Reef Rescue Marine Monitoring Program

Final Report of AIMS Activities 2009/10
Project 3.7.8 Inshore Water Quality Monitoring

**Britta Schaffelke, John Carleton, Jason Doyle, Miles Furnas,
Kevin Gunn, Michele Skuza, Margaret Wright, Irena Zagorskis**

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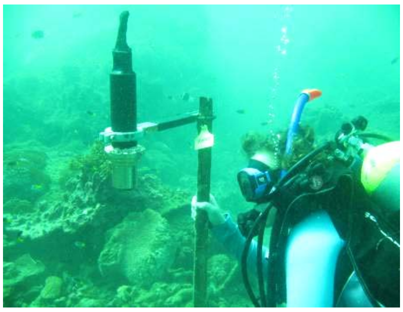

Australian Institute of Marine Science
PMB No 3
Townsville MC Qld 4810

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Executive Summary

The AIMS monitoring activities as part of the Reef Rescue Marine Monitoring Program (MMP) in 2009/10 were largely an extension of activities established under previous arrangements from 2004 to 2009 and are grouped into two components, Inshore Marine Water Quality Monitoring (reported in this Final report) and Inshore Coral Reef Monitoring (reported in May 2010, Thompson et al. 2010b).

Water quality monitoring in the inshore lagoon was carried out at 14 fixed coral reef locations in four NRM regions, the Wet Tropics (N=5), Burdekin (N=3), Mackay Whitsunday (N=3) and Fitzroy regions (N=3). This included direct water sampling and analyses of a comprehensive suite of dissolved and particulate nutrients and carbon, suspended solids, chlorophyll *a* and salinity, as well as using state of the art sensors with long-term data logging capacity for measurements of temperature, chlorophyll and turbidity. Sampling of the longest available time series of water quality data for the Great Barrier Reef (GBR) in coastal waters between Cape Tribulation and Cairns from 1989 to the present was also continued under the MMP (N=6 fixed open water sampling locations).

- Sustained long-term monitoring of the coastal and inshore GBR lagoon is fundamental to determine the status of marine water quality and of long-term trends in response to changes in land use and to Reef Plan and Reef Rescue actions. The MMP water quality monitoring has now completed its 5th year and the results have improved our understanding of the spatial and temporal variability of biogeochemical and physical variables in the GBR inshore lagoon. The site-specific water quality in the inshore GBR shows clear gradients away from river mouths and is influenced by flood events and resuspension.

- The Water Quality Guidelines for the Great Barrier Reef Marine Park (GBRMPA 2009; hereafter called "the Guidelines") was used as a framework to interpret the water quality values obtained at the fourteen core sampling sites and to identify areas/locations with potential water quality issues. In addition to these indicator-specific assessments of compliance with or exceedances of the Guidelines, we propose here an interim water quality index. The index aggregates the compliance/exceedance assessments for each of five indicators (turbidity/suspended solids, chlorophyll, particulate nitrogen and phosphorus, Secchi depth) into an overall rating for the water quality at each of the 20 fixed sampling sites (Six Cairns Transect and 14 core reefs; see Table below). The colour scheme used is consistent with Paddock to Reef Reporting and colours reflect the status of water quality: red (very poor), orange (poor), yellow (fair), light green (good), dark green (very good).

- The water quality indices at seven out of the eleven Wet Tropics sites were rated as 'good' or 'very good'. The indices at the other four sites were rated as 'fair' (Snapper and Dunk islands) or 'very poor' (two sites of the Cairns Transect). Annual mean turbidity at Dunk and Snapper islands was above the Guidelines in all three years of instrumental monitoring and 5 year means of Secchi depth (and PP concentration at Dunk Island) did not comply with the Guidelines. At sites of the Cairns Transect, the five year means of four out of five indicators (except for PN) exceeded the Guidelines.

The four sites with a water quality index of less than 'good' are closest to major river mouths (the Daintree, Barron and Tully rivers, respectively) and are also surrounded by a very shallow coastal area prone to wind-driven resuspension of fine sediments.

Region	Location	Turbidity/SS	Chlorophyll	PN	PP	Secchi
Wet Tropics	*Cape Tribulation*	2*	2*	2	2	0
	Snapper Island North	0	1	2	2	0
	Port Douglas	2	2	2	2	0
	Double Island	2*	2*	2	2	2
	Green Island	2*	2*	2	2	2
	Yorkey's Knob	0*	0*	2	0	0
	Fairlead Buoy	0*	0*	2	0	0
	Fitzroy Island	2	2	2	2	2
	High Island	2	2	2	2	0
	Russell Island (Franklands)	2	2	2	2	2
	Dunk Island	0	2	2	0	0
Burdekin	Pelorus / Orpheus Island	2	1	2	2	0
	Pandora Reef	2	1	2	2	0
	Magnetic Island	0	2	0	0	0
Mackay Whitsund.	Double Cone Island	1	1	2	2	0
	Daydream/West Molle Island	0	1	2	2	0
	Pine Island	0	0	2	2	0
Fitzroy	Barren Island	2	1	2	2	2
	Humpy Island	2	1	2	2	2
	Pelican Island	*0*	*0*	*2*	*0*	*0*

- The longest time series of water quality data for the GBR, the AIMS Cairns Transect, showed relationships between concentrations of six water quality variables and several human-related and natural environmental factors, including; vegetation clearing rates on the adjacent catchment, increased land area under crops and periods of high rainfall and episodes of strong winds. However, the relatively infrequent sampling of the Cairns Transect and MMP core sites (two to three times per year) limits the statistical power of any analyses and the high inherent variability in the data makes the interpretation difficult.

- Of the three sites in the Burdekin Region, the water quality index of the two sites located in the midshelf water body was 'good', while the Magnetic Island site that is closer to the mainland and to riverine influence had a 'very poor' rating. Annual mean turbidity levels at Magnetic Island in all three years of monitoring and long term means of PP exceeded the Guidelines. Exceedances of the chlorophyll Guidelines were measured in individual years at Pelorus Island and Pandora Reef.

- The water quality index at the three sites in the Mackay Whitsunday Region was 'fair' (Daydream and Double Cone islands) and 'poor' (Pine Island). Annual mean turbidity levels at Pine and Daydream islands exceeded the Guidelines in all three years of monitoring, and the chlorophyll Guidelines were exceeded in all three years at Pine Island and during two years at Daydream Island.

- In the Fitzroy Region, only the most inshore site, Pelican Island had a water quality index rated as "very poor". At this site, the annual means of turbidity and chlorophyll exceeded the Guidelines and long-term means of PP and Secchi depth also did not comply. The water quality at Barren and Humpy islands was rated "very good".

- MMP water quality compliance assessments based on measured or calculated chlorophyll concentration and turbidity were carried out using two approaches: site-specific instrumental monitoring (validated and supplemented by analyses of water samples) at the 14 core coral reefs and broad-scale monitoring using ocean colour remote sensing imagery (reported separately, Brando et al. 2010). At this time, we consider the logger data to provide a good description of water quality at our 14 core coral reef sites. Continued instrumental and remotely sensed monitoring of chlorophyll and turbidity will deliver information essential for determining whether further management action may be required at individual locations or regions that continue to show high chlorophyll and turbidity levels relative to the Guidelines.

- In the future, we need to develop an integrated assessment and reporting framework that integrates all three sampling approaches (direct water sampling, instruments and remote sensing) for reporting of GBR lagoon water quality. This will permit a confident and comprehensive evaluation of the overall status of coastal and inshore waters and support the integrated "Paddock to Reef" reporting of progress towards the Reef Plan and Reef Rescue goals and targets.

1. Introduction to the Program

The Reef Rescue Marine Monitoring Program (MMP), formerly known as Reef Water Quality Protection Plan Marine Monitoring Programme (Reef Plan MMP), was designed and developed by the Great Barrier Reef Marine Park Authority (GBRMPA) and is now funded by the Australian Government's Reef Rescue initiative. In 2009 the MMP was integrated into the Marine Tropical Sciences Research Facility (MTSRF) and has been managed by the Reef and Rainforest Research Centre (RRRC).

The MMP forms an integral part of the *Paddock to Reef Integrated Monitoring, Modelling and Reporting Program*, which is a key action of Reef Plan 2009 and is designed to evaluate the efficiency and effectiveness of implementation and report on progress towards the Reef Plan and Reef Rescue goals and targets. The Paddock to Reef Program involves the development of an annual report card on Reef water quality and ecosystem status, to be preceded by a Baseline Report Card published in late 2010. The MMP contributes assessments and information to both of these products.

The Australian Institute of Marine Science (AIMS) and the RRRC entered into a co-investment contract in May 2010 to provide monitoring activities under the MMP for the period 2009/10.

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

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

The first component, the Inshore Marine Water Quality Monitoring, is reported in this Final Report, presenting the results of AIMS water quality monitoring activities over the period 01 May 2009 to 30 April 2010, with inclusion of data from the previous MMP monitoring since 2005.

Outcomes from the Inshore Coral Reef Monitoring component were reported earlier in May 2010 (Thompson et al. 2010b) and have been externally reviewed. Complete Final Reports of both AIMS components, after peer review and revision, are scheduled for completion on 01 October 2010.

2. Inshore Marine Water Quality Monitoring

2.1 Introduction

Coastal areas around the world are under increasing pressure by human population growth, intensifying land use and urban and industrial development. As a result, increased loads of suspended sediment, nutrients and pollutants such as pesticides and other chemicals invariably enter coastal waters and lead to a decline in estuarine and coastal marine water quality, manifested as eutrophication and increased water turbidity. Many tropical coastal regions are considered to be at great risk because of strong economic and population growth paired with limited environmental management. However, after decades of decline, some areas along the coasts of wealthier countries, generally in the temperate northern hemisphere, are showing signs of water quality improvements due to significant regulatory and policy intervention over the last two decades (see e.g. Cloern 2001, Nixon 2009).

It is well documented in the scientific literature that sediment and nutrient loads carried by land runoff into the coastal and inshore zones of the Great Barrier Reef (GBR) have increased since European settlement and this increase has been implicated in the decline of some coral reefs and seagrass meadows in these zones (reviewed in Brodie *et al.* 2008). Concern about these negative effects of land runoff triggered the formulation of the Reef Water Quality Protection Plan (Reef Plan) for catchments adjacent to the GBR World Heritage Area by the Australian and Queensland governments in 2003 (Anon. 2003). The Reef Plan was revised and updated in 2009 (Anon. 2009) and has two primary goals:

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

Reef Plan actions also include the establishment of water quality monitoring programs extending from the paddock to the Reef (Anon. 2010), to assess the effectiveness of the Reef Plan's implementation, which are now predominantly funded by the Australian Government's Reef Rescue initiative. The MMP is an integral part of this monitoring to provide reliable physicochemical and biological data to investigate the effects of changes in inputs from the GBR catchments on marine water quality and inshore ecosystems.

Interpretation of the MMP inshore reef water quality monitoring results is supported by an understanding of the ecosystems of the GBR, their underlying biological and chemical processes and their physical drivers. This knowledge is still developing and has improved greatly over the last decade. The water quality-related processes in the costal and inshore GBR have to be viewed in context of the whole system, including the GBR lagoon, the adjacent coast and the neighbouring Coral Sea.

The biological productivity of the Great Barrier Reef (GBR) is sustained by nutrients (e.g. nitrogen, phosphorus, silicate, iron), which are supplied by a number of processes and sources (Furnas *et al.* 1997; Furnas 2003, Furnas *et al.* in review). These include upwelling of nutrient-enriched subsurface water from the Coral Sea, rainwater, fixation of gaseous nitrogen by (cyano-)bacteria and freshwater runoff from adjacent catchments. Land runoff is the largest source of new nutrients to the inshore GBR (Furnas 2003, Furnas *et al.* in review), transported into the GBR lagoon especially during monsoonal flood events (Devlin and Brodie 2005, Devlin and Schaffelke 2009). However, most of the inorganic nutrients used by marine plants and bacteria on a day-to-day basis come from recycling of nutrients already within the GBR ecosystem (Furnas *et al.* 2005, Furnas *et al.* in review).

To understand the effects of land runoff on GBR coastal and inshore waters and biota, it is important to understand the fundamental processes that control the fate and impact of freshwater, sediment, nutrients and pesticides delivered from catchments into the receiving waters of the GBR lagoon. Important are the water flows, exchange rates and residence times (="flushing time"), which are influenced by large- to meso-scale oceanographic processes. Water residence times in the GBR lagoon are still debated as different approaches have delivered very different results. Hancock *et al.* (2006), Wang *et al.* (2007) and Choukroun *et al.* (2010) estimate residence times of weeks, indicating a well-flushed system, while Brinkman *et al.* (2002) and Luick *et al.* (2007) estimate much longer residence times of several months. However, water residence times may not accurately reflect the period of time materials such as sediments, nutrients and pesticides remain in the GBR lagoon. This time is not only determined by physical transport and flushing but also by other processes such as biological uptake and transformation, sedimentation and burial, resuspension and remineralisation, which are not yet qualified on a whole-of-GBR scale although a recent comprehensive nutrient budget has been assembled by Furnas et al. (in review). Analysis of satellite imagery of flood plumes suggest residence times in the GBR coastal and inshore zones of several weeks (Schroeder *et al.* in prep.) and rapid episodic transport of flood-borne material into the midshelf and outer shelf reef regions (Devlin and Schaffelke 2009). The currently developed whole-of-GBR hydrodynamic model is likely to deliver improved estimates of residence times as well as resolve trajectories and spatial distribution of major freshwater inputs (current MTSRF project led by M. Herzfeld, CSIRO, and R. Brinkman, AIMS). This model will become the foundation for future sediment dynamics, biogeochemical and ecological modelling, which will provide an improved capacity to predict changes in water quality in space and time in response to changing land use and runoff load scenarios.

The information gathered under the current MMP sampling program has much improved our understanding of the spatial distribution and temporal variability of water quality in the coastal and inshore GBR. This includes detailed information about the site-specific state of water quality around inshore coral reefs (this report), wide-field spatial patterns in water quality measured by remote sensing (separate report by CSIRO), detailed information about water quality in flood plumes (separate report by JCU) and information about herbicide levels in the inshore GBR (separate report by UQ).

Before the MMP, information on water quality data in the coastal and inshore areas of the GBR lagoon was limited to a handful of research studies (Walker and O'Donnell 1981, Schaffelke *et al.* 2003 and references therein, Cooper *et al.* 2007). However, extensive water sampling throughout the GBR lagoon over the last 25 years had established typical concentration ranges of nutrients, chlorophyll *a* and other water quality parameters and described the occurrence of persistent latitudinal, cross-shelf and seasonal variations in these concentrations (Furnas *et al.* 1997, Furnas 2005, Brodie *et al.* 2007, De'ath and Fabricius 2008). While concentrations of most nutrients, suspended particles and chlorophyll *a* are normally low, water quality conditions in the coastal and inshore zones can abruptly change and nutrient levels increase dramatically for short periods following disturbance events (wind-driven re-suspension, cyclonic mixing, river flood plumes; see e.g. Furnas 1989, Schaffelke *et al.* 2009, Devlin and Schaffelke 2009, Brodie *et al.* 2010). However, nutrients introduced, released or mineralised into GBR lagoon waters during these events are generally rapidly taken up by pelagic and benthic algae and microbial communities (Alongi and McKinnon 2005), sometimes fuelling short-lived phytoplankton blooms and high levels of organic production (Furnas 1989, Furnas *et al.* 2005).

The key objective of this component of the MMP– 'Inshore Marine Water Quality Monitoring' is to:

- *describe spatial and temporal distributions of GBR marine water quality variables at permanent monitoring sites at selected inshore reefs and open water sites.*

The data have various applications:

- As a baseline and start of a long-term time series against which future change can be measured, e.g. in response to land management changes as part of the Reef Plan and Reef Rescue initiatives, as a result of climatic events or other long-term systemic changes.
- As environmental variables for correlative analyses with biological indicators, such as the status of coral reef communities. Analyses using the MMP water quality data were carried out as part of the MMP (see Thompson *et al.* 2010a, Uthicke *et al.* 2010) and the data have also supported complementary research, e.g. of MTSRF projects (Fabricius *et al.* 2010). It is anticipated that these data will be more widely used in the future as they are developing into a valuable data resource.

2.2 Methods

In the following an overview is given of the sample collection, preparation and analyses methods. Detailed documentation of the AIMS methods used in the MMP can be found in a separate QAQC report (Reef & Rainforest Research Centre Ltd (2010)).

Sample locations

The 14 fixed sampling locations, spanning four NRM regions, are congruent with the 14 'core' sites of the inshore coral reef monitoring component of the MMP. At these sites, detailed manual and instrumental water sampling was undertaken (see below) as well as annual surveys of reef status, including assessments of coral recruitment (see Thompson *et al.* 2010b). Sampling of the six open water stations of the 'AIMS Cairns Transect' was also continued (Table 1, Figure 1).

Table 1 Locations selected for inshore water quality monitoring (water sampling during research cruises in July 2009, October 2009 and February 2010 and continuous deployment of autonomous water quality instruments). The six locations of the 'AIMS Cairns Transect' (open water sampling) are in italics. Shaded cells indicate locations in the "midshelf" water body, as designated by the GBRMPA Water Quality Guidelines (GBRMPA 2009); all other locations are in the "open coastal" water body.

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

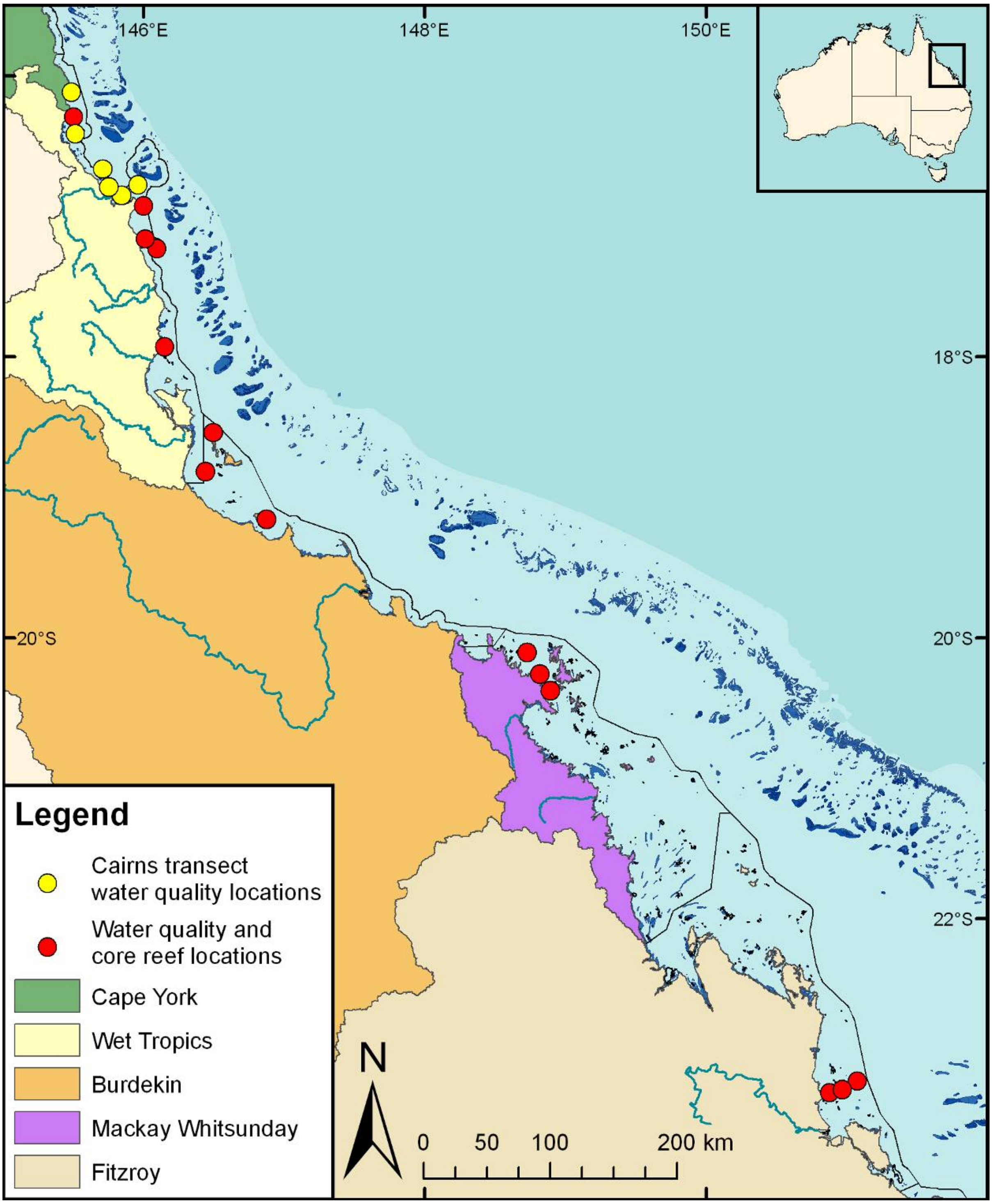


Figure 1 Sampling locations under the Reef Rescue MMP inshore marine water quality task. Red symbols indicate the 14 locations where autonomous water quality instruments (temperature, chlorophyll and turbidity) were deployed and regular water sampling was undertaken. Yellow symbols are the locations of the 'Cairns Transect', which have been sampled by AIMS since 1989. NRM region boundaries are represented by coloured catchment areas and the black line for marine boundaries.

Direct water sample collection, preparation and analyses

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

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 chlorophyll *a*. 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 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 water samples were 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. Separate samples for DOC analysis were filtered, acidified with 100 µl of AR-grade HCl and stored at 4°C until analysis. Separate sub-samples for $Si(OH)_4$ were filtered and stored at room temperature until analysis.

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

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

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

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

Particulate nitrogen (PN) was determined by high-temperature combustion of filtered particulate matter on glass fibre filters using an ANTEK 9000 NS nitrogen analyser (Furnas *et al.* 1995). The analyser was calibrated using AR Grade EDTA for the standard curve and marine sediment BCSS-1 as a control standard.

Particulate phosphorus (PP) was 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 was standardised using orthophosphoric acid and dissolved sugar phosphates as the primary standards.

The particulate organic carbon content (POC) of material collected on filters was 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 were placed in pre-combusted (950°C) ceramic sample boats. Inorganic C on the filters (e.g. $CaCO_3$) was removed by acidification of the sample with 2M hydrochloric acid. The filter was then introduced into the sample oven (950°C), purged of atmospheric CO_2 and the remaining organic carbon was then combusted in an oxygen stream and quantified by IRGA. The analyses were standardised using certified reference materials (e.g. MESS-1).

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

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

Details about QAQC procedures are given in Appendix 2.

Autonomous Water Quality Loggers

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

The Eco FLNTUSB instruments used in the MMP inshore water quality monitoring perform simultaneous *in situ* measurements of chlorophyll fluorescence, turbidity and temperature. The fluorometer monitors chlorophyll concentration by directly measuring the amount of chlorophyll fluorescence emission, using blue LEDs (centred at 455 nm and modulated at 1 kHz) as the excitation source. The instrument measures as range of chlorophyll pigments, not just chlorophyll *a*, and in the following the instrument data are referred to as "chlorophyll", in contrast to data from the direct water sampling which measures specifically "chlorophyll *a*". A blue interference filter is used to reject the small amount of red light emitted by the LEDs. The blue light from the sources enters the water at an angle of approximately 55–60 degrees with respect to the end face of the unit. The red fluorescence emitted (683 nm) is detected by a silicon photodiode positioned where the acceptance angle forms a 140-degree intersection with the source beam. A red interference filter discriminates against the scattered blue excitation light.

Turbidity is measured simultaneously by detecting the scattered light from a red (700 nm) LED at 140 degrees to the same detector used for fluorescence. The instruments were used in 'logging' mode and recorded a data point every 10 minutes for each of the three parameters, which was a mean of 50 instantaneous readings.

Pre- and post-deployment checks of each instrument included measurements of the maximum fluorescence response, the dark count (instrument response with no external fluorescence, essentially the 'zero' point) and of a dilution series of a pure plankton culture (for chlorophyll fluorescence) and of a 4000 NTU Formazin turbidity standard in a custom-made calibration chamber (see Schaffelke *et al.* 2007 for details on the calibration procedure). After retrieval from the field locations, the instruments were cleaned and data downloaded and converted from raw instrumental records into actual measurement units (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 (WISKI©-TV, Kisters). Instrumental data were validated by comparison with chlorophyll and suspended solid concentration obtained by analyses of water samples collected close to the instruments, which was carried out at each change-over (see Appendix 2).

Data analysis

Comparison with trigger values from the GBR Water Quality Guidelines

The Water Quality Guidelines for the Great Barrier Reef Marine Park (GBRMPA 2009) 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. Table 2 gives a summary of the Guidelines for five water quality variables in four cross-shelf water bodies. The MMP inshore monitoring locations are mostly located in the open coastal water body, with four sites (Russell Is., Pelorus Is., Pandora Rf and Barren Is.) located in the Midshelf water body, which has the same Guidelines trigger values.

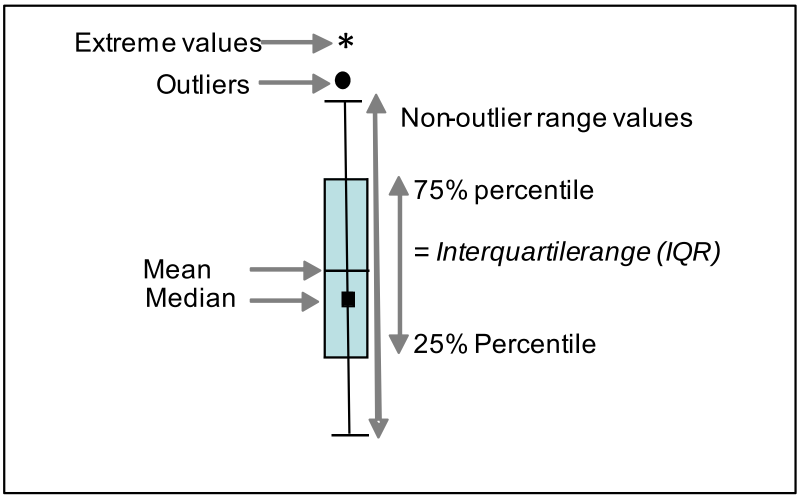
Table 2 Trigger values from the GBRMPA Water Quality Guidelines for the Great Barrier Reef Marine Park (GBRMPA 2009).

