		0.625	0.247												
	Magnetic - Picnic Bay[4]	6		0.280	0.162					3		0.745	0.249				
Mackay Whitsunday	Line Reef[5]					8		0.222	0.090					10		0.464	0.175
	Hook Passage[5]	8		0.230	0.073					8		0.453	0.127				
	Shute Harbour Jetty[6]	4	0.473	0.425	0.181					6	1.038	0.663	0.269				
	Dent Passage[5]	8		0.281	0.121					10		0.528	0.252				
	Mackay Marina Wall[6]	6	0.428	0.259	0.143					5	0.260	0.434	0.185				

Table A1-2.1- continued **Chlorophyll monitoring by community groups**, cross-shelf transects and coastal stations: **summary chlorophyll** *a* values (µg L^{-1}) for wet and dry seasons from May 2007 to April 2008.

		Dry season 2007/08								Wet season 2007/08							
NRM Region	Station name	Inner shelf				Outer shelf				Inner shelf				Outer shelf			
Fitzroy	Lillies (LIL)[7]	10		2.624	3.601					4	1.206	0.599	0.077				
	Rosslyn Bay Marina Wall[8]	4		0.571	0.217					2	1.231	0.998	0.456				
	Oyster Rocks (OR)[7]	6	0.559	0.950	0.546					2	1.335	0.588	0.053				
	Boyne River (BR)[7]	5		0.666	0.300					2	0.831	1.883	1.983				
	Wild Cattle Creek (WC)[7]	10	0.649	0.788	0.543					4		0.480	0.112				
	Seal Rocks (SR)[7]	10		0.493	0.299					4	0.591	0.555	0.071				
	Colosseum Inlet (COL)[7]	5	1.055	0.678	0.334					2	0.900	3.100	3.408				
Burnett Mary	Hervey Bay-QSS2[9]	1		0.615													
	Hervey Bay-QSS1[9]	5		0.228	0.134					2		0.200	0.021				
	Woongarra Burnett River[10]	6	1.545	0.893	0.345					4	0.835	0.938	0.772				
	Woongarra Burkitts Reef[10]	6	0.950	0.529	0.182					4	0.975	0.819	0.663				
	Woongarra Hoffman's Rocks[10]	6	1.759	0.503	0.195					4		0.755	0.547				
	Woongarra Barolin Rocks[10]	6	8.665	0.468	0.153					4	0.605	0.844	0.764				
	Woongarra Double Rock[10]	6	1.628	0.558	0.210					4	0.875	0.853	0.690				

Sampling organisations: [1]Undersea Explorer, [2]Fitzroy Island resort, [3]Sunferries, [4]GBRMPA, [5]FantaSea, [6]Mackay Whitsunday Healthy Waterways, [7]Tannum Sands Coastcare, [8]Cap Reef, [9]Queensland Sea Scallops, [10]Woongarra Marine Park Monitoring & Education Project

Appendix 1 to Chapter 3 - Inshore Coral Reef Monitoring

Table A1-3.1 Sediment analysis for locations samples in 2007. Grain size distribution and carbon and nitrogen as percentage of total sample.

NRM Region	Primary Catchment	Reef	Grain size fractions (% of total sample)											Carbon / Nitrogen (%)			
			Clay (0.00006mm - 0.0039mm)	Very fine silt (0.0039mm - 0.0078mm)	Fine silt (0.0078mm - 0.0156mm)	Medium silt (0.0156mm - 0.031mm)	Course silt (0.031mm - 0.0625mm)	Very fine sand (0.0625mm - 0.125mm)	Fine sand (0.125mm - 0.250mm)	Medium sand (0.250mm - 0.5mm)	Coarse sand (0.5mm - 1.0mm)	Very coarse sand (1.0mm - 1.4mm)	Very coarse sand / granules (> 1.4mm)	Total Carbon	Organic Carbon	Inorganic Carbon	Total Nitrogen
Wet Tropics	Johnstone	Fitzroy Is (West)	1.69	1.55	1.45	1.52	2.82	6.99	16.66	28.21	21.54	2.88	14.68	9.82	0.35	9.47	0.04
		High Is (West)	1.35	1.29	1.08	1.19	1.29	3.26	18.10	34.33	24.81	3.68	9.62	10.17	0.26	9.91	0.04
		High Is (East)	0.02	0.10	0.11	0.17	0.18	0.37	1.24	6.89	37.73	16.77	36.42	10.77	0.19	10.58	0.03
		Frankland Group (West)	5.57	4.92	4.69	4.53	5.59	12.61	19.90	19.35	12.68	1.70	8.46	8.90	0.51	8.39	0.08
		Frankland Group (East)	0.57	0.59	0.57	0.57	0.83	1.72	5.97	19.73	28.64	8.94	31.88	10.60	0.23	10.37	0.03
	Tully	North Barnard Group	0.85	0.99	1.15	1.31	1.63	5.77	14.34	22.02	23.45	6.89	21.61	9.70	0.27	9.43	0.03
		Dunk Is (North)	1.18	1.18	1.15	1.40	1.74	1.89	7.39	18.44	21.34	6.12	38.18	8.89	0.24	8.65	0.03
Burdekin	Burdekin	Pelorus & Orpheus Is (West)	0.80	0.85	0.79	0.69	0.84	2.54	9.83	26.44	28.93	7.14	21.15	10.76	0.19	10.57	0.03
		Pandora Reef	0.50	0.52	0.45	0.33	0.56	0.75	3.41	18.82	28.82	8.71	37.14	10.74	0.19	10.55	0.03
		Havannah Is	1.11	1.20	1.27	1.53	2.34	4.53	13.13	26.56	24.35	5.04	18.94	10.35	0.25	10.11	0.04
		Geoffrey Bay	1.42	1.59	1.91	2.46	2.38	5.28	14.46	22.27	19.99	5.12	23.12	8.69	0.29	8.40	0.04
		Middle Reef	13.49	11.60	10.98	9.34	9.51	12.01	11.42	11.35	6.48	0.25	3.56	5.47	0.77	4.70	0.08
Mackay / Whitsunday	Proserpine	Double Cone Is	5.43	5.25	6.50	8.33	9.08	9.51	11.30	18.23	16.94	3.07	6.36	8.05	0.56	7.49	0.09
		Daydream Is	13.43	13.07	14.51	15.65	15.80	12.62	6.71	4.35	1.09	0.00	2.77	5.09	0.79	4.29	0.10
		Dent Is	11.15	10.03	10.03	9.90	11.83	13.07	10.38	12.54	9.02	0.17	1.87	7.09	0.67	6.42	0.09
		Pine Is	6.65	6.60	8.18	10.78	12.27	11.79	9.48	12.92	10.65	0.64	10.04	6.28	0.66	5.62	0.09
		Seaforth Is	7.72	6.36	7.20	9.13	10.95	10.77	11.31	16.03	11.59	0.73	8.21	8.27	0.49	7.79	0.08
Fitzroy Basin Association	Fitzroy	North Keppel Is (South)	1.63	1.44	1.45	1.52	2.90	10.70	20.24	21.04	16.03	4.17	18.88	9.18	0.48	8.70	0.05
		Barren Is (West)	0.25	0.41	0.40	0.50	0.81	1.50	9.55	25.25	23.07	4.60	33.67	10.10	0.28	9.81	0.05
		Humpy and Halfway Is	0.57	0.61	0.51	0.76	0.69	2.09	14.78	31.63	28.42	6.30	13.64	8.98	0.22	8.76	0.04
		Pelican Is	0.33	0.51	0.53	0.45	0.73	1.29	5.29	26.64	33.08	7.92	23.23	7.59	0.17	7.42	0.03

Table A1-3.2 ANOVA summary tables of spatial and temporal variation in univariate community attributes; 2005 to 2007, 2006 to 2007 and for settlement to tiles 2007 only.

