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Reef Rescue Marine Monitoring Program:

2009/2010 Synthesis Report


DEEDI


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GBRMPA


ACTFR

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Reef & Rainforest Research Centre Ltd
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Acronyms and Abbreviations

AIMS	Australian Institute of Marine Science
C	Carbon
CDOM	Coloured Dissolved Organic Matter
Chl *a*	Chlorophyll *a*
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEEDI	Queensland Department of Employment, Economic Development and Innovation
DERM	Queensland Department of Environment and Resource Management
DIN	Dissolved inorganic nitrogen
DIP	Dissolved inorganic phosphorus
EnTox	National Research Centre for Environmental Toxicology, University of Queensland
FQ	Fisheries Queensland
GBR	Great Barrier Reef
GBRMP	Great Barrier Reef Marine Park
GBRMPA	Great Barrier Reef Marine Park Authority
HC	Hard coral
JCU	James Cook University
MA	Macroalgae
ML	Mega-litres
MTSRF	Marine and Tropical Sciences Research Facility
N	Nitrogen
NASA	National Aeronautics and Space Administration
NRM	Natural Resource Management
NTU	Nephelometric Turbidity Units
P	Phosphorus
PCA	Principal Component Analysis
PN	Particulate Nitrogen
PP	Particulate Phosphorous
PSII herbicide	Photosystem II inhibiting herbicide
PSII-HEq	PSII – Herbicide Equivalent
QLD	Queensland
RRMMP	Reef Rescue Marine Monitoring Program
RRRC	Reef and Rainforest Research Centre Ltd
SC	Soft coral
SE	Standard Error
SPM	Suspended particulate matter
TSS	Total suspended solids

About This Report

The Reef Rescue Marine Monitoring Program supports the *Reef Water Quality Protection Plan 2009*[1], a joint commitment of the Queensland and Australian Governments, and the Australian Government Reef Rescue initiative.

This report provides a synthesis of information collected as part of the Marine Monitoring Program during 2009/10. The MMP is a key component of assessing long-term improvements in inshore water quality and marine ecosystem health that are expected to occur with the adoption of improved land management practices in Great Barrier Reef catchments under Reef Water Quality Protection Plan and Reef Rescue.

The Marine Monitoring Program assesses the long-term health of key marine ecosystems – inshore coral reefs and seagrasses – and the condition of water quality in the inshore Great Barrier Reef lagoon. The data and information presented in this synthesis report will provide the foundation for the Great Barrier Reef Water Quality and Ecosystem Health component of the 2011 Reef Water Quality Protection Plan annual water quality reports. The information provided in the following reports provides the basis for this report; the reports are available on the Reef and Rainforest Research Centre (RRRC)[2] and Great Barrier Reef Marine Park Authority websites:

- Schaffelke, B., Carleton, J., Doyle, J., Furnas, M., Gunn, K., Skuza, M., Wright, M. and Zagorskis, I. (2010) *Reef Rescue Marine Monitoring Program. Annual Report of AIMS Activities 2009/10, Project 3.7.8 Inshore Water Quality Monitoring.* Report submitted to the Reef and Rainforest Research Centre. Australian Institute of Marine Science, Townsville.
- Devlin, M., McKinna, L., Lewis, S. and Harkness, P. (2010) *Reef Rescue Marine Monitoring Program: Terrestrial runoff in the Great Barrier Reef (3.7.2b) – Flood Plume Monitoring for 2009/10, Annual Report*. ACTFR Catchment to Reef Group, James Cook University, Townsville.
- McKenzie, L., Unsworth, R. and Waycott, M. (2010) *Reef Rescue Marine Monitoring Program: Intertidal Seagrass, Annual Report for the Sampling Period 1 September 2009 to 31 May 2010*. Fisheries Queensland, Department of Employment, Economic Development and Innovation (DEEDI), Cairns.
- Kennedy, K., Bentley, C., Paxman, C., Dunn, A., Heffernan, A., Kaserzon, S. and Mueller, J. (2010) *Annual Report – Monitoring of organic chemicals in the Great Barrier Reef using time integrated monitoring tools (2009-2010).* Reef Rescue Marine Monitoring Program Project 3.7.8. National Research Centre for Environmental Toxicology (EnTox), The University of Queensland, Brisbane.
- Brando, V.E., Schroeder, T., Dekker, A.G. and Park, Y.J. (2010*) Reef Rescue Marine Monitoring Program: Using Remote Sensing for GBR wide water quality. Annual Report for 2009/10 Activities.* CSIRO Land and Water, Canberra.
- Thompson, A., Davidson, J., Uthicke, S., Schaffelke, B., Patel, F. and Sweatman, H. (2011) *Reef Rescue Marine Monitoring Program. Annual Report of AIMS Activities 2010 Project 3.7.1b Inshore Coral Reef Monitoring*. Report submitted to the Reef and Rainforest Research Centre. Australian Institute of Marine Science, Townsville.

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[1] http://www.reefplan.qld.gov.au/

[2] http://www.rrrc.org.au/mmp/index.html

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Executive Summary

The Reef Rescue Marine Monitoring Program (MMP) undertaken in the Great Barrier Reef (GBR) lagoon assesses the long-term effectiveness of the Australian and Queensland Government's Reef Water Quality Protection Plan (Reef Plan) and Reef Rescue initiative. Established in 2005, the program is a critical component in the assessment of GBR-wide and regional water quality as land management practices are improved across GBR catchments. The program also forms an integral part of the Reef Plan Paddock to Reef Integrated Monitoring, Modelling and Reporting Program[3]. The data and information presented in this synthesis of 2009/10 MMP monitoring activities provides a foundation for the Great Barrier Reef Water Quality and Ecosystem Health component of the 2011 Reef Plan annual water quality report.

This document presents the results of the 2009/10 monitoring period as well as trend analysis, where possible, for the program's five year duration. The results of water quality and ecosystem health monitoring – inshore coral reefs and intertidal seagrass meadows – are presented at GBR-wide and regional scales. Suspended sediments, nutrients and pesticides are the main water quality constituents of concern in the GBR; all of which are monitored along the inshore GBR within twenty kilometres of the coastline during ambient and flood conditions.

During the 2009/10 monitoring period, river flows for the northern section of the Wet Tropics and for the Cape York regions were below the long-term median. However, river flows in the Burdekin, Mackay Whitsunday, Fitzroy and Burnett Mary regions exceeded the long-term median, in some cases up to four times (e.g. Fitzroy River). These flood events did influence regional water quality.

Water quality was monitored using a variety of techniques and, for the first time, *in situ* results were reported on a five-point rating scale (Interim Water Quality Index) from 'very poor' to 'very good'. Four sites were rated as having 'very poor' water quality – Yorkey's Knob and Fairlead Buoy in the Wet Tropics region, Magnetic Island in the Burdekin region and Pelican Island in the Fitzroy region, and one site – Pine Island in the Fitzroy region – was rated as having 'poor' water quality. Six sites were rated as having 'very good' water quality – Double, Green, Fitzroy and Russell Islands in the Wet Tropics region, and Barren and Humpy Islands in the Fitzroy region. These results are based on *in situ* instrumental data which provides a direct and accurate measure of water quality at the sites monitored. Remote sensing techniques have been developed to give a GBR-wide perspective of water quality. While positive advances have been made, further work is required to improve confidence in the results through validation and better integration with *in situ* monitoring data.

Water quality sampling of GBR flood plumes showed high concentrations of all water quality parameters moving offshore with plume waters. Concentrations of water quality parameters remained high (relative to ambient values) for days to weeks after peak flow in the Mackay Whitsunday and Fitzroy regions, and are indicative of the long-term influence of flood plume conditions on inshore marine environments.

Pesticides were monitored in both ambient and flood conditions. Data was reported as the maximum photosystem II Herbicide Equivalent (PSII-HEq) concentration in the GBR and assessed in the context of a Pesticide Index rating scale of 1 to 5. The pesticides contributing the most to the PSII-HEq (diuron, atrazine and hexazinone) are associated with herbicides used in sugarcane production and other cropping such as horticulture and grains (Lewis *et al*. 2009, Brodie *et al*. 2009). The dominant contributor at all monitoring sites during both wet

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[3] http://www.reefplan.qld.gov.au/publications/paddock-to-reef.shtm

and dry seasons was diuron. Hexazinone and atrazine also contributed a significant proportion and these vary between regions, with atrazine typically contributing a higher relative proportion at sites in the Burdekin and Fitzroy regions, and hexazinone contributing a higher proportion at sites in the Wet Tropics and Mackay Whitsunday regions. The Pesticide Index profiles indicated that the Mackay Whitsunday region, which has 56% of the catchment area associated with agricultural activities (predominantly sugarcane and beef cattle grazing), should be a priority catchment in terms of management of pesticide loads to the GBR. In particular, the highest PSII-HEq maximum concentration (500 ng/L) was detected in 2009/10 at Sarina Inlet, south of Mackay, which has significant areas of seagrass and inshore coral reefs. Pesticide sampling in flood plume waters detected diuron as the dominant pesticide, while tebuthiuron, atrazine and hexazinone were also detected. Concentrations of all pesticides were highly dependent on sample timing relative to event flows.

Examination of the ecosystem health monitoring results for the five years of MMP data indicates that some coral reefs in the Tully-Herbert sub-region of the Wet Tropics, as well as the Burdekin and Fitzroy regions, are showing signs of impacts from a combination of turbidity, sedimentation and recent disturbances. A decline in coral cover in the Mackay Whitsunday region occurred in concert with low rates of coral cover increase and poor settlement of coral larvae, with these indicators of ecosystem recovery not progressing as well as models would predict (Thompson and Dolman 2010). Seagrass meadows in all regions were at best in a ‘moderate’ state and had declined between 2008/09 and 2009/10, with particularly poor results for seagrass abundance in coastal habitats in the Burdekin, Mackay Whitsunday and Burnett Mary regions. Seagrass reproductive effort was poor in all regions except Cape York.