	Water Body			
Parameter	Enclosed coastal (Wet Tropics/Central Coast)	Open coastal	Midshelf	Offshore
Chlorophyll a (µg L^{-1})	2.0	0.45	0.45	0.40
Secchi (m)	1.0/1.5	10.0	10.0	17.0
Suspended solids (mg L^{-1})	5.0/15.0	2.0	2.0	0.7
Particulate nitrogen (µg L^{-1})	n/a	20.0	20.0	17.0
Particulate phosphorus (µg L^{-1})	n/a	2.8	2.8	1.9

Summary statistics and data presentation

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. Summary statistics of these depth-weighted mean values are presented as box and whisker plots (see box below for definitions and details of the box plots used) for the water quality constituents for which Guideline trigger values (GBRMPA 2009 and Table 2) are available: chlorophyll *a*, particulate nitrogen (PN), particulate phosphorus (PP), suspended solids (SS) and Secchi depth. Available data are combined (2005/06 to 2009/10) for each of the 14 sampling locations and presented separately for dry and wet seasons. The dry season was defined as May to October, the wet season as November to April. The results are reported separately for each of four monitored NRM regions: the Wet Tropics, Burdekin, Mackay Whitsunday and Fitzroy NRM regions (using the marine boundaries of each NRM region, as provided by the GBRMPA). This allows the characterisation of the water quality at each site and a comparison along regional gradients, generally away from the coast. Complete water quality data for all variables (depth-weighted mean values for each station and sampling occasion) are reported in Appendix 1.

Daily averages of the chlorophyll concentrations and turbidity levels measured by the Eco FLNTUSB instruments at each of 14 locations were summarised and presented as monthly box and whisker plots (see box below for definitions and details of the box plots used). Annual means and medians were also calculated per site based on the DERM 'water year" (October to October), the former for comparison with the Guidelines. The turbidity trigger value (1.54 NTU) was derived by transforming the suspended solids trigger value in the Guidelines (2 mg L^{-1}) using an equation based on a comparison between direct water samples and instrumental turbidity readings (see Schaffelke *et al.* 2009).



Comparison between water quality on and adjacent to coral reefs

Water quality data collected directly above the reef framework close to the water quality instruments were compared with data collected from a similar depth at adjacent open-water ship stations (see above) by an unbalanced, four-way, fixed factor, multivariate analysis of variance which employed permutation methods and was based on the Gower Metric association measure (PERMANOVA, Anderson *et al.* 2008). The year factor contained three levels (2007/08, 2008/09, 2009/10), the seasonal factor contained two levels (wet and dry), the regional factor contained four levels (Wet Tropics, Burdekin, Mackay Whitsunday, Fitzroy) and the environment factor contained two levels (on reef and open water). Replication varied from three locations in the Fitzroy, Mackay Whitsunday and Burdekin regions to five locations in the Wet Tropics Region. All thirteen collected water quality variables were included (concentrations of chlorophyll a, PN, PP, POC, DIP, DOC, Si, DON, DOP, NO_2, NO_3 and NH_4 and total suspended solids). The Gower Metric was deemed the most appropriate resemblance measure as the water quality variables employed in the analyses are essentially environmental in nature rather than biological; the variables are on different scales with few zero values and the various physical and chemical variables should be given equal weight (e.g. equal differences between values have the same influence on association regardless of scale). Data were square root transformed prior to the analysis to ameliorate the effects of a number of stations with disparately high readings.

Subsequent to the PERMANOVA analysis, the Gower Metric association matrix was subjected to a Principal Coordinate Analysis (PCO) to elucidate any higher order interactions noted in the PERMANOVA and to determine which variables were associated with the reef and open-water environments. PCO results were summarized in a bi-plot containing the distribution of sampling stations in two-dimensional space and the correlations of water quality variables with the PCO axes. The critical probability level for significance testing was set *a priori* at 5% in all analyses.

Temporal trend analysis of the Cairns Transect water quality data

Data from the 'Cairns 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 *a*, 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. From 2008/09 only six of the initial 11 sites were continued to be sampled after a statistical analysis indicated that this reduced number of stations would provide enough information for a robust time series analysis.

The water quality parameters measured include the suite of nutrients measured at the sampling locations. For the analysis of temporal trends we have chosen a subset of six parameters, chlorophyll *a* (μgL^{-1}), particulate nitrogen (PN, μgL^{-1}), particulate phosphorus (PP, μgL^{-1}), suspended solids (SS, mgL^{-1}), dissolved organic nitrogen (DON, μgL^{-1}) and dissolved organic phosphorus (DOP, 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, 2008, 2009) 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 R statistical package (R_Development_Core_Team 2010).

Interim site-specific water quality index

We developed a simple water quality index to generate an overall assessment of water quality at each of the 20 sampling sites (14 sites congruent with MMP inshore reef monitoring sites and with FLNTUSB instruments, 6 open water sites of the Cairns Water Quality Transect). We consider this index as "interim" as further research and data analyses need to be undertaken to refine, for example, the quantification of exceedances and the weighting of the water quality parameters.

The index aggregates scores given to five indicators in comparison with the GBR Water Quality Guidelines (GBRMPA 2009). The five indicators were:

1. Turbidity measured by FLNTUSB instruments
   (or suspended solids concentration, SS, in water samples for Cairns Transect sites);
2. Chlorophyll measured by FLNTUSB
   (or chlorophyll *a* concentrations in water samples for Cairns Transect sites);
3. Particulate nitrogen (PN) concentrations in water samples;
4. Particulate phosphorus (PP) concentrations in water samples;
5. Secchi depth.

Decision rules for these indicators and scores were as follows:

1. Turbidity/ suspended solids
   a. Turbidity measured by FLNTUSB instruments: annual mean values (see Table 7) were used for this assessment.
      If all three annual means of data were *below* the Guidelines, a score of 2 was given;
      If all three annual means of data were *above* the Guidelines, a score of 0 was given;
      If one or two annual means of data were above the Guidelines, a score of 1 was given
   b. SS concentration, SS (Cairns Transect sites): the overall mean from five years of sampling was used for this assessment. A score of 2 was given to means that exceeded the Guidelines, a score of 1 for means that were exactly the Guideline trigger value, and a score of 2 for means below the Guidelines.
      If the overall mean was *below* the Guidelines, a score of 2 was given;
      If the overall mean was *above* the Guidelines, a score of 0 was given
      If the overall mean was exactly the Guidelines trigger value, a scoer of 1 was given.

2. Chlorophyll
   a. Chlorophyll measured by FLNTUSB : annual mean values (see Table 7) were used for this assessment.
      All three annual means of data < Guidelines = 2
      All three annual means of data > Guidelines = 0
      One or two annual means > Guidelines = 1
   b. Chlorophyll *a* concentrations (Cairns Transect sites): the overall mean from five years of sampling was used for this assessment.

Overall mean < Guidelines = 2
Overall mean > Guidelines = 0
Overall mean exactly Guidelines trigger value=1.

3. Particulate nitrogen (PN) concentrations in water samples): the overall mean from five years of sampling was used for this assessment.
   - Overall mean < Guidelines = 2
   - Overall mean > Guidelines = 0
   - Overall mean exactly Guidelines trigger value=1.

4. Particulate phosphorus (PP) concentrations in water samples): the overall mean from five years of sampling was used for this assessment.
   - Overall mean < Guidelines = 2
   - Overall mean > Guidelines = 0
   - Overall mean exactly Guidelines trigger value=1.

5. Secchi depth: the overall mean from five years of sampling was used for this assessment.
   - Overall mean < Guidelines = 2
   - Overall mean > Guidelines = 0
   - Overall mean exactly Guidelines trigger value=1.

The indicator scores were added for each site and then converted into an overall proportional score relative to the maximum possible score by dividing this sum by 10 (i.e. the maximum rating that could be achieved if all assessments returned a positive score of 2) and multiplying by 100 (to convert into a percentage scale). The proportional scores were expressed on a five point scale and converted to a colour scheme for reporting whereby:

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

2.3 Results and Discussion

Comparison between water quality on and adjacent to coral reefs

In the regional summaries following this section the water quality data presented are combinations of results from water samples collected by divers close to the water quality instruments and from samples collected from a number of depths at adjacent open-water ship stations. This year we compared the results from these two sampling environments as we now have sufficient data available for an appropriate analysis ('on reef' sampling started in October 2007 when instrumental water quality monitoring commenced).

As the primary interest lies in the differences in water quality between reef and open-water sites, only the primary factor of sampling environment ('on reef' vs. 'adjacent reef') and all higher level interactions concerning this factor were investigated (see shaded cells in Table 3). All other factors were ignored. A high level interaction existed between season and sampling environment (P = 0.037, Table 3). As a consequence of this interaction, pair-wise comparisons between reef and open-water environments were made separately for the dry and wet season (Table 4). The water quality was significantly different (P = 0.001) between environments in both seasons. Average similarities within and between environments (Table 4) indicate that variability during the wet season was higher, with 'adjacent reef' sites at that time having the greatest dispersion in multi-dimensional space (smallest within sites similarities).

Table 3 Results of PERMANOVA analysis applied to annual, seasonal, regional and environmental differences in water quality. Shaded cells indicate the primary environment factor or interactions involving this factor. Df= degrees of freedom, SS= sum of squares, MS= mean square. Bold print and red font denotes significant results. The Season x Environment interaction was investigated in further pair-wise comparisons (Table 4).

Source	df	SS	MS	Pseudo-F	P(perm)	Unique permutations
Year	2	4253.9	2126.90	27.910	0.001	999
Season	1	4719.1	4719.10	61.925	0.001	999
Region	3	2750.0	916.68	12.029	0.001	999
Environment (On/ adjacent)	1	2094.5	2094.50	27.485	0.001	999
Year x Season	2	1775.0	887.48	11.646	0.001	999
Year x Region	6	1202.1	200.35	2.629	0.001	999
Year x Environment	2	240.8	120.40	1.580	0.121	997
Season x Region	3	1489.7	496.56	6.516	0.001	996
Season x Environment	1	182.1	182.07	2.389	0.037	999
Region x Environment	3	90.3	30.10	0.395	0.980	998
Year x Season x Region	6	1989.0	331.49	4.350	0.001	999
Year x Season x Environment	2	32.0	16.02	0.210	0.990	997
Year x Region x Environment	6	261.4	43.57	0.572	0.970	998
Season x Region x Environment	3	75.1	25.03	0.328	0.988	999
Year x Season x Region x Environment	6	126.2	21.03	0.276	1.000	996
Res	171	13031.0	76.21			
Total	218	33427.0				

The biplot from the Principal Coordinate Analysis confirms the findings of the pair-wise comparisons in that the 95% confidence ellipses for the group bivariate means are larger during the wet season at both 'on reef' and 'adjacent reef' sites and the centroids, as these ellipses are further apart than those in the dry season (Fig. 2). The primary axis, explaining 36.2% of total variation, appears to be associated with season and the second axis, explaining 21.8% of variation, associated with sampling environment. Overlaying the vectors for the water quality variables indicates that concentrations of all variables were highest during the wet season, with concentrations of the DIN compounds NO_2, NO_3 and NH_4 highest at 'on reef' sites during the wet season and concentrations of particulate water quality variables (chlorophyll *a*, suspended solids and particulate nutrients and carbon) highest at 'adjacent reef' sites.

Table 4 Pairwise comparisons between reef and open water environments during the dry and wet seasons. Average similarities are for the Gower Metric. Bold print denotes significant differences.

Comparisons	t	P(perm)	Average Similarities		
			Within 'on reef' sites	Within 'adjacent reef' sites	Between 'on reef' and 'adjacent reef' sites
Dry Season	4.107	0.001	87.653	87.612	86.205
Wet Season	3.374	0.001	83.233	80.573	80.487

Several other studies have reported that DIN in water close to reef surfaces are generally higher compared with open waters outside the reef tract, which has been attributed to reefal nitrogen fixation, bacterial ammonia oxidation and subsequent nitrification and excretion by reef biota (Webb and Wiebe 1978, Andrews and Müller 1983, Crossland *et al.* 1984, Ayukai 1993, Wilkinson *et al.* 1984, D'Elia and Wiebe 1990, Schaffelke *et al.* 2003).

We chose to report depth-weighted averages for particulates by combining reef and open water sampling environments. The combination of all available water quality data allows, in our opinion, for the best characterisation of the water quality at the 14 core reef sites and for comparison of the variables with the Guidelines.

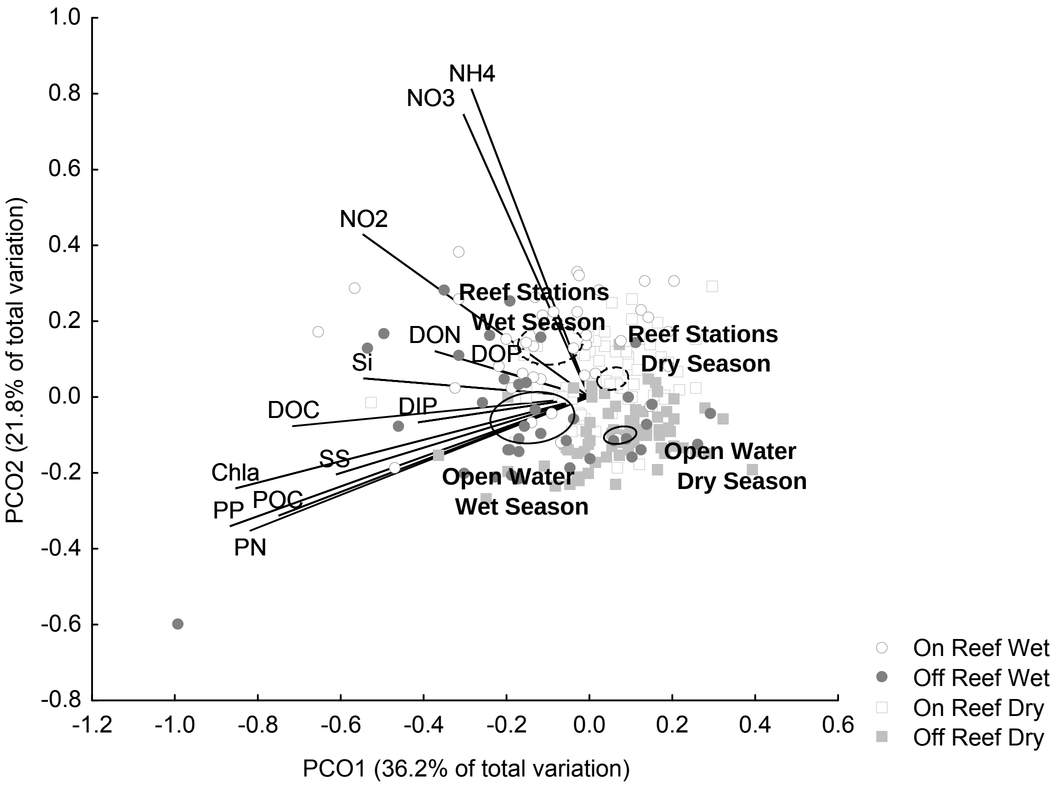


Figure 2 Biplot of principal coordinate analysis emphasising the effects of sampling environment ('on reef' vs. 'adjacent reef') and season ('wet' vs. 'dry'). Ellipses encompass 95% confident regions for the bivariate mean of stations sampled in each environment during two seasons. Dashed ellipses represent 'on reef' stations, solid ellipses 'adjacent reef' or open water stations.

Region Reports: Wet Tropics Region

The Wet Tropics NRM Region comprises the catchments of the Daintree, Mossman, Barron, Mulgrave- Russell, Johnstone, Tully, Murray and Herbert rivers. The main primary land uses in the region are sugar cane, bananas, dairy, grazing, horticulture and forestry. The region has a higher proportion of forest and National Park area than the other three regions considered in this report (Brodie *et al.* 2003).

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Figure 3 Reef Rescue MMP water quality sampling sites (red symbols) in the Wet Tropics NRM Region at Snapper Island, Fitzroy Island, High Island, Russell Island and Dunk Island. Yellow symbols are the six sites of the AIMS Cairns Transect.

The five reef water quality sampling sites in the Wet Tropics Region are located along the coast to capture the influence of the main rivers in this region (Figure 3; see Table 1 for details). There are also six additional open water sampling locations along the Cairns Transect (Figures 1, 3). Most of the major rivers in the Wet Tropics Region had above-median discharge since the start of the MMP monitoring from 2005/06 to 2008/09, whereas the year 2004/05 was below the long-term median (Table A1-2 in Appendix 1). Noteworthy were major flood events of the Barron in 2007/08 and the Herbert in 2008/09. In 2009/10, only the Daintree and Russell rivers had above median discharge; no discharge data were available for the Herbert River post October 2009 (Table A1-2 in Appendix 1).

The results from the direct water sampling are presented as seasonal summary statistics over five years of monitoring for the water quality parameters for which Guideline trigger values were available (GBRMPA 2009) (Figure 4). Detailed results for all water quality variables for the sampling year 2009/10 are in Appendix 1, Tables A1-3 to A1-8. The direct water sampling results over five years show that the water quality at the inshore reef locations in the Wet Tropics Region is generally good, when rated in comparison to the Guidelines. Concentrations of chlorophyll *a*, particulate nitrogen (PN), particulate phosphorus (PP) and suspended solids (SS) are within the Guidelines at Snapper, Fitzroy, and Russell islands (Figure 4). Wet season long-term averages of chlorophyll *a* and PP exceeded the Guidelines at High and Dunk islands, and suspended solid Guidelines were exceeded in both seasons at Dunk Island. However, all Wet Tropics locations, except for Russell Island during the wet season, had Secchi readings above the trigger value, which indicates impaired water clarity (Figure 4).

The instrumental water quality monitoring data confirm that the water quality at the five coral reef locations in the Wet Tropics Region was generally good. The annual mean values of chlorophyll and turbidity were below the Guidelines at Fitzroy, High and Russell islands (Tables 6, 7). The exceedance of the chlorophyll *a* Guidelines at Snapper Island in 2009/10 is likely to be an artefact as data are only available to June 2010, hence biasing the annual "water year" mean (October to October) toward higher wet season values. At all locations, the time series show regular seasonal cycles of chlorophyll concentrations, with higher values during the summer (as described in Brodie *et al.* 2007). These high values are likely to be a combination of two factors, an inherent seasonal increase and the response to nutrient inputs by large flood events of the Wet Tropics rivers during the three years of instrumental monitoring (Figures 5, 6). Without a longer time series spanning wet and dry years, these two factors cannot be distinguished with any certainty.

Annual means of turbidity at Snapper and Dunk islands exceeded the turbidity Guidelines in all three years of instrumental monitoring. Inspection of the turbidity time series at these two sites shows high variability of turbidity values throughout the year, not limited to periods of river floods (Figures 5c and 6f), and 34-53% of the daily means were above the Guidelines (Table 7). Eight and 11% of daily mean turbidity values over the whole time series at Snapper and Dunk islands, respectively, were also above the 5 NTU biological threshold suggested by Cooper *et al.* (2007, 2008), above which corals are likely to experience severe photo-physiological stress due to light limitation. The high turbidity events are caused by resuspension of fine, clay/silt-sized, sediment particles throughout the year during strong winds. Resuspension is recognised as one of the major drivers of turbidity in the inshore GBR lagoon (e.g. Larcombe *et al.* 1995, Wolanski *et al.* 2007). The turbidity at the reef sites is likely to be influenced by the regional oceanography, bathymetry and sediment quality. For example, Snapper Island is very close to the mouth of the Daintree River and Dunk Island is close to the very shallow area of Rockingham Bay, both areas that are influenced by river runoff and are prone to high turbidity due to sediment resuspension. However, it is interesting that the sediment quality directly at the reef locations is very different between these two high-turbidity sites. While Snapper Is. has a very high proportion of clay/silt sized particles with high organic carbon content, Dunk Is. has not (sediment quality data in Thompson *et al.* 2010b). In contrast, Russell Is. has fine, organic-rich sediments (ibid.) but is a site with generally low water turbidity (Figure 6e). Thompson *et al.* (2010b) suggest that the complex topography of the abundant corals and sheltered nature of the site facilitates fine sediment accumulation but at the same time reduces the resuspension of these locally available fine sediments. This emphasises that local physical and oceanographic conditions will also influence the water quality around coral reefs.

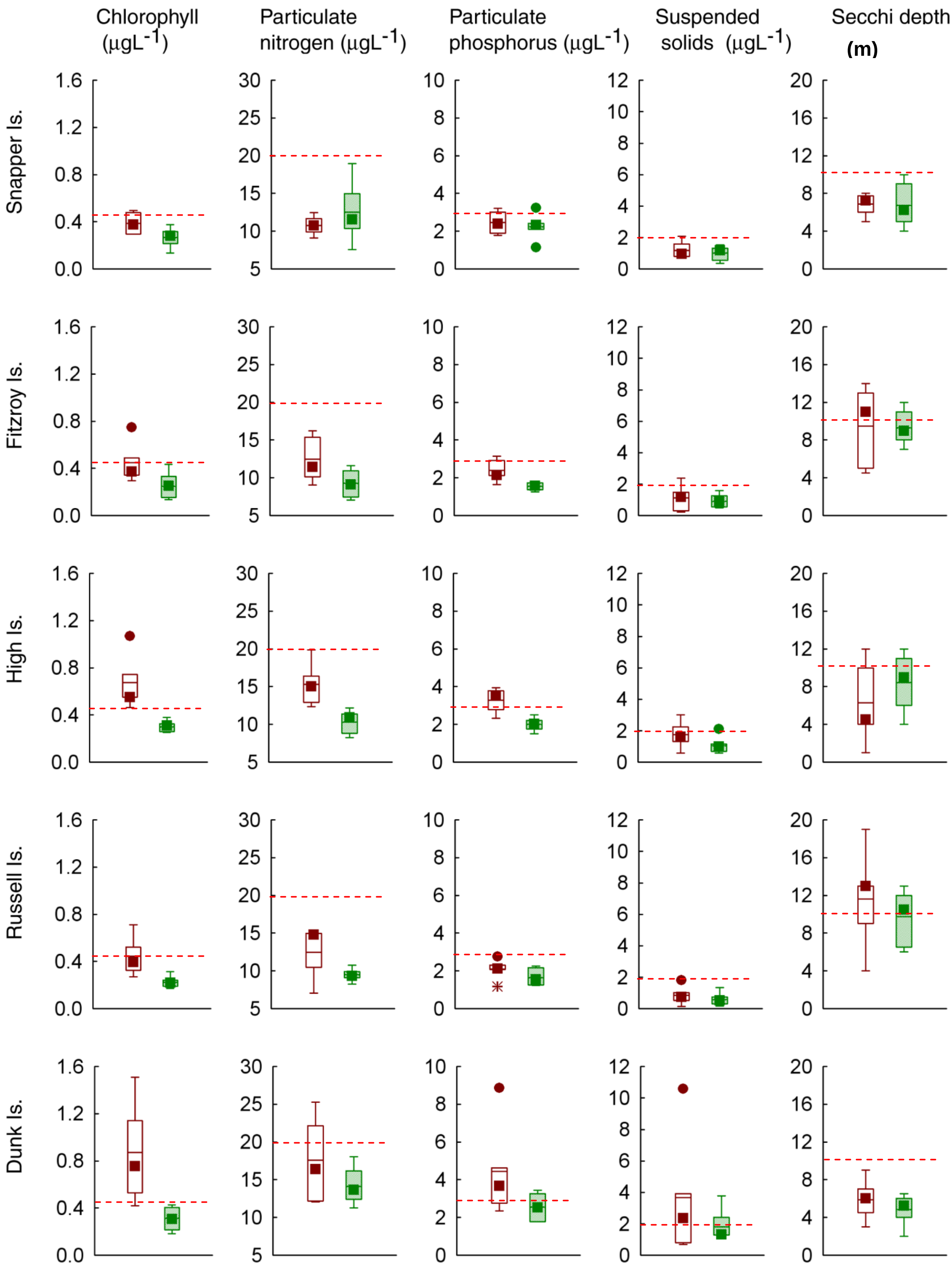

Figure 4 Summary of concentrations of chlorophyll *a*, particulate phosphorus, particulate nitrogen (µg L-1), suspended solids (mg L-1) and Secchi depth (m) at reef locations in the Wet Tropics Region over five sampling years (2005/06 to 2009/10). Dry season values (May- Oct) = shaded boxes, wet season (Nov-Apr)= white boxes. See page 9 for more details about the box plot presentation. Broken lines are the GBR Water Quality Guidelines values (GBRMPA 2009).