Hard coral cover (Fourth-root) visit 1&3					
Source	Numerator df	Denominator df	F	Error term	P
Catchment	5	24.68	11.510	Site (Reef(Catchment))	**<0.001**
Reef (Catchment)	18	24.60	3.667		**0.002**
Depth	1	22.87	1.727	Depth * Site(Reef(Catchment))	0.202
Depth * Catchment	5	23.08	1.987		0.119
Depth * Reef(Catchment)	17	22.68	3.890		**0.002**
Year	1	26.04	10.716	Year * Site(Reef(Catchment))	**0.025**
Year* Catchment	5	26.30	2.315		**<0.001**
Year * Reef (Catchment)	18	26.14	2.209		0.080
Year * Depth	1	25.25	2.85	Residual	0.222
Year * Depth * Catchment	5	25.55	0.572		**0.017**
Year * Depth * Reef(Catchment)	17	25.08	0.455		0.693

Macroalgal cover (Fourth-root) visit 1&3					
Source	Numerator df	Denominator df	F	Error term	P
Catchment	5	45.81	22.289	Site (Reef(Catchment))	**<0.001**
Reef (Catchment)	18	45.71	15.265		**<0.001**
Depth	1	38.70	4.702	Depth * Site(Reef(Catchment))	**0.036**
Depth * Catchment	5	38.89	4.582		**0.002**
Depth * Reef(Catchment)	17	38.55	0.831		0.650
Year	1	38.36	36.897	Year * Site(Reef(Catchment))	**<0.001**
Year* Catchment	5	38.68	6.573		**<0.001**
Year * Reef (Catchment)	18	38.46	1.772		0.068
Year * Depth	1	20.57	0.104	Residual	0.750
Year * Depth * Catchment	5	20.77	1.391		0.268
Year * Depth * Reef(Catchment)	17	20.39	1.646		0.141

Table A1-3.2 continued

Soft coral cover (Fourth-root) visit 1&3					
Source	Numerator df	Denominator df	F	Error term	P
Catchment	5	26.21	3.102	Site (Reef(Catchment))	0.025
Reef (Catchment)	18	26.13	4.733		**<0.001**
Depth	1	24.30	2.019	Depth * Site(Reef(Catchment))	0.168
Depth * Catchment	5	24.50	2.188		0.088
Depth * Reef(Catchment)	17	24.12	2.421		0.023
Year	1	49	3.454	Year * Site(Reef(Catchment))	0.069
Year* Catchment	5	49	13.502		**<0.001**
Year * Reef (Catchment)	18	49	1.383		0.183
Year * Depth	1	49	1.241	Residual	0.271
Year * Depth * Catchment	5	49	1.153		0.346
Year * Depth * Reef(Catchment)	17	49	0.568		0.899

Density of juvenile colonies per m2 of available substrate visit 1&3					
Source	Numerator df	Denominator df	F	Error term	P
Catchment	5	25.65	8.565	Site (Reef(Catchment))	**<0.001**
Reef (Catchment)	18	25.53	2.456		0.019
Depth	1	24.21	3.492	Depth * Site(Reef(Catchment))	0.074
Depth * Catchment	5	24.46	2.336		0.073
Depth * Reef(Catchment)	17	23.98	0.310		0.992
Year	1	49	10.646	Year * Site(Reef(Catchment))	**0.002**
Year* Catchment	5	49	6.811		**<0.001**
Year * Reef (Catchment)	18	49	0.850		0.636
Year * Depth	1	49	0.523	Residual	0.473
Year * Depth * Catchment	5	49	0.116		0.988
Year * Depth * Reef(Catchment)	17	49	0.746		0.741

Juvenile hard coral richness (genera) visit 1&3					
Source	Numerator df	Denominator df	F	Error term	P
Catchment	5	23.67	26.473	Site (Reef(Catchment))	**<0.001**
Reef (Catchment)	18	23.58	2.935		**0.008**
Depth	1	22.12	46.470	Depth* Site(Reef(Catchment))	**<0.001**
Depth * Catchment	5	22.36	2.259		0.084
Depth * Reef(Catchment)	17	21.94	1.443		0.207
Year	1	48.45	114.877	Year * Site(Reef(Catchment))	**<0.001**
Year* Catchment	5	48.45	12.726		**<0.001**
Year * Reef (Catchment)	18	48.47	2.871		**0.002**
Year * Depth	1	48.52	0.548	Residual	0.463
Year * Depth * Catchment	5	48.52	1.942		0.104
Year * Depth * Reef(Catchment)	17	48.57	2.049		**0.026**

Table A1-3.2 continued

Richness soft coral recruits (genera) visit 1&3					
Source	Numerator df	Denominator df	F	Error term	P
Catchment	5	24.97	5.265	Site (Reef(Catchment))	**<0.001**
Reef (Catchment)	18	24.88	3.973		**0.001**
Depth	1	23.18	0.082	Depth * Site(Reef(Catchment))	0.494
Depth * Catchment	5	23.39	0.614		0.276
Depth * Reef(Catchment)	17	22.98	0.938		0.360
Year	1	49	0.036	Year * Site(Reef(Catchment))	0.850
Year* Catchment	5	49	7.647		**<0.001**
Year * Reef (Catchment)	18	49	1.278		0.243
Year * Depth	1	49	1.651	Residual	0.205
Year * Depth * Catchment	5	49	0.263		0.931
Year * Depth * Reef(Catchment)	17	49	0.952		0.523

Richness hard coral (genera) visit 1&3					
Source	Numerator df	Denominator df	F	Error term	P
Catchment	5	53.36	19.756	Site (Reef(Catchment))	**<0.001**
Reef (Catchment)	18	53.26	3.902		**<0.001**
Depth	1	40.68	28.041	Depth * Site(Reef(Catchment))	**<0.001**
Depth * Catchment	5	40.82	4.717		**0.002**
Depth * Reef(Catchment)	17	40.59	1.223		0.291
Year	1	28.26	1.188	Year * Site(Reef(Catchment))	0.285
Year* Catchment	5	28.53	5.614		**0.001**
Year * Reef (Catchment)	18	28.40	0.512		0.929
Year * Depth	1	24.50	0.015	Residual	0.902
Year * Depth * Catchment	5	24.75	1.219		0.330
Year * Depth * Reef(Catchment)	17	24.28	0.795		0.683

Richness soft coral (genera) visit 1&3					
Source	Numerator df	Denominator df	F	Error term	P
Catchment	5	25.15	3.022	Site (Reef(Catchment))	**0.029**
Reef (Catchment)	18	24.70	5.576		**<0.001**
Depth	1	24.21	0.016	Depth * Site(Reef(Catchment))	0.900
Depth * Catchment	5	24.46	1.248		0.318
Depth * Reef(Catchment)	17	24.00	0.765		0.712
Year	1	48	10.177	Year * Site(Reef(Catchment))	**0.003**
Year* Catchment	5	48	7.507		**<0.001**
Year * Reef (Catchment)	18	48	0.750		0.738
Year * Depth	1	48	2.435	Residual	0.125
Year * Depth * Catchment	5	48	0.411		0.839
Year * Depth * Reef(Catchment)	17	48	0.355		0.988