While this report does not directly correlate the 2009/10 water quality results to the condition of coral and seagrass communities in each region, there are a number of observations that should be highlighted. In the Burdekin (Magnetic Island) and Fitzroy (Pelican Island) regions, coral health indicators were ‘very poor’, and water quality status was also ‘poor’. In areas where water quality was considered ‘very poor’, coral health indicators were also ‘poor’ or neutral, although the relationship between coral reef health and water quality is not necessarily linear (Thompson *et al.* 2010b, Uthicke *et al.* 2010). Seagrass health in proximity to these locations also showed negative results for most indicators. Comparison of pesticide results across monitoring years showed some indication of increasing PSII-HEq concentrations at Fitzroy Island (Wet Tropics region), Magnetic Island (Burdekin region) and North Keppel Island (Fitzroy region). There are some links between these pesticide results and ecosystem status, with the Fitzroy Island and Magnetic Island sites in close proximity to coral and seagrass communities showing negative results for most biological health indicators.

The results of the other components of the Reef Plan Paddock to Reef Integrated Monitoring, Modelling and Reporting Program for 2009/10, including management practice adoption and effectiveness, catchment condition and catchment loads, will be made available through the annual Report Card and supporting Technical Report (to be released in 2011; see www.reefplan.gov.au).

1. Introduction

Water quality is a key factor influencing the health of the Great Barrier Reef (GBR) and its catchments, with flow-on effects for the communities, industries and ecosystems that rely on good water quality. Substantial investment is being made by both the Australian and Queensland Governments to halt and reverse the decline of water quality entering the GBR lagoon. The Reef Rescue Marine Monitoring Program (MMP) was established in 2005 to assess the long-term status and health of GBR ecosystems. It is a critical component in the assessment of long-term improvement in regional marine water quality that will occur as best land management practices are adopted across GBR catchments under the Reef Rescue initiative. The program forms an integral part of the Paddock to Reef Program supported through the Reef Plan and Reef Rescue initiatives.

The Reef Plan aims to minimise the risk of non-point source pollution from broad-scale land use in adjacent catchments to the GBR ecosystem. The two primary goals of the Reef Plan are to, (i) halt and reverse the decline in water quality entering the GBR by 2013, and (ii) ensure that by the year 2020 the quality of water entering the GBR from adjacent catchments has no detrimental impact on the health and resilience of the GBR. The Reef Plan is underpinned by a suite of targets linking land management, water quality and ecosystem health from the paddock to the reef to achieve the 2020 goal. The Reef Plan and Reef Rescue initiatives work together to improve the water quality of the GBR lagoon by increasing the adoption of land management practices that reduce the run-off of nutrients, pesticides and sediments from agricultural land.

A key action of the Reef Plan is the development and implementation of the Paddock to Reef Integrated Monitoring, Modelling and Reporting Program (herein referred to as the Paddock to Reef Program). The reporting framework for the Paddock to Reef Program is driven by the Reef Plan goals and targets, and the principles outlined in the Reef Plan monitoring and evaluation strategy. A Baseline Report of management practice adoption, water quality and ecosystem health (in 2009) was prepared in 2010, and subsequent annual reports that detail improvements in land management practices and catchment, end of catchment and inshore marine water quality will be produced each year. For the marine component of the reporting, progress towards Reef Plan goals will be measured using the results of the MMP, assessed against the Water Quality Guidelines for the Great Barrier Reef Marine Park (GBRMPA 2009) and the condition of seagrass and corals (as indicators of ecosystem health and resilience).

The MMP consists of four monitoring components and is a collaborative effort between a consortium of monitoring providers, in partnership with the North Queensland based Reef and Rainforest Research Centre (RRRC) and Great Barrier Reef Marine Park Authority (GBRMPA), and funded by the Australian Government Caring for our Country Program.

This synthesis report presents the results of the 2009/10 monitoring period as well as trend analysis for the five years of the program, where possible. The results of the MMP are presented at GBR-wide and regional scales. Additional water quality trend information has been derived from long-term monitoring data from the Wet Tropics region, with the Cairns Transect monitored since 1989.

The design of the MMP in 2004, including the selection of indicators, sites and sampling frequency, was underpinned by an understanding of the relationships between water quality and ecosystem health in the GBR and other tropical marine systems (see Haynes *et al.* 2006). Since the commencement of the MMP, new knowledge generated through research programs including the Marine and Tropical Science Research Facility (MTSRF) has provided critical information for the continued improvement of the application of water quality and ecosystem health indicators and a better understanding of ecosystem processes and relationships to aid in data interpretation. Comprehensive summaries of these relationships are provided in several recent publications including the 2008 *Synthesis of evidence to support the Scientific Consensus Statement on Water Quality in the Great Barrier Reef* (Brodie *et al.* 2008) and a series of synthesis reports prepared for the water quality components of the MTSRF[4]. Based on this understanding, the MMP is designed with a selection of indicators that measure the drivers and response relationships between water quality and coral reef and seagrass ecosystem health.

A brief overview of the design and methods of the MMP is provided in Section 2. For comprehensive information on each of the monitoring sub-programs, including objectives and detailed methods, refer to the individual sub-program reports (see About This Report, page vii), and the *Reef Rescue Marine Monitoring Program Quality Assurance/ Quality Control Methods and Procedures Manual* (RRRC 2010)[5].

The data and information presented in this synthesis report will provide the foundation for the Great Barrier Reef Water Quality and Ecosystem Health component of the reporting products for the Reef Plan Paddock to Reef Integrated Monitoring, Modelling and Reporting Program. Further information on this program is available at www.reefplan.qld.gov.au.

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[4] http://www.rrrc.org.au/publications/synthesis_products.html

[5] http://www.rrrc.org.au/mmp/mmp_pubs.html

2. Methods

In 2009/10, the MMP continued to assess the condition of water quality in the inshore GBR lagoon and the condition of key GBR marine ecosystems for the period July 2009 to June 2010. The MMP has two core sub-programs:

- Inshore GBR water quality monitoring; and
- Inshore GBR biological monitoring of seagrass meadows and coral reefs, including biological indicators.

A number of different pollutants such as suspended sediments, nutrients and pesticides are discharged from the GBR catchments to the GBR. A pollutant is defined here as a concentration or load of material that is elevated above natural levels that are known to cause environmental harm. Each of the pollutants has different sources, pathways and impacts on GBR ecosystems. The three main pollutant categories of concern include:

- Sediments, especially the fine, mud-sized fraction (<63 µm) which may potentially be influencing the long-term turbidity of coastal and inshore areas;
- Nutrients, particularly dissolved inorganic nitrogen and phosphorus and particulate nitrogen and phosphorus; and
- Pesticides, particularly the photosystem II inhibiting herbicides (PSII herbicides) diuron, hexazinone, atrazine, ametryn, tebuthiuron and simazine.

These were monitored along the inshore GBR within twenty kilometres of the coastline (Figure 2.1) during ambient and flood conditions (Schaffelke *et al.* 2010, Devlin *et al.* 2010a, Kennedy *et al.* 2010). Measures of turbidity, chlorophyll *a* (chl *a*) and coloured dissolved organic matter (CDOM) were also monitored for all GBR waters using remote sensing (Brando *et al*. 2010a). The MMP has been designed to utilise traditional monitoring techniques such as grab sampling, automated water quality loggers, passive sampling of pesticides and remote sensing technologies, in combination with marine biological monitoring of seagrass and coral reefs. The biological indicators include seagrass abundance, reproductive effort (seed banks and flowering), nutrient status (leaf tissue nutrients and epiphyte abundance), environmental light availability (McKenzie *et al*. 2010), reef benthic cover, and coral demographics, diversity and recruitment (Thompson *et al*. 2011). Information on the sampling location, frequency and approaches to data interpretation for each of these components is provided below.

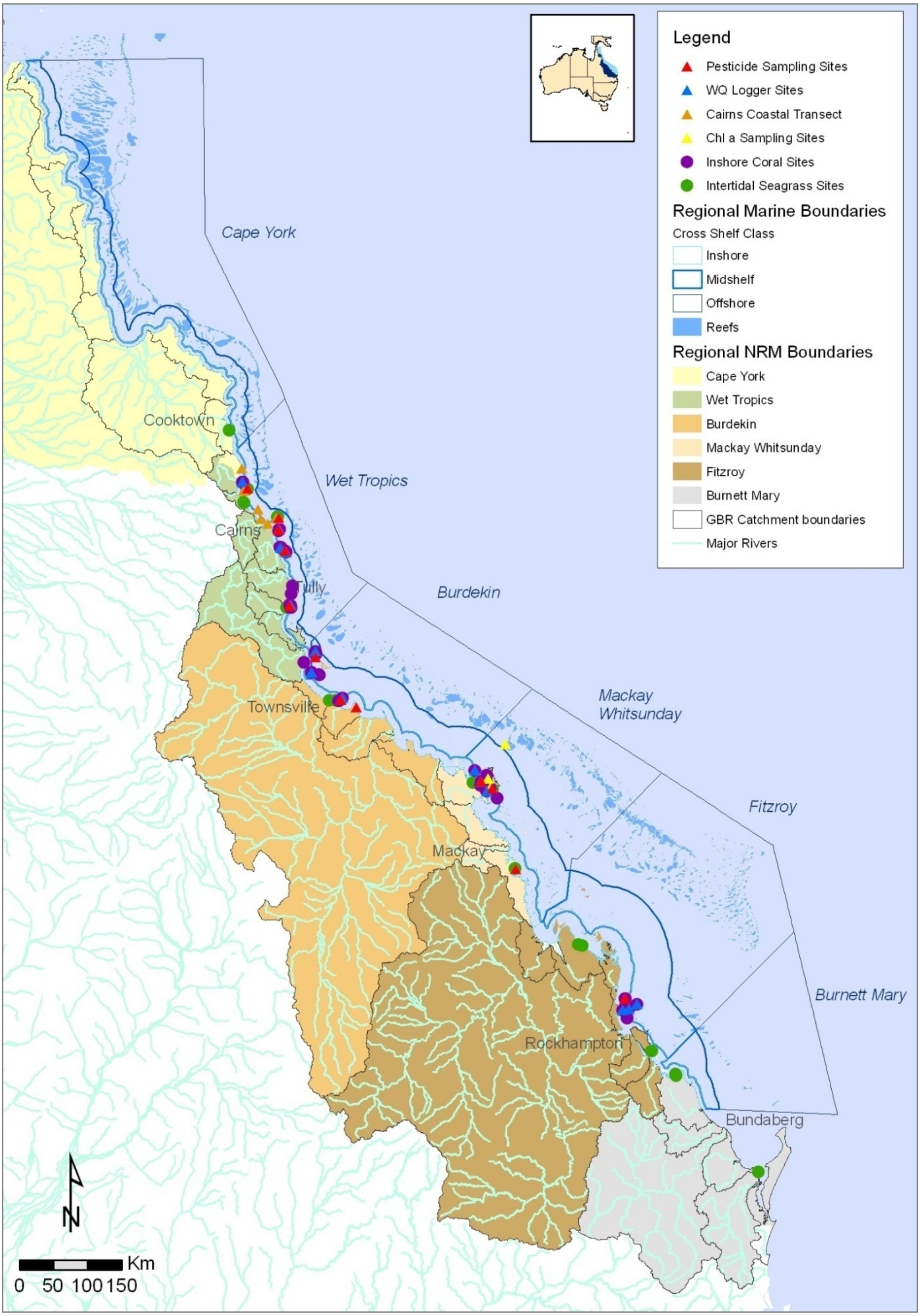

Figure 2.1: Reef Rescue Marine Monitoring Program sampling sites for 2009/10.