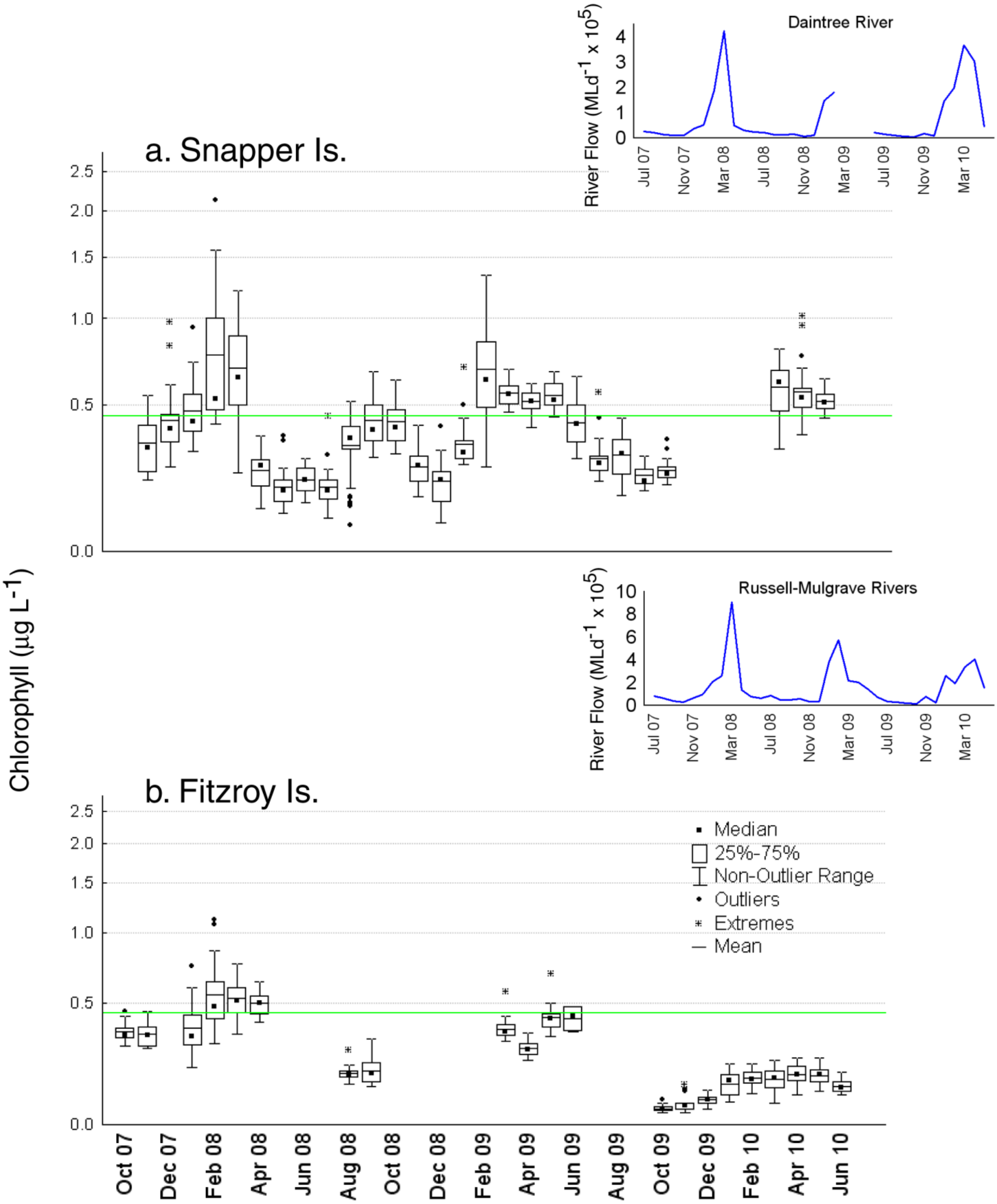

Figure 5 Monthly summary statistics of chlorophyll (µg L^{-1}; a, b) and turbidity (NTU; c, d) time-series collected by Eco FLNTUSB instruments at Snapper and Fitzroy islands in the Wet Tropics NRM Region. Additional panels represent the daily discharge from the nearest, up-current river (ML x 10^5). Horizontal green and red lines are the GBR Water Quality Guidelines values (GBRMPA 2009). Turbidity trigger value (red line) was derived by transforming the suspended solids trigger value (see Schaffelke *et al.* 2009). See page 9 for more details about the box plot presentation.

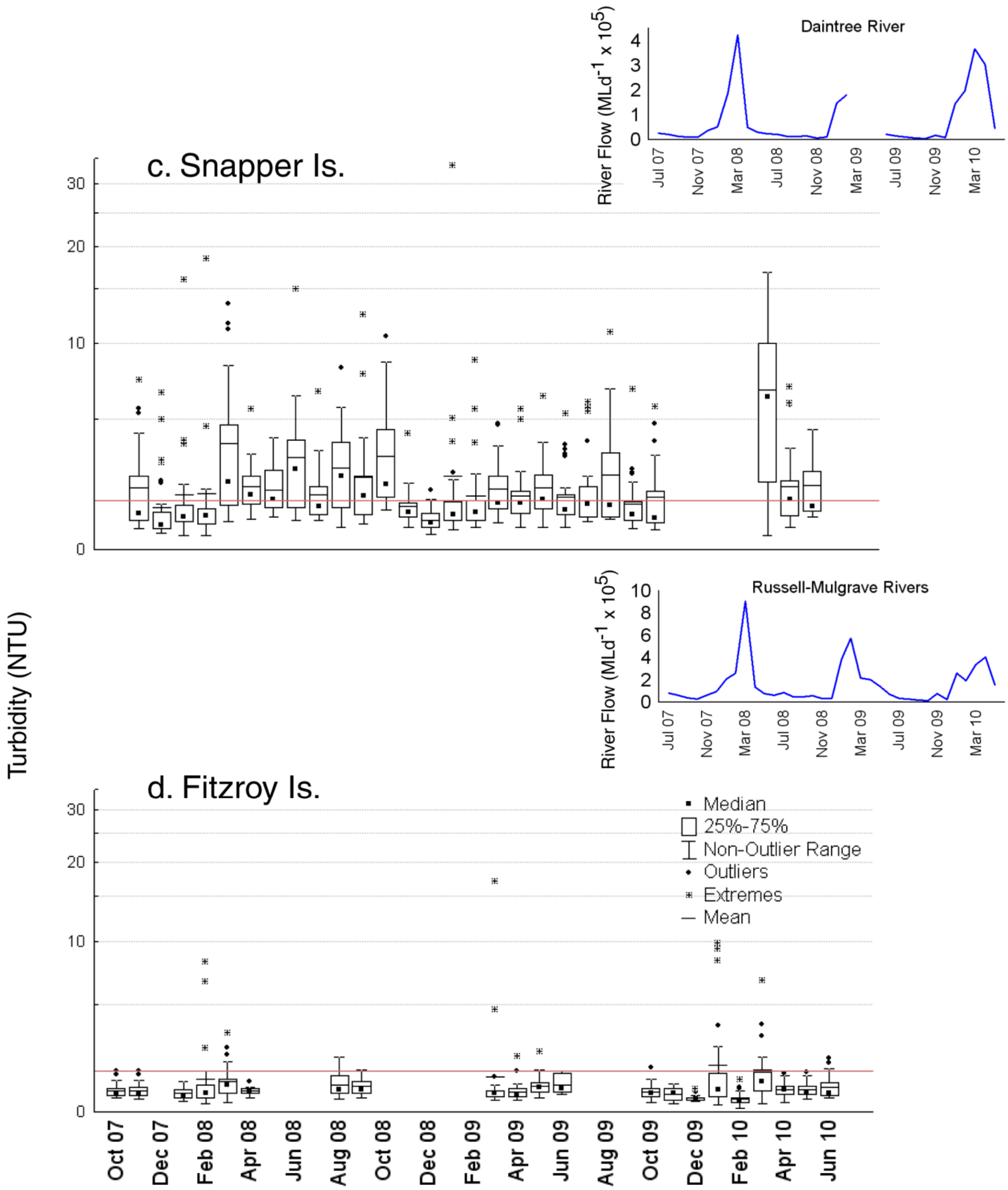

Figure 5 continued

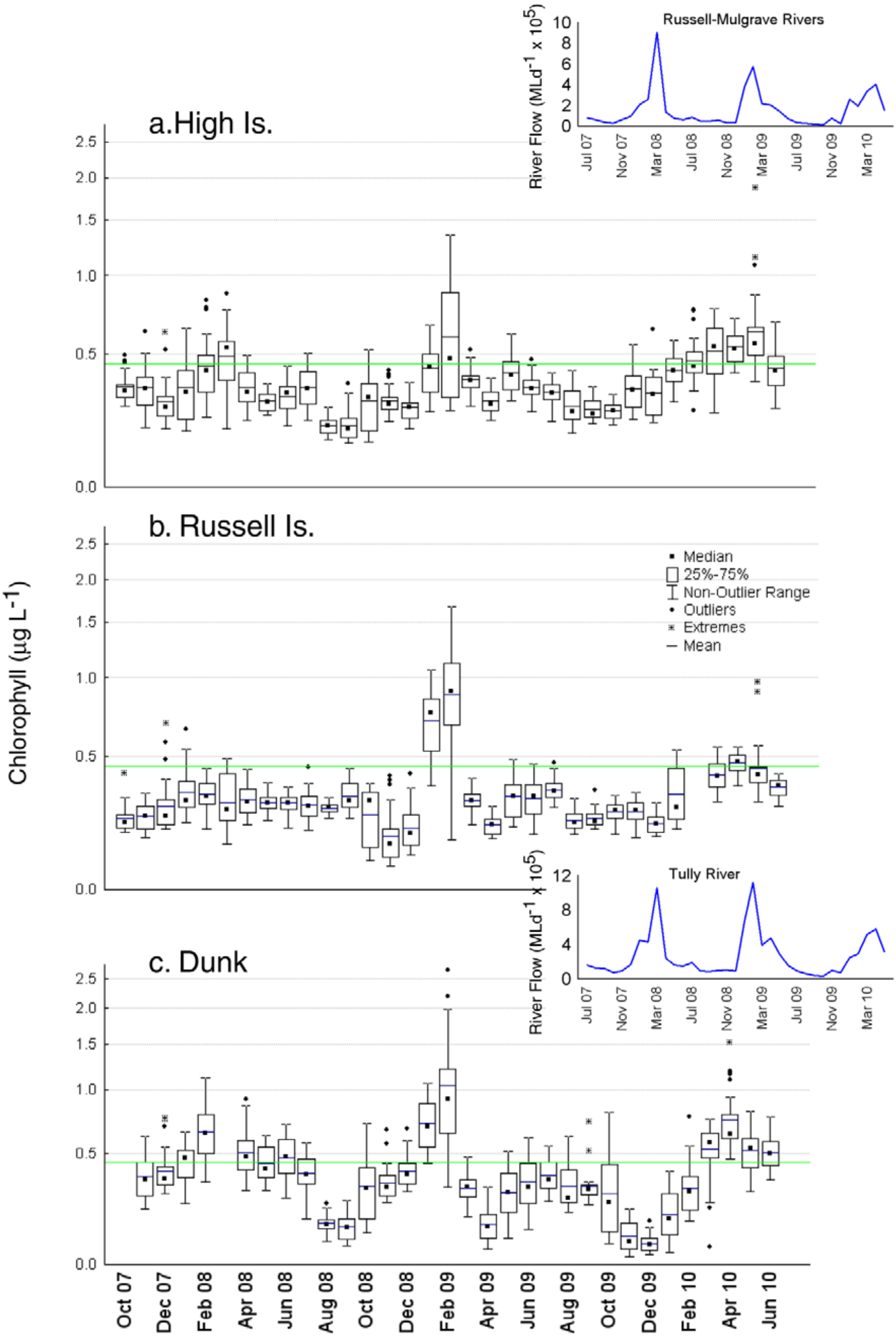

Figure 6 Monthly summary statistics of chlorophyll (µg L^{-1}; a, b, c) and turbidity (NTU; d, e, f) time-series collected by Eco FLNTUSB instruments at High, Russell and Dunk islands in the Wet Tropics NRM Region. Other details as in Fig. 5.

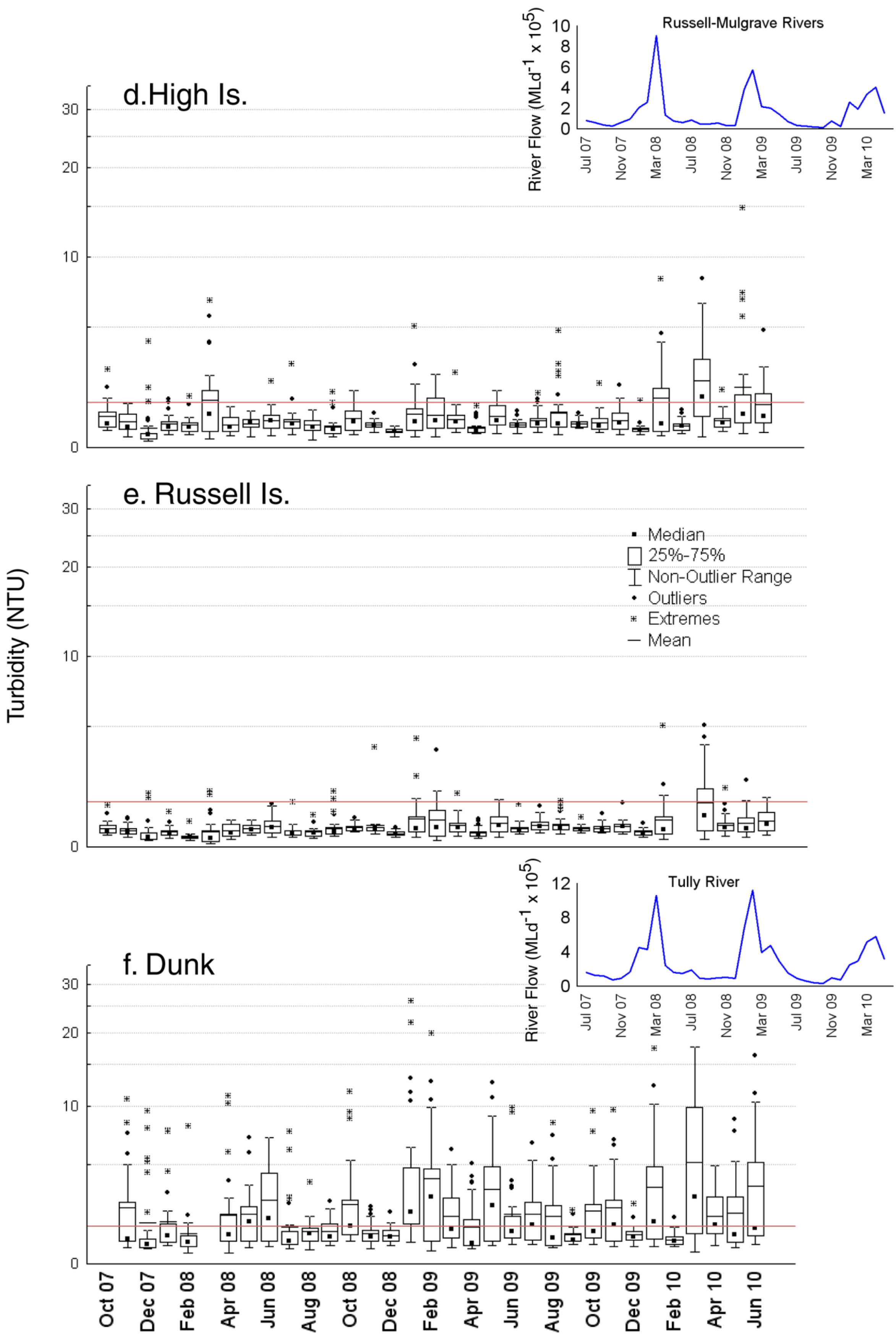

Figure 6 continued

Cairns long-term water quality transect

The long-term time series of water quality parameters sampled since 1989 along the 'AIMS Cairns Transect' (see Figures 1, 3 and Table 1 for sampling locations) was continued and the updated data were reanalysed. Four out of six parameters showed significant long-term patterns (Figure 7, Table 5). Long-term trends in dissolved organic phosphorus (DOP), particulate nitrogen (PN) and suspended solids (SS) were non-linear, while particulate phosphorus (PP) showed a linear trend of declining values over time. SS concentrations increased in the early to late 1990s, peaked around 1999 and then declined. PN concentrations were also highest around 1999, then decreased and stayed on a similar level since about 2004. Concentrations of DOP peaked in ca. 2003 and have declined since. Chlorophyll *a* concentrations show multi-year fluctuations, albeit just not statistically significant (p= 0.053, Table 5), with high values at the start of the time series and again around 1999.

In addition to the long-term trends, some variables had clear seasonal trends (Table 5, Figure 8). The partial effects for the factor "Months" over all sampling years showed that SS steadily increased from January to August/September and then declined. Chlorophyll *a* concentrations were highest during summer, from January to March/April, with a smaller secondary peak during spring, in September/October (see also Brodie *et al.* 2007). PN showed a similar pattern with two peaks, in late summer (March, April) and in spring (September, October). DON, DOP and PP concentrations showed no significant variation across months.

Table 5 Cairns Long-Term Water Quality Transect. Analyses of variance assessing the significance of trends over time, by years and months. Df= degrees of freedom, F= Variance ratio, P= probability.

Response Variable	Source	df	F	Pr (>F)	Deviance explained %
Particulate nitrogen	Years	6	7.031	<0.001	61.7
	Months	3	3.022	0.040	
	Residuals	42			
Particulate phosphorus	Years	1	9.127	<0.004	25.4
	Months	3	1.868	0.1482	
	Residuals	46			
Suspended solids	Years	2	8.531	<0.001	47.1
	Months	3	5.059	0.005	
	Residuals	41			
Chlorophyll *a*	Years	6	2.176	0.053	48.8
	Months	3	6.310	0.001	
	Residuals	42			
Dissolved organic nitrogen	Years	2	2.713	0.088	38.7
	Months	3	0.467	0.710	
	Residuals	15			
Dissolved organic phosphorus	Years	4	7.963	<0.01	52.8
	Months	3	1.910	0.142	
	Residuals	44			

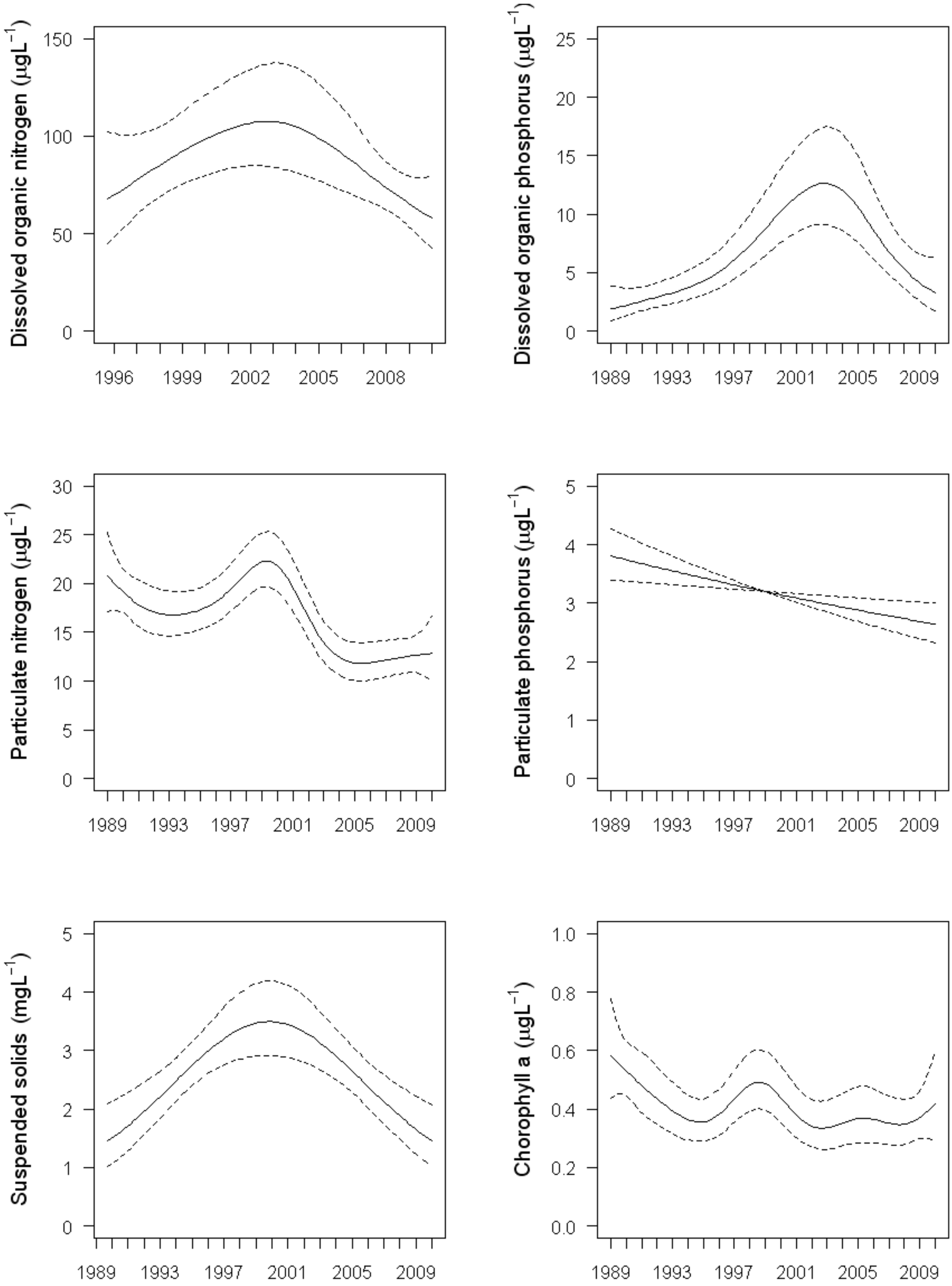

Figure 7 Cairns Long-Term Water Quality Transect. Smooth trends over sampling years from 1989 to 2010 (partial effects) for the water quality parameters dissolved organic nitrogen (µg L^{-1}), dissolved organic phosphorus (µg L^{-1}), particulate nitrogen (µg L^{-1}), particulate phosphorus (µg L^{-1}), suspended solids (mg L^{-1}) and chlorophyll *a* (µg L^{-1}). Broken lines are 95% confidence intervals.

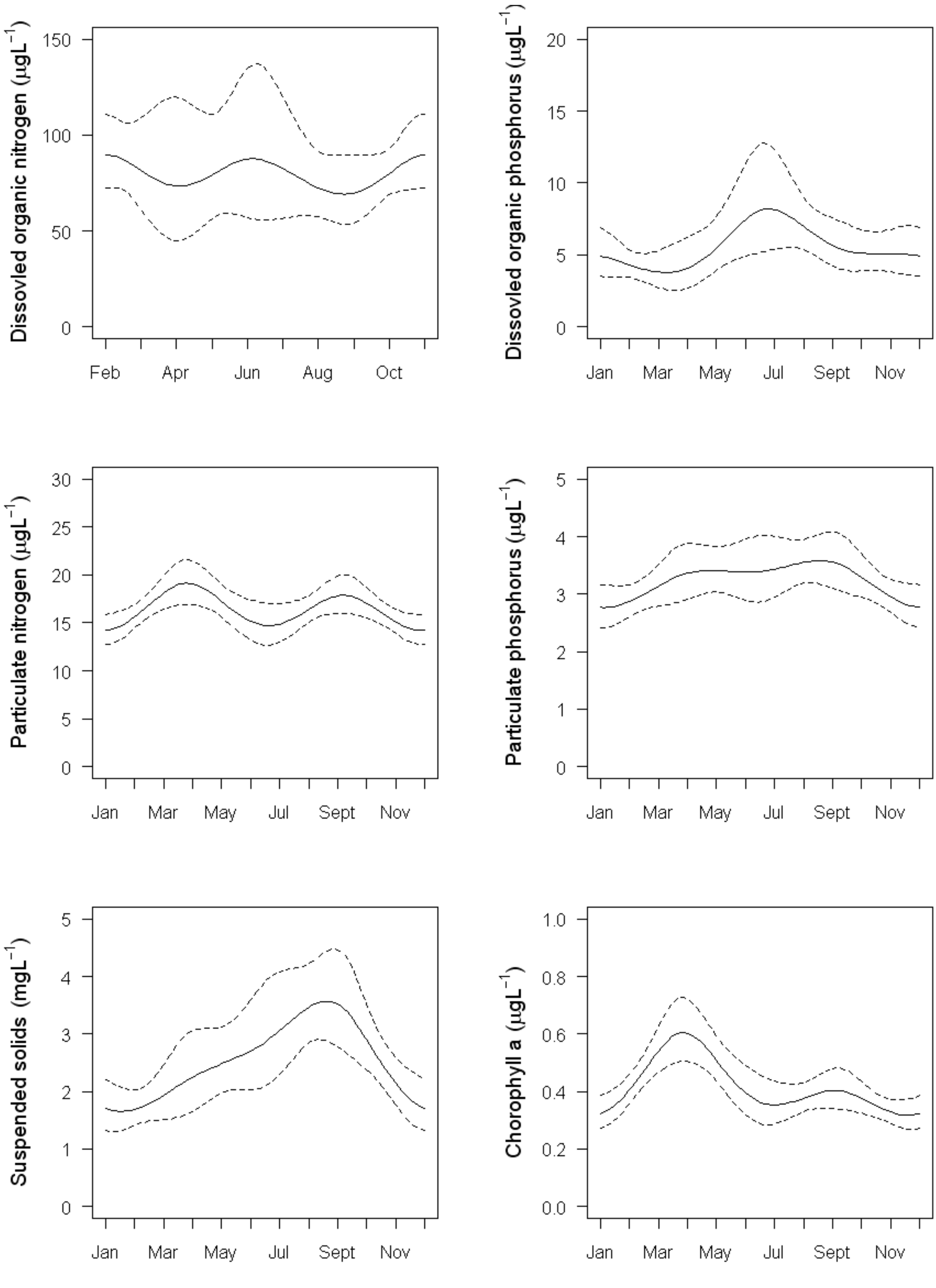

Figure 8 Cairns Long-Term Water Quality Transect. Smooth trends over sampling months from 1989 to 2010 (partial effects) for the water quality parameters dissolved organic nitrogen (µg L^{-1}), dissolved organic phosphorus (µg L^{-1}), particulate nitrogen (µg L^{-1}), particulate phosphorus (µg L^{-1}), suspended solids (mg L^{-1}) and chlorophyll *a* (µg L^{-1}). Broken lines are 95% confidence intervals.

An analysis of the factors influencing the inter-annual variation in water quality variables at sites along the Cairns Transect is underway. Results so far indicate that flood and resuspension events at the time of sampling have a prominent effect on the water quality variables (Schaffelke and Carleton *et al.* in prep.).

Modelled suspended sediment and nutrient loads for the Barron River do not indicate a significant change over the period of time the Cairns Transect was sampled and loads were predominantly related to variability of river flow (John Armour, pers. comm.). However, our data exploration suggests that the concurrence of land clearing, increase in cropping area and climatic factors are good candidates to explain the high values in water quality variables measured along the Cairns Transect in the late 1990s to early 2000s (Figures 9 and 10).