Table A1-3.2 continued

Recruit counts hard coral per m² (Fourth Root) visit 1&3					
Source	Numerator df	Denominator df	F	Error term	P
Catchment	5	24.93	7.203	Site(Reef(Catchment))	**<0.001**
Reef (Catchment)	18	24.86	1.529		0.162
Depth	1	22.91	0.644	Depth * Site(Reef(Catchment))	0.4301
Depth * Catchment	5	23.08	4.497		**0.005**
Depth * Reef(Catchment)	17	22.74	1.123		0.392
Year	1	49	13.958	Year * Site(Reef(Catchment))	**<0.001**
Year* Catchment	5	49	6.803		**<0.001**
Year * Reef (Catchment)	18	49	2.792		**0.002**
Year * Depth	1	49	0.143	Residual	0.707
Year * Depth * Catchment	5	49	0.214		0.955
Year * Depth * Reef(Catchment)	17	49	1.077		0.401

Recruits on tiles (log e) visit 1&3					
Source	Numerator df	Denominator df	F	Error term	P
Catchment	1	45	66.411	Site*Reef(Catchment)	<0.001
Reef (Catchment)	9	45	16.041		<0.001
Year	1	45	181.918	Residuals	<0.001
Year* Catchment	2	45	1.664		0.204
Year * Reef (Catchment)	9	45	7.604		<0.001

Table A1-3.2 continued, 2006 to 2007.

Hard coral cover (Fourth-root) visit 2&3					
Source	Numerator df	Denominator df	F	Error term	P
Catchment	5	25.86	20.595	Site (Reef(Catchment))	**<0.001**
Reef (Catchment)	18	25.79	4.451		**<0.001**
Depth	1	23.80	2.295	Depth * Site(Reef(Catchment))	0.143
Depth * Catchment	5	23.97	2.728		**0.043**
Depth * Reef(Catchment)	17	23.63	5.61		**<0.001**
Year	1	26.04	10.716	Year * Site(Reef(Catchment))	**0.003**
Year* Catchment	5	26.30	2.315		0.072
Year * Reef (Catchment)	18	26.14	2.209		**0.032**
Year * Depth	1	25.25	2.85	Residual	0.104
Year * Depth * Catchment	5	25.55	0.572		0.721
Year * Depth * Reef(Catchment)	17	25.08	0.455		0.951

Table A1-3.2 continued

Macroalgal cover (Fourth-root) visit 2&3					
Source	Numerator df	Denominator df	F	Error term	P
Catchment	5	57.92	45.022	Site (Reef(Catchment))	**<0.001**
Reef (Catchment)	18	57.73	15.152		**<0.001**
Depth	1	33.38	5.654	Depth * Site(Reef(Catchment))	**0.023**
Depth * Catchment	5	33.59	1.472		0.225
Depth * Reef(Catchment)	17	33.22	2.524		**0.011**
Year	1	38.63	23.405	Year * Site(Reef(Catchment))	**<0.001**
Year* Catchment	5	38.91	6.09		**<0.001**
Year * Reef (Catchment)	18	38.80	2.092		**0.027**
Year * Depth	1	22.48	1.027	Residual	0.322
Year * Depth * Catchment	5	22.63	3.796		**0.012**
Year * Depth * Reef(Catchment)	17	22.33	2.625		**0.017**

Soft coral cover (Fourth-root) visit 2&3					
Source	Numerator df	Denominator df	F	Error term	P
Catchment	5	26.29	6.069	Site (Reef(Catchment))	**<0.001**
Reef (Catchment)	18	26.22	4.857		**<0.001**
Depth	1	24.16	2.128	Depth * Site(Reef(Catchment))	0.157
Depth * Catchment	5	24.33	1.996		0.115
Depth * Reef(Catchment)	17	24.01	3.129		**0.005**
Year	1	49	3.536	Year * Site(Reef(Catchment))	0.066
Year* Catchment	5	49	0.467		0.799
Year * Reef (Catchment)	18	49	0.680		0.813
Year * Depth	1	49	2.439	Residual	0.125
Year * Depth * Catchment	5	49	1.534		0.197
Year * Depth * Reef(Catchment)	17	49	1.126		0.358

Density of juvenile colonies per m2 of available substrate visit 2&3					
Source	Numerator df	Denominator df	F	Error term	P
Catchment	5	25.62	6.073	Site (Reef(Catchment))	**<0.001**
Reef (Catchment)	18	25.55	1.801		0.085
Depth	1	23.53	2.621	Depth * Site(Reef(Catchment))	0.119
Depth * Catchment	5	23.70	3.772		**0.012**
Depth * Reef(Catchment)	17	23.37	1.807		0.092
Year	1	25.52	2.819	Year * Site(Reef(Catchment))	0.105
Year* Catchment	5	25.78	2.495		0.057
Year * Reef (Catchment)	18	25.67	0.535		0.914
Year * Depth	1	24.29	0.001	Residual	0.977
Year * Depth * Catchment	5	24.55	0.934		0.477
Year * Depth * Reef(Catchment)	17	24.07	0.935		0.549

Table A1-3.2 continued

Juvenile hard coral richness (genera) visit 2&3					
Source	Numerator df	Denominator df	F	Error term	P
Catchment	5	21.37	25.562	Site (Reef(Catchment))	**<0.001**
Reef (Catchment)	18	21.27	2.994		**0.009**
Depth	1	19.73	38.701	Depth* Site(Reef(Catchment))	**<0.001**
Depth * Catchment	5	19.94	2.298		0.084
Depth * Reef(Catchment)	17	19.52	2.387		**0.034**
Year	1	25.83	196.635	Year * Site(Reef(Catchment))	**<0.001**
Year* Catchment	5	26.09	6.770		**<0.001**
Year * Reef (Catchment)	18	25.88	1.370		0.227
Year * Depth	1	25.23	4.497	Residual	**0.044**
Year * Depth * Catchment	5	25.55	0.560		0.729
Year * Depth * Reef(Catchment)	17	24.98	1.589		0.143

Richness hard coral (genera) visit 2&3					
Source	Numerator df	Denominator df	F	Error term	P
Catchment	5	24.10	13.026	Site (Reef(Catchment))	**<0.001**
Reef (Catchment)	18	23.98	2.937		**0.007**
Depth	1	22.65	35.231	Depth * Site(Reef(Catchment))	**<0.001**
Depth * Catchment	5	22.90	5.343		**0.002**
Depth * Reef(Catchment)	17	22.43	1.213		0.329
Year	1	49	0.969	Year * Site(Reef(Catchment))	0.330
Year* Catchment	5	49	3.365		**0.011**
Year * Reef (Catchment)	18	49	1.039		0.437
Year * Depth	1	49	0.550	Residual	0.462
Year * Depth * Catchment	5	49	0.150		0.979
Year * Depth * Reef(Catchment)	17	49	1.155		0.334

Richness soft coral recruits (genera) visit 2&3					
Source	Numerator df	Denominator df	F	Error term	P
Catchment	5	25.29	8.015	Site (Reef(Catchment))	**<0.001**
Reef (Catchment)	18	25.23	3.792		**0.001**
Depth	1	23.18	0.482	Depth * Site(Reef(Catchment))	0.494
Depth * Catchment	5	23.34	1.358		0.276
Depth * Reef(Catchment)	17	23.02	1.165		0.360
Year	1	49	12.531	Year * Site(Reef(Catchment))	**<0.001**
Year* Catchment	5	49	0.829		0.535
Year * Reef (Catchment)	18	49	1.254		0.259
Year * Depth	1	49	3.317	Residual	0.075
Year * Depth * Catchment	5	49	1.394		0.243
Year * Depth * Reef(Catchment)	17	49	0.885		0.594