2.1 Water quality monitoring

In situ water quality monitoring in the inshore lagoon was carried out at fourteen fixed coral reef locations in four 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, chl *a*[6] 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 continued at the six fixed open water sites in the Cairns Transect; the longest available time-series of water quality data for the GBR in coastal waters between Cape Tribulation and Cairns from 1989 to 2010.

Remote sensing of three water quality parameters (chl *a*, CDOM and TSS) for all GBR waters used MODIS Aqua images representing a time series from November 2002 with spatial coverage at 1 km resolution, nominally on a daily basis (except overcast days). Estimates of water quality parameters were retrieved using two algorithms developed specifically for the optically complex waters of the GBR lagoon (Brando *et al.* 2008; Brando *et al.* 2010a; Brando *et al.* 2010b; Schroeder *et al.* 2008). These regionally parameterised algorithms account for the significant variation in concentrations of CDOM and TSS in GBR waters and achieve more accurate retrievals than other available algorithms (Brando *et al.* 2010a, Brando *et al.* 2010b). In 2009/10, remote sensing applications continued to be applied in all regions including Cape York and Burnett Mary however, there has been limited assessment of this high frequency/high spatial coverage data across the years to report trends at this stage. This could be done retrospectively using archived remote sensing data. Further discussion on the methods of retrieving data using remote sensing techniques are included in Appendix 1 and Brando *et al*. (2010a).

Ambient water quality and pesticide data were assessed against the Water Quality Guidelines for the Great Barrier Reef Marine Park (the Guidelines, GBRMPA 2009; Table 2.1). The Guidelines are defined for annual mean values and estimates are made for seasonal variation of chl *a*, suspended solids and particulate nutrient values for the wet and dry seasons. Assessment of the water quality data against the Guidelines highlighted areas that require further consideration with regard to regional and seasonal variations. In an effort to combine water quality parameters to provide an indicator of general water quality conditions and exceedance of the Guidelines, an interim Water Quality Index was developed for reporting *in situ* water quality monitoring results. The Index aggregates the Guidelines exceedance scores for five indicators to give an overall rating for the water quality at each of the twenty fixed sampling sites (six Cairns Transect and fourteen core reefs). The five indicators are: turbidity (or suspended solids [SS] concentration for Cairns Transect sites), chl *a*, particulate nitrogen (PN), particulate phosphorus (PP), and secchi depth. Decision rules for the Index are outlined in Appendix 2 (from Schaffelke *et al.* 2010). The proportional scores were expressed on a five point scale and converted to a colour scheme for reporting. The Water Quality Index is considered 'interim' as further research and data analyses are needed to refine the quantification of Guideline exceedances and the weighting of the water quality parameters.

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[6] Three different methods are used to measure chlorophyll in the MMP: the direct sampling (ambient and flood) and remote sensing measure chlorophyll *a* specifically, and the *in situ* water quality loggers measure a range of chlorophyll pigments, not just chlorophyll *a*, and is referred to as 'chlorophyll'.

Table 2.1: Trigger values from the *Water Quality Guidelines for the Great Barrier Reef Marine Park* (GBRMPA 2009). Seasonal adjustments were calculated according to the information provided in the Guidelines (to two significant figures).

	Water body			
Parameter	Enclosed coastal	Inshore	Midshelf	Offshore
Chl *a* (µg/L)	2.0	0.45 *0.3^1/0.6^2	0.45 *0.3^1/0.6^2	0.4 *0.3^1/0.6^2
Secchi depth (m)	1.0/1.5**	10	10	17
Suspended solids (mg/L)	5.0/15**	2.0 *1.6^1/2.4^2	2.0 *1.6^1/2.4^2	0.7 *0.6^1/0.8^2
Particulate nitrogen (µg/L)	Not available	20 *16^1/24^2	20 *16^1/24^2	17 *14^1/20^2
Particulate phosphorus (µg/L)	Not available	2.8 *2.2^1/3.4^2	2.8 *2.2^1./3.4^2	1.9 *1.5^1/2.3^2
Pesticide	Reliability		99% species protection (ng/L)***	
Diuron	Moderate		900	
Atrazine	Moderate		600	
Ametryn	Moderate		500	
2,4-D	Moderate		800	
Endosulfan	Moderate		5	
Chorpyrifos	High		0.5	
Simazine	Low		200	
Hexazinone	Low		1200	
Tebuthiuron	Low		20	
Methoxymethlymercury chloride (MEMC)	Low		0.2	
Diazinon	Low		0.03	

Notes:

* Seasonal adjustment: Winter^1 / Summer^2. Note: Chl *a* values are ~40% higher in summer and ~30% lower in winter than mean annual values. Seasonal adjustments for SS, PN and PP are approximately ±20%of mean annual values.

** Geographical adjustment: Wet Tropics/Central Coast.

*** Guideline values have been converted from µg/L to ng/L to be comparable to the pesticide sampling results.

Water quality monitoring for ambient concentrations of pesticides was conducted on a bi-monthly basis during the dry season. The concentration of organic pollutants (pesticides and herbicides) at fourteen inshore reef sites were estimated using time integrated passive sampling techniques and compared to the Guidelines. These techniques are particularly suitable for monitoring long-term trends in exposure across different seasons and providing a more complete assessment of exposure in these ecosystems.

The passive sampling techniques utilised are:

- SDB-RPS EmporeTM Disk (ED) based passive samplers for relatively hydrophilic organic chemicals with relatively low octanol-water partition coefficients such as the PSII herbicides (e.g. diuron); and
- Polydimethylsiloxane (PDMS) and Semipermeable Membrane Devices (SPMDs) passive samplers for organic chemicals which are relatively more hydrophobic such as chlorpyrifos (an organophosphate insecticide).

Pesticide monitoring was discontinued at four sites in 2009/10: Pixies Garden (Cape York region), Tully River (Wet Tropics region), Daydream Island and Pioneer River (Mackay Whitsunday region). New sites were added to complement existing biological monitoring at Green Island (Wet Tropics region), Pioneer Bay and Sarina Inlet (both Mackay Whitsunday region). A total of twelve sites are now monitored.

Over the five years of the MMP, the most frequently detected and abundant pesticides at inshore reef sites are those that act on photosystem II, the PSII herbicides: diuron, atrazine, hexazinone and tebuthiuron. The presence of these herbicides (that inhibit photosynthesis through the PSII pathway) in the GBR is particularly concerning due to the potential for impacts on a range of species including corals, seagrass and macroalgae. In 2008/09, a Pesticide (PSII herbicide equivalent) Index was developed which provides a mode of action based integrative assessment of PSII herbicide equivalent (PSII-HEq) concentration. The Pesticide Index is based in part on the Guideline trigger value for diuron (Table 2.2) and has five categories ranging from ≤10 ng/L (category 5) to >900 ng/L (category 1) to report against using the maximum PSII-HEq concentration detected in each monitoring year (Table 2.2).

Table 2.2: Pesticide Index reporting categories using combined PSII herbicide equivalent (PSII-HEq) concentrations.

Category	Concentration (ng.L^{-1})	Description
5	PSII-HEq ≤ 10	No published scientific papers that demonstrate any effects on plants or animals based on toxicity or a reduction in photosynthesis. The upper limit of this category is also the detection limit for pesticide concentrations determined in field collected water samples
4	10 < PSII-HEq ≤ 50	Published scientific observations of reduced photosynthesis for two diatoms.
3	50 < PSII-HEq < 250	Published scientific observations of reduced photosynthesis for two seagrass species and three diatoms.
2	250 ≤ PSII-HEq ≤ 900	Published scientific observations of reduced photosynthesis for three coral species.
1	PSII-HEq > 900	Published scientific papers that demonstrate effects on the growth and death of aquatic plants and animals exposed to the pesticide. This concentration represents a level at which 99% of tropical marine plants and animals are protected, using diuron as the reference chemical.

2.2 Flood water quality monitoring

Sampling of flood plumes in 2009/10 was carried out in the marine areas adjacent to the Tully, Burdekin, Pioneer, Proserpine, O'Connell and Fitzroy Rivers (in the Wet Tropics, Burdekin, Mackay Whitsunday and Fitzroy regions respectively) and for a range of periods following peak flow. The aim was to measure flood plumes at the height of the peak flow and to characterise primary, secondary and tertiary water types however, this was not always possible due to weather constraints and increasing latitudinal sampling effort. Sampling the peak flow allows better characterisation of the plume water types. Monitoring was carried out over peak flow and throughout wet season conditions to try to account for the longer term changes associated with flood events. This report presents the water quality results and mapping of the riverine plumes monitored in 2009/10, as well as the exposure of inshore ecosystems to plume water types.