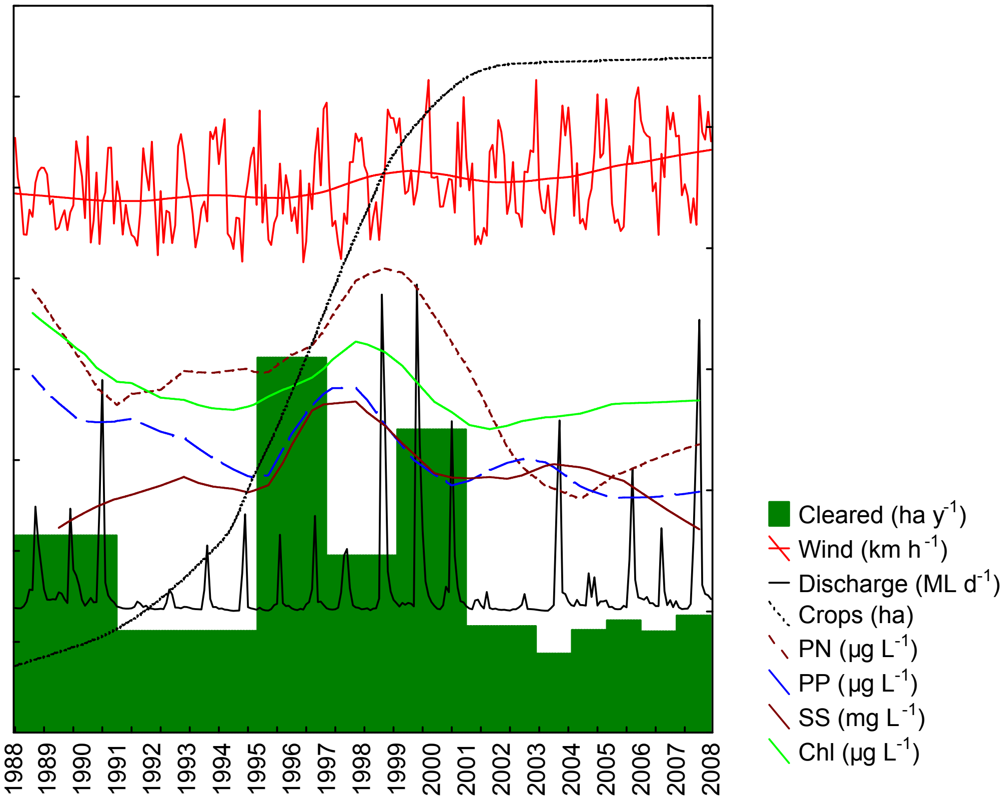

Figure 9 Potential drivers of water quality along the Cairns Transect. Daily discharge rates (ML d^{-1}) of the Barron River (black line), mean wind strength (km h^{-1}) at weather stations on Low Isles and Green Island (red line, data from Bureau of Meteorology) and clearing rates (ha y^{-1}) of woody vegetation in the Barron River catchment (green histogram; data from Dept. Nat. Res. 1999, Dept. Nat. Res. Mines 2000-2006, Dept. Nat. Res. Water 2007, 2008, Dept. Env. Res. Managemement 2009). Superimposed on these potential drivers are Lowess smooth trends for hectares under cultivation in the Barron River catchment and Lowess smooth trends for concentrations in coastal waters of chlorophyll *a*, particulate phosphorus, particulate nitrogen (µg L^{-1}) and suspended solids (mg L^{-1}).

Very high vegetation clearing rates were reported before or during the years (1996-2001) when high concentrations of water quality variable were measured at the Cairns Transect stations (Figure 9). The three major flood events in 1999, 2000 and 2001 followed periods of significant clearing in the catchment and also coincided with a period of strong winds (Figure 9). In the period from 1995 to 2000 the area under cropping in the Barron catchment increased by more than 300 ha per year

(Figure 9), a distinct increase from the previous rate of less than 100h per year. From 2000 onwards the cropped area in the Barron catchment has remained stable.

Concentrations of PP and SS responded relatively quickly to land clearing (Figure 9) while increases in concentrations of chlorophyll *a* and PN lagged behind land clearing alone and were associated with an increase in river discharge and wind strength. The impact of land clearing on water quality becomes apparent from data collected between the wet seasons in 2004 and 2009. During this period land clearing was relatively low and particulate concentrations in coastal waters remained relatively constant or decreased (SS, Figure 9) even though there was a steady increase in wind strength and river discharge.

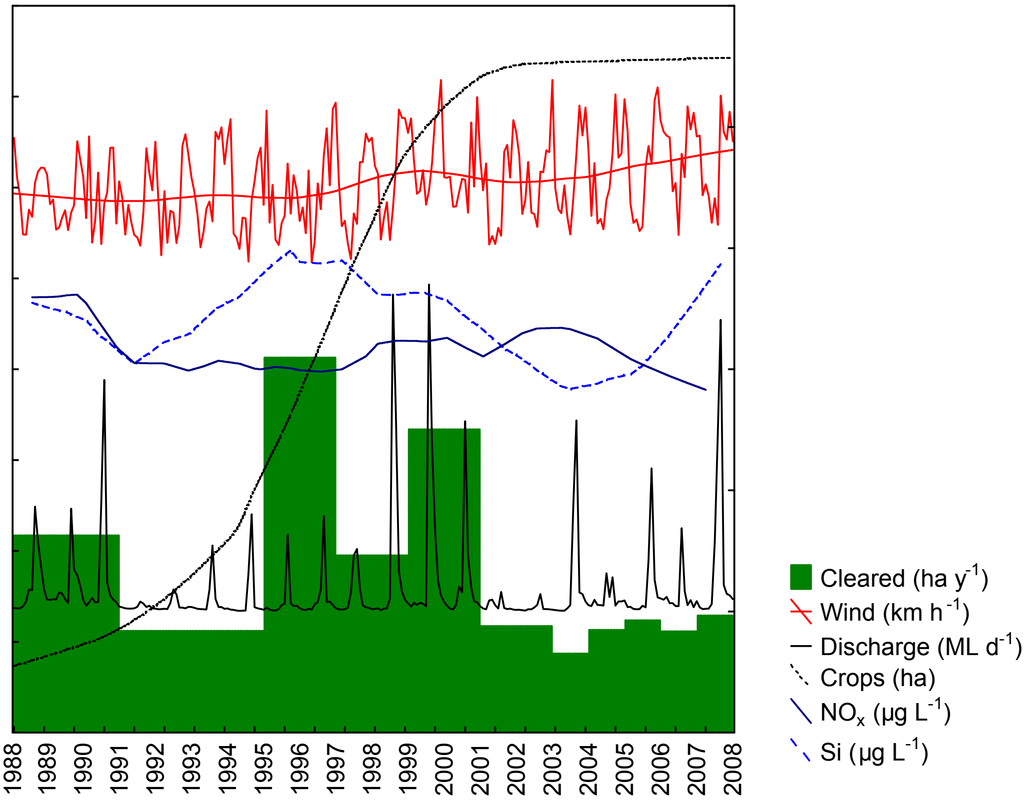

Figure 10 Lowess smooth trends for concentrations of NO_x and Si (µg L^{-1}) in coastal waters are overlaid on plots of potential drivers of water quality. Legend for water quality drivers is the same as in Fig. 9.

Silicate concentrations appear to be more influenced by river discharge alone and show a rapid increase from 2004 onwards which corresponded with an increase in the flow of the Barron River, while concentrations of NO_x only show a weak relationship to river floods in 1999, 2000 and 2004 but not in 2008 (Figure 10).

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Region Reports: Burdekin Region

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

The three water quality sampling sites in the Burdekin Region are located on a gradient away from the Burdekin River mouth (Figure 11). The Burdekin River had major flood events in 2008 and 2009, after annual flows had been below the long-term median since 2001(Table A1-2 in Appendix 1). In 2010 the discharge was lower than in the two preceding years but still above the long-term median flow. The sampling site at Magnetic Island is also influenced by local runoff and runoff from the Ross River and the sites at Pandora Reef and Pelorus Island by the Herbert River as well as the smaller creeks and rivers north of Townsville, i.e. the Bohle and Black rivers and Crystal Creek. Data for the for the Herbert River and for the smaller streams except for the Black River were not available at time of reporting. For this reason, we compare water quality of the three Burdekin Region sites mainly to the Burdekin flow.

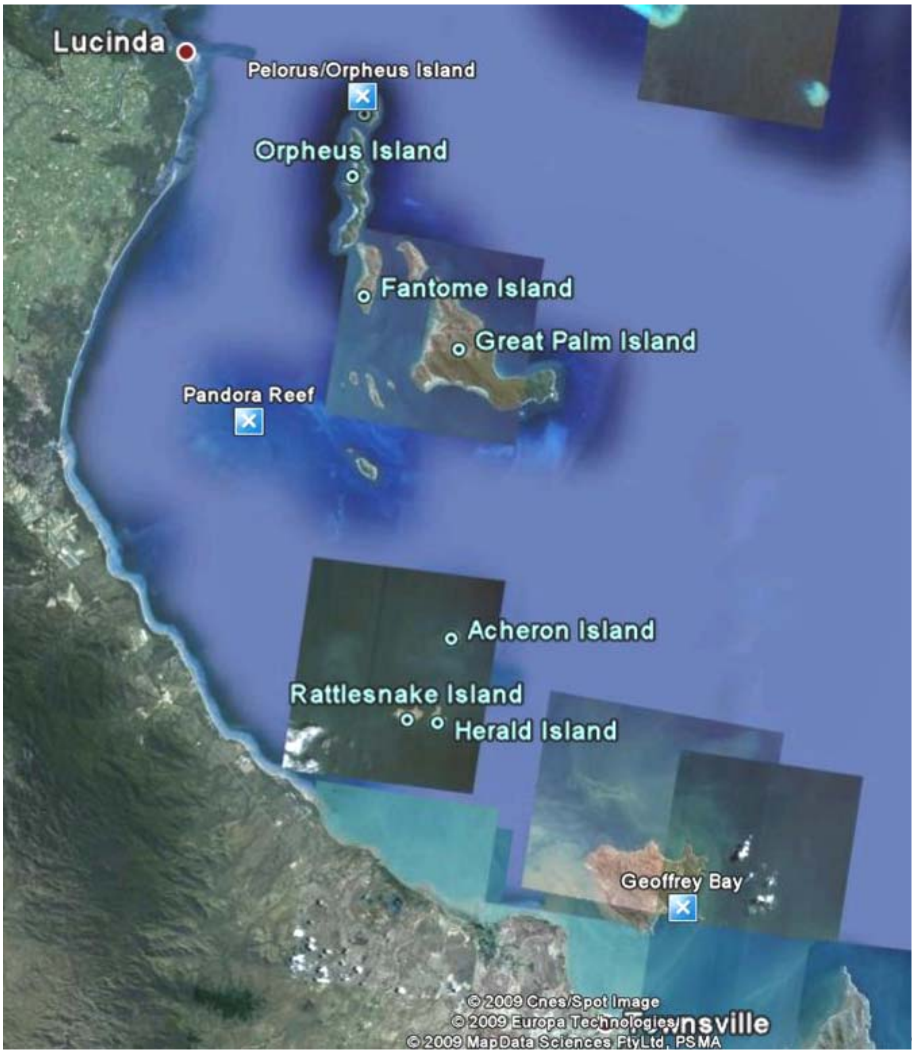

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Figure 11 Reef Rescue MMP water quality sampling sites (blue squares) in the Burdekin NRM Region at Pelorus Island, Pandora Reef and Magnetic Island (Geoffrey Bay).

The results from the direct water sampling over five years of monitoring are presented as seasonal summary statistics for the water quality parameters for which Guideline trigger values were available (GBRMPA 2009) (Figure 12). Detailed results for all water quality variables for the sampling year 2009/10 are in Appendix 1, Tables A1-3 to A1-8. The direct summary results show that the water quality at the inshore reef locations in the Burdekin Region is characterised by seasonally high chlorophyll *a* concentrations and low water clarity throughout the year, when compared with the Guidelines. Guideline values for wet season means of chlorophyll *a* and for Secchi depth in both seasons were exceeded at all three locations. Geoffrey Bay, Magnetic Island, generally had the highest seasonal means of the three locations in this region and the long-term means of all variables at this site exceeded trigger values during both seasons, except for PN in the dry season (Figure 12). Water quality at Pelorus Island in the Palm Islands group and at Pandora Reef were similar, with lower concentrations of the four water quality variables and higher Secchi depth readings, compared to Geoffrey Bay. Mean wet season concentrations of PP just exceeded the Guidelines at Pandora Reef.

The instrumental water quality monitoring data confirmed the high turbidity levels at Geoffrey Bay, Magnetic Island, with all annual means and 36-46% of all daily records exceeding the Guidelines (Table 7). Eight percent of daily records over the whole period (October 2007 to June 2010) were above the suggested 5 NTU limit for severe coral photo-physiological stress due to light limitation (Cooper *et al.* 2007, 2008). Most of the high turbidity events (> 5 NTU) at all three sites were associated with flood influences during the 2008, 2009 and 2010 wet seasons (Figure 13d-f, note data gaps at Pelorus Is. during the 2008 wet season).

Annual chlorophyll means at Pelorus Island during 2008/09 and 2009/10 and at Pandora Reef during 2007/08 exceeded the Guidelines, whereas annual means at Geoffrey Bay were compliant in all three years (Table 6; note that the 2009/10 year is incomplete as records were only obtained to June 2010 hence biasing the annual "water year" mean (October to October) toward higher wet season values). At all three locations, the chlorophyll time series show regular seasonal cycles (as described in Brodie *et al.* 2007), with high values during the summer; however this cycle was less pronounced during the 2010 summer (note data gaps at Geoffrey Bay). The discharge of the Burdekin River in 2010, while above the long-term median, was three times lower than the big flood events in 2008 and 2009. It is possible that the lower chlorophyll concentrations measured at all three locations were a response to this lower river inflow. A longer time series, including a few drier (below median river discharge) years would be required to prove this point.

The extreme variability of the turbidity record indicates that Geoffrey Bay and, to a lesser extent, Pandora Reef are regularly experiencing wind-driven resuspension events, which leads to frequent spikes in turbidity outside the wet season. The Pelorus Island sampling location is more protected from prevailing winds and is characterised by generally lower turbidity. However, the relatively high chlorophyll concentrations at this site are surprising and may be driven by factors other than resuspension. We need a few drier years to establish the range of turbidity levels at reef sites in this region that are not in direct response to a flood event. A fine sediment budget for Cleveland Bay indicates that fine sediment imported into the bay during above-median river flows would accumulate, because resuspension and transport during strong trade winds only lead to some export (Lambrechts *et al.* 2010). Only the enhanced sediment remobilisation during cyclones leads to a net export of fine sediments. The sediment quality on the reefs at the three monitoring sites has not appreciably changed over the last four years (Thompson *et al.* 2010b).

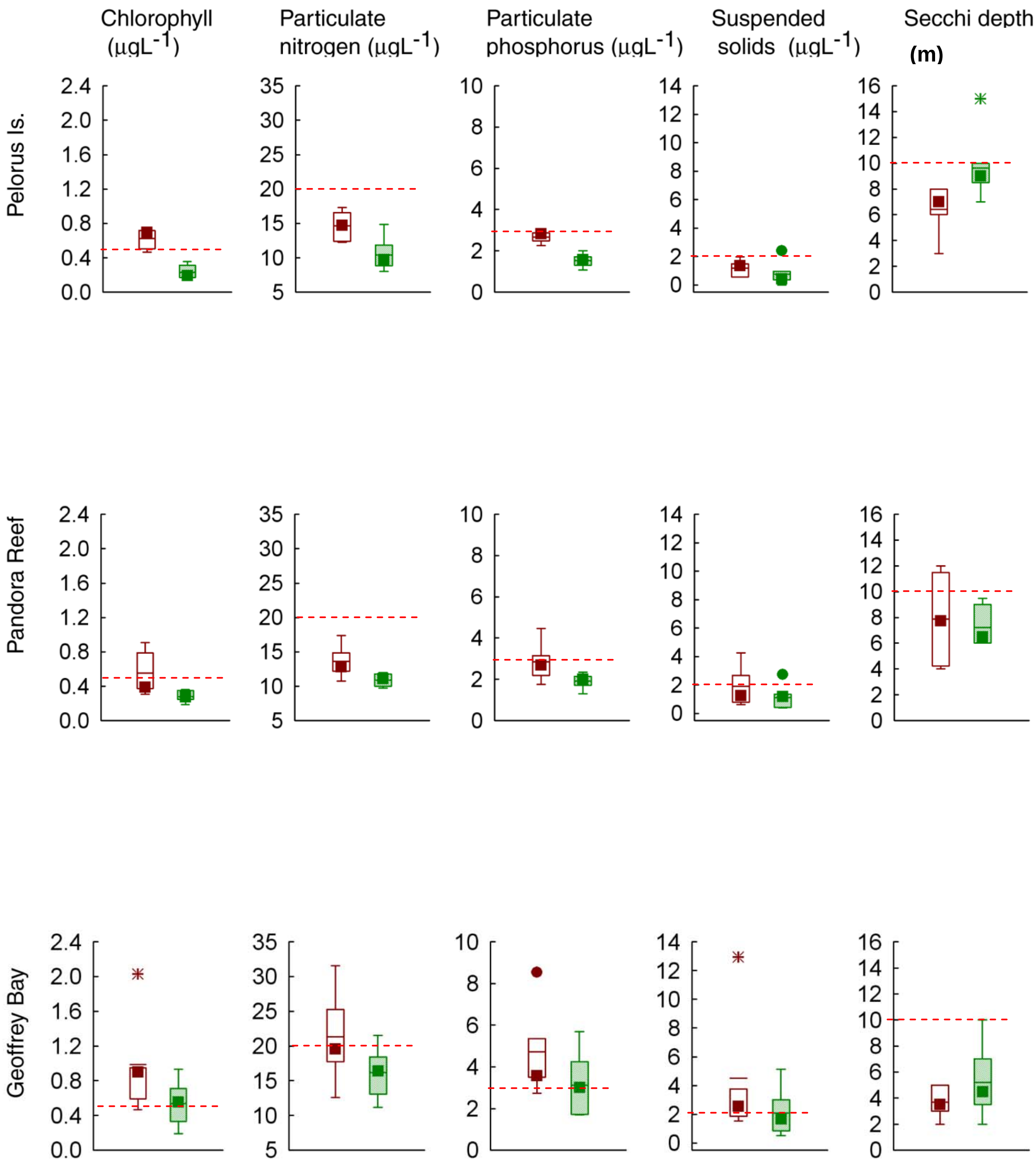


Figure 12 Summary of concentrations of chlorophyll *a*, particulate phosphorus, particulate nitrogen (µg L-1), suspended solids (mg L-1) and Secchi depth (m) at sampling sites in the Burdekin Region over five sampling years (2005/06 to 2009/10). Dry season values (May- Oct) = shaded boxes, wet season (Nov-Apr)= white boxes. Other details as in Figure 4.

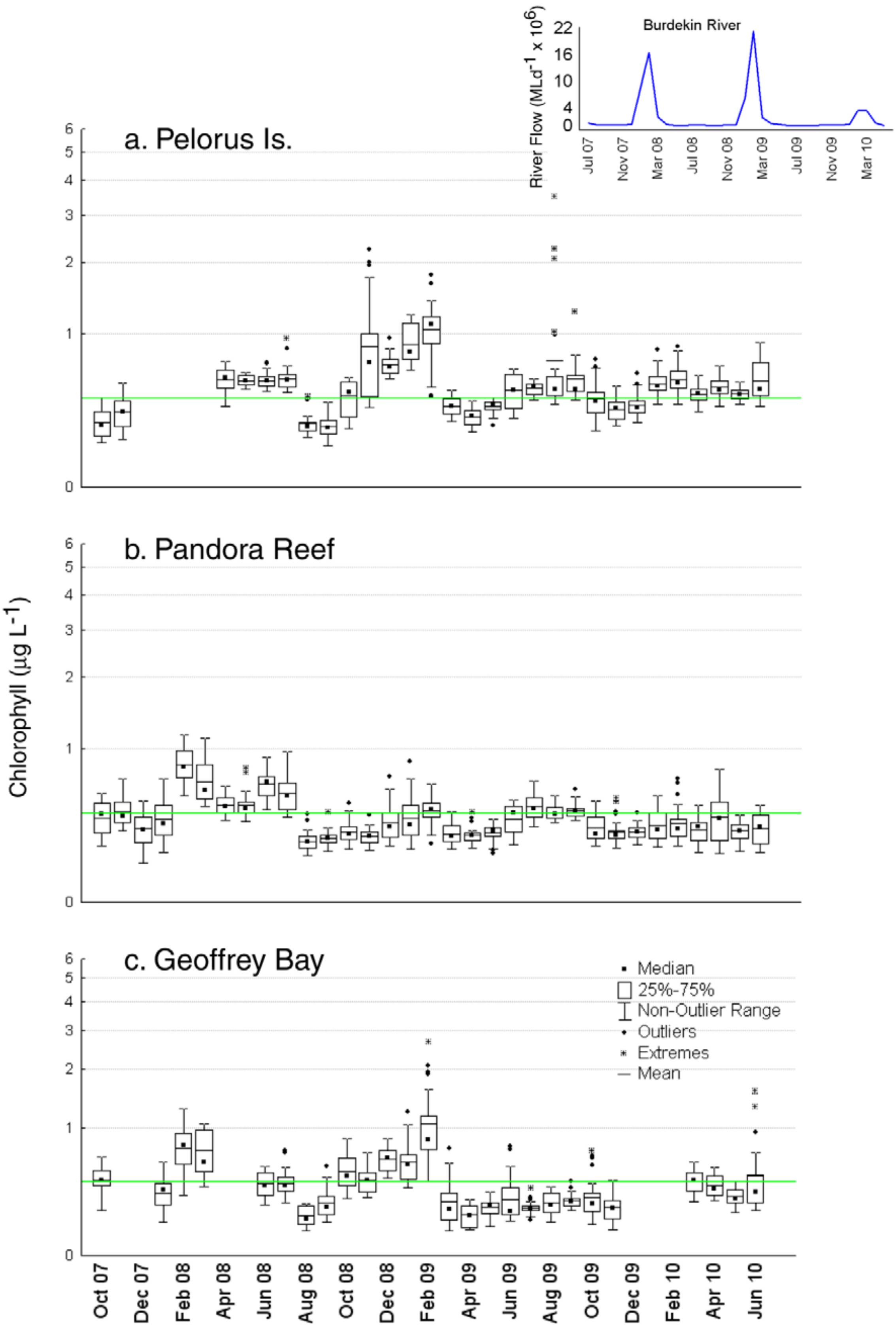


Figure 13 Monthly summary statistics of chlorophyll (µg L^{-1}; a, b, c) and turbidity (NTU; d, e, f) time-series collected by Eco FLNTUSB instruments at Pelorus Is., Pandora Rf. and Magnetic Is. (Geoffrey Bay) in the Burdekin NRM Region. Other details as in Fig. 5.