Table A1-3.2 continued

Recruit counts hard coral per m2 (Fourth Root) visit 2&3					
Source	Numerator df	Denominator df	F	Error term	P
Catchment	5	25.21	5.132	Site(Reef(Catchment))	**0.002**
Reef (Catchment)	18	25.15	1.238		0.305
Depth	1	23.07	0.463	Depth * Site(Reef(Catchment))	0.503
Depth * Catchment	5	23.23	3.369		**0.020**
Depth * Reef(Catchment)	17	22.92	1.785		0.097
Year	1	25.84	1.40	Year * Site(Reef(Catchment))	0.247
Year* Catchment	5	26.11	2.141		0.092
Year * Reef (Catchment)	18	25.97	0.807		0.677
Year * Depth	1	24.90	0.306	Residual	0.586
Year * Depth * Catchment	5	25.18	1.234		0.323
Year * Depth * Reef(Catchment)	17	24.66	0.986		0.502

Recruits on tiles (log e) visit 2&3					
Source	Numerator df	Denominator df	F	Error term	P
Catchment	2	60	37.192	Site*Reef(Catchment)	<0.001
Reef (Catchment)	9	60	22.953		<0.001
Year	1	60	54.063	Residuals	<0.001
Year* Catchment	2	60	40.132		<0.001
Year * Reef (Catchment)	9	60	7.122		<0.001

ANOVA summary table of spatial variation in coral settlement to tiles in 2007.

Recruits on tiles (log e) visit 3 only					
Source	Numerator df	Denominator df	F	Error term	P
Catchment	3	75	78.917	Residuals	<0.001
Reef (Catchment)	11	75	14.72		<0.001

Table A1-3.3 Known disturbances to coral communities at Reef Plan Marine monitoring locations.

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%)
		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)

Table A1-3.3 continued.

NRM region	Catchment	Reef	Bleaching 1998	Bleaching 2002	Flood plumes 1991-99	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		
		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 (to be determined)	Coral Bleaching Jan 2006 (25% at 2m and 33% at 5m)
		North Keppel Is	1 (15%)	0.89 (36%)	1991, 2008 (to be determined)	Coral Bleaching Jan 2006 (60% at 2m and 44% at 5m)
		Middle Is	1 (56%)	1 (Nil)	1991, 2008 (to be determined)	Coral Bleaching Jan 2006 (62% at 2m and 38% at 5m)
		Humpy & Halfway Is	1 (6%)	1 (26%)	1991, 2008 (to be determined)	Coral Bleaching Jan 2006 (25% at 2m and 27% at 5m)
		Pelican Is	1.00	1.00	1991, 2008 (to be determined)	Coral Bleaching Jan 2006 (Nil)
		Peak Is	1.00	1.00	1991, 2008 (to be determined)	Coral Bleaching Jan 2006 (Nil)

Table A1-3.3 continued.

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

NRM Region	Primary Catchment	Reef	Survey Year	Depth	Total hard coral cover	Acroporidae	Agariciidae	Dendrophylliidae	Euphylliidae	Faviidae	Fungiidae	Merulinidae	Mussidae	Oculinidae	Pectiniidae	Pocilloporidae	Poritidae	Siderastreidae
Wet Tropics	Daintree	Snapper Is (North)	2007	2	58.8	53.9				1.6	0.6	0.2		0.8		0.5	0.6	0.5
Wet Tropics	Daintree	Snapper Is (North)	2007	5	59.5	15.3	15.4			1.8	0.9	1.8	0.1	1.3	2.3	2.3	18.4	
Wet Tropics	Daintree	Snapper Is (South)	2007	2	23.8	3.5	0.1	0.1		1.3				0.5		0.4	17.3	0.4
Wet Tropics	Daintree	Snapper Is (South)	2007	5	49.6	5.0	5.4	0.6		9.4	1.1	0.1	0.1	0.4	0.1	0.1	26.2	1.1
Wet Tropics	Johnstone	Fitzroy Is (West)	2007	2	29.1	16.0	0.1			1.9	0.1	0.3	0.3	1.6		1.6	7.2	0.1
Wet Tropics	Johnstone	Fitzroy Is (West)	2007	5	18.9	5.1	0.1		0.3	2.3	0.1	0.6	0.9	0.8	0.1	0.3	8.3	0.1
Wet Tropics	Johnstone	Fitzroy Is (East)	2007	2	34.0	27.5				1.9		0.1	0.1	0.1		1.1	3.1	
Wet Tropics	Johnstone	Fitzroy Is (East)	2007	5	43.6	27.8		0.3	0.2	3.1		0.2	0.3	1.1		4.4	6.3	
Wet Tropics	Johnstone	High Is (West)	2007	2	55.0	8.1	0.2			1.1	0.4	0.1	0.8	0.3		0.4	43.7	
Wet Tropics	Johnstone	High Is (West)	2007	5	18.3	1.4	1.1			0.9	0.2		0.2	0.4	0.1		14.0	
Wet Tropics	Johnstone	High Is (East)	2007	2	58.7	47.6		0.3	0.1	3.7	0.2	0.1	0.9	0.4		0.6	5.0	0.1
Wet Tropics	Johnstone	High Is (East)	2007	5	33.3	15.0	0.1	0.2		2.6	0.1	0.1	0.1	0.7		0.4	13.9	0.1
Wet Tropics	Johnstone	Frankland Group (West)	2007	2	29.4	4.1	3.3			0.2		0.1		0.2		0.5	21.0	
Wet Tropics	Johnstone	Frankland Group (West)	2007	5	65.9	0.2	2.4				0.1					0.1	63.2	
Wet Tropics	Johnstone	Frankland Group (East)	2007	2	12.5	10.1				1.2		0.1		0.1		0.2	0.8	0.1
Wet Tropics	Johnstone	Frankland Group (East)	2007	5	11.4	3.9	0.1			1.3	0.1	0.5	0.1	0.4	0.1	2.2	2.6	0.1
Wet Tropics	Tully	North Barnard Group	2007	2	2.5	1.9		0.1		0.3							0.3	
Wet Tropics	Tully	North Barnard Group	2007	5	3.8	1.7	0.2	0.1		0.5		0.1		0.1	0.1	0.1	0.9	
Wet Tropics	Tully	Dunk Is (North)	2007	2	8.3	3.0	0.1	1.3		2.5		0.6		0.2		0.3	0.3	
Wet Tropics	Tully	Dunk Is (North)	2007	5	15.2	8.1	0.1	2.3		2.4	0.4		0.1	0.1	0.6	0.6	0.5	0.1
Burdekin	Burdekin	Pelorus & Orpheus Is (West)	2007	2	11.1	5.3				0.7	0.5		0.2		0.1	3.6	0.7	
Burdekin	Burdekin	Pelorus & Orpheus Is (West)	2007	5	8.9	3.8	0.3	0.1		0.9	0.4	0.1	0.1		0.3	0.4	2.7	0.1
Burdekin	Burdekin	Pandora Reef	2007	2	5.0	0.9				1.3		0.1					1.5	1.1
Burdekin	Burdekin	Pandora Reef	2007	5	16.2	1.4	0.1			11.5	0.9	0.3	0.3	0.4	1.3		0.3	
Burdekin	Burdekin	Havannah Is	2007	2	17.0	10.3		1.9		1.4		0.4	0.3	0.6	0.2		1.9	0.1
Burdekin	Burdekin	Havannah Is	2007	5	12.7	1.4	0.8	2.6		2.4	1.3	1.3	0.3	0.6	0.5		1.4	0.2
Burdekin	Burdekin	Geoffrey Bay	2007	2	20.0	11.8	0.6	1.6		3.1	0.1	0.4		0.6	0.1		1.6	0.2
Burdekin	Burdekin	Geoffrey Bay	2007	5	26.5	6.4	3.0	1.9	0.1	5.7	1.9	1.6	0.1	0.4	1.2		4.3	
Burdekin	Burdekin	Middle Reef	2007	2	53.8	4.6	13.4	1.4		1.5	0.3	0.4	0.3	1.4	0.3		30.2	