The development of techniques for plume classification is ongoing and in 2009/10 used the analysis of both field data and remote sensing imagery. Flood plume categories were defined based upon the concentration of water quality parameters which can be readily derived from ocean colour remote sensing. Plume types were classified using qualitative criteria:

i. *Primary* water types were defined as having a high total suspended sediments (TSS) load, minimal chl *a* and high CDOM.

ii. *Secondary* water types were defined as a region where CDOM is still high however, the TSS has reduced. In this region, it was deemed that increased light and nutrient availability prompted phytoplankton growth, thus secondary plumes exhibit high chl *a*, high CDOM and low TSS.

iii. *Tertiary* water types are the region of the plume that exhibit no elevated TSS and reduced amounts of chl *a* and CDOM when compared with that of the secondary plume. This region can be described as being the transition between a secondary plume and ambient conditions.

Pesticide monitoring in flood conditions was undertaken using time-integrated passive sampling on a monthly basis, and direct water sampling (grabs) techniques during peak flow periods. Time-integrated assessments of pesticide concentration in water may differ markedly from concentrations measured during flood events. Direct water sampling provides an indication of the peak concentrations that may be present in flood plume waters but is highly dependent on sampling location and timing in relation to peak discharge and pesticide application.

2.3 GBR inshore biological monitoring

The biological monitoring component focused on inshore coral reefs and intertidal and inshore fringing reef seagrass meadows.

The 2010 coral reef monitoring continued to survey benthic organism cover, coral genera numbers, juvenile-sized coral colonies numbers and sediment quality at 24 inshore reef locations in four regions: the Wet Tropics, Burdekin, Mackay Whitsunday and Fitzroy regions. Coral recruitment monitoring also continued at three core sites in each of the four regions (Table 2.3).

For the first time in the MMP, the density and composition of foraminiferal (foram) assemblages were analysed in 2009/10 as part of the sediment sampling, and reported as a FORAM index (Hallock *et al.* 2003). The index summarises foram assemblages based on the relative proportions of species classified as either symbiont bearing, opportunistic or heterotrophic and is used as an indicator of coral reef water quality in Florida and the Caribbean Sea (Hallock *et al.* 2003). Symbiotic relationships with algae are advantageous to forams in clean coral reef waters low in dissolved inorganic nutrients and particulate food sources, whereas heterotrophy becomes advantageous in areas of higher turbidity and availability of inorganic and particulate nutrients (Hallock 1981). The FORAM index shows a faster response to environmental change than the other coral reef indicators and has been successfully tested on GBR reefs showing consistency with water quality variables (Uthicke and Nobes 2008, Uthicke *et al.* 2010).

Table 2.3: Summary of sampling methods applied for the inshore coral reef monitoring in 2010.

Survey Method	Information provided	Transect coverage	Spatial coverage
Photo Point Intercept	Percentage cover of the substratum of major benthic habitat components	Approximately 25 cm belt along upslope side of transect form which 160 points were sampled	Full sampling design
Demography	Size structure and density of juvenile (<10 cm) coral communities	Belt transect 34 cm wide along the upslope side	Full sampling design
Scuba Search	Incidence of factors causing coral mortality	Belt transect of 2 m width centred on transect	Full sampling design
Settlement Tiles	Larval supply	Clusters of six tiles in the vicinity of the start of the 1st, 3rd and 5th transects at the 5m sites	12 core reefs and 5 m depth only
Sediment sampling	Grain size distribution and the chemical content of nitrogen, organic carbon and inorganic carbon. Community composition of foraminifera	Sampled from available sediment deposits within the general area of transects	5 m depth only Forams on 14 core reefs

Regional estimates of coral reef community status, based on performance (level, rate and direction of change) were developed from four indicators from 2005 to 2010: coral cover, macroalgae cover, juvenile hard coral density and settlement of coral spat. The rules applied to determine whether a region or sub-region received a positive, neutral, or negative score for any of the indicators are described in Appendix 3.

Seagrass monitoring was conducted at thirty sites during the 2009/10 monitoring period (see Figure 2.1) to assess trends in seagrass status, and as bioindicators of ecosystem health associated with changing water quality. Sites were monitored bi-annually (pre- and post-wet season) at locations between Cooktown in the north and Hervey Bay in the south. Sites included nine inshore (intertidal coastal and estuarine habitats) and six offshore (reef intertidal habitats). Each site was monitored for seagrass habitat community status (percent cover, species composition and edge mapping) and seagrass environmental status (light availability and nutrient status). Metrics of nutrient status and light availability to the plant (leaf tissue nutrient ratios) were determined following laboratory analysis of annually collected seagrass samples. The ability for seagrass habitats to recover following disturbance is linked to their reproductive ability, so two measures of seagrass reproductive effort (presence of seeds and the number of reproductive structures on the plant) were also assessed bi-annually as a measure of meadow resilience to changing environmental conditions.

Additional information was collected on canopy height, macro-algae cover, epiphyte cover and macro-faunal abundance, and monitoring of within canopy temperatures was recorded at all established sites. Mapping the edge of the seagrass meadow within one hundred metres of each monitoring site was conducted at all sites in the late dry and late monsoon monitoring periods. Edge mapping was used to determine if changes in seagrass abundance were the result of the meadow shrinking/increasing in distribution or the plant increasing/decreasing in density, or both. Extent of seagrass within the mapping area was compared against each sites baseline (year when first monitored).

Four indicators have been chosen for reporting seagrass status for the MMP, and these were divided into community and environmental status recognising the role of seagrass as a bioindicator:

- *Seagrass community status*: seagrass abundance, reproductive effort; and
- *Seagrass environment status*: light availability (seagrass tissue C:N ratio), nutrient status (seagrass tissue N:P and C:P ratios, and epiphyte abundance).

The approach developed for reporting each of these indicators is included in detail in Appendix 4 as it is reported for the MMP for the first time for application in the Paddock to Reef Report Card. The final result is a seagrass index, defined as the average score (0-100) of the four seagrass status indicators chosen for the MMP. Each indicator is equally weighted as there is currently no preconception that it should be otherwise. The overall index is rated and coloured according to the standard scheme adopted by the Paddock to Reef reporting.

2.4 Reporting boundaries

Reporting boundaries have been defined for the MMP as follows (Figure 2.2):

- *Regional boundaries*: defined in accordance with the NRM catchment boundaries with marine extensions agreed to by the GBRMPA; and
- *Cross-shelf boundaries:* defined in accordance with the Water Quality Guidelines for the Great Barrier Reef Marine Park 2009 (GBRMPA 2009). The Guidelines define five distinct water bodies:
  - enclosed coastal;
  - open coastal;
  - midshelf;
  - offshore; and
  - the Coral Sea.

The MMP monitors in open coastal (herein referred to as inshore), midshelf and offshore waters and therefore enclosed coastal waters and the Coral Sea are not defined or mapped in Figure 2.2. However, the aggregation of the enclosed coastal and open coastal water bodies has implications for assessment of the remote sensing data. The Guideline values for chl *a* and TSS for the enclosed coastal waters are higher than those for the open coastal water body and therefore, the relative area of exceedance of the Guidelines for the open coastal is likely to be overestimated. It is recommended that the GBR enclosed coastal water body boundary be defined to assist in overcoming these issues for future reporting.

The approximate distances of the water body delineations for each of the regions is discussed in the Guidelines (GBRMPA 2009, pg. 11-13).

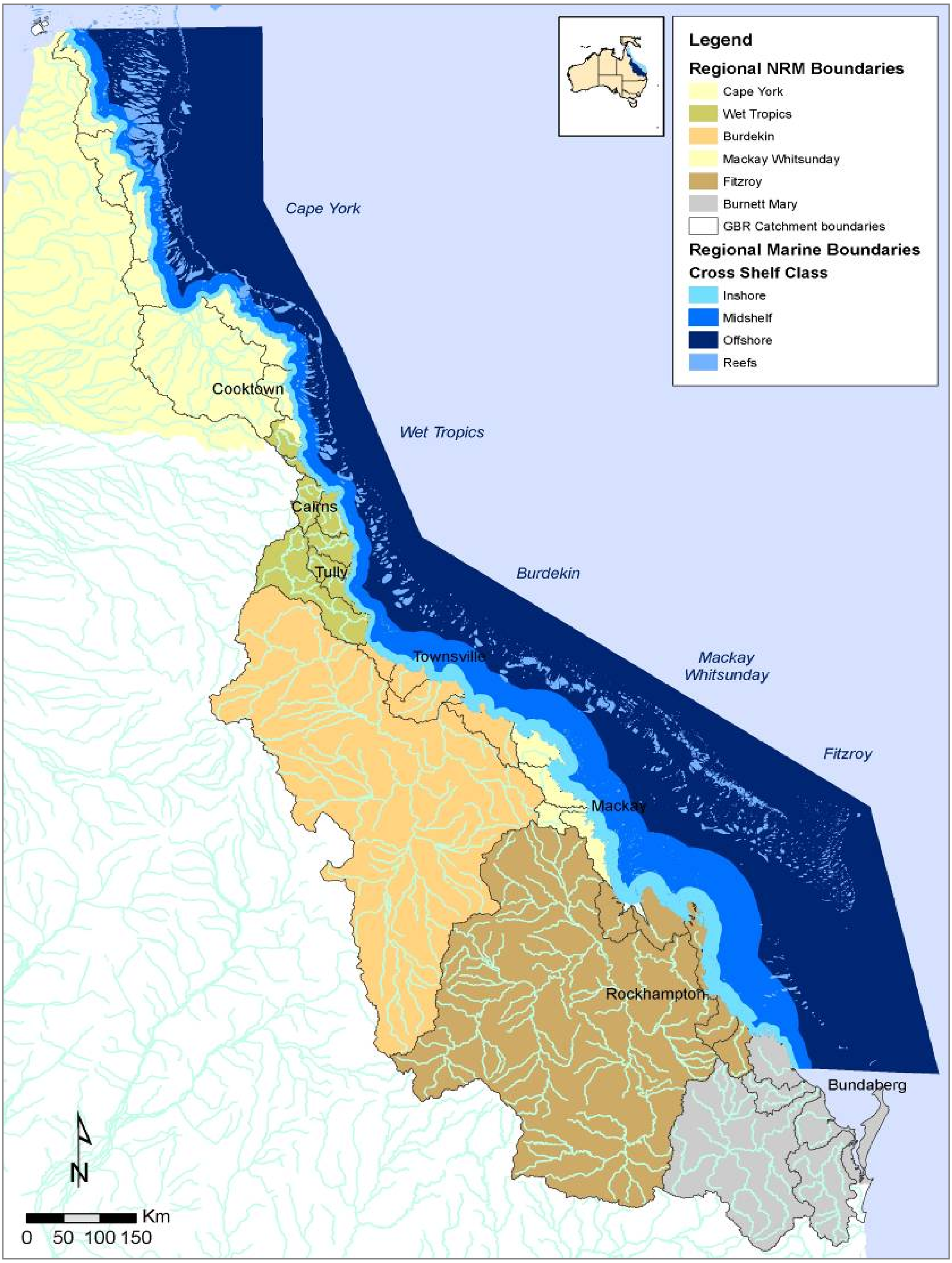


Figure 2.2: Regional and cross-shelf boundaries defined for the Reef Rescue Marine Monitoring Program 2009/10 reporting.