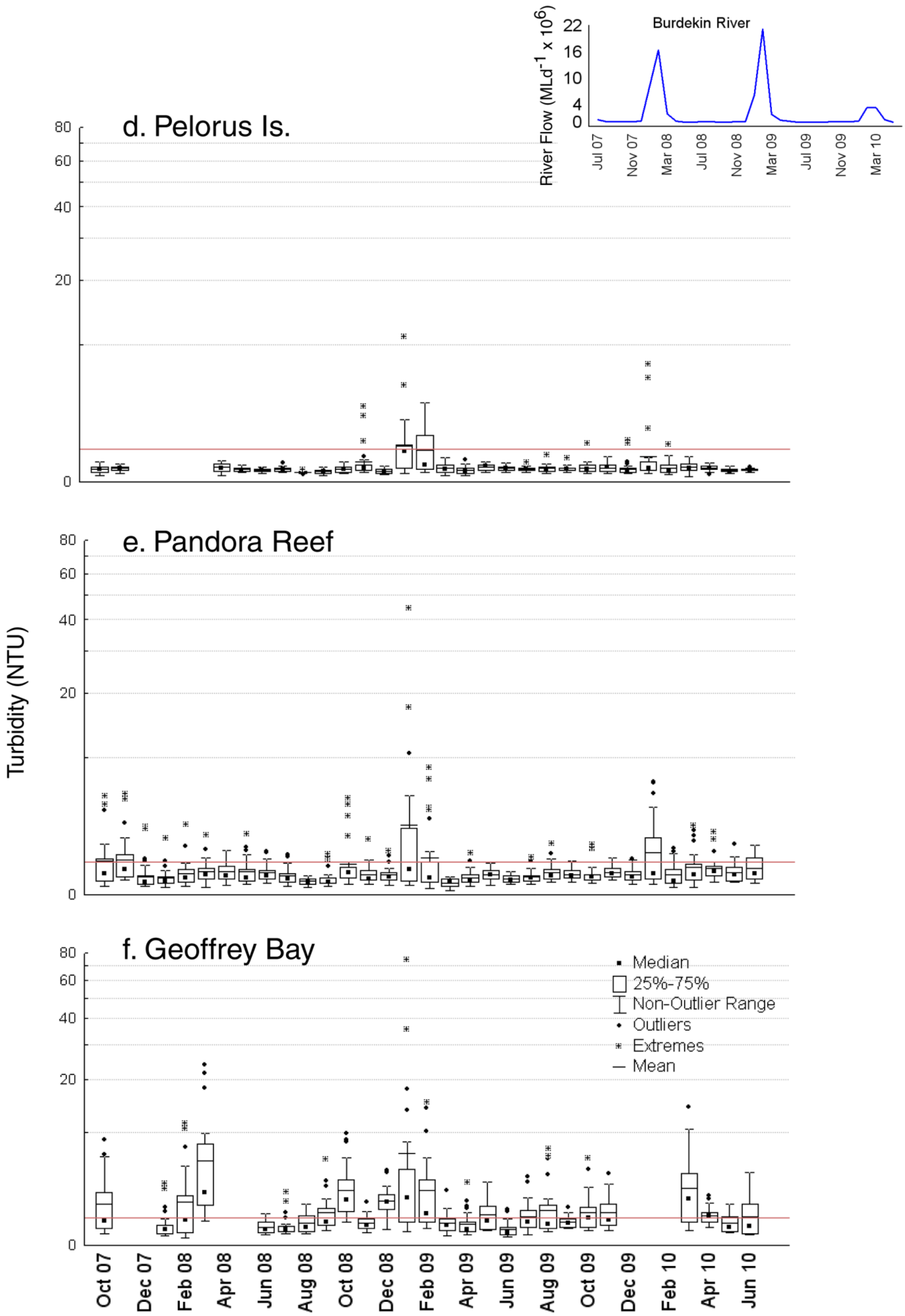


Figure 13 continued

Region Reports: Mackay Whitsunday Region

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

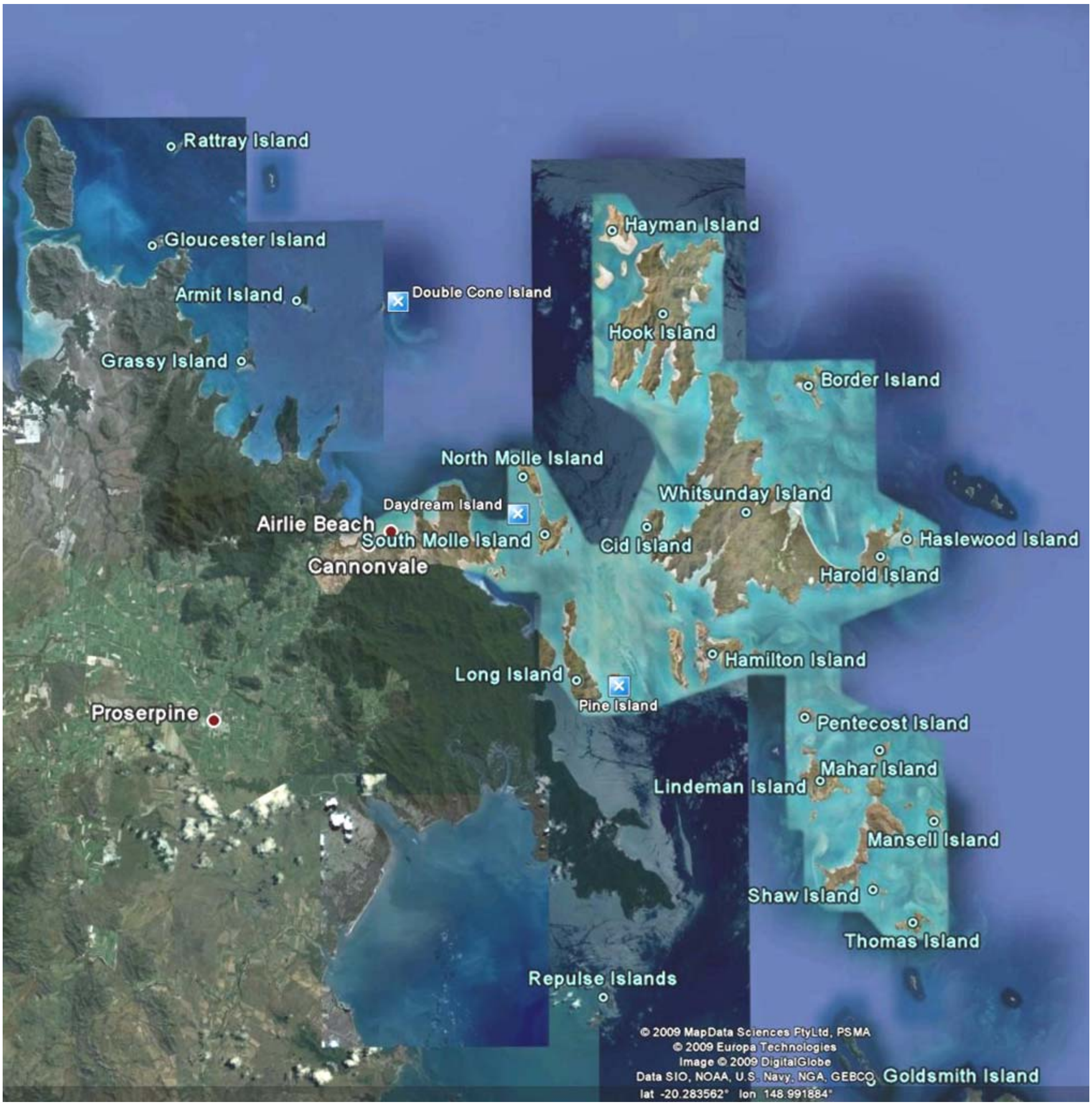


Figure 14 Reef Rescue MMP water quality sampling sites (blue squares) in the Mackay Whitsunday NRM Region at Double Cone Island, Daydream Island and Pine Island.

The three sampling locations in the Mackay Whitsunday Region are located away from direct riverine influence of the three major rivers in this region (Figure 14). The Proserpine, O'Connell and Pioneer rivers had above long-term median flows during the past four years and major floods during the 2008 wet season (Table A1-2 in Appendix 1). The Pioneer also had a major flood during the 2010 wet season. On 21 March 2010, Tropical Cyclone Ului crossed the coast in the Whitsundays. There was significant damage to the MMP coral monitoring sites at Daydream Island, but only little or no damage was observed at the other survey sites (A. Thompson, pers. comm.). The water quality instruments were fortunately unaffected by the cyclone passing.

The results from the direct water sampling over five years of monitoring are presented as seasonal summary statistics for the water quality parameters for which Guidelines values were available (GBRMPA 2009) (Figure 15). Detailed results for all water quality variables for the sampling year 2009/10 are in Appendix 1, Tables A1-3 to A1-8. The direct water sampling results show that water quality at the inshore reef locations in the Mackay Whitsunday Region is characterised by seasonally high chlorophyll *a* concentrations and low water clarity throughout the year, when compared to the Guidelines. Guidelines values for wet season means of chlorophyll *a* and Secchi depth in both seasons were exceeded at all three locations (Figure 15). Suspended solids means exceeded dry season trigger values at both Daydream and Pine Island. Double Cone Island generally had lower values of all water quality variables, which is not surprising as this monitoring location is furthest away from both the coast and the influence of the rivers in this region.

The instrumental water quality monitoring data showed a similar pattern for chlorophyll and turbidity to the direct water sampling results (Figure 16). The instrumental readings confirm the gradient of turbidity at the three locations in line with their distance away from riverine influence. Turbidity values were highest at Pine Island and lowest at Double Cone Island. Annual turbidity means for Pine and Daydream islands were above the Guidelines in all three years (Table 7). At Double Cone Island, only the annual mean in 2009/10 exceeded the Guidelines, but note that the 2009/10 record is incomplete as data were only obtained to June 2010, biasing the annual "water year" mean (October to October) toward higher wet season values. At Pine and Daydream islands, 14% and 8%, respectively, of daily records over the whole period (October 2007 to June 2010) were above the suggested 5 NTU limit for severe coral photo-physiological stress due to light limitation (Cooper *et al.* 2007, 2008). At all three sites, the turbidity was generally higher during the summer and may be related to river discharge, which was above median for the last four years (Table A1-2) and very high in 2008 (Figure 16d-f). Sediment quality at the Whitsundays reef sites has changed over the last four years with steadily increasing proportions of silt and clay sized particles (Thompson *et al.* 2010), which may be easily resuspended. The detailed turbidity records, especially at Pine and Daydream islands, showed regular increases and decreases correlated with the strong tidal flows in this region, and high turbidity values were associated with the summer king tides (data not shown). In contrast, wind-driven resuspension seems to have less influence on the turbidity of the three Mackay Whitsunday locations, even at the relatively exposed Double Cone Island site. A reason for this might be that these islands are surrounded by relatively deep water, which would result in less resuspension in the surrounding area that might affect reefs more strongly than local resuspension, as indicated at some sites in the Wet Tropics and the Burdekin regions (see above). The passage of TC Ului left a clear signal in the raw turbidity and chlorophyll records (10 minute readings) at all three locations (Figure 17). At Pine Is., extremely high turbidity readings were observed during the following period of high tides and wind, a week after the cyclone.

Annual chlorophyll means derived from instruments exceeded the Guidelines at Pine and Daydream islands during 2007/08 and 2008/09, at Double Cone only in 2007/08, and at Pine also in 2009/10 (Table 6; note that the 2009/10 year is incomplete as records were only obtained to June 2010 hence biasing the annual "water year" mean (October to October) toward higher wet season values). At Pine and Daydream islands more than 70% of the daily records were above the trigger value in 2007/08 and 2008/09, which is higher than at any other monitoring site. At Daydream Is., the time series shows regular seasonal cycles of chlorophyll concentrations (as described in Brodie *et al.* 2007), with high values during the summer. This is less pronounced at Pine Is. Double Cone Is. has too many data gaps to properly interpret these seasonal cycles (Figure 16a-c). The seasonal chlorophyll cycles do not appear to be directly correlated with annual discharge from the adjacent rivers but a longer time series with a few more wet and dry years would be beneficial for a better interpretation of this.

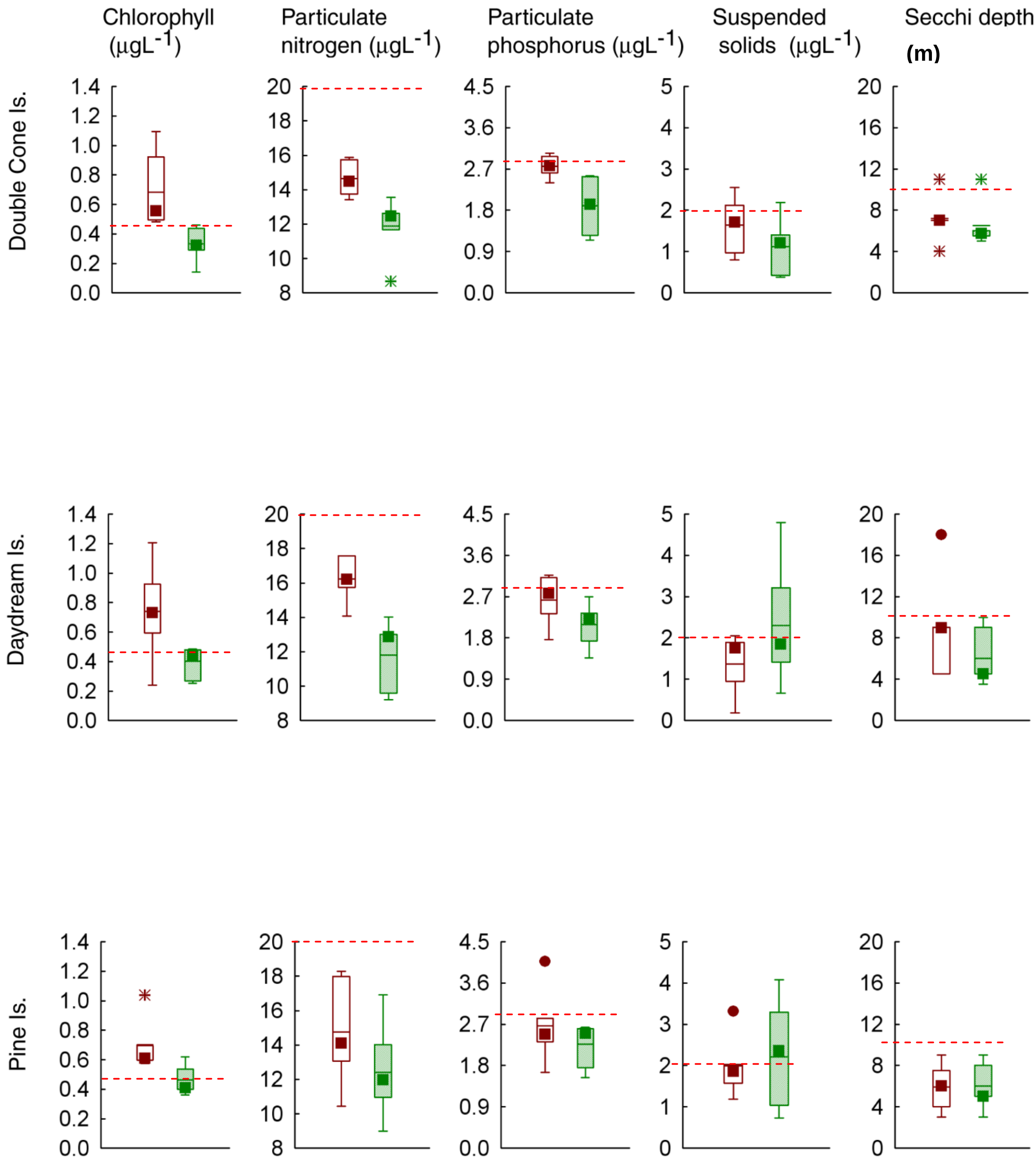


Figure 15 Summary of concentrations of chlorophyll *a*, particulate phosphorus, particulate nitrogen (µg L-1), suspended solids (mg L-1) and Secchi depth (m) at sampling sites in the Mackay Whitsunday NRM Region five sampling years (2005/06 to 2009/10). Dry season values (May- Oct) = shaded boxes, wet season (Nov-Apr)= white boxes. Other details as in Figure 4.

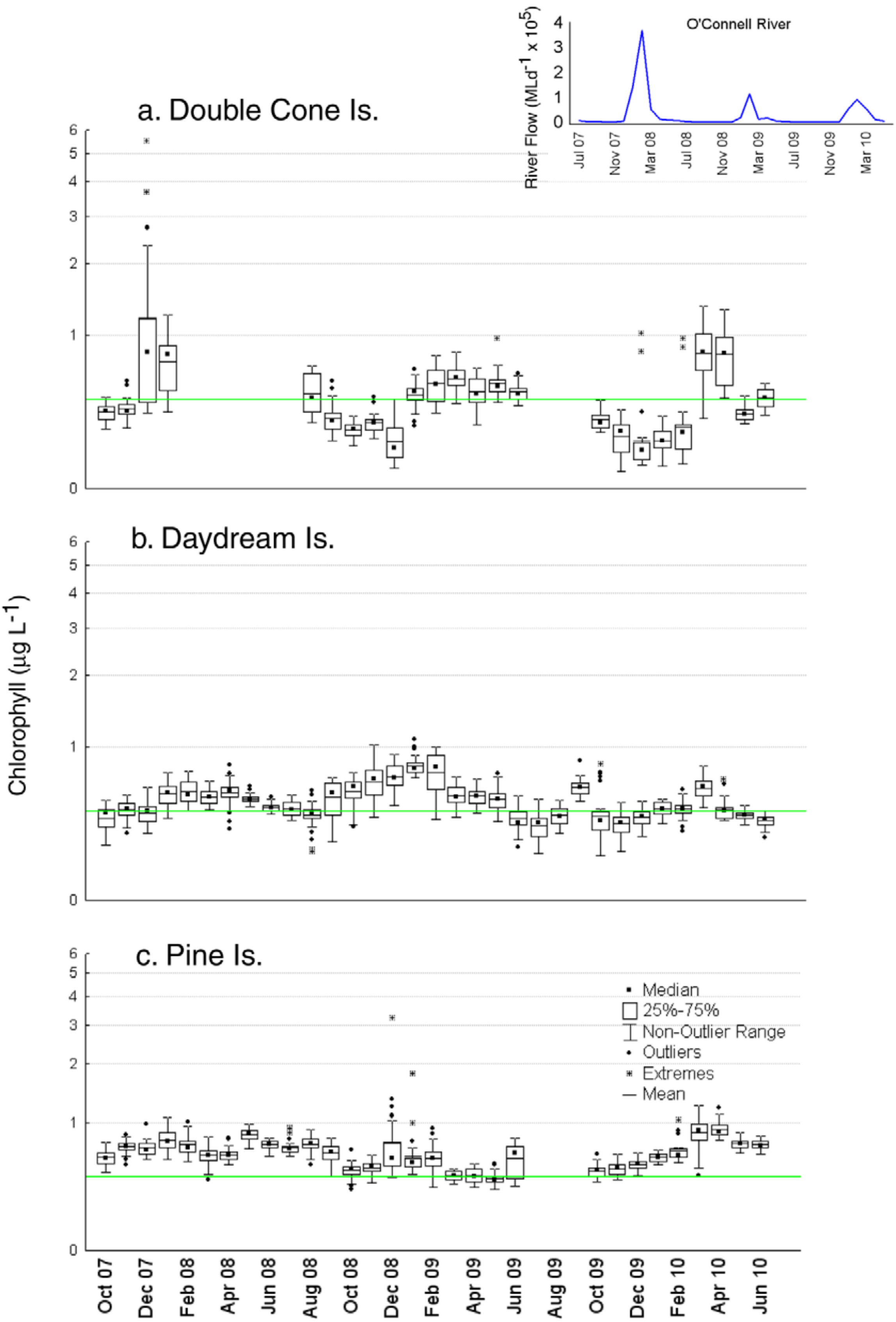


Figure 16 Monthly summary statistics of chlorophyll (µg L^{-1}; a, b, c) and turbidity (NTU; d, e, f) time-series collected by Eco FLNTUSB instruments at Double Cone, Daydream and Pine islands in the Mackay Whitsunday NRM Region. Other details as in Figure 5.

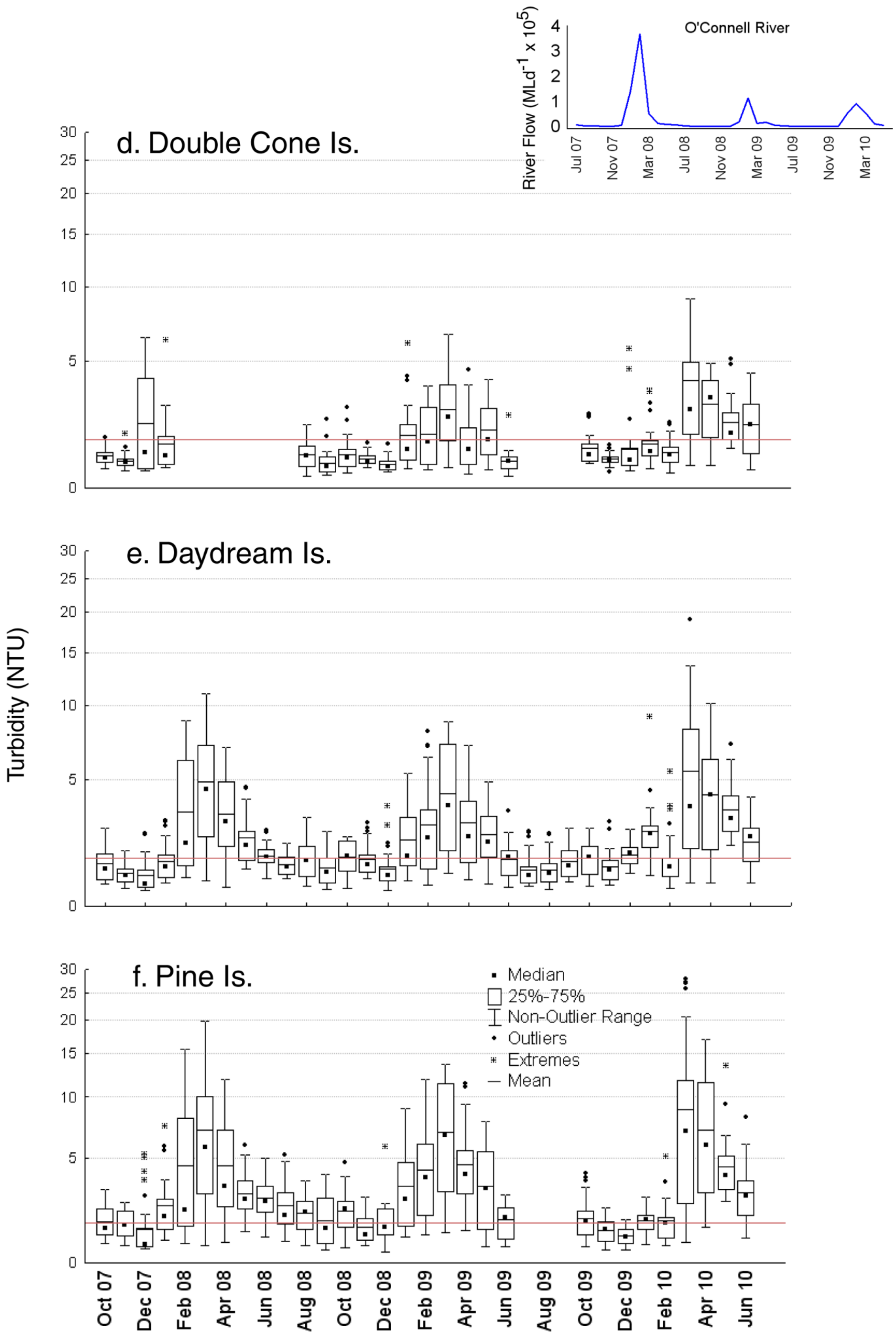
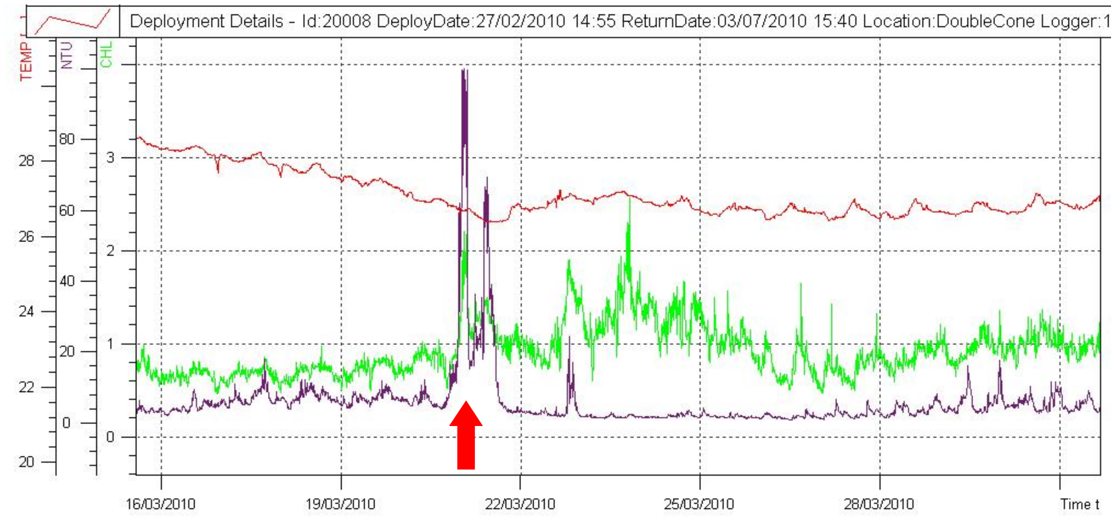
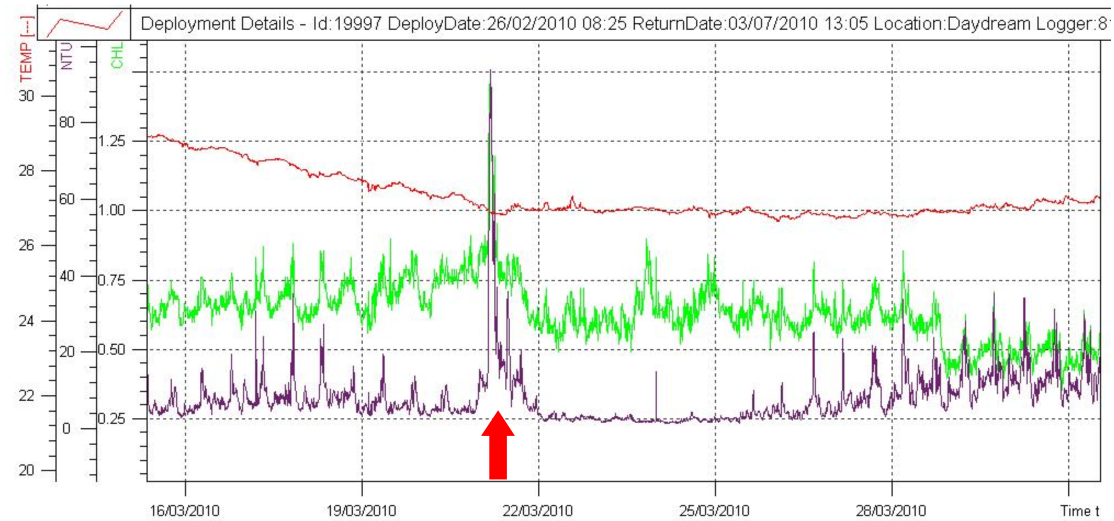


Figure 16 continued

a



b



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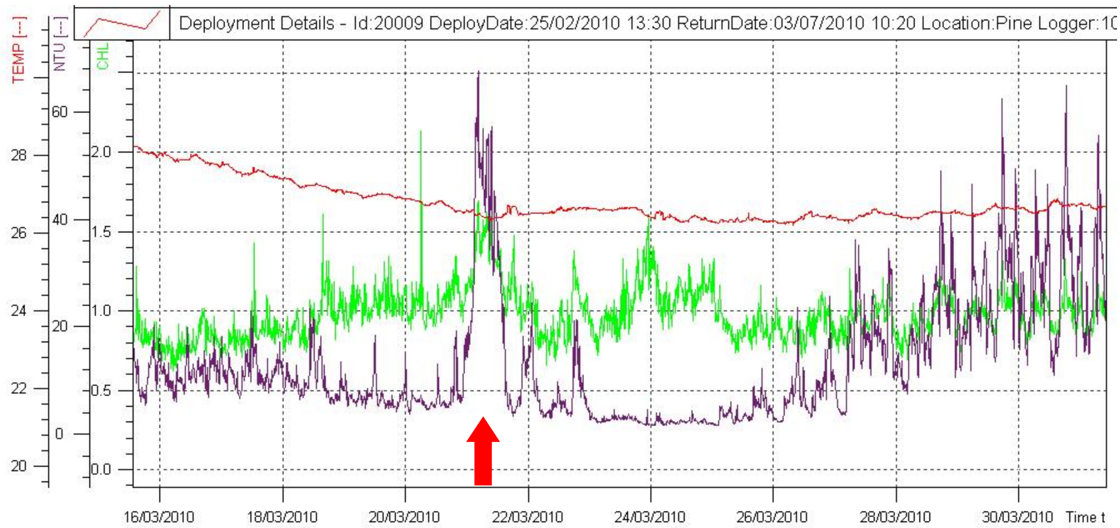

Figure 17 Passage of TC Ului on 21 March 2010 (red arrows). Raw data records of chlorophyll (µg L^{-1}; green line) turbidity (NTU; purple line) and temperature (ºC, red line) collected by Eco FLNTUSB instruments at Double Cone, Daydream and Pine islands in the Mackay Whitsunday NRM Region.