Table A1-3.4 continued

NRM Region	Primary Catchment	Reef	Survey Year	Depth	Total hard coral cover	Acroporidae	Agariciidae	Dendrophylliidae	Euphyllidae	Faviidae	Fungiidae	Merulinidae	Mussidae	Oculinidae	Pectiniidae	Pocilloporidae	Poritidae	Siderastreidae
Mackay / Whitsunday	Proserpine	Double Cone Is	2007	2	39.2	21.7	0.1	1.9		1.8	0.3	2.1	2.0	2.9	1.1	0.1	5.1	0.1
				5	70.2	7.1	2.6			3.7	0.8	0.6	3.0	1.3	0.8		50.5	0.1
		Daydream Is	2007	2	36.6	34.1		0.1		0.3	0.1	0.1	0.3	0.1	0.9		0.6	
				5	48.8	42.3	0.1			1.2	0.1	0.3	0.1		1.1	0.1	3.5	
		Dent Is	2007	2	49.9	22.7	1.3	0.8		0.8	0.6	0.3	1.4	1.9	2.3	0.1	17.9	0.2
				5	43.2	13.8	4.5	0.3		1.5	0.5	1.1	1.1	1.8	6.6	0.1	11.8	0.1
		Pine Is	2007	2	42.2	12.7	0.2		0.3	1.3	0.8	0.9	0.6	20.4	2.5	0.2	2.2	
				5	42.0	4.5	3.6	0.1	0.3	1.6	2.4	0.8	2.6	8.1	9.7	0.2	8.1	
		Seaforth Is	2007	2	22.1	1.4	7.8	0.2		2.5	0.2	0.1	0.5		0.2	0.1	9.1	0.1
				5	15.8	1.1	1.9	0.6		3.1	0.2	0.3	0.9		0.3		7.4	
Fitzroy Basin Association	Fitzroy	North Keppel Is	2007	2	19.2	18.3					0.8	0.1				0.1		
				5	27.3	26.3				0.1	0.2		0.3		0.1		0.1	0.3
		Barren Is	2007	2	43.1	41.3	0.4			0.4		0.3	0.1			0.5		0.1
				5	71.4	71.4												
		Humpy and Halfway Is	2007	2	53.6	53.0										0.4	0.1	
				5	32.9	32.3				0.3			0.1				0.1	0.1
		Pelican Is	2007	2	51.5	45.8		0.6		1.9		0.1	0.1			1.1	0.8	1.1
				5	24.5	0.1		3.8		7.8		2.8	0.6	0.1	0.4	0.4	5.6	3.0

Table A1-3.5 Composition of coral reef communities represented by common soft coral families (% cover)

NRM Region	Primary Catchment	Reef	Survey Year	Depth	Total soft coral cover	ALCYONIIDAE	ANTHOTHELIDAE	BRIAREIDAE	CLAVULARIINAE	ELLISELLIDAE	GORGONIAN SPP	HELIOPORIDAE	NEPHTHEIDAE	TUBIPORIDAE	XENIIDAE
Wet Tropics	Daintree	Snapper Is (North)	2007	2	15.6	0.6		0.8	14.1						
				5	1.5	0.4		1.0	0.1						
		Snapper Is (South)	2007	2	3.2	1.7		0.2				1.3			
				5	13.5	0.2		9.1		0.1		4.2			
	Johnstone	Fitzroy Is (West)	2007	2	38.8	38.3		0.4						0.1	
				5	30.2	30.0		0.1					0.1		
		Fitzroy Is (East)	2007	2	4.9	2.7		0.2	0.4				0.8		0.8
				5	6.6	4.4		0.1	1.5		0.1		0.4		0.1
		High Is (West)	2007	2	5.4	2.9						2.3	0.2		
				5	3.2	2.1		0.4				0.7			
		High Is (East)	2007	2	9.4	4.9		4.4	0.1						
				5	9.2	0.9		8.2	0.1						
		Frankland Group (West)	2007	2	8.4	4.0			4.0			0.4			0.1
				5	1.4	1.4									
		Frankland Group (East)	2007	2	0.6	0.4			0.1			0.1			
				5	5.9	5.7		0.2							
	Tully	North Barnard Group	2007	2	0.8	0.1		0.8							
				5	0.8			0.8							
		Dunk Is (North)	2007	2	0.1	0.1									
				5	0.4	0.1		0.1			0.2				
Burdekin	Burdekin	Pelorus & Orpheus Is (West)	2007	2	35.1	30.4		0.7	1.6				2.2		0.3
				5	37.6	30.4		4.8	0.3	0.1			2.1		
		Pandora Reef	2007	2	0.1				0.1						
				5	0.3	0.2			0.1						
		Havannah Is	2007	2	3.6	1.1		2.4					0.1		
				5	4.8	0.4		4.4							
		Geoffrey Bay	2007	2	0.5	0.1		0.4							
				5	0.8	0.5		0.3							0.1
		Middle Reef	2007	2	4.9	4.9									

Table A1-3.5 continued

NRM Region	Primary Catchment	Reef	Survey Year	Depth	Total soft coral cover	ALCYONIIDAE	ANTHOTHELIDAE	BRIAREIDAE	CLAVULARIINAE	ELLISELLIDAE	GORGONIAN SPP	HELIOPORIDAE	NEPHTHEIDAE	TUBIPORIDAE	XENIIDAE
Mackay / Whitsunday	Proserpine	Double Cone Is	2007	2	11.1	6.5		4.7							
				5	7.4	5.1		2.3							
		Daydream Is	2007	2	13.6	13.5		0.1							
				5	6.1	6.1									
		Dent Is	2007	2	12.1	5.8		6.3							
				5	3.2	3.1	0.1	0.1							
		Pine Is	2007	2	1.6	0.9		0.6							0.1
				5	4.5	4.1		0.4							
		Seaforth Is	2007	2	9.3	7.2	2.1								
				5	5.2	1.3	3.6			0.1	0.1				0.1
Fitzroy Basin Association	Fitzroy	North Keppel Is	2007	2	0.2	0.2									
				5	0.0										
		Barren Is	2007	2	21.1	1.0									20.1
				5	3.9	0.0									3.9
		Humpy and Halfway Is	2007	2	6.7	0.5									6.2
				5	0.5	0.4									0.1
		Pelican Is	2007	2	9.9	8.1							0.5		1.4
				5	13.4	10.1		0.2		0.1	1.8		0.2	0.2	0.9