3. GBR-wide Results

3.1 Drivers of inshore GBR water quality

Water quality in the GBR is influenced by a large array of factors including land-based runoff and river flow, point source pollution, current and tides, and extreme weather conditions, as well as natural nutrient pools and nitrogen fixation by organisms. The primary factors assessed in the MMP are river discharge, temperature and extreme weather events. The roles these factors play in influencing the quality of inshore waters was considered in 2008/09 using a comparative analysis of the last five years of MMP water quality data (see Schaffelke *et al.* 2009). The data showed that there were significant high-level interactions between sampling years, the seasons and geographic regions – meaning that none of these individual factors can be considered in isolation as an overarching driving factor influencing water quality in the GBR. The data also showed that there was a clear water quality gradient away from the river mouths and that flood events and resuspension in the GBR lagoon are significant driving factors in influencing water quality. It is therefore important to consider GBR water quality as a product of a range of interacting factors.

Figure 3.1 shows a comparison of fresh water discharge for the 2009/10 wet season compared to the long-term median for each region of the GBR (note that the median calculated for the Cape York and Burnett Mary Regions are calculated using less than ten years' data). Notably, river flows in the Wet Tropics and Cape York regions were below the long-term median, while river flows in the Burdekin, Mackay Whitsunday, Fitzroy and Burnett Mary regions exceeded the long-term median.

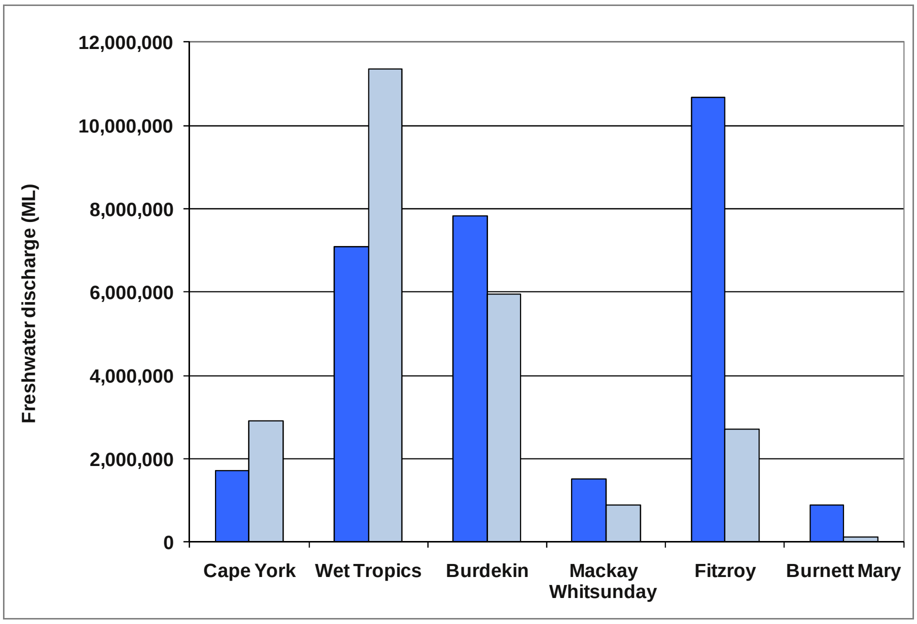


Figure 3.1: Comparison of freshwater discharge for the 2009/10 wet season (October 2009 to September 2010) against the long-term median for each region of the GBR. Data are aggregated from data supplied by the Queensland Department of Environment and Resource Management for each river. Long-term medians were estimated from annual total flows (October to September each year).

Collectively, freshwater discharge from all of the GBR rivers in 2009/10 was ~1.5 times the annual long-term median flow (Table 3.1; showing the annual freshwater discharge for each of the GBR rivers from 2001-2010). Heavy and persistent flooding occurred in many rivers draining into the GBR from January to April 2010. The largest flows were generally seen in the southern catchments, particularly the Mackay Whitsunday rivers and the Fitzroy River (Table 3.1). The Fitzroy River flow was four times above the long-term median flow which is comparable with the flows of the 2007/08 wet season when the largest flood since 1991 occurred (Table 3.1). While a long-term median flow is not available for the Burnett River, discharge in 2009/10 (869,681 ML) was eight times greater than the median flow recorded over the previous nine years (106,888 ML). Notably, river flow in the Wet Tropics rivers was below the long-term median for all rivers (0.6-0.8 times median levels) except for the Daintree River which was 1.5 times the long-term median flow. The flow in the Burdekin River was slightly above the median value. In 2007/08, both the Burdekin and Fitzroy Rivers experienced extensive flooding, and the Burdekin River flooded again in the 2008/09 wet season. River flow peaked in all GBR rivers between mid-February and mid-March 2010.

Table 3.1: Annual freshwater discharge (ML) for the major GBR rivers (based on Water Year of October to September).

Region	River	Long-term median discharge (ML)	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Cape York	Normanby	N/A **2,345,831 (3 yrs)										1.2
Wet Tropics	Daintree	727,872	1.4*		0.2	2.0	0.7	1.7	1.0	1.2		1.5
	Barron	689,957	1.2	0.2	0.2	1.4	0.6	1.1	0.6	2.3	1.1	0.7
	Mulgrave	751,149		0.2	0.4	1.5		1.2	1.0	1.2	0.9	0.7
	Russell	1,193,577	1.0	0.4	0.5	1.1	0.8	1.1	1.1	0.9	0.9	0.8
	North Johnstone	1,746,102	1.2	0.4	0.5	1.3	0.8	1.2	1.2	1.1	1.1	0.8
	South Johnstone	820,304	1.0*	0.4	0.4		0.7	1.2	1.1	1.0	1.2	0.7
	Tully	3,074,666	1.2	0.4	0.5	1.1	0.7	1.2	1.3	1.0	1.2	0.7
	Herbert	3,067,947	1.5	0.3	0.2	1.1	0.4	1.3	1.3	1.1	3.1	0.9
Burdekin	Burdekin	5,982,681	1.5	0.7	0.3	0.3	0.7	0.4	1.6	4.6	5.0	1.3
Mackay Whitsunday	Proserpine	17,140	0.8	1.2	1.1	0.6	1.4	1.2	2.6	4.5	3.8	2.7
	O'Connell	145,351	1.0	0.6	0.2*		0.5	0.6	1.2	1.6	1.1	1.4
	Pioneer	671,839							1.3	2.0	1.4	1.9
Fitzroy	Fitzroy	2,827,222	1.1	0.2			0.3*	0.2	0.4	4.3	0.7	3.8
Burnett Mary	Burnett	N/A **106,888 (9 yrs)										8.1
Total		21,715,807										

Note: Long-term (LT) median discharges were estimated from available long-term time series and included data up until 2000. n/a indicates that suitable long-term time-series were not available. ** For the Normanby and Burnett rivers no suitable long-term time-series data were available and the median of the available data has been used To allow for comparison of the river flow in 2010 relative to previous years. The total long-term median discharge for the GBR excludes these figures. Missing values represent years where >15% of daily flow estimates were not available, where as an * indicates that between 5% and 15% of daily observations were missing. Discharge estimates for 2010 only include data up to 10 June 2010. Colours highlight years where flow exceeded the median by 50-100% (yellow), 100-200% (orange), and more than 200% (red). All data supplied by the Queensland Department of Environment and Resource Management.

Flood plumes extended across inshore waters of the southern and northern GBR but had a more limited influence on far northern GBR waters (Figure 3.2). The freshwater extents are compiled by defining a CDOM threshold of 0.2 m^{-1} that represents the maximum influence of freshwater due to the strong relationship between CDOM and the adsorption curve, with a distinct marine signal (see Brando *et al.* 2010a). The CDOM maximum provides a conservative estimate of freshwater extent as the river plumes could have extended further in cloudy or overcast days and may not have been captured with the satellite imagery. The extent and inter-annual variability of freshwater plumes in the GBR lagoon were found to be highly correlated with river flow data from stream gauges. The estimated freshwater extent in the Fitzroy and Burnett Mary regions was higher than in 2008/09 and comparable with the 2007/08 wet season when the largest flood since 1991 occurred in the Fitzroy River. In the Cape York and Wet Tropics regions, estimated freshwater extent was less than in previous wet season, reflecting flow conditions generally below long-term median levels.