Region Reports: Fitzroy Region

The Fitzroy NRM Region has the largest catchment area draining into the GBR. The climate is dry tropical with highly variable rainfall, high evaporation rates and prolonged dry periods, followed by infrequent major floods. By area, cattle grazing is the primary land use (Brodie *et al.* 2003). Fluctuations in climate and cattle numbers greatly affect the state and nature of vegetation cover, and therefore, the susceptibility of soils to erosion, which leads to runoff of suspended sediments and associated nutrients.

The three sampling locations in Keppel Bay are located on a gradient extending away from the Fitzroy River mouth (Figure 18). The Fitzroy River had two major flood event during the monitoring period, in 2008 and in 2010 (Table A1-2 in Appendix 1). For most of the past 10 years, annual flows have been below the long-term median.

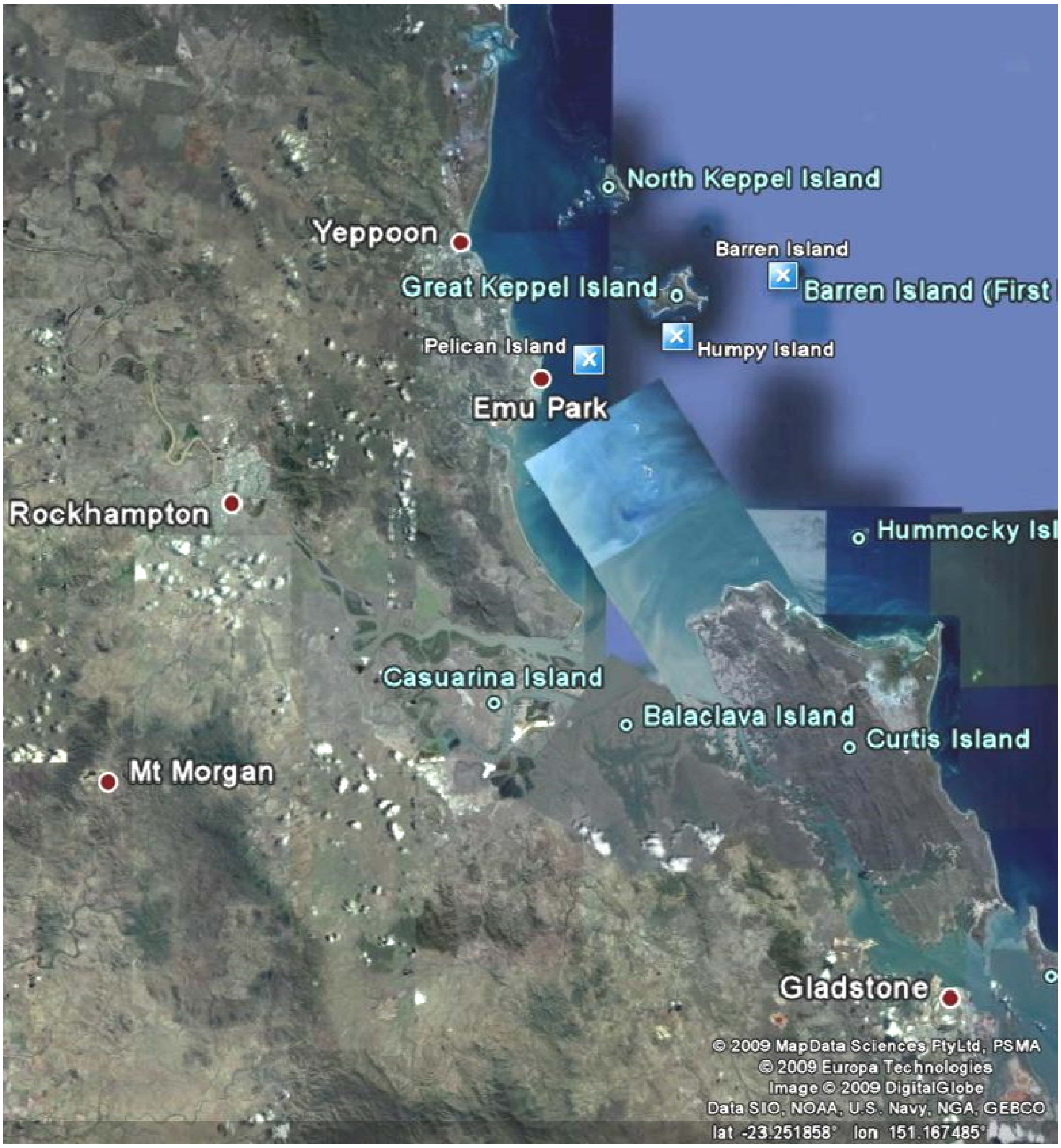

Figure 18 Reef Rescue MMP water quality sampling sites (blue squares) in the Fitzroy NRM Region at Pelican Island, Humpy Island and Barren Island.

The results from the direct water sampling over five years of monitoring are presented as seasonal summary statistics for the water quality parameters for which Guidelines trigger values were available (GBRMPA 2009) (Figure 19). Detailed results for all water quality variables in the sampling year 2009/10 are in Appendix 1, Tables A1-3 to A1-8. The direct water sampling results show that the water quality at the monitored inshore reef locations in the Fitzroy Region varies substantially along the gradient away from the coast (Figure 9). All variables exhibited highest values at Pelican Island, the most inshore location. The Guidelines for concentrations of PP, SS and Secchi depth were exceeded at Pelican Island during both the wet and dry seasons, and for chlorophyll *a* and PN concentrations during the dry season. In contrast, the water quality variables at Barren Island, the location furthest offshore, were within the Guidelines, except for chlorophyll *a* concentrations during the wet season. At Humpy Island, all five water quality variables exceeded the Guidelines during the wet season.

The instrumental water quality monitoring data showed a similar pattern to the direct water sampling results (Figure 20). The instrumental readings confirm the clear gradient of locations away from the Fitzroy River mouth. Annual means at Pelican Island exceeded the chlorophyll *a* and turbidity Guidelines in 2007/08 and 2008/09 (Table 6 and 7). In 2009/10 all three location exceeded the chlorophyll Guidelines and Pelican and Humpy islands the turbidity Guidelines, but note that the 2009/10 record is incomplete as data were only obtained to June 2010, biasing the annual “water year” mean (October to October) toward higher wet season values.

The time series of chlorophyll concentrations measured by instruments at all three locations show regular seasonal cycles with high values during summer (as described in Brodie *et al.* 2007), albeit with large data gaps due to instrument failures at Humpy and Barren islands (Figure 20a-c). The seasonal cycles, however, do not seem to be correlated with annual discharge from the Fitzroy River, they are as pronounced in a dry year as in two extreme flood years. Multi-year chlorophyll time series including both wet and dry years will be needed to distinguish between responses to land runoff and inherent seasonal cycles, most likely controlled by seasonality of temperatures and daylengths.

Pelican Island had the highest turbidity of all 14 inshore GBR monitoring locations. 29 % of daily records at Pelican Is. over the whole instrumental monitoring period (October 2007 to June 2010) were above the suggested 5 NTU limit for severe coral photo-physiological stress (Cooper *et al.* 2007, 2008). While turbidity was generally higher during summer, and only slightly higher during the two major flood events, Pelican Island regularly experienced wind-driven resuspension events, leading to frequent spikes in turbidity (Figure 20d). The turbidity time series at Humpy and Barren islands showed that the water was generally very clear, especially during the dry seasons (Figure 20e, f). While all three sampling locations are relatively exposed to the prevailing winds, Humpy and Barren islands are further offshore and their more reefal sediments had a very low proportion of clay-silt-sized particles (see Thompson *et al.* 2010b), which is likely to result in lower turbidity during wind-driven resuspension events.

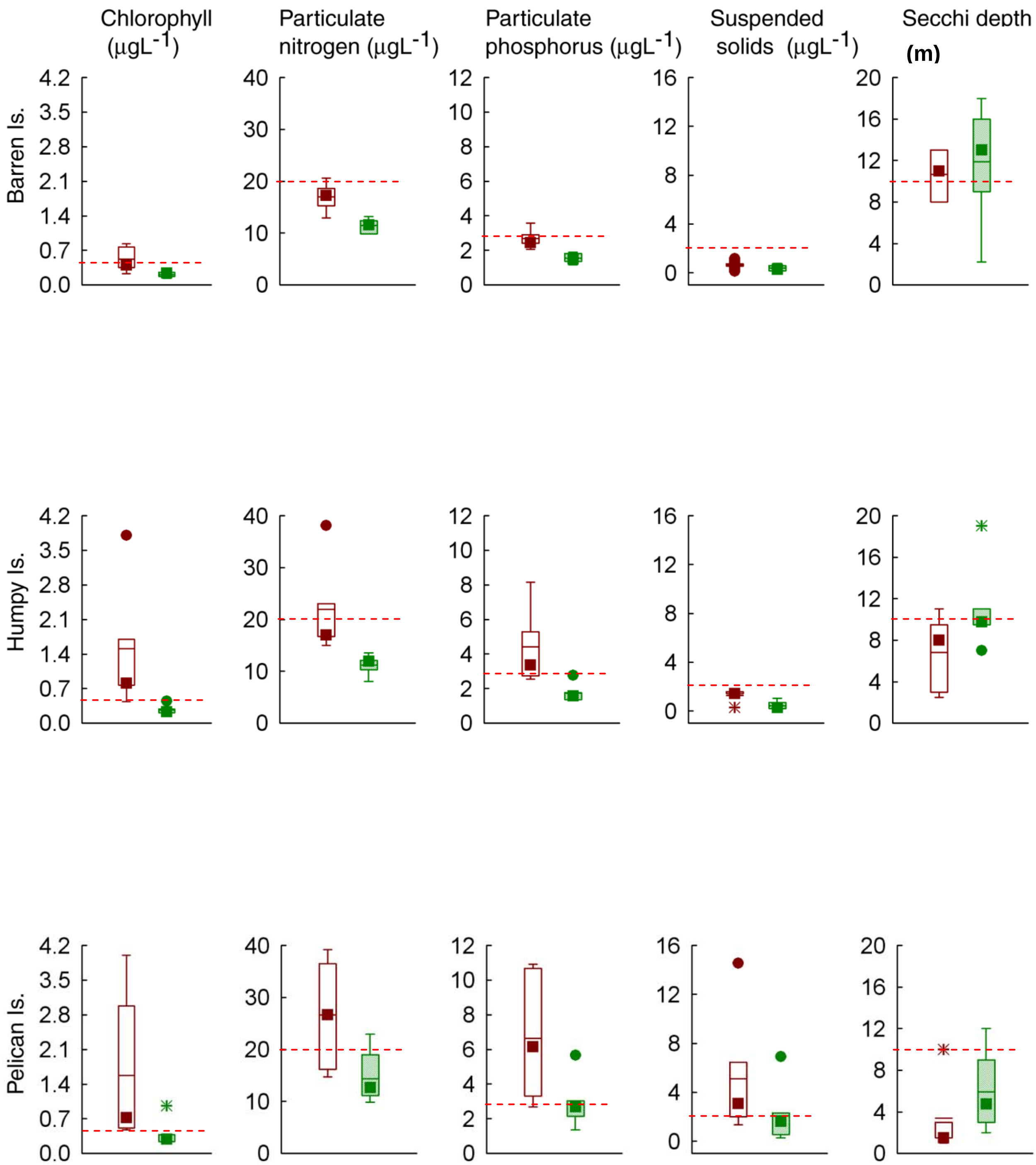

Figure 19 Summary of concentrations of chlorophyll *a*, particulate phosphorus, particulate nitrogen (µg L-1), suspended solids (mg L-1) and Secchi depth (m) at sampling sites in the Fitzroy NRM Region over five sampling years (2005/06 to 2009/10). Dry season values (May- Oct) = shaded boxes, wet season (Nov-Apr)= white boxes. Other details as in Figure 4.

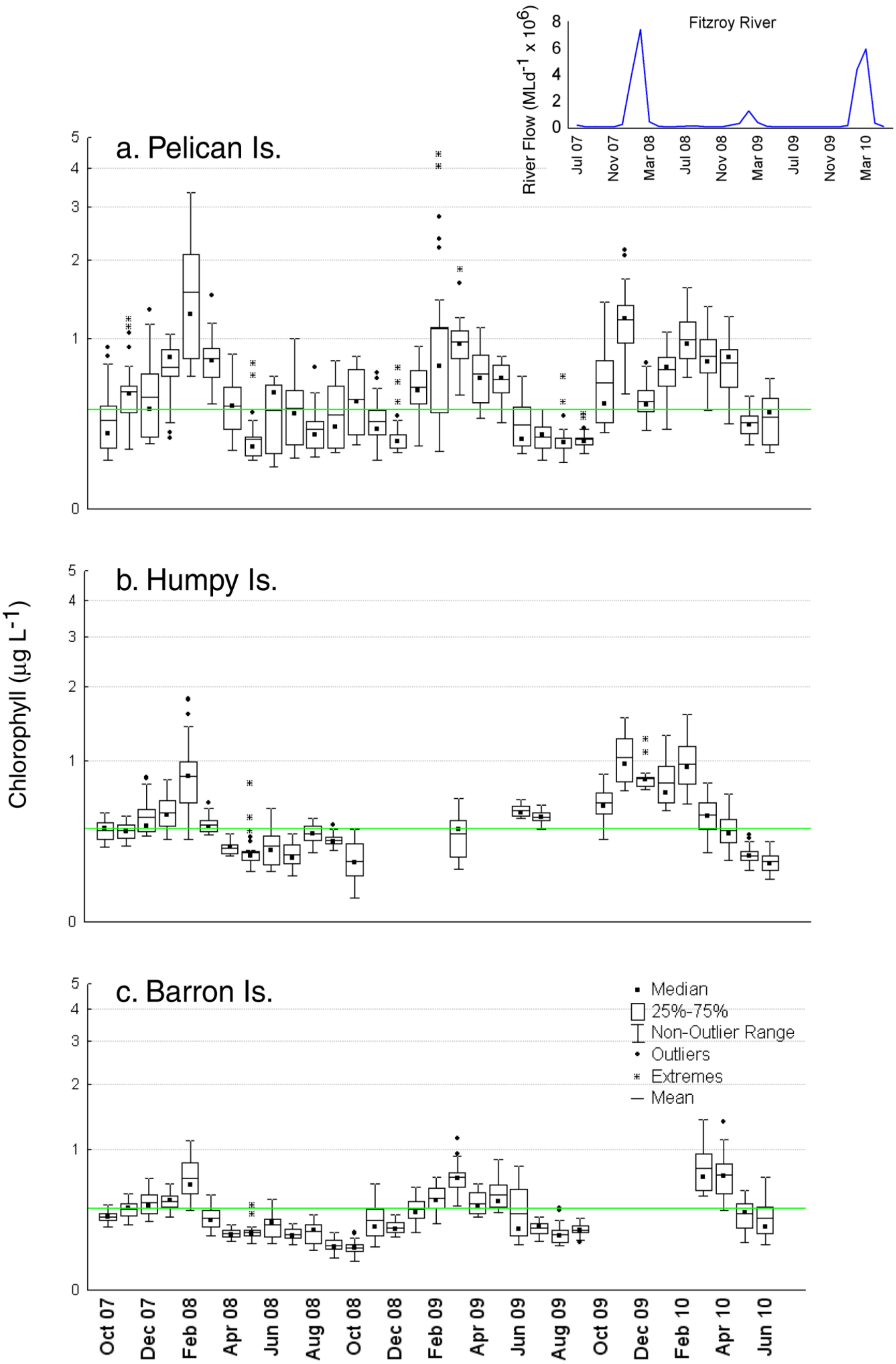

Figure 20 Monthly summary statistics of chlorophyll (µg L^{-1}; a, b, c) and turbidity (NTU; d, e, f) time-series collected by Eco FLNTUSB instruments at Pelican, Humpy and Barron islands in the Fitzroy NRM Region. Additional panel represents the daily discharge from the Fitzroy River (ML x 10^6). Other details as in Figure 5.

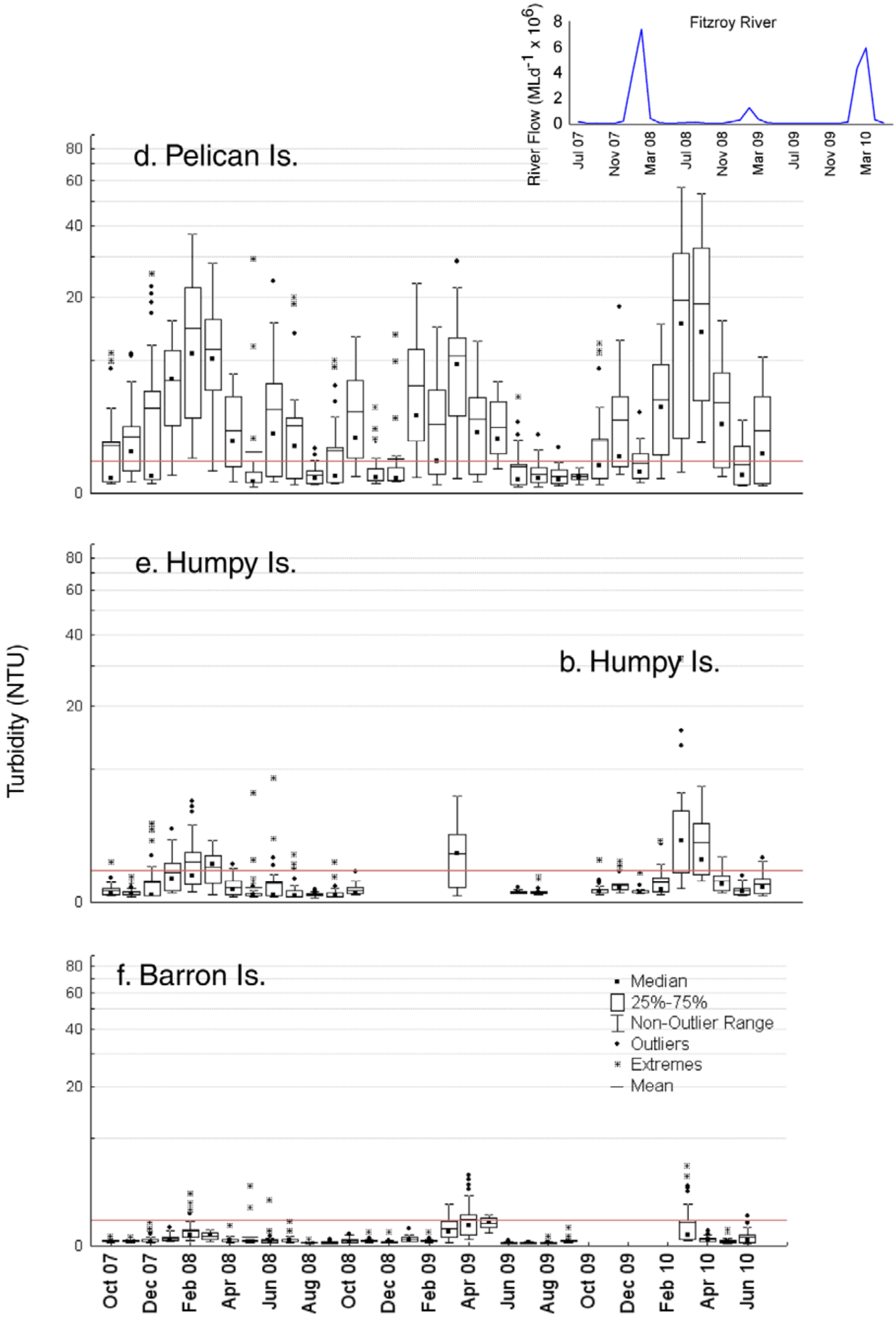

Figure 20 Continued

Table 6 Summary of chlorophyll (µg L^{-1}) data from deployments of WET Labs Eco FLNTUSB Combination Fluorometer and Turbidity Sensors at 14 inshore reef sites. N= number of daily means in the annual time series (based on 'water year', October to October); SE= standard error; "% d> trigger" refers to the percentage of days within the annual record with mean values above the chlorophyll *a* trigger values in the GBRMPA Water Quality Guidelines for the Great Barrier Reef Marine Park (GBRMPA 2009). Red and green shading highlight the annual means that are above or below, respectively, the trigger values.

NRM region	Location	October 2007 to October 2008					October 2008 to October 2009					October 2009 to June 2010				
		N	Annual mean	SE	Annual median	%d >trigger	N	Annual mean	SE	Annual median	%d >trigger	N	Annual mean	SE	Annual median	%d >trigger
Wet Tropics	Snapper Island	355	0.38	0.01	0.33	26	368	0.39	0.01	0.35	37	102	0.48	0.02	0.51	69
	Fitzroy Island	250	0.37	0.01	0.37	30	113	0.34	0.01	0.34	8	263	0.12	0.00	0.13	0
	High Island	359	0.32	0.01	0.30	14	368	0.34	0.01	0.31	12	273	0.43	0.01	0.42	41
	Russell Island	360	0.28	0.00	0.27	2	368	0.34	0.01	0.27	15	256	0.33	0.01	0.31	17
	Dunk Island	336	0.41	0.01	0.39	38	368	0.40	0.02	0.32	26	274	0.36	0.02	0.33	39
Burdekin	Pelorus/Orpheus Island	259	0.44	0.01	0.45	50	368	0.62	0.02	0.52	66	269	0.52	0.02	0.48	62
	Pandora Reef	361	0.50	0.01	0.47	55	368	0.39	0.01	0.37	29	274	0.36	0.01	0.33	15
	Magnetic Island	273	0.45	0.01	0.41	41	368	0.43	0.02	0.34	35	204	0.36	0.01	0.33	21
Mackay Whitsunday	Double Cone Island	199	0.60	0.04	0.44	49	276	0.44	0.01	0.46	53	272	0.41	0.02	0.33	31
	Daydream Island	360	0.50	0.01	0.49	71	368	0.58	0.01	0.56	76	278	0.44	0.01	0.43	38
	Pine Island	364	0.72	0.01	0.72	100	292	0.56	0.01	0.52	75	259	0.69	0.01	0.67	96
Fitzroy	Barren Island	366	0.38	0.01	0.35	26	368	0.40	0.01	0.37	33	130	0.60	0.03	0.55	65
	Humpy Island	363	0.45	0.01	0.41	37	143	0.40	0.01	0.40	41	277	0.64	0.02	0.62	67
	Pelican Island	365	0.58	0.02	0.49	54	366	0.54	0.02	0.42	47	275	0.71	0.02	0.66	73

Table 7 Summary of turbidity (NTU) data from deployments of WET Labs Eco FLNTUSB Combination Fluorometer and Turbidity Sensors at 14 inshore reef sites. N= number of daily means in the annual time series (October to October); SE= standard error; "% d> trigger" refers to the percentage of days within the annual record with mean values above the trigger values in the GBRMPA Water Quality Guidelines for the Great Barrier Reef Marine Park (GBRMPA 2009). Red and green shading highlight the annual means that are above or below, respectively, the trigger values. The turbidity trigger value (1.54 NTU) was derived by transforming the suspended solids trigger value in the Guidelines (2 mg L^{-1}) using an equation based on a comparison between direct water samples and instrumental turbidity readings (see Schaffelke *et al.* 2009).

NRM region	location	October 2007 to October 2008					October 2008 to October 2009					October 2009 to June 2010				
		N	Annual mean	SE	Annual median	%d >trigger	N	Annual mean	SE	Annual median	%d >trigger	N	Annual mean	SE	Annual median	%d >trigger
Wet Tropics	Snapper Island	355	2.20	0.12	1.38	46	368	1.87	0.12	1.26	37	102	3.20	0.35	1.64	53
	Fitzroy Island	250	0.85	0.05	0.70	6	113	0.93	0.15	0.71	7	263	0.88	0.07	0.66	8
	High Island	359	0.81	0.03	0.67	6	368	0.84	0.03	0.70	8	273	1.25	0.09	0.76	19
	Russell Island	360	0.49	0.01	0.42	2	368	0.63	0.02	0.54	4	256	0.74	0.04	0.54	7
	Dunk Island	336	2.01	0.13	1.08	34	368	2.31	0.15	1.27	40	274	2.57	0.19	1.24	40
Burdekin	Pelorus / Orpheus Island	259	0.50	0.01	0.48	0	368	0.74	0.04	0.55	7	269	0.70	0.06	0.53	3
	Pandora Reef	361	0.96	0.04	0.71	13	368	1.17	0.14	0.74	10	274	1.13	0.06	0.85	17
	Magnetic Island	273	2.11	0.17	1.10	36	368	2.32	0.24	1.30	42	204	1.89	0.12	1.40	46
Mackay Whitsunday	Double Cone Island	199	1.15	0.07	0.84	17	276	1.42	0.07	0.98	30	272	1.88	0.12	1.22	42
	Daydream Island	360	2.00	0.10	1.39	45	368	1.99	0.08	1.48	49	278	2.63	0.14	1.91	63
	Pine Island	364	2.86	0.15	2.06	65	292	3.10	0.16	2.18	65	259	3.49	0.27	1.80	62
Fitzroy	Barren Island	366	0.37	0.02	0.25	2	335	0.46	0.03	0.25	6	130	0.61	0.08	0.34	7
	Humpy Island	363	0.88	0.06	0.41	17	143	0.89	0.09	0.45	11	277	1.50	0.19	0.61	21
	Pelican Island	365	5.07	0.36	2.15	56	366	3.40	0.24	1.20	44	275	6.85	0.64	2.60	62

3. Conclusions

Scientists and managers have realised that ongoing management of human pressures on regional and local scales, such as enhanced nutrient runoff and overfishing, is vital to provide corals and reef organisms with the maximum resilience to cope with global stressors such as climate change (Bellwood *et al.* 2004, Marshall and Johnson 2007, Carpenter *et al.* 2008, Mora 2008). The management of water quality remains an essential requirement to ensure the long-term protection of the coastal and inshore reefs of the GBR. The Reef Plan and Reef Rescue initiatives are the key management tools to improve water quality entering the GBR and will, in the long-term, improve coastal and inshore marine water quality.