Table A1-3.6 Number of juvenile hard coral colonies (<10cm) observed over 34m^2

NRM Region	Primary Catchment	Reef	Survey Year	Depth	Total juveniles	Acroporidae	Agariciidae	Astrocoeniidae	Dendrophylliidae	Euphyllidae	Faviidae	Fungiidae	Merulinidae	Mussidae	Oculinidae	Pectiniidae	Pocilloporidae	Poritidae	Siderastreidae
Wet Tropics	Daintree	Snapper Is (North)	2007	2	442	270	1				12	67	1	1	11		17	24	38
				5	227	40	5		12		59	29	3	7	31	9	14	17	1
		Snapper Is (South)	2007	2	635	224			7	1	88	31	1	1	43	1	23	183	32
				5	183	27	4		1		32	19	7	2	6	6	2	49	28
	Johnstone	Fitzroy Is (West)	2007	2	466	167	2		1	2	117	15	10	19	58	2	28	43	2
				5	574	93	9		3	8	88	47	17	38	102	14	20	133	2
		Fitzroy Is (East)	2007	2	333	75			2		177		6	36	7		6	22	2
				5	464	112	3		1	6	165	4	4	54	15	1	43	39	17
		High Is (West)	2007	2	310	103	10		6		68	8	7	13	24	13	16	40	2
				5	462	65	33		14	5	100	26	14	19	39	15	3	124	5
		High Is (East)	2007	2	155	55			4	1	50	1		4	2		13	24	1
				5	359	51	2	1	39		118	3	7	16	9	5	7	79	22
		Frankland Group (West)	2007	2	249	32	24			1	13	30	1	15	37	1	16	78	1
				5	178	21	9				8	51	2	3	21	2	11	50	
		Frankland Group (East)	2007	2	236	87			1		80	4	3	9	6	1	8	31	6
				5	548	72	5		6	4	163	25	14	31	34	10	49	105	30
	Tully	North Barnard Group	2007	2	153	86			22		26	4			6		4	4	1
				5	446	74	2		218		54	8	2	3	3	12	9	33	28
		Dunk Is (North)	2007	2	514	106	1		106		247	1	3	2	4	1	10	11	22
				5	504	101		2	78	1	211	1	8	6	6	3	31	29	27
Burdekin	Burdekin	Pelorus & Orpheus Is (West)	2007	2	452	91	6		10	3	161	32	10	30	32	38	3	34	2
				5	430	53	12		7		148	11	6	43	8	71	6	64	1
		Pandora Reef	2007	2	44	18					7	2	3		7		3	3	1
				5	136	10	1		1		27	48	6		32	2		8	1
		Havannah Is	2007	2	210	49			4		61	27	5	9	13	1	1	39	1
				5	341	27	8		15	2	41	60	17	16	49	29	3	71	3
		Geoffrey Bay	2007	2	322	83	16		32		101	14	2	3	6	1		49	15
				5	545	79	13		62	6	232	17	18	14	25	15	3	56	5
		Middle Reef	2007	2	255	33	12		67		76	20	5	4	11	3	1	20	3
Mackay / Whitsunday	Proserpine	Double Cone Is	2007	2	219	67		1	4	2	51	9	10	20	8	5	4	34	4
				5	173	19	5	1	2	4	36	14	8	22	11	16	1	34	
		Daydream Is	2007	2	319	61	6	2	7	3	58	35	17	65	4	28	5	27	1
				5	345	80	9	2	4	2	74	20	8	47	3	52	2	40	2
		Dent Is	2007	2	221	102	4		3	1	25	15	8	18	4	9	4	26	2
				5	290	67	6	1	15	1	48	20	8	39	12	20	8	43	2
		Pine Is	2007	2	371	146	6	4	2	10	27	28	6	23	11	9	1	97	1
				5	340	72	20	2	17	9	51	9	12	36	6	42	5	56	3
		Seaforth Is	2007	2	514	79	16		10	5	147	33	11	67	18	18	2	106	2
				5	445	60	18		10	10	150	18	10	79	2	30	1	55	2
Fitzroy Basin Association	Fitzroy	North Keppel Is	2007	2	119	66					6	45						1	1
				5	81	44					13	21				1		1	1
		Barren Is	2007	2	181	83			19		43		1	1			32		2
				5	31	24								2			4		1
		Humpy and Halfway Is	2007	2	189	151					27		1				6	4	
				5	132	39			9		70			1			2	11	
		Pelican Is	2007	2	230	114			8		53			26			9	17	3
				5	172	21			32		67	1	1	14			1	28	7

Table A1-3.7 Number of juvenile (<10cm) soft coral colonies observed over 34m^2

										Alyconiidae						Nephtheidae						Xeniidae			
NRM Region	Primary Catchment	Reef	Survey Year	Depth	Total juveniles	Briareum	Clavularia	Isis / Jasminisis	Junceella	Cladiella	Klyxum	Lobophytum	Rhytisma	Sarcophyton	Sinularia	Capnella	Lemnalia	Scleronephthya	Stereonephthya	Other Nephtheidae	Cespitularia	Efflatournaria	Sympodium	Xenia	Other Xeniidae
Wet Tropics	Daintree	Snapper Is (North)	2007	2	30	16	7							2	5										
				5	19	8	1							2	7									1	
		Snapper Is (South)	2007	2	62	30								1	31										
				5	21	11								1	9										
	Johnstone	Fitzroy Is (West)	2007	2	221	6				10	4	7	59	13	32										
				5	203	21					6	15	82	31	46	2									
		Fitzroy Is (East)	2007	2	79	3	8			10	1			3	12	5							33	4	
				5	32	3	4				10		3	1	11										
		High Is (West)	2007	2	23					2	2	5		4	10										
				5	64	10					15	5		10	16									8	
		High Is (East)	2007	2	77	6				55	4	1		5	6										
				5	53	16	6			3	19	1	1	3	4										
		Frankland Group (West)	2007	2	99	7	66					8		5	4	2								7	
				5	51	3	14				3	1		4	26										
		Frankland Group (East)	2007	2	33	2	2			2	6	1		6	7								6	1	
				5	66	6	4				10	4		14	22									6	
	Tully	North Barnard Group	2007	2	14	1	1			4	2			3	3										
				5	15	2					6			3	4										
		Dunk Is (North)	2007	2	9						1			5	3										
				5	12						4			5	3										
Burdekin	Burdekin	Pelorus & Orpheus Is (West)	2007	2	341	18	33				21	17		87	120			3	7		1			33	1
				5	269	17	10				11	13		48	74			69	27						
		Pandora Reef	2007	2	9		6			3															
				5	14		8				1	1			2						1				1
		Havannah Is	2007	2	34	4					2	1		11	15									1	
				5	58	14					5	1		12	26										
		Geoffrey Bay	2007	2	14	6					2				6										
				5	64				2		17			15	28						2				
		Middle Reef	2007	2	42						5			29	8										
Mackay / Whitsunday	Proserpine	Double Cone Is	2007	2	78	8				9	19	2		15	22	2									1
				5	185	11					35	1		29	107		2								
		Daydream Is	2007	2	163						27	3		80	53										
				5	174						35			93	37				9						
		Dent Is	2007	2	109	12					2	4		72	13									6	
				5	152	9					6	2		121	14										
		Pine Is	2007	2	32	16					9			3	3	1									
				5	35						3			6	26										
		Seaforth Is	2007	2	95	16					5	1		22	41			1						2	7
				5	80	5					11	2		33	18				1					1	9
Fitzroy Basin Association	Fitzroy	North Keppel Is	2007	2																					
				5	1									1											
		Barren Is	2007	2	6572						2													6570	
				5	2059																			2059	
		Humpy and Halfway Is	2007	2	472									2	2	1					410			57	
				5	27						5			1							19				2
		Pelican Is	2007	2	571						7	3		26	14	31								479	11
				5	176				1		7			39	18	29			1					73	8

Table A1-3.8 Mean richness of hard coral genera from the two sites at each reef and depth as estimated from demography transects. The richness of all hard coral genera and the richness of hard coral genera represented by juvenile colonies (<10cm) are presented.