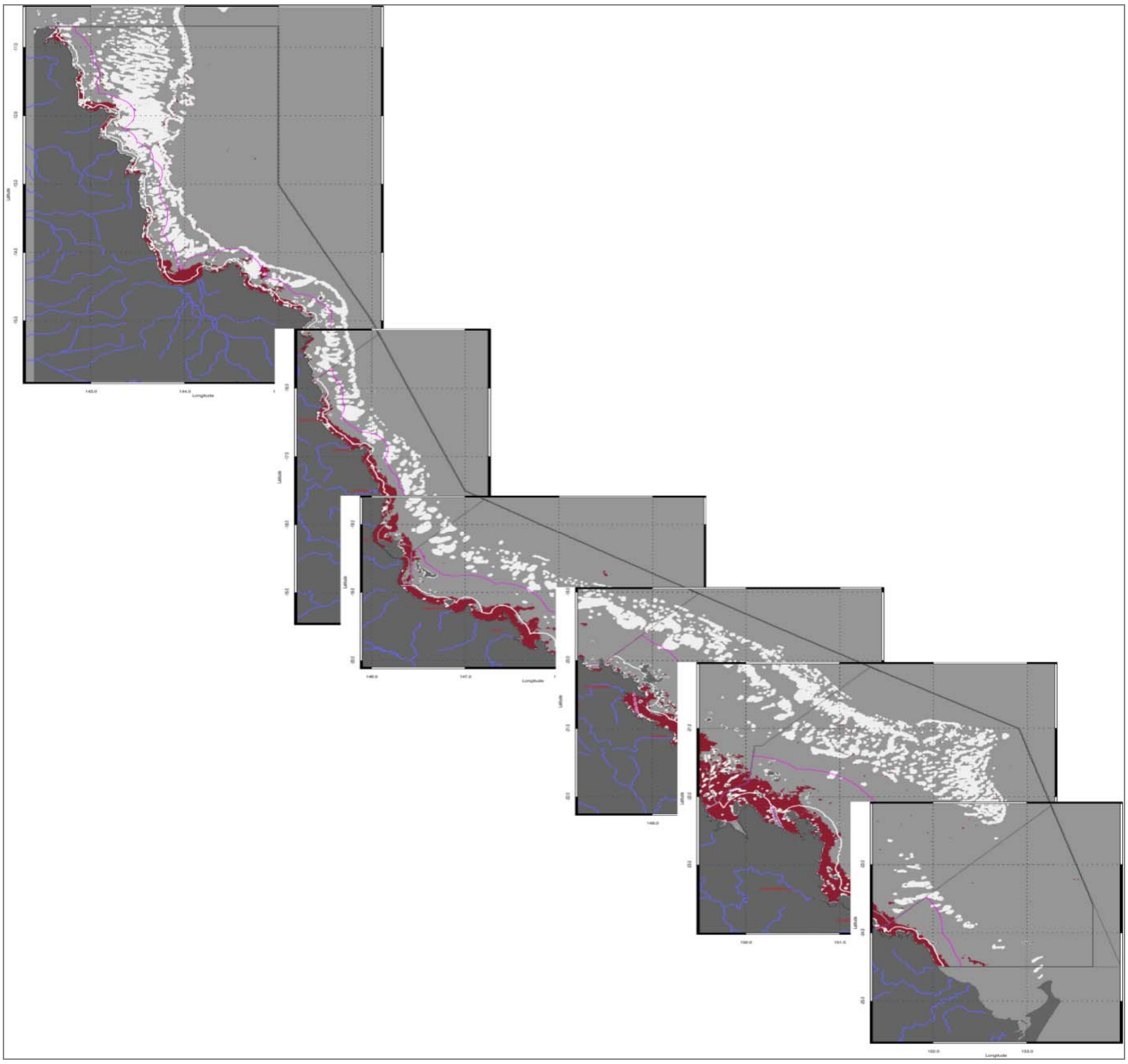


Figure 3.2: Freshwater extent maps (maximum CDOM concentrations as a proxy for estimated flood extent) for the 2009/10 wet season (November 2009 to April 2010) for the GBR. Pixels are mapped in dark red when the CDOM seasonal maximum values for the year exceed the threshold of 0.2 m^{-1}. The white line represents inshore boundary; pink line represents midshelf boundary. Source: CSIRO.

Water temperature data are reported for the period of January 2005 to June 2010 as the deviation from long-term (July 1999 to June 2008) weekly averages (Figure 3.3). Prolonged exposures to temperatures above the local mean have been shown to cause stress to corals that may increase susceptibility to disease (Bruno *et al.* 2007), cause coral bleaching and in severe cases, mortality (Berkelmans 2002). Seasonal average temperatures were exceeded for prolonged periods in the summer of 2005/06 in the Burdekin, Mackay Whitsunday and Fitzroy regions (Figure 3.3). In the Fitzroy Region these high summer temperatures resulted in widespread bleaching and subsequent loss of coral cover on most of the reefs included in this study period. There were also slight declines in coral cover over this period on reefs in the Mackay Whitsunday region. These reefs were visited in December 2005 when no bleaching was evident. If temperature stress was responsible for the slight declines in coral cover in this region it would most likely have occurred in late January and February as was the case in the Fitzroy region (Diaz-Pulido *et al.* 2009). In the Burdekin region reefs at Magnetic Island were visited frequently over this period of high temperature with no bleaching observed (Berkelmans, pers. comm., 2010). Temperature deviations above the long-term averages in the period April 2006 to June 2010 have been relatively minor and/or short-lived and did not caused notable mortality to corals in any regions. Temperatures in November and December 2008 in the Burdekin and Mackay Whitsunday regions were aseasonally high however, they were alleviated by heavy rainfall in the following months. Coral bleaching did occur in early 2009 but was most likely due to exposure to low salinity (as observed by van Woesik *et al.* 1995) with bleached corals rarely observed more than 0.5 m below lowest astronomical tides. The bleaching of corals in very shallow waters did not affect overall coral cover along the fixed transects monitored as they were in slightly deeper water. The exception were reefs in Cleveland Bay (Burdekin region) where low salinity penetrated to several meters causing stress and mortality among corals at shallow (two metres depth) locations at both Geoffrey Bay and Middle Reef.

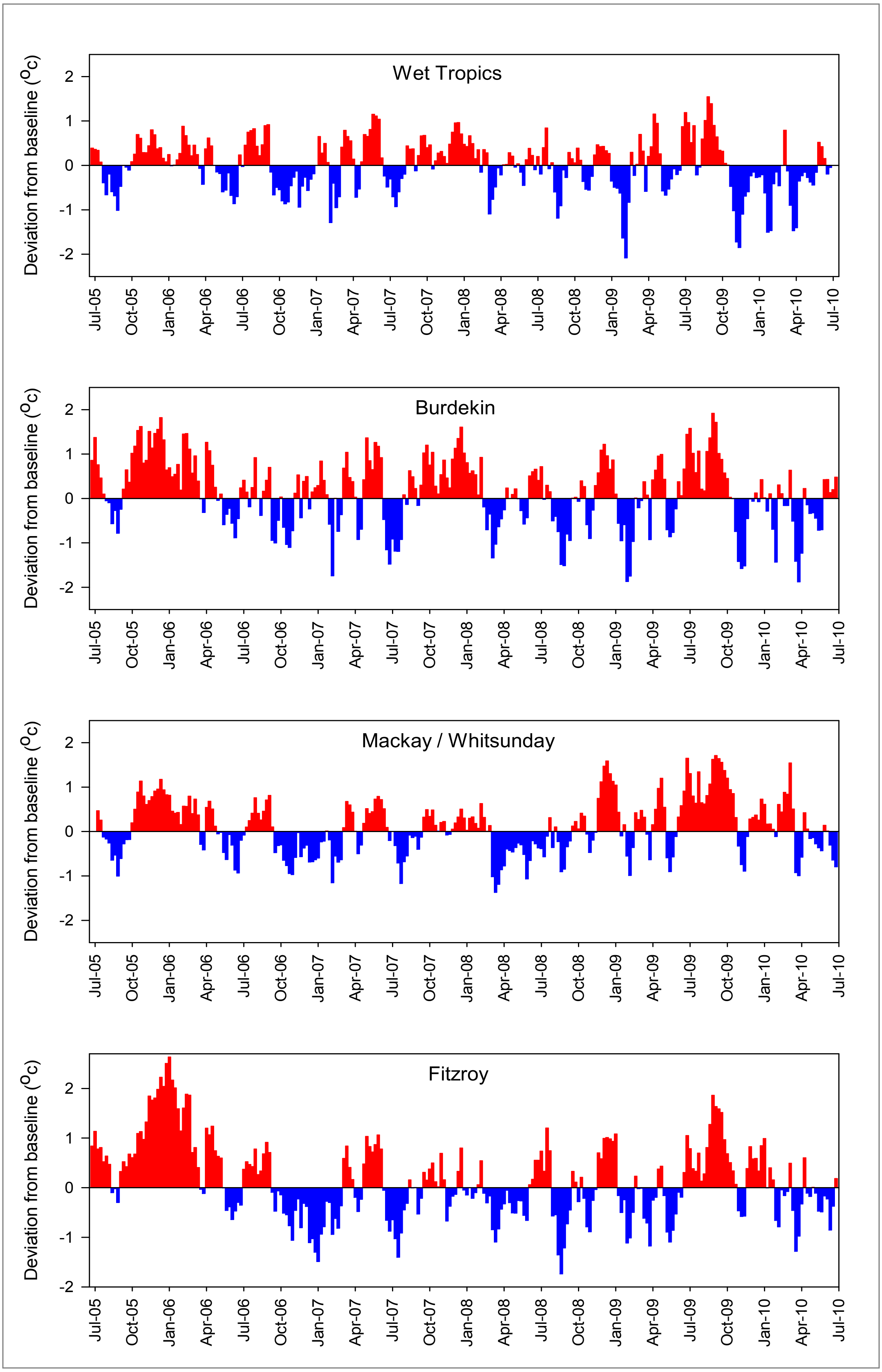


Figure 3.3: Sea temperature monitoring 2005 to 2010. Data presented are weekly deviations from regional climatology (based on records from July 1999 to June 2008). Source: Thompson *et al.* (2011).

3.2 Water quality results

As described in Section 2, water quality data is collected using several methods. The five years of *in situ* water quality data collected through the MMP have improved the understanding of the spatial and temporal variability of biogeochemical and physical variables in the GBR inshore lagoon. The site-specific water quality data in the inshore GBR generally show clear gradients away from river mouths and is influenced by flood events and resuspension.