Sustained long-term monitoring of the coastal and inshore GBR lagoon is fundamental to determine the status of marine water quality and long-term trends related to changes in land use and Reef Plan and Reef Rescue actions. The MMP water quality monitoring has now completed its 5th year and the results have improved our understanding of the spatial and temporal variability of biogeochemical and physical variables in the GBR inshore lagoon. The state of water quality in the inshore GBR shows clear gradients away from river mouths (previously described by Cooper *et al.* 2007) and is influenced over short time periods by flood events and sediment resuspension. Statistical analyses show significant year-to-year, seasonal and regional variability (Schaffelke *et al.* 2009), which means that no single factor or process can be considered in isolation. For example, since the start of the MMP sampling, the extent of river discharge has been different in each year and resuspension appears to be very location-specific.

The longest time series of water quality data for the GBR, the AIMS Cairns Transect, showed relationships between concentrations of six water quality variables and several human-related and natural environmental factors, including; vegetation clearing rates on the adjacent catchment, increased land area under crops and periods of high rainfall and episodes of strong winds.
High land clearing rates from 1996-2001 were associated with high concentrations of particulate phosphorus and suspended solids, while increases in concentrations of chlorophyll *a* and particulate nitrogen lagged behind land clearing alone and were associated with an increase in river discharge and wind strength. After 2004, land clearing was relatively low and particulate concentrations in coastal waters remained relatively constant or decreased even though there was a steady increase in wind strength and river discharge. The relatively infrequent sampling of the Cairns Transect and MMP core sites (two to three times per year), however, limits the statistical power of any analyses and the high inherent variability in the data makes the interpretation difficult.

The broad suite of manually-sampled data are important when interpreted in conjunction with the continuous instrumental water quality monitoring at core reef sites. The instruments currently monitor only three variables (chlorophyll fluorescence, turbidity and temperature) but over long periods at a high frequency (every ten minutes). Chlorophyll fluorescence is considered to be a useful measure of phytoplankton biomass which, in turn, generally reflects nutrient availability. Turbidity and temperature are important physical water quality variables that influence the environmental suitability of a water body for marine biota, which in a GBR context is particularly relevant for coral reef development. Globally, all three indicators are widely used in water quality monitoring programs (e.g. Bricker 2003, European Community 2005, OSPAR 2005, HELCOM 2009). In assessments of eutrophication in other parts of the world other indicators are usually included in addition e.g., phytoplankton productivity and species composition, oxygen concentration and abundance of benthic macrophytes (ibid.).

The high-intensity sampling by the *in situ* loggers has greatly improved our understanding of the natural variability and range of physical and biological conditions at the 14 core reef sites. The time series produced by instrumental monitoring produce data of sufficient density to confidently apply the Guidelines (GBRMPA 2009), based on annual averages, for compliance/exceedance assessments.

In addition to these indicator-specific assessments, we propose here an interim water quality index that aggregates the compliance/exceedance assessments for each of five indicators to give an overall rating for the water quality at each of the 20 fixed sampling sites (Six Cairns Transect and 14 core reefs; Table 8).

Table 8 Interim site-specific water quality index. The index aggregates scores given to five indicators in comparison to the GBR Water Quality Guidelines (GBRMPA 2009), turbidity measured by FLNTUSB instruments (or suspended solids concentration, SS, in water samples for Cairns Transect sites), chlorophyll (measured by FLNTUSB or in water samples for Cairns Transect sites), particulate nitrogen (PN), particulate phosphorus (PP), Secchi depth. The colour scheme used is consistent with Paddock to Reef Reporting and the assessment method is described in Section 2.2. In brief, colours reflect status of water quality: red (very poor), orange (poor), yellow (fair), light green (good), dark green (very good). The six locations of the 'AIMS Cairns Transect' (open water sampling) are in italics. Underlines locations are in the "midshelf" water body, as designated by the GBR Water Quality Guidelines (GBRMPA 2009); all other locations are in the "open coastal" water body.

Region	Location	Turbidity/SS	Chlorophyll	PN	PP	Secchi
Wet Tropics	*Cape Tribulation*	2*	2*	2	2	0
	Snapper Island North	0	1	2	2	0
	Port Douglas	2	2	2	2	0
	Double Island	2*	2*	2	2	2
	Green Island	2*	2*	2	2	2
	Yorkey's Knob	0*	0*	2	0	0
	Fairlead Buoy	0*	0*	2	0	0
	Fitzroy Island	2	2	2	2	2
	High Island	2	2	2	2	0
	Russell Island (Franklands)	2	2	2	2	2
	Dunk Island	0	2	2	0	0
Burdekin	Pelorus / Orpheus Island	2	1	2	2	0
	Pandora Reef	2	1	2	2	0
	Magnetic Island	0	2	0	0	0
Mackay Whitsund.	Double Cone Island	1	1	2	2	0
	Daydream/West Molle Island	0	1	2	2	0
	Pine Island	0	0	2	2	0
Fitzroy	Barren Island	2	1	2	2	2
	Humpy Island	2	1	2	2	2
	Pelican Island	*0*	*0*	*2*	*0*	*0*

These assessments showed that the water quality index at seven out of the eleven Wet Tropics sites was rated as ‘good’ or ‘very good’. The exceptions were Snapper and Dunk islands, which rated ‘fair’. These two sites are close to river mouth and were scored poorly with regard to water clarity; annual mean turbidity was above the Guidelines in all three years of instrumental monitoring and 5 year means of Secchi depth (and PP concentration at Dunk Island) did not comply with the Guidelines. Chlorophyll values were below the Guidelines at all sites. The two sites of the Cairns Transect that were closest to the mainland coast and the Barron River mouth achieved an overall ‘poor’ rating of water quality, because the 5 year means of four out of five indicators (except for PN) exceeded the Guidelines. Of the three sites in the Burdekin Region, the water quality index of the two sites located in the midshelf water body was ‘good’, while the Magnetic Island site that is closer to the mainland and to riverine influence had a ‘very poor’ rating. Annual mean turbidity levels at Magnetic Island in all three years of monitoring and long term means of PP exceeded the Guidelines. Exceedances of the chlorophyll Guidelines were measured in individual years at Pelorus Island and Pandora Reef. The water quality index at the three sites in the Mackay Whitsunday Region was ‘fair’ (2 sites) and ‘poor’ (1 site, Pine Island). Annual mean turbidity levels at Pine and Daydream islands exceeded the Guidelines in all 3 years of monitoring, and the chlorophyll *a* Guidelines were exceeded in individual years. In the Fitzroy Region, only the most inshore site, Pelican Island had a water quality index rated as “very poor”. The annual means of turbidity and chlorophyll exceeded the Guidelines and long-term means of PP and Secchi depth also did not comply.

The means of all available Secchi depth data for 20 fixed locations show that 17 sites have lower readings (more turbid water) than the Guidelines (Table 8). The exceptions were the Barren, Russell and Green island sites. However, the *in situ* logger data only confirmed turbidity exceedances at sites generally highly exposed to land runoff or in shallow coastal areas with high resuspension. This discrepancy indicates that the Guidelines for Secchi depth and suspended solids (on which the calculated turbidity value is based) need further cross-validation.

MMP water quality compliance assessments based on measured or calculated chlorophyll concentration and turbidity were carried out using two approaches: site-specific instrumental monitoring at the 14 core coral reefs and broad-scale monitoring using ocean colour remote sensing imagery. Our compliance/exceedances assessment based on instrumental data differed from the results of the remote sensing based assessment on 2008/09 data (Brando *et al.* 2010), which suggests a higher rate of non-compliance. Calculated annual chlorophyll means based on ocean colour imagery exceeded the Guidelines in more than 50% of the Wet Tropics inshore water body, as did annual chlorophyll and turbidity means in the Burdekin Region and turbidity means in the Mackay Whitsunday Region, and 35% of the inshore area of the Fitzroy Region for both chlorophyll and suspended solids.

At this early stage of the comparison process, the difference in outcomes is not surprising. While remote sensing data have a very high and broad spatial coverage it has less temporal resolution than the *in situ* loggers (1-2 vs 144 data points per day). At this time, we consider the logger data to provide a better description of water quality at our 14 core coral reef sites and has the advantage of coverage through wet season flood events when satellite images are often not available due to cloud cover. High frequency water quality data are required to update and improve the MMP analysis of coral community composition changes in response to environmental factors (e.g., Thompson *et al.* 2010a). Future work and additional data sets are needed to compare and integrate the two approaches, particularly, the degree to which remotely sensed data can be used to reliably characterize the water quality environment close to coral reefs.

Continued instrumental and remotely sensed monitoring of chlorophyll and turbidity will deliver information essential for determining whether further management action may be required at individual locations or regions that continue to show high chlorophyll and turbidity levels relative to the Guidelines. Another future task is the development of integrated assessment metrics for reporting of GBR lagoon water quality that permit a confident and comprehensive evaluation of the overall status of coastal and inshore waters. We are currently seeking funding from the Reef Rescue R&D initiative for this project.

There are still 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. Water column concentrations of dissolved nutrients are much lower at GBR inshore reef sites than in Florida Bay (Boyer *et al.* 1999), Biscayne Bay (Florida; Caccia and Boyre 2005), the Florida Keys (Lirman and Fong 2007), La Parguera (Puerto Rico, Hertler *et al.* 2009) and San Andrés Island, Caribbean Colombia (Gavio *et al.* 2010). Chlorophyll concentrations and turbidity/suspended solids levels at our sites were similar or higher compared to Biscayne Bay (Caccia and Boyer 2005) and the Florida Keys (Lirman and Fong 2007) but lower compared to Florida Bay (Boyer *et al.* 1999) and Puerto Rico (Hertler *et al.* 2009).

We have previously investigated ratios of nutrients and carbon in GBR coastal waters (Schaffelke *et al.* 2008). Low ratios of DIN to PO_4^{-3} indicate high levels of bioavailable dissolved phosphorus relative to dissolved nitrogen, especially during the dry season. Seasonal nitrogen inputs during summer flood events are a significant water quality issue, because they supports higher phytoplankton production (Furnas 2005), leading to increased chlorophyll levels. To date, it is unclear what the consequences of high PO_4^{-3} availability are, but it is possible that certain types of phytoplankton (e.g. N-fixing cyanobacteria such as *Trichodesmium* spp.) may benefit from these conditions. Ratios of carbon-nitrogen-phosphorus (C:N:P) in the particulate fraction were slightly elevated compared to the Redfield ratio (C_{106}:N_{16}:P_1), which represents an average molecular ratio of carbon, nitrogen and phosphorus in oceanic phytoplankton (Redfield 1958). This indicates higher carbon concentrations than expected most likely as detritus particles and marine snow. Enhanced organic matter concentrations in marine systems can be a symptom of eutrophication (*sensu* Nixon 1995). Enhanced chlorophyll levels are also widely considered a symptom of eutrophication (e.g. Cloern 2001).

While persistent elevated chlorophyll values were only found at some of the core reef monitoring sites, the remote sensing results indicate that high values (relative to the Guidelines) occur widely throughout the inshore waters of the Wet Tropics and Burdekin regions. Very high levels of nutrients, chlorophyll and organic matter are measured during flood plume events and in these situations, GBR waters could be considered episodically eutrophic (Devlin et al, 2009, Devlin and Schaffelke 2009). However, organic matter accumulation is complex, dependent on both input and transformation processes as well as hydrodynamics. We can currently only speculate how long the influence of a flood event lasts and how it is perpetuated through the food web. A MTRSF research project has also focused on the questions of how long discharged fine particles remain in the system and undergo re-suspension and how water clarity changes throughout the year and from year to year, especially after flood events. Results to date indicate that flood-delivered fine sediment remains in the coastal zone for long after the event leading to recurring high turbidity events through wind-driven resuspension (Wolanski *et al.* 2008, Lambrechts *et al.* 2010). Some coastal and inshore reefs in the GBR and elsewhere show signs of degradation that are consistent with eutrophication and fine sediment accumulation (Fabricius 2005, in press; Fabricius and Dea'th 2004, 2010). Analyses of MMP data also indicated that the particulate components of water quality (suspended sediment and particulate nutrients and organic carbon) are the most important drivers of changes in inshore reef community composition (Thompson *et al.* 2010a, Uthicke *et al.* 2010).

Effective management of coastal water quality has to consider ecosystem-wide responses, cascading effects and ecological feedbacks as well as interactions with other pressures on the coastal zone (Cloern 2001, Duarte 2009, Nixon 2009). Water quality, impacts of land runoff and eutrophication have to be considered as part of global change. We need to better understand the complex responses and thresholds of coastal ecosystems to anthropogenic pressures including their sometimes unpredictable responses to management actions such as nutrient reduction (Duarte 2009). Programs like the MMP will allow us to both measure the trajectories of change and to improve our ecosystem understanding of the coastal and inshore Great Barrier Reef.

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Appendix 1: Additional Information

Table A1-1 Details of deployments and log of failures of WETLabs ECO FLNTUSB instruments deployed at inshore reef locations for water quality monitoring.

Location	Serial no.	Deployment	Retrieval	Event date	Event title	Comments
Snapper	827	26/02/2009	16/06/2009		Deployment Problem	Temperature not functioning for entire deployment 26 Feb - 16 June 2009.
	827			29/10/2009	Other	temperature sensor was not properly connected, appears OK now
	828	16/06/2009	12/10/2009			
	837	12/10/2009	04/03/2010		Deployment Problem	Failed during deployment. Records recovered for 12 Oct 2009 to 22 Oct 2009
	837			29/03/2010	Sent to WET Labs	Due to customer feedback Wetlabs found manufacturing issues with lower battery pack which caused decreased battery life. Replaced battery board & upgraded battery pack.
	827	4/03/2010	27/06/2010		Deployment Problem	Logger failed during deployment, last record 28 May 2010 11:36:47 PM. Data post 21 May 2010 11:50:18 PM discarded.
	827			27/07/2010	Sent to WET Labs	Logger failed. In water time since last calibration 65 weeks
	837	27/06/2010	Still deployed			
Fitzroy	837	25/02/2009	14/06/2009			
	838	14/06/2009	10/10/2009			unreliable records: deleting Chl & NTU 12/08/2009 12:00:25 AM to end record 10/10/2009 03:45:49 PM Temperature ok.
	838	23/12/2009			Sent to WET Labs	replaced optics head as optics shotglass cracked.
	826			19/05/2009	Sent to WET Labs	Replaced preamp components and installed new processor board. During testing, shutter position sensors in the optical head failed, installed new optical head.
	826	10/10/2009	03/03/2010			New style logger. Chl output appears to be 'blocky'. Maybe due to new style LED?
	838	3/03/2010	28/06/2010			High NTU 11 March 2010.
	826	28/06/2010	Still deployed			
High	825	24/02/2009	14/06/2009			
	839	14/06/2009	10/10/2009			
	825	10/10/2009	02/03/2010			

	839	2/03/2010	28/06/2010			
	839			27/07/2010	Sent to WET Labs	Standard service. In water time since last calibration 76 weeks
	825	28/06/2010	Still deployed			
Russell	840	24/02/2009	14/06/2009			
	824	14/06/2009	10/10/2009		Deployment Problem	Temp record goes crazy mid deployment jump from 22 to 64 with bad records beginning 08:55:13 AM 4 Aug 2009 until end record.
	824			11/11/2009	Sent to WET Labs	Short found on the processor board. The processor board replaced under warranty. 24 Nov 2009
	840	10/10/2009	02/03/2010		Deployment Problem	Logger stopped recording prematurely on 16 Feb 2010 04:50:04 AM.
	840			29/03/2010	Sent to WET Labs	Polished optics head due to scratches.
	824	2/03/2010	25/06/2010			
	840	25/06/2010	Still deployed			
Dunk	353	27/02/2009	17/06/2009			
	841	17/06/2009	13/10/2009		Deployment Problem	Thermistor failed 19 Sep 2009 07:49:57 AM.
	841			16/11/2009	Sent to WET Labs	Instrument died, damaged beyond repair. The head cracked through the optics. The thermistor must be replaced also, but not cost effective to replace parts - WET Labs offered discount towards a replacement FLNTUSB, then subsequently replaced under warranty.
	1329	13/10/2009	05/03/2010		Deployment Problem	New instrument. Warranty replacement for 820.
	828	5/03/2010	29/06/2010			
	828			27/07/2010	Sent to WET Labs	Standard service. In water time since last calibration 80 weeks
	1329	29/06/2010	Still deployed			
Pelorus	823	23/02/2009	17/06/2009			
	818	17/06/2009	08/10/2009			

	818			23/12/2009	Sent to WET Labs	Standard service.
	823	8/10/2009	01/03/2010		Deployment Problem	Temperature records dropped out 24 Dec 2009 09:31:09 AM until recovery 1 Mar 2010. Temp appeared to restart when logger out of water after recovery.
	823			29/03/2010	Sent to WET Labs	Polished optics head due to scratches. Rewired & verified correct battery pack operation plus did standard service.
	818	1/03/2010	24/06/2010			
	823	24/06/2010	Still deployed			
Pandora	822	22/02/2009	13/06/2009			
	815	13/06/2009	08/10/2009			
	815	23/12/2009			Sent to WET Labs	replaced optics head as optics shotglass cracked.
	822	8/10/2009	06/03/2010			
	815	6/03/2010	29/06/2010			
	822	29/06/2010	Still deployed			
Geoffrey	352	22/02/2009	12/06/2009			
	351	12/06/2009	07/10/2009			Barnacle on biowiper. Little fish living under logger - may possibly interefere with logger reading - ie. in field of view? Fish moved to new logger when the replacement installed.
	352	7/10/2009	28/02/2010			Record ended prematurely at 07:11:07AM 15 Dec 2009 before going into 'one second mode' until log end 06:55:09PM 15 Dec 2009.
	352			29/03/2010	Sent to WET Labs	Replaced optics head due to delamination. Rewired & verified correct battery pack operation plus did standard service.
	351	28/02/2010	04/07/2010			
	351			27/07/2010	Sent to WET Labs	Standard service. In water time since last calibration 75 weeks
	352	4/07/2010	Still deployed			
DoubleCone	845	20/02/2009	11/06/2009			
	1043	11/06/2009	06/10/2009		Deployment Problem	Logger failed during deployment. Records recovered from 11 June until last record 30 June 2009 01:40:16 AM. Battery flat & optical sensors not responding

	1043			11/11/2009	Sent to WET Labs	Short found on the processor board. The processor board being replaced under warranty. 1 Dec 2009
	353	6/10/2009	27/02/2010		Deployment Problem	
	1043	27/02/2010	03/07/2010			
	353	3/07/2010	Still deployed			
Daydream	846	19/02/2009	10/06/2009			
	819	10/06/2009	05/10/2009			
	842	5/10/2009	26/02/2010			
	819	26/02/2010	03/07/2010			
	842	3/07/2010	Still deployed			
Pine	842	20/02/2009	10/06/2009			
	1044	10/06/2009	04/10/2009		Deployment Problem	NTU and Chl stopped working midnight 16 Jul 2009. Last good record 16 Jul 11:56:06 PM. Temperature continued to function. In lab optical sensors do not respond to fluoro stick.
	1044			11/11/2009	Sent to WET Labs	Short found on the processor board. The processor board being replaced under warranty. 24 Nov 2009
	843	4/10/2009	25/02/2010		Deployment Problem	Mid deployment NTU & Chl record dropped out between 24 Jan 2010 - 9 Feb 2010, came back until end deployment 17 Mar 2010.
	843			29/03/2010	Sent to WET Labs	Wetlabs unable to replicate failure during deployment, but based on historical data replaced processor board on 843. Standard service including updated battery pack,
	1044	25/02/2010	03/07/2010			
	843	3/07/2010	Still deployed			
Barren	816	17/02/2009	08/06/2009			
	1091	8/06/2009	01/10/2009			
	845	1/10/2009	23/02/2010		Deployment Problem	Logger damaged during deployment. Logger clamp broken and logger found lying on the surrounding coral. No data recovered for entire deployment 1 Oct 2009 to 23 Feb 2010. (anchor damage?)
	845			29/03/2010	Sent to WET	Logger died. No data recovered. Insurance claim pursued by GBRMPA.

					Labs	
	1091	23/02/2010	01/07/2010			Newer style logger.
	1729	1/07/2010	Still deployed			New instrument.
Humpy	844	17/02/2009	08/06/2009			Records for 17 Feb - 26 March 2009 before the logger went into '1 second mode' and failed.
	844			30/10/2009	Sent to WET Labs	Processor board failed. Replaced plus retuned and serviced.
	821	8/06/2009	14/08/2009		Deployment Problem	Craig Humphrey recovered for us after I determined it should not have been redeployed. Shutter was open, stopped, log ended 20 Jul 2009, no fouling.
	821			8/09/2009	Sent to WET Labs	Found loose pull-up resistor on processor board. Resoldered and reliably turns on. Std service inc firmware upgrade etc.
	846	14/08/2009	02/10/2009		Deployment Problem	Craig Humphrey deployed for us. Bad Chl & NTU data at beginning of deployment 14 Aug to 16 Sep 2009, but latter part of deployment ok (very unusual). Chl high & NTU flat -perhaps obstruction on optical face?
	846			11/11/2009	Sent to WET Labs	Evaluation and testing of this logger did not show any evident failures for the unit. Found the instrument responds well, has good battery voltage, good current draw and no shorts on the processor board. Replacing the processor board on the unit.
	816	2/10/2009	24/02/2010		Deployment Problem	Temperature not working for entire deployment 2 Oct 2009 - 24 Feb 2010.
	816			29/03/2010	Other	Repaired temperature problem at AIMS.
	844	24/02/2010	02/07/2010			
	816	2/07/2010	Still deployed			
Pelican	817	17/02/2009	08/06/2009			
	843	8/06/2009	01/10/2009			Algae wrapped around biowiper therefore lost data after 28 Sep 2009 09:28:09 PM.
	817	1/10/2009	24/02/2010			
	817			29/03/2010	Sent to WET Labs	Completed standard service, including updated version of battery pack.
	846	24/02/2010	01/07/2010			
	817	1/07/2010	Still deployed			

Table A1-2 Annual freshwater discharge (ML) for the major GBR Catchment rivers in proximity to the sampling sites of the inshore reef water quality sampling. Shaded cells highlight years for which river flow exceeded the median annual flow as estimated from available long-term time series for each river. Discharge data supplied by the Queensland Department of The Environment and Natural Resource Management. Long-term medians were estimated from annual totals available on www.nrw.qld.gov.au/watershed; accessed 10/08/2010. 2009/10 records are to 10 June 2010. * incomplete gauging record.

Region	River	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10
	Daintree	1,182,848	57,463	138,088	1,429,454	490,222	1,253,555	715,530	874,013	423,711*	1,147,846
Wet Tropics	Barron	852,458	165,895	113,644	950,206	392,223	745,779	471,359	1,582,470	781,081	539,064
	Mulgrave	781,990*	183,890	333,262	1,132,754	432,522*	1,014,701	757,914	938,122	689,845	602,261
	Russell	1,176,637	433,935	615,927	1,345,243	990,734	1,299,019	1,276,654	1,075,370	1,213,227	1,624,432
	North Johnstone	2,073,998	657,433	819,665	2,316,733	1,483,325	2,170,982	2,083,947	1,886,425	1,990,957	1,017,125
	South Johnstone	796,845*	345,066	311,763	432,040*	542,835	1,014,726	955,321	811,656	1,045,508	654,669
	Tully	3,556,981	1,208,801	1,442,043	3,283,940	2,200,706	3,624,129	4,149,772	3,232,667	3,769,840	2,507,335
	Herbert	4,661,616	929,933	688,775	3,303,782	1,481,771	3,874,894	4,089,009	3,312,563	9,573,120	152,352*
Burdekin	Burdekin	8,765,755	4,485,312	2,092,834	1,516,194	4,328,246	2,191,850	9,170,162	27,970,750	30,090,023	7,845,420*
Mackay Whitsunday	Proserpine	14,486	19,973	18,676	10,344	23,770	20,395	44,750	76,490	63,263	49,501
	O'Connell	147,717	85,202	23,236	23,973	75,989	84,072	256,362	596,356	167,111	212,608
	Pioneer	731,538	218,405	111,677	44,931	196,180	72,849	716,325	1,300,639	931,111	1,308,586
Fitzroy	Fitzroy	3,120,928	579,616	2,734,901	1,310,320	920,295	677,845	886,272	12,051,412	2,192,808	10,677,915

Table A1-3 Concentrations of dissolved inorganic nitrogen species (µg L^{-1}) at three sampling occasions in 2009/10.

Region	Location	Date	NH_4	NO_2	NO_3	Date	NH_4	NO_2	NO_3	Date	NH_4	NO_2	NO_3
Wet Tropics	Snapper Island	16/06/2009	0.3	0.2	1.3	12/10/2009	0.3	0.2	1.1	04/03/2010	1.6	0.7	2.2
	Fitzroy Island	14/06/2009	0.4	0.2	0.6	10/10/2009	0.3	0.2	1.2	03/03/2010	0.8	0.3	0.1
	High Island	14/06/2009	0.8	0.1	0.8	10/10/2009	0.5	0.2	0.9	02/03/2010	2.2	0.2	0.1
	Russell Island	14/06/2009	0.2	0.1	0.6	10/10/2009	0.1	0.3	0.7	02/03/2010	0.6	0.2	0.4
	Dunk Island	17/06/2009	0.6	0.1	0.5	13/10/2009	0.8	0.1	1.2	05/03/2010	0.9	0.3	0.4
Burdekin	Pelorus/Orpheus Island	17/06/2009	0.1	0.1	0.3	08/10/2009	0.8	0.3	0.4	01/03/2010	2.0	0.2	0.4
	Pandora Reef	13/06/2009	0.3	0.2	1.1	08/10/2009	0.6	0.2	2.4	06/03/2010	1.4	0.4	3.5
	Geoffrey Bay	12/06/2009	0.5	0.1	0.4	07/10/2009	0.3	0.2	0.2	28/02/2010	4.1	0.5	4.3
Mackay Whitsunday	Double Cone Island	11/06/2009	0.2	0.1	0.3	06/10/2009	0.5	0.2	0.2	27/02/2010	2.5	0.2	0.4
	Daydream Island	10/06/2009	0.2	0.2	0.3	05/10/2009	0.5	0.2	0.5	26/02/2010	1.5	0.5	1.3
	Pine Island	10/06/2009	0.6	0.1	0.4	04/10/2009	1.1	0.2	0.3	25/02/2010	0.3	0.2	1.1
Fitzroy	Barren Island	08/06/2009	0.3	0.1	0.8	01/10/2009	0.8	0.1	0.3	23/02/2010	1.3	0.1	1.7
	Humpy Island	08/06/2009	1.1	0.1	0.7	02/10/2009	0.3	0.1	0.3	24/02/2010	0.4	0.2	1.3
	Pelican Island	08/06/2009	0.2	0.1	0.6	01/10/2009	0.7	0.2	0.2	23/02/2010	1.4	2.1	19.6

Table A1-4 Concentrations of total dissolved nitrogen and particulate nitrogen (µg L^{-1}) at three sampling occasions in 2009/10.