NRM Region	Primary Catchment	Reef	Survey Year	Depth	Richness	Juv. Richness
Wet Tropics	Daintree	Snapper Is (North)	2007	2	9.7	6
				5	24.5	22.5
		Snapper Is (South)	2007	2	10.7	14.5
				5	17.0	18
	Johnstone	Fitzroy Is (West)	2007	2	15.5	25.5
				5	19.5	28.5
		Fitzroy Is (East)	2007	2	13.5	19
				5	18.0	26.5
		High Is (West)	2007	2	15.5	29.5
				5	14.0	31
		High Is (East)	2007	2	14.5	13.5
				5	18.5	27.5
		Frankland Group (West)	2007	2	7.0	15.5
				5	5.0	16.5
		Frankland Group (East)	2007	2	10.5	17.5
				5	13.5	31.5
	Tully	North Barnard Group	2007	2	4.5	12
				5	10.0	19.5
		Dunk Is (North)	2007	2	11.0	17.5
				5	14.5	20
Burdekin	Burdekin	Pelorus & Orpheus Is (West)	2007	2	11.0	29
				5	14.5	30
		Pandora Reef	2007	2	9.0	9
				5	15.5	17
		Havannah Is	2007	2	13.5	23
				5	18.0	27
		Geoffrey Bay	2007	2	12.0	17.5
				5	21.0	26.5
		Middle Reef	2007	2	14.5	21
Mackay / Whitsunday	Proserpine	Double Cone Is	2007	2	19.5	24
				5	10.5	27
		Daydream Is	2007	2	11.5	31
				5	17.5	28.5
		Dent Is	2007	2	23.0	25
				5	17.5	29
		Pine Is	2007	2	21.5	22
				5	18.0	32
		Seaforth Is	2007	2	17.0	31
				5	3.0	33
Fitzroy Basin Association	Fitzroy	North Keppel Is	2007	2	5.5	5.5
				5	8.5	8.5
		Barren Is	2007	2	2.0	9.5
				5	3.0	5
		Humpy and Halfway Is	2007	2	4.0	7.5
				5	11.0	7.5
		Pelican Is	2007	2	12.0	11.5
				5	47.0	14.5

Table A1-3.9 Total numbers of coral recruits in 2007 recorded on terracotta tiles at each reef and depth. Values in bold are average numbers of recruits per tile.

NRM Region	Primary Catchment	Reef	Non-isoporan Acroporidae	Pocilloporidae	Poritidae	Isoporan Acroporidae	Other	Unknown	Total	Mean	Island Mean	Region Mean
Wet Tropics	Russell-Mulgrave-Johnstone	Fitzroy Is (West)	5638	286	611	0	5	23	6563	**182.31**	234.04	178.04
		Fitzroy Is (East)	9905	85	222	0	22	54	10288	**285.78**		
		High Is (West)	3006	68	49	0	8	8	3139	**87.19**	136.46	
		High Is (East)	6252	163	252	0	5	14	6686	**185.72**		
		Frankland Group (West)	1029	46	335	0	8	14	1432	**39.78**	163.61	
		Frankland Group (East)	9735	463	115	0	9	26	10348	**287.44**		
Burdekin	Burdekin	Pelorus & Orpheus Is (West)	1014	180	45	0	33	19	1291	**35.86**	35.86	32.53
		Pandora Reef	1065	20	20	0	20	55	1180	**32.78**	32.78	
		Geoffrey Bay	1005	1	19	0	12	5	1042	**28.94**	28.94	
Mackay Whitsunday	Proserpine	Double Cone Is	1305	49	88	0	18	24	1484	**41.22**	41.22	60.02
		Daydream Is	3067	198	129	6	29	25	3454	**95.94**	95.94	
		Pine Is	1384	5	71	0	62	22	1544	**42.89**	42.89	
Fitzroy Basin Association	Fitzroy	Barren Is	548	214	0	5	0	2	769	**21.36**	21.36	42.13
		Humpy and Halfway Is	1791	117	9	0	2	68	1987	**55.19**	55.19	
		Pelican Is	1182	573	14	0	12	13	1794	**49.83**	49.83	

Appendix 2: QA/QC 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 Plan 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	0.56 µg L^{-1}*
NH4	1.1 µg L^{-1}*
TDN	21 µg L^{-1}*
PN	0.54 µg $filter^{-1}$
PO4	0.9 µg L^{-1}*
TDP	2.5 µg L^{-1}*
PP	0.09 µg L^{-1}
Si	2.5 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 2006/07.

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	0-18.3*	2-6
NO3+ NO2	4.0-8.7*	2-6
NH4	2.5-14.9*	2-6
TDN	1.0-12.9*	5-6
PN	5.5	21
PO4	0.9-8.4*	2-9
TDP	1.8-4.7*	5-6
PP	2.5	5
Si	4.7-11.9*	4-7
DOC	1.8-3.4*	19-34*
POC	5.0	52
Chl	0.7	19
SS	n/a**	
Salinity	0.03	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 2007/08.
**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 ammonium, 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	12.0*	35	20
NO3+ NO2	11-15.9*	21-31	29-35
NH4	8.9-10.6*	22-86	5-9
TDN	6.6-19.1*	49-82	5-37
PN	9.5	223	10
PO4	7.7-13.8*	28-86	7-22
TDP	11.7-18.1*	47-86	16-38
PP	7.2	237	7
Si	9.4-10.5*	50-72	11-16
DOC	3.1-3.6*	84-91	1-2
POC	12.1	220	17
Chl	8.6	211	10
SS	15.6	188	20
Salinity	n/a**		

*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 2007/08.
**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 PN, PP, 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, with about 60% the batches returning readings outside the 20% limit (Table A2-2.4). Especially the phosphate and TDP analysis returned recoveries of above 110%. This outcome could not be sufficiently explained and will be further explored. One reason could be that one of the reference materials used (bottle #5 from round 12 of the NLLNCT) is relatively highly concentrated compared t the GBR lagoon samples.
To assure that the monitoring results were accurate, additional QAQC samples were included in all batches for dissolved nutrient analyses, e.g. spike samples, which retuned acceptable results (see below).

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

Parameter (analyte)	Average recovery (%)	N
NO2	n/a	
NO3+ NO2	82.4-129.0*	3-5
NH4	85.3-122.1*	3-5
TDN	80.2-120.0*	4
PN	103.5	21
PO4	107.2-139.3*	3-5
TDP	115.6-120.2*	4-6
PP	95.6**	5
Si	89.2-131.2*	3-6
Chl	102.3	19
SS	n/a***	
Salinity	100.01	4

*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

SPIKE RECOVERY

As a further measure to ensure analytical accuracy, spikes of known concentration were added to natural seawater samples on board of the research vessel, during the normal sample preparation. The final concentration was well within the range of values in natural seawater in the GBR lagoon so that the samples would not compromise the analysis. The spike samples were labelled with sample codes like the regular water samples in order to include them in analytical batches without knowledge of the analyst. Recovery of the spikes was overall acceptable, i.e. within 90-110% of the expected value, with the exception of one PO4 batch exceeding 110% and one TDP batch below 90% (Table A2-2.5).

Table A2-2.5 Summary of average recovery of nutrient spikes added to natural samples. 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.