The *in situ* water quality data was assessed against an interim Water Quality Index (see Appendix 2, Schaffelke *et al.* 2010). The Index aggregates the exceedance assessments for each of five indicators (turbidity/suspended solids, chlorophyll, particulate nitrogen, particulate phosphorus, Secchi depth) into an overall rating for the water quality at each of the twenty fixed sampling sites (six Cairns Transect and fourteen core reefs). Each site was given a status assessment ranging from 'very poor' to 'very good' (Table 3.2).

Table 3.2: Interim Water Quality Index (decision rules in Appendix 2). The colour coding reflects status of water quality: red (very poor), orange (poor), yellow (fair), light green (good), dark green (very good). The six Cairns Transect sites are in italics. Underlined locations are in the 'midshelf' and all other locations are in 'open coastal', as designated by the Guidelines. Measurements marked with an asterisk (*) indicate that direct water sampling data was used.

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 Whitsunday	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*

Following the rating scale developed for the Interim Water Quality Index, four sites were rated as having ‘very poor’ water quality – Yorkey’s Knob and Fairlead Buoy in the Wet Tropics region, Magnetic Island in the Burdekin region and Pelican Island in the Fitzroy region, and one site – Pine Island in the Fitzroy region – was rated as having ‘poor’ water quality.

Remote sensing data was used for the second year to assess exceedance of the Guidelines; the relative area of the GBR where the annual mean value of chl *a* and TSS exceeds the Guideline values for each of the regions and reporting boundaries in the GBR. Table 3.3 summarises these results for each water body for chl *a* and TSS. These estimates are based on a high number of observations ranging from hundreds of thousands valid observations for inshore areas in the wet season, to millions for the offshore area in the dry season. A greater number of valid observations should provide greater confidence in the results. The number of valid observations for each pixel location typically ranges from around 30 to 90 for each season; pixels with less than five valid observations are masked in addition to all reef and island areas. A relative rating of the number of valid observations has been developed to assist in interpretation of the information and to provide a rapid indication of variability between regions and water bodies (Table 3.3).

The metrics for the assessment of exceedance to the Guidelines have been modified compared to the 2008/09 MMP synthesis report (Johnson *et al*. 2010). The surface area used as the basis for the relative area of exceedance now reports the actual number of pixels with valid observations for each reporting region instead of the surface area of the whole water body. Accordingly, the reported surface areas are lower than those reported in 2008/09 (10-20% lower depending on the region) affecting in turn the reported relative areas for each water body where the mean or the median exceeded the Guideline value. Also as a result of the stricter quality control of the imagery, the number of available observations for each pixel is lower than for the 2008/09 MMP synthesis report. This affects the estimates of the annual and seasonal mean and median values for the reported variables. To enable a comparison with the results of the 2008/09 reporting period, the values were recomputed and presented in Appendix 1.

For all reporting regions except Mackay Whitsunday, the inshore water body shows high areas of exceedance of the chl *a* Guideline (56-83% of the relative area of the water body; Table 3.3). The results in previous years presented a similar pattern of high areas of exceedance (51-84% of relative area of the water body). However, the exceedance of the TSS Guideline in the inshore area of the Mackay Whitsunday region was higher than in all other regions (69%) and was also elevated in the midshelf (40%) and offshore (64%) areas. These relatively high results may be due to high river flows in the region over an extended period. However, closer examination is warranted as *in situ* results for TSS in this region were also elevated at some sites at different times of the year and the annual mean turbidity levels at Pine and Daydream Islands exceeded the Guidelines in all three years of monitoring (see Section 4.4.1).

The assessment of the exceedance of the Guidelines is described in detail in the regional reporting sections for chl *a* and TSS. As noted in Section 2.4, the inshore area includes the open coastal and enclosed coastal waters the latter of which have not been delineated by GBRMPA. As the Guideline values for chl *a* and TSS for the enclosed coastal waters are higher than those for the open coastal water body (Table 2.1), the relative area of exceedance for the inshore area is likely to be an over-estimate. In addition, caution should be used when interpreting the results for the Cape York and Burnett Mary regions in particular, as limited field information was used for the parameterization and validation of the remote sensing results. Further limitations of the data are included in Appendix 1 and Section 5 (Discussion and Conclusions).

Remote sensing information can also be presented as a series of mapping products. For example, the annual median chl a values for the 2009/10 reporting period (1 May 2009 to 30 April 2010) is shown in Figure 3.4. During the dry season an inshore to offshore gradient in chl *a* concentration was observed, with the inshore waters in the Wet Tropics and Burdekin regions having elevated concentrations of chl *a* over the monitoring period. Detailed maps for the wet and dry season for each region are presented in Brando *et al.* (2010a).

Table 3.3: Summary of exceedances of annual mean Guideline values of chl *a* and non-algal particulate matter (as a measure of TSS) for the 2009/10 reporting period (1 May 2009 to 30 April 2010) for the inshore, midshelf and offshore water bodies. Values higher than 50% are shaded grey.

Region	Rating of the number of valid observations			Chl *a*: Relative area (%) of the water body where the annual mean value exceeds the Guideline value (inshore and midshelf = 0.45 µg/L; offshore = 0.4 µg/L)			TSS: Relative area (%) of the water body where the annual mean value exceeds the Guideline value (inshore and midshelf = 2 mg/L; offshore = 0.7 mg/L)		
	Inshore	Midshelf	Offshore	Inshore	Midshelf	Offshore	Inshore	Midshelf	Offshore
Cape York*	1	2	4	56	4	0	45	44	26
Wet Tropics	1	1	3	81	16	0	23	3	30
Burdekin	1	2	3	65	2	0	39	0	30
Mackay Whitsunday	1	2	3	32	3	0	69	40	64
Fitzroy	1	3	4	66	5	0	43	7	50
Burnett Mary*	1	3	4	83	4	0	12	0	48

* Caution should be used when interpreting the results for the Cape York and Burnett Mary regions, and offshore regions, as limited field parameterisation and validation has been conducted. Note: The rating of valid observations is classified as follows: 1= <500,000 valid observations; 2 = 500,000-1,000,000 valid observations; 3 = 1,000,000-2,000,000 valid observations; 4 = >2,000,000 valid observations. A greater number of valid observations should provide greater confidence in the results.

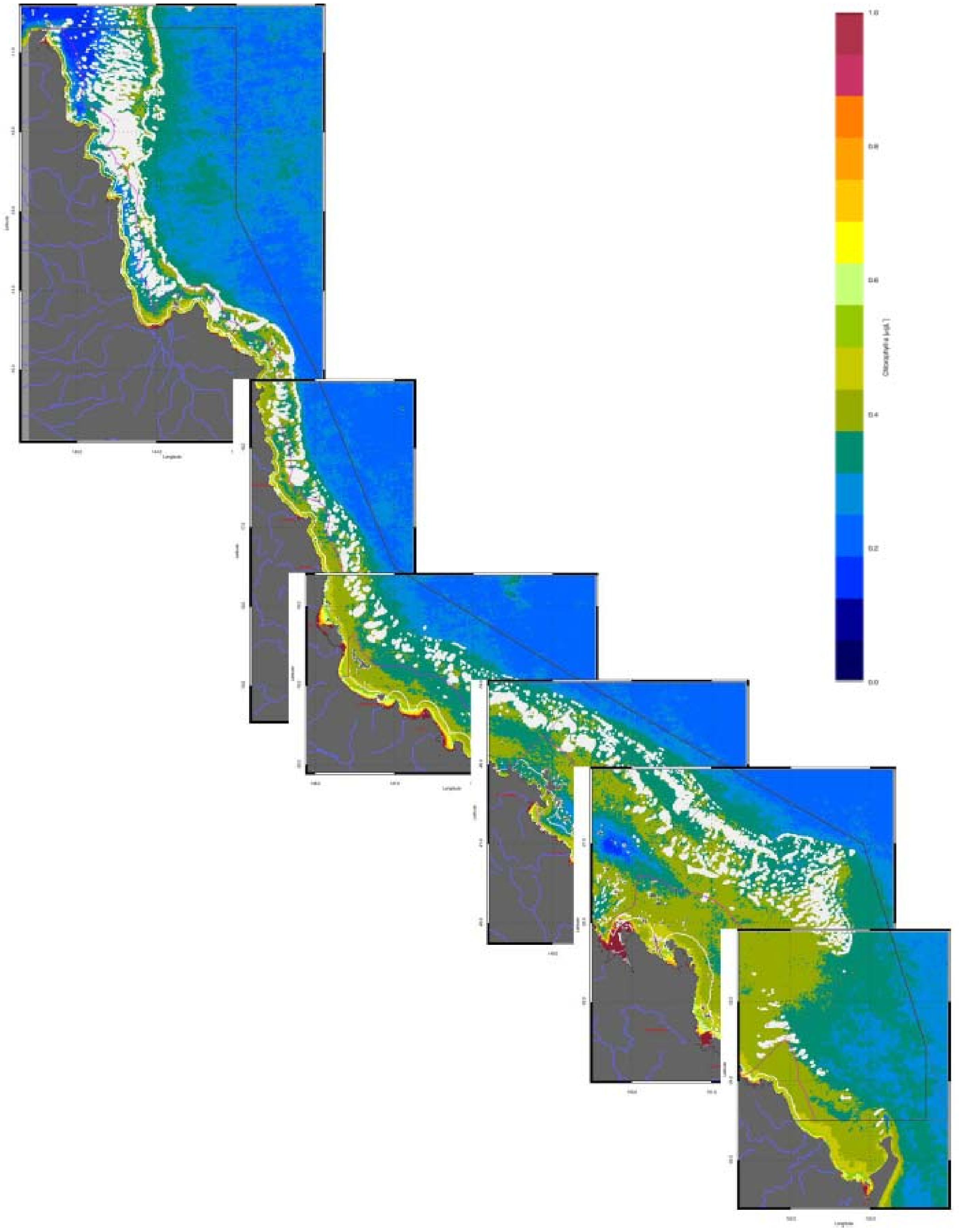


Figure 3.4: Collation of the median annual chl *a* for the 2009/10 reporting period (1 May 2009 to 30 April 2010) for the Great Barrier Reef. The white line represents inshore boundary; pink line represents midshelf boundary. Source: CSIRO.