Region	Location	Date	TDN	PN	Date	TDN	PN	Date	TDN	PN
Wet Tropics	Snapper Island	16/06/2009	15.0	41.2	12/10/2009	11.1	75.8	04/03/2010	12.5	68.7
	Fitzroy Island	14/06/2009	9.8	43.2	10/10/2009	7.5	65.6	03/03/2010	16.2	69.2
	High Island	14/06/2009	10.9	53.3	10/10/2009	8.8	72.1	02/03/2010	15.0	80.8
	Russell Island	14/06/2009	10.8	58.0	10/10/2009	9.3	72.8	02/03/2010	15.0	77.1
	Dunk Island	17/06/2009	12.4	39.2	13/10/2009	12.8	74.7	05/03/2010	16.4	76.5
Burdekin	Pelorus/Orpheus Island	17/06/2009	14.8	34.1	08/10/2009	9.7	73.6	01/03/2010	17.3	81.2
	Pandora Reef	13/06/2009	9.8	62.7	08/10/2009	10.3	81.1	06/03/2010	12.8	72.4
	Geoffrey Bay*	12/06/2009	11.1	54.8	07/10/2009	16.8	89.4	28/02/2010	17.7	97.6
Mackay Whitsunday	Double Cone Island	11/06/2009	12.5	49.9	06/10/2009	12.6	70.8	27/02/2010	15.9	73.7
	Daydream Island	10/06/2009	11.0	57.5	05/10/2009	12.9	61.8	26/02/2010	15.7	71.2
	Pine Island	10/06/2009	12.0	44.1	04/10/2009	11.9	60.8	25/02/2010	18.0	80.6
Fitzroy	Barren Island	08/06/2009	9.8	61.0	01/10/2009	12.4	66.8	23/02/2010	18.6	92.9
	Humpy Island	08/06/2009	10.3	60.5	02/10/2009	11.9	64.6	24/02/2010	38.2	140.2
	Pelican Island	08/06/2009	12.9	66.7	01/10/2009	19.0	71.1	23/02/2010	39.2	181.8

Table A1-5 Concentrations of dissolved inorganic phosphorus (PO_4), total dissolved phosphorus (TDP) and particulate phosphorus (PP), all in µg L^{-1}, at three sampling occasions in 2009/10.

Region	Location	Date	PO_4	TDP	PP	Date	PO_4	TDP	PP	Date	PO_4	TDP	PP
Wet Tropics	Snapper Island	16/06/2009	3.1	8.4	2.3	12/10/2009	3.1	6.0	1.9	04/03/2010	2.8	5.7	2.8
	Fitzroy Island	14/06/2009	2.1	9.6	1.7	10/10/2009	2.8	6.4	1.4	03/03/2010	1.8	7.5	2.9
	High Island	14/06/2009	1.9	8.6	2.5	10/10/2009	3.1	5.2	1.5	02/03/2010	2.1	8.8	3.5
	Russell Island	14/06/2009	1.6	8.3	2.2	10/10/2009	3.2	6.9	2.3	02/03/2010	2.5	6.6	2.3
	Dunk Island	17/06/2009	1.6	7.4	1.8	13/10/2009	3.0	6.3	2.3	05/03/2010	2.5	12.2	3.7
Burdekin	Pelorus/Orpheus Island	17/06/2009	0.9	7.3	2.0	08/10/2009	2.9	7.2	1.6	01/03/2010	2.6	6.7	2.9
	Pandora Reef	13/06/2009	2.0	10.2	2.0	08/10/2009	3.6	8.4	2.1	06/03/2010	3.4	7.7	2.2
	Geoffrey Bay*	12/06/2009	3.3	10.9	1.7	07/10/2009	2.6	7.8	4.2	28/02/2010	4.3	9.1	3.5
Mackay Whitsunday	Double Cone Island	11/06/2009	3.2	8.9	2.5	06/10/2009	3.0	6.6	2.4	27/02/2010	2.9	7.4	3.0
	Daydream Island	10/06/2009	4.1	10.7	2.3	05/10/2009	3.9	7.3	2.7	26/02/2010	2.8	6.5	3.2
	Pine Island	10/06/2009	4.2	11.5	2.5	04/10/2009	3.8	7.3	2.6	25/02/2010	3.0	7.7	2.8
Fitzroy	Barren Island	08/06/2009	2.2	8.0	1.7	01/10/2009	3.1	9.4	1.9	23/02/2010	2.0	5.3	2.9
	Humpy Island	08/06/2009	2.8	9.1	1.8	02/10/2009	2.5	7.6	2.8	24/02/2010	19.8	23.0	8.1
	Pelican Island	08/06/2009	3.8	12.7	2.7	01/10/2009	1.5	7.1	3.0	23/02/2010	31.2	32.7	8.3

Table A1-6 Concentrations of dissolved organic carbon (DOC), particulate organic carbon (POC), and silicate, all in µg L^{-1}, at three sampling occasions in 2009/10.

Region	Location	Date	DOC	POC	Si	Date	DOC	POC	Si	Date	DOC	POC	Si
Wet Tropics	Snapper Island	16/06/2009	772.9	108.2	187.1	12/10/2009	830.2	94.9	103.0	04/03/2010	789.9	95.8	119.3
	Fitzroy Island	14/06/2009	689.2	94.2	99.7	10/10/2009	676.6	70.9	19.9	03/03/2010	1077.9	107.9	135.4
	High Island	14/06/2009	738.6	90.1	218.2	10/10/2009	729.9	71.9	36.4	02/03/2010	871.0	142.4	157.6
	Russell Island	14/06/2009	720.5	74.6	118.5	10/10/2009	766.5	85.0	22.4	02/03/2010	836.5	87.7	210.6
	Dunk Island	17/06/2009	819.7	100.5	200.5	13/10/2009	737.6	111.9	123.8	05/03/2010	779.0	167.2	232.0
Burdekin	Pelorus/Orpheus Island	17/06/2009	725.5	92.2	59.9	08/10/2009	739.6	105.1	77.7	01/03/2010	898.2	104.5	221.9
	Pandora Reef	13/06/2009	761.6	92.7	104.4	08/10/2009	750.9	106.9	109.9	06/03/2010	942.3	102.0	217.7
	Geoffrey Bay*	12/06/2009	758.2	70.1	135.9	07/10/2009	871.7	200.3	90.7	28/02/2010	1260.3	127.0	759.4
Mackay Whitsunday	Double Cone Island	11/06/2009	710.5	85.7	45.4	06/10/2009	777.0	119.7	51.1	27/02/2010	937.1	131.7	78.4
	Daydream Island	10/06/2009	710.3	87.0	49.2	05/10/2009	747.1	114.0	56.8	26/02/2010	904.8	118.6	72.1
	Pine Island	10/06/2009	732.1	68.5	52.1	04/10/2009	760.5	96.3	53.1	25/02/2010	924.5	113.6	143.5
Fitzroy	Barren Island	08/06/2009	830.8	115.0	19.8	01/10/2009	734.0	83.5	33.7	23/02/2010	917.1	188.2	28.1
	Humpy Island	08/06/2009	849.4	75.5	19.6	02/10/2009	782.7	130.9	19.3	24/02/2010	1982.3	308.8	1197.5
	Pelican Island	08/06/2009	883.9	113.2	65.6	01/10/2009	794.2	149.4	12.2	23/02/2010	2356.9	368.7	1607.0

Table A1-7 Concentrations of chlorophyll *a* (μg L^{-1}) at three sampling occasions in 2009/10.

Region	Location	Date	Chlorophyll *a*	Date	Chlorophyll *a*	Date	Chlorophyll *a*
Wet Tropics	Snapper Island	16/06/2009	0.38	12/10/2009	0.27	04/03/2010	0.46
	Fitzroy Island	14/06/2009	0.33	10/10/2009	0.15	03/03/2010	0.49
	High Island	14/06/2009	0.31	10/10/2009	0.26	02/03/2010	0.75
	Russell Island	14/06/2009	0.31	10/10/2009	0.24	02/03/2010	0.52
	Dunk Island	17/06/2009	0.18	13/10/2009	0.31	05/03/2010	0.75
Burdekin	Pelorus/Orpheus Island	17/06/2009	0.36	08/10/2009	0.15	01/03/2010	0.69
	Pandora Reef	13/06/2009	0.19	08/10/2009	0.36	06/03/2010	0.39
	Geoffrey Bay*	12/06/2009	0.19	07/10/2009	0.70	28/02/2010	0.59
Mackay Whitsunday	Double Cone Island	11/06/2009	0.31	06/10/2009	0.32	27/02/2010	1.10
	Daydream Island	10/06/2009	0.44	05/10/2009	0.49	26/02/2010	1.21
	Pine Island	10/06/2009	0.40	04/10/2009	0.41	25/02/2010	1.04
Fitzroy	Barren Island	08/06/2009	0.25	01/10/2009	0.24	23/02/2010	0.84
	Humpy Island	08/06/2009	0.21	02/10/2009	0.31	24/02/2010	3.81
	Pelican Island	08/06/2009	0.30	01/10/2009	0.28	23/02/2010	4.00

Table A1-8 **Secchi depth** (m), concentrations of **total suspended solids** (SS, mg L-1) and **salinity** (dimensionless) at three sampling occasions in 2009/10.

Region	Location	Date	Secchi	SS	Salinity	Date	Secchi	SS	Salinity	Date	Secchi	SS	Salinity
Wet Tropics	Snapper Island	16/06/2009	6.5	1.2	33.80	12/10/2009	9.0	0.6	35.22	04/03/2010	7.5	1.1	33.20
	Fitzroy Island	14/06/2009	7.0	1.0	34.37	10/10/2009	10.0	0.9	34.94	03/03/2010	4.5	1.2	32.81
	High Island	14/06/2009	4.0	1.2	33.36	10/10/2009	11.0	0.8	35.00	02/03/2010	4.5	1.6	32.44
	Russell Island	14/06/2009	6.5	0.8	33.96	10/10/2009	11.0	0.6	34.94	02/03/2010	9.0	0.5	32.43
	Dunk Island	17/06/2009	5.0	1.3	33.71	13/10/2009	6.5	1.4	35.18	05/03/2010	7.0	2.3	32.86
Burdekin	Pelorus/Orpheus Island	17/06/2009	9.0	0.8	34.46	08/10/2009	15.0	0.4	35.12	01/03/2010	3.0	1.4	32.56
	Pandora Reef	13/06/2009	9.5	0.6	34.20	08/10/2009	6.0	1.2	35.11	06/03/2010	12.0	0.8	33.13
	Geoffrey Bay*	12/06/2009	10.0	0.5	34.29	07/10/2009	3.5	1.9	35.75	28/02/2010	3.0	2.5	29.88
Mackay Whitsunday	Double Cone Island	11/06/2009	5.5	1.3	34.41	06/10/2009	6.0	1.4	35.28	27/02/2010	4.0	2.6	34.05
	Daydream Island	10/06/2009	4.5	1.8	34.46	05/10/2009	4.5	3.2	35.27	26/02/2010	4.5	1.8	25.56
	Pine Island	10/06/2009	5.0	2.7	34.47	04/10/2009	5.0	3.3	35.27	25/02/2010	6.0	1.2	33.70
Fitzroy	Barren Island	08/06/2009	13.0	0.3	35.25	01/10/2009	16.0	0.4	35.31	23/02/2010	8.0	0.5	35.17
	Humpy Island	08/06/2009	9.5	0.2	35.32	02/10/2009	10.0	0.8	35.36	24/02/2010	2.5	1.6	29.35
	Pelican Island	08/06/2009	3.5	1.6	35.43	01/10/2009	9.0	0.6	35.67	23/02/2010	1.5	2.4	27.97

Appendix 2: QAQC Information

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 DVD.

Limits of detection

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

Table A2-1 Limit of detection (LOD) for analyses of marine water quality parameters.

Parameter (analyte)	LOD
NO2	0.14 - 0.28 µg L^{-1}*
NO3+ NO2	0.56 - 0.70µg L^{-1}*
NH4	0.70 - 0.84 µg L^{-1}*
TDN	5 – 23.8 µg L^{-1}*
PN	1.0 µg $filter^{-1}$
PO4	0.93 – 1.24 µg L^{-1}*
TDP	2.8 - 3.7 µg L^{-1}*
PP	0.09 µg L^{-1}
Si	1.4 – 3.6 µg L^{-1}*
DOC	0.1 mg L^{-1}
POC	1.0 µg $filter^{-1}$
Chlorophyll *a*	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 2009/10.

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). Average coefficients of variation (CV) were at or below 10% for samples analysed for TDN, PN, PP, Si, DOC, POC and chlorophyll. Average CVs were above 10% but below 20% for all other parameters, except for NO_2 which returned an average CV of 25%. Some individual sample pairs had high CVs (see row N with CV > 20%). In the case of samples analysed for PN, PP, SS and chlorophyll *a* 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 as much as possible.

Table A2-2 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	25	205	37
NO3+ NO2	16	208	25
NH4	12	206	15
TDN	10	320	14
PN	10	315	14
PO4	12	209	19
TDP	12	324	18
PP	6	273	4
Si	8	206	8
DOC	3	321	0-1
POC	10	298	13
Chlorophyll *a*	7	384	5
SS	13	225	20
Salinity	n/a*		

*n/a: no replicate samples collected for salinity

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

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 A2-3)

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, POC, chlorophyll, SS and salinity was within this limit (Table A2-4). 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 is being assessed using z-scores of the results returned from analysis of NLLNCT certified reference material. According to the NLLNCT instructions, accuracy deemed good if results below 1 z-score, satisfactory if below 2 z-scores. In each analytical batch, two bottles with different concentrations were analysed. In 2009/10 we used bottles #5 and #7 from Round 14 of the NLLNCT. For all nutrient analyses, z-scores for the #5 bottle (lower concentrations) were within 1 z-score (Table A2-5) and, hence, accuracy was deemed good. Only one out of three TDP batches returned a result within 2 z, deemed acceptable. The z-scores for the #7 bottle (higher concentrations) were generally within 2z for all variables (Table A2-5). One batch of each, TDN, TDP, NOx and Si returned z-scores above 2. Bottle #7 generally returned worse result as it had much higher concentrations than the GBR lagoon samples and generally required analysis at a different sensitivity range. To assure that the monitoring results were accurate, additional QAQC samples were included in all batches (e.g. in-house reference seawater that allows for batch to batch comparison, added nutrient spikes) which usually return acceptable results.

Table A2-3 Summary of coefficients of variation (CV, in %) of replicate measurements (N) of a standard or reference material.

Parameter (analyte)	CV (%)	N
NO2	2-4*	3-5
NO3+ NO2	5-9*	3-5
NH4	4-18*	3-5
TDN	1-20*	3-5
PN	12-20	13-28
PO4	2-7*	3-5
TDP	5-9*	3-5
PP	22	8
Si	1-6*	3-5
DOC	2-6*	33-67
POC	5-10**	42-44
Chlorophyll *a*	0.65	12
SS	n/a***	
Salinity	<1	4-7

*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 2009/10.
** two different reference materials used in each batch
***n/a= no suitable standard material available for analysis of this parameter

Table A2-4 Summary of average recovery of known analyte concentrations.

Parameter (analyte)	Average recovery (%)	N
PN	103-113	13-28
PP	93*	8
POC	100-101	42-44
Chlorophyll *a*	100	12
SS	n/a**	
Salinity	100	5

*PP: data are adjusted using a batch-specific efficiency factor (recovery)
**n/a= no suitable reference material available for analysis of this parameter

Table A2-5 Summary of average Z-scores of replicate measurements (N) of a standard or reference material.

Parameter (analyte)	Z-score for **bottle #5 ***	Z-score for **bottle #7 ***	N
NOx	-0.49 to -0.51	-1.54 to 2.16	3
NH4	-0.42 to 0.42	-0.28 to 0.38	3
TDN	-1.00 to -0.69	-1.92 to -0.85	3
PO4	0.92 to 0.99	1.16 to 1.45	3
TDP	0.13 to 1.84	-0.69 to 2.50	3
Si	-0.01 to 0.39	-2.63 to 0.53	3

* NLLNCT reference samples round 14, bottles #5 and #7 analysed with samples collected in 2009/10.
**Accuracy of analysis of dissolved nutrients is estimated for each individual analytical batch, the range given is the range of average Z-scores from batches analysed with samples collected in 2009/10.

Procedural blanks

Wet filter blanks (filter placed on filtration unit and wetted with filtered seawater, then further handled like samples) were prepared during the on-board sample preparation to measure contamination during the preparation procedure for PN, PP, POC and chlorophyll. The instrument readings (or actual readings, in case of chlorophyll) from these filters were compared to instrument readings from actual water samples. On average, the wet filter blank values were around or below 3% of the measured values for PN and chlorophyll (Chl) (Table A2-6) and we conclude that contamination due to handling was minimal. Wet filter blanks (as well as filter blanks using pre-combusted filters) for PP and POC generally returned measureable readings, which indicates that the filter material contains traces of phosphorus and organic carbon. The blank values are relatively constant and were subtracted from sample results to adjust for the inherent filter component.

Wet filter blanks for SS analysis (filter placed on filtration unit and wetted with filtered seawater, rinsed with distilled water, then further handled like samples) were prepared during the on-board sample preparation. The mean weight difference of these filter blanks (final weight - initial filter weight) was 0.00018g (n=12). This value indicated the average amount of remnant salt in the filters ("salt blank"). The salt blank was about 13% of the average sample filter weight (Table A2-6). 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 A2-6 Comparison of instrument readings of wet filter blanks to actual sample readings

	PP (absorbance readings)	PN (instrument readings)	Chl (µg L^{-1})	SS (mg $filter^{-1}$)	POC (µg $filter^{-1}$)
Average of blank readings	0.007	1318	0.002	0.18	5.95
N of blank readings	24	30	18	12	22
Average of sample readings	0.082	44800	0.498	1.34	28.1
N of sample readings	635	618	771	478	642
Average of blanks as % of average sample readings	9%	3%	0.5%	13%	21%

Validation by alternative methods

Chlorophyll a

To validate the results of the chlorophyll *a* analysis by fluorometry (which is the routinely applied standard method for samples collected under Reef Rescue MMP), a number of samples (collected separately from surface waters after the main Niskin cast) were analysed at AIMS by HPLC (a more elaborate technique yielding high resolution detection of various phytoplankton pigments). The results show a good agreement between these two standard methods, however the fluorometry method showed values on average 10% lower than those obtained by the HPLC technique (Figure A2-1). This small difference is most likely due to differences in extraction methods and hence, extraction efficiency. When the same extract is used for analysis by both instruments the agreement is very good (y=0.99x, R^2=0.995, N=6). The differences in extraction efficiency between these two methods do not affect the reliability and usefulness of the results obtained by fluorometry which applies the internationally accepted US EPA standard method and has been used at AIMS for about 20 years.

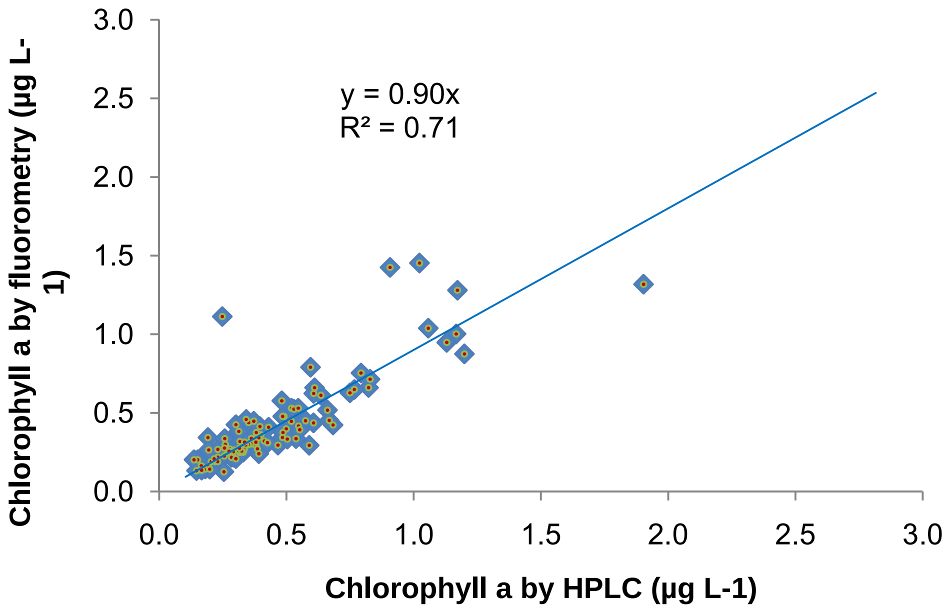

Figure A2-1 Match-up of duplicate samples analysed for chlorophyll a by fluorometry and HPLC.

Validation of ECO FLNTUSB instrument data

Direct water samples were collected and analysed for comparison to instrument data acquired at the time of manual sampling. The match-up of these data (Figure A2-2) showed relatively good correlations for both chlorophyll and turbidity (which was validated using suspended solids concentrations in the water column). The FLNTUSB loggers measured on average about 7% higher chlorophyll values than values obtained from water samples, which is likely to be due to the instrument measuring a wider range of chlorophylls than just chlorophyll *a*. The agreement between instrument-measured chlorophyll and chlorophyll in direct water samples was relatively good in the lower concentration range (~<0.6 µg L^{-1}), the range of the majority of the field samples. However, the values were very variable in the higher range, especially in samples collected during flood events. This could be due to extreme patchiness in the water or to optical interference by fluorescent compounds abundant in dissolved organic matter (Wright and Jeffrey 2006).

The relationship between optically measured turbidity and total suspended solids analysed on filters was good, and the equation [TSS (mgL-1)] = 1.3 x FLNTUSB Turbidity (NTU)] can be used for conversion between these two variables. The equation has been the same in last two year's estimates (Schaffelke *et al.* 2008, 2009).

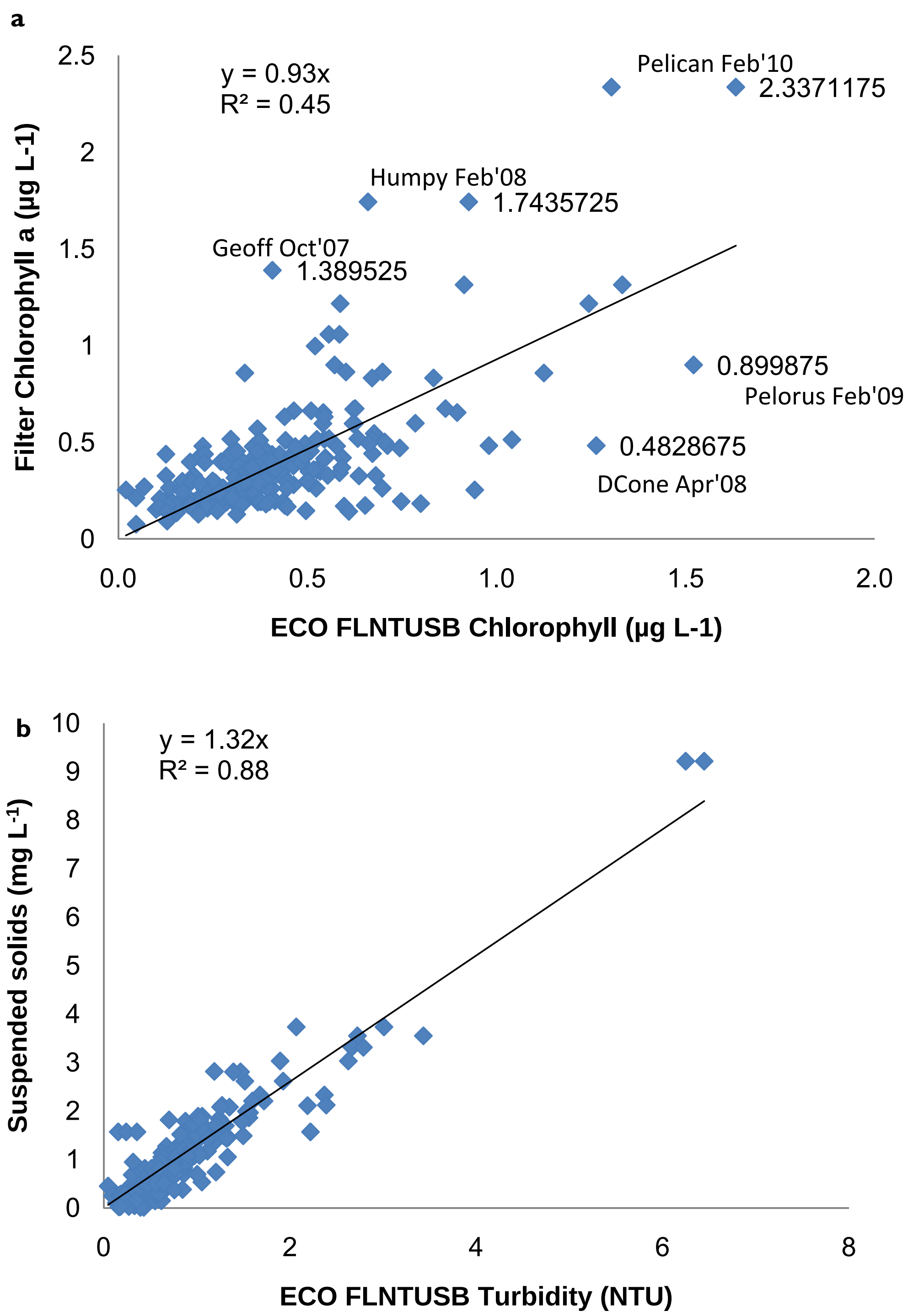

Figure A2-2 Match-up of instrument readings of a) chlorophyll a (µg L-1) and b) turbidity (NTU) from field deployments of WET Labs Eco FLNTUSB Combination Fluorometer and Turbidity Sensors with values from standard laboratory analysis of concurrently collected water samples.