Parameter (analyte)	Average recovery (%)	N
NO3	95-109*	2-6
TDN	92-105	2-6
PO4	101-115	2-6
TDP	82-101	2-6

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 and chlorophyll. The instrument readings (or actual readings, in case of chl) 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 and we conclude that contamination due to handling was minimal.

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 8% 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 ($\mu g\ L^{-1}$)	SS (mg $filter^{-1}$)	POC (μg $filter^{-1}$)
Average of blank readings	0.002	647	0.007	0.15	6.78
N of blank readings	10	7	4	35	28
Average of sample readings	0.092	43615	0.514	1.83	40.7
N of sample readings	477	396	422	388	456
Average of blanks as % of average sample readings	2.1	1.5	1.3	8.2	1.5

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.

Appendix 4: List of Presentations given on the Program

Schaffelke B. Overview of Reef Plan MMP monitoring programme. Presentation to CoreMap delegation from Indonesia. 09 August 2007, AIMS, Townsville.

Schaffelke B. Reef Plan Marine Monitoring Programme- *Inshore WQ Monitoring*. Presentation at Reef Plan MMP Synthesis Workshop 10-12 Sep. 2007.

Thomson A. Reef Plan Marine Monitoring Programme- *Inshore Coral Reef Monitoring*. Presentation at Reef Plan MMP Synthesis Workshop 10-12 Sep. 2007.

Schaffelke B. Overview of Reef Plan MMP monitoring programme. Presentation to staff from the Department of State Development. 13 March 2008, AIMS, Townsville.

Neale SJ, Thomson D, Thompson A, Schaffelke B. The influence of water quality and larval supply on coral recruitment to nearshore reefs of the Great Barrier Reef. Oral presentation at the 11th International Coral Reef Symposium 2008, Fort Lauderdale 7-11 July 2008.

Uthicke S, Schaffelke B, Thompson A, Thomson D. Water Quality in nearshore areas of the Great Barrier Reef: a large scale monitoring program and an assessment of the use of benthic foraminifera as water quality indicators. Oral presentation at the 11th International Coral Reef Symposium 2008, Fort Lauderdale 7-11 July 2008.

Appendix 5: Summary of completion of contracted monitoring tasks

Task	Description	Progress
	Schedule 1: Inshore Marine Water Quality Monitoring	
2.1	Routine (3 or 4 monthly) collection of water samples for analysis of chlorophyll a, dissolved and particulate nutrient species, DOC and suspended sediment concentrations, and salinity and turbidity analysis in inshore waters of the GBR lagoon at data logger sites listed in Table 5. At each site samples collected should include those: a) subtidally, within the adjacent reef boundary layer; b) subtidally, in the immediate vicinity of the data logger; and c) a water column profile in the vicinity of the data logger.	Dry season cruises completed in October 2007, all 14 sites sampled and samples analysed (100%). Wet season cruises completed in March 2008, all 14 sites sampled and samples analysed (100%).
2.2	Continuous deployment (including set-up of sites and routine change-over every 3-4 months) of autonomous environmental loggers (chlorophyll fluorescence, turbidity, temperature and (if available) light with appropriate antifouling wipers) deployed at 14 inshore reef sites (Table 1). Loggers will be supplied and remain the property of the GBRMPA.	Deployment at all 14 sites completed in October 2007 (100%), analysis completed of data to Feb/March 2008. Ongoing change-over. Light loggers not yet available from GBRMPA.
2.3	Routine acquisition, management and storage of data downloaded from autonomous environmental data loggers (chlorophyll fluorescence, turbidity and temperature) (2.2 above).	see 2.2; New data management system for routine acquisition and processing of water quality instrument data developed and applied.
2.4	Manage the technical aspects of monthly collection and analysis of surface water samples for measurement of chlorophyll a concentrations, salinity and secchi disk readings at sites situated along four (4) cross-shelf networks identified in Table 2. (Establishment and maintenance of the sampler network and day-to-day liaison with operators will be carried out with the assistance of the GBRMPA). Sites will need to be identified by GPS at each sampling occasion	Regular sampling only along the two Far Northern cross-shelf networks. The other 3 (and 1 additional) networks are unreliable or in-operational. Waiting for review of locations/operators with GBRMPA. All received samples were analysed.
2.5	Manage the technical aspects of monthly collection and analysis of surface water samples for measurement of chlorophyll a concentrations, secchi disk readings and salinity at coastal sites identified in Table 2. (Maintenance of sampler network and day to day liaison with operators will be carried out with the assistance of the GBRMPA).	Ongoing sampling at 8 out of 11 established locations; 4 locations sampled irregularly or unreliable. Secchi disc roll-out not implemented, waiting for review of locations with GBRMPA. All received samples were analysed.
2.6	Timely provision of program Progress Reports and Final Reports specified in Table 3.	Progress Report 1 in January 2008 (after signing of contract) Progress Report 2 in May 2008 This Final Report
2.7	Appropriate QA/QC procedures identified in the Marine Monitoring Program QA/QC Manual (2005) to be an integral component of all aspects of sample collection and analysis. This is to include continued participation in appropriate inter-laboratory comparisons, proficiency testing and the use of standard reference materials.	Ongoing commitment to QAQC procedures.

Schedule 2: Inshore Coral Reef Monitoring		
2.1	Collection of annual underwater digital image records of % cover of sessile benthic organisms along transects established at sites identified in Table 1 using AIMS LTMP survey techniques modified for inshore coastal reefs.	Surveys completed at all 23 prescribed locations (>100%), analyses completed.
2.2	Concurrent annual diver surveys of juvenile corals (1 – 10 cm, identified to genus) in transects at fixed sites on reefs identified in Table 1 and recording of appropriate condition indices including size	
2.3	Deployment or multiple deployments (dependent on the occurrence of split spawnings) in (October / December) and retrieval (December / February) of coral settlement plates at three Wet Tropics, three Burdekin, three Mackay-Whitsunday and three Fitzroy region reefs identified in Table 1 for identification and enumeration of year-0 coral recruits (non-isoporan acroporids; isoporan acroporids; pocilloporids; poritids, other).	All settlement plates deployed in October 2007 and changed-over in December 2007 (100%) and retrieved in February-April 2008, analyses completed.
2.4	Deployment (October / December) and retrieval (December/ February) of passive samplers at recruitment sites concurrently with coral recruitment settlement plates. Passive samplers are to be provided by the GBRMPA.	All passive samplers deployed in October 2007 and retrieved in December 2007 (100%).
2.5	Collection of sediment samples for grain size analysis at all coral monitoring sites (every two years) and collection of other innovative water quality indicators (e.g. forams) at the 14 core monitoring sites on an annual basis.	All samples collected (100%), analyses completed.
2.6	Maintenance and acquisition of seawater temperature data collected by temperature data loggers deployed at sites specified in Table 1.	Deployment at all 27 sites completed in July 2007 (100%), regular change-over and maintenance ongoing.
2.7	The monitoring partner's Project Manager and other nominated personnel to attend and contribute to a 3-day workshop to be held in Townsville in late September 2008 to present GBR coral reef status data analyses to enable collaborative completion of a synthesis and integration report.	By September 2008
2.8	Timely provision of program Progress Reports and Final Reports specified in Table 2.	Progress Report 1 in January 2008 (after signing of contract) Progress Report 2 in May 2008 This Final Report
2.9	Appropriate QA/QC procedures identified in the Marine Monitoring Program QA/QC Manual (2005) to be an integral component of all aspects of sample collection and analysis. This is to include continued participation in appropriate inter-laboratory comparisons, proficiency testing and the use of standard reference materials.	Ongoing commitment to QAQC procedures.