All of the PSII herbicides passive sampler data was reported as the maximum PSII Herbicide Equivalent (PSII-HEq) concentration in the GBR and assessed in the context of the Pesticide Index rating scale of 1 to 5. The dominant contributor to the Pesticide Index at all monitoring sites during both wet and dry seasons was diuron due to its relative abundance and relative potency as a PSII inhibitor. Hexazinone and atrazine also contributed a significant proportion and these vary between regions, with atrazine typically contributing a higher relative proportion at sites in the Burdekin and Fitzroy regions and hexazinone contributing a higher proportion at sites in the Wet Tropics and Mackay Whitsunday regions (Figure 3.5). The Pesticide Index profiles indicated that the Mackay Whitsunday region, which has 56% of the catchment area associated with agricultural activities (predominantly sugarcane production and beef cattle grazing) should be a priority catchment in terms of management of pesticide loads to the GBR. In particular, the highest PSII-HEq maximum concentration (500 ng/L) was detected in 2009/10 at Sarina Inlet, which has significant areas of seagrass and inshore coral reefs. The pesticides contributing the most to the PSII-HEq (diuron, atrazine and hexazinone) are associated with herbicides used in sugarcane production and other cropping in GBR catchments such as horticulture and grains (Lewis *et al*. 2009, Brodie *et al*. 2009a).

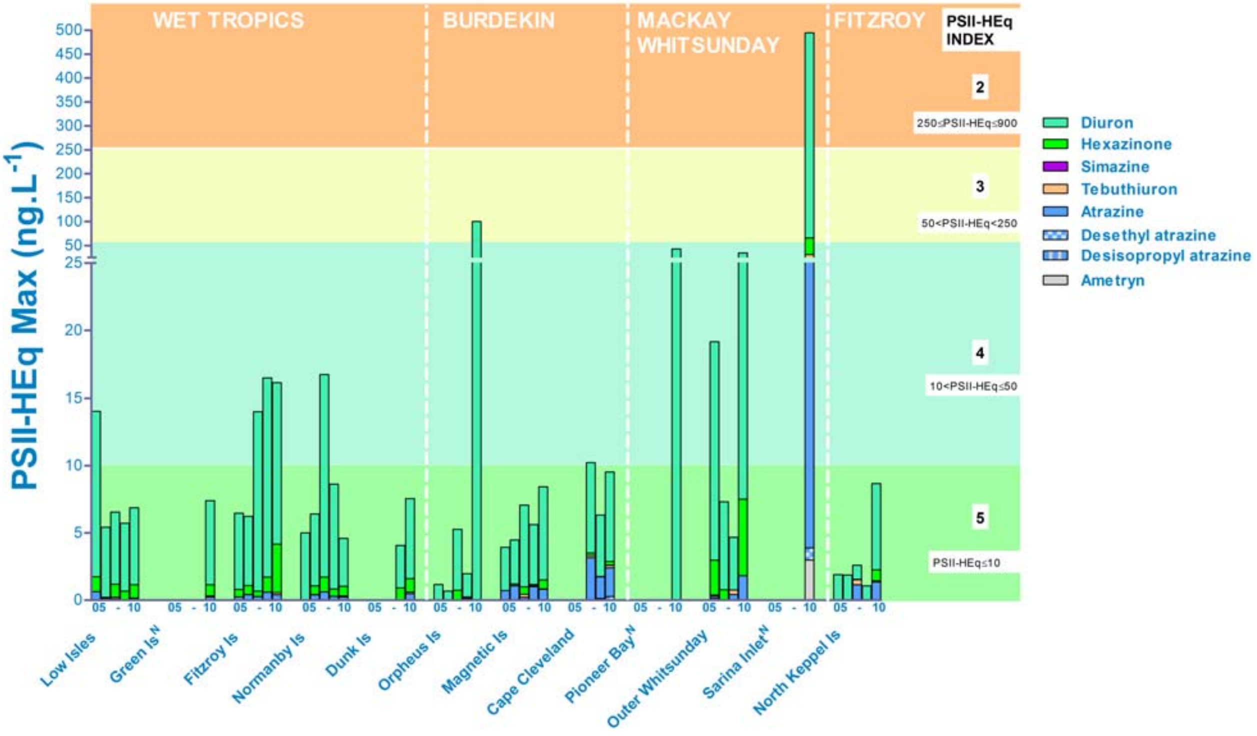


Figure 3.5: The PSII-HEq maximum concentrations (ng/L) and Pesticide Index rating (1–5) for monitoring conducted from 2005/06 to 2009/10. ^{N} = New sites added in 2009/10.

Maximum PSII-HEq concentrations detected in each monitoring year were typically observed during the wet season rather than the dry season (Kennedy *et al.* 2010). A notable exception to this was the maximum concentration of 100 ng/L detected during the dry season at Orpheus Island in the Burdekin region in 2009/10, which may be indicative of more localised sources of diuron (e.g. local application or leaching from antifoulant paints). Comparisons between all monitoring years showed some indication of increasing PSII-HEq maximum concentrations at Fitzroy Island in the Wet Tropics region, Magnetic Island in the Burdekin region and North Keppel Island in the Fitzroy region. Assessment of temporal trends in the Mackay Whitsunday region is not possible due to incomplete monitoring records for the Outer Whitsunday site and a range of new sites being incorporated in 2009/10.

Since diuron is the dominant contributor to PSII-HEq it is important to illustrate the ranges in the maximum concentration of diuron within these regions. Maximum diuron concentrations ranged from 3.6–12 ng/L, 6.7–100 ng/L, 27–429 ng/L and 6.4 ng/L in the Wet Tropics, Burdekin, Mackay Whitsunday and Fitzroy regions respectively (Figure 3.5).

There were no exceedances of Guideline trigger values for individual PSII herbicides in 2009/10 at inshore reef and coastal sites (Table 4.2, Section 4). The least frequently detected PSII herbicides were ametryn and simazine. Ametryn was only detected at Cape Cleveland (0.10 ng/L) and Sarina Inlet (2.3 ng/L) in 2009/10. Simazine was only detected at Magnetic Island and Cape Cleveland in the Burdekin region. The maximum concentrations of tebuthiuron (2.2–4.7 ng/L) were observed in the Burdekin region and at North Keppel Island (14 ng/L) in the Fitzroy region, which had the highest concentration in 2009/10 and approached the Guideline trigger value for tebuthiuron (20 ng/L). The increased presence of tebuthiuron in the Burdekin and Fitzroy regions is likely to be associated with grazing activities within these regions since tebuthiuron is used control woody weeds on grazing lands (Lewis *et al*. 2009, Brodie *et al*. 2009a, Packett *et al*. 2009). In addition, chlorpyrifos (not a PSII inhibiting pesticide) concentrations exceeded the Guidelines at sites in the Wet Tropics region.

There are differences between sites across the regions with respect to the relative abundance of different PSII herbicides which may be related to dominant agricultural land use within these regions. For example, atrazine was frequently the most abundant herbicide at sites in the Burdekin region and during peak events at North Keppel Island in the Fitzroy region. However the highest maximum concentrations of atrazine were observed in the Mackay Whitsunday region (1.1–170 ng/L). Atrazine is commonly used in sugarcane practices and therefore high abundances reflect dominant land uses in the area (Rohde *et al*. 2008, Brodie *et al*. 2009a, Lewis *et al*. 2009). Hexazinone maximum concentrations ranges were higher in the Wet Tropics region (2.2–9.5 ng/L) and in the Mackay Whitsunday region (11–91 ng/L), which is also a herbicide commonly used in sugarcane (Lewis *et al*. 2009, Brodie *et al*. 2009a).

3.3 Flood monitoring results

Sampling of flood plumes in 2009/10 was carried out in the marine areas adjacent to the Tully, Burdekin, Pioneer, Proserpine, O'Connell and Fitzroy Rivers (in the Wet Tropics, Burdekin, Mackay Whitsunday and Fitzroy regions respectively) in a range of periods following peak flow (Table 3.4). Analysis of plume water quality concentrations and the plume extent used a combination of field sampling and mapping techniques using currently available remote sensing algorithms and true colour imagery.

Table 3.4: Summary of sampling regime and flow characteristics of all river plumes monitored during 2009/10.

River	Region	Sampling dates	Parameters measured	Peak flow date(s)
Tully-Murray	Wet Tropics	31 Dec 2009 to 18 Mar 2010	TSS, DIN, DIP, chl *a*	27 Mar 2010
Burdekin	Burdekin	24 Feb 2010	TSS, DIN, DIP, chl *a*	22 Feb 2010 and 24 Mar 2010
Pioneer	Mackay Whitsunday	8 Feb, 4 Mar and 5 Mar 2010	TSS, DIN, DIP, chl *a*	31 Jan 2010 and 21 Mar 2010
Proserpine	Mackay Whitsunday	8 Feb, 4 Mar and 5 Mar 2010	TSS, DIN, DIP, chl *a*	21 Mar 2010
O'Connell	Mackay Whitsunday	8 Feb, 4 Mar and 5 Mar 2010	TSS, DIN, DIP, chl *a*	21 Mar 2010
Fitzroy	Fitzroy	25 April 2010	TSS, DIN, DIP, chl *a*	1 Mar 2010 and 12 Mar 2010

In most cases, concentrations of water quality parameters were lower outside of the peak flow periods as the highest concentrations, particularly for TSS, DIN and PSII herbicides, are closely linked to the first flush and high flow. Other parameters, such as chl *a*, tend to peak several days to weeks after high flow periods, driven by the higher nutrient availability with appropriate light conditions. Sampling throughout the wet season in periods outside of the peak flow events but still within times of elevated flow, indicated that concentrations of dissolved and particulate nutrients, CDOM, chl *a* and TSS are still elevated above Guideline values and contribute to high annual concentrations of TSS and chl *a*. Results from all regions showed large spatial areas with elevated concentrations of CDOM and chl *a* concentrations above Guideline values for periods of days to weeks after the largest flow event. Regionally specific results are presented in Section 4.

Pesticide sampling was undertaken in plume waters adjacent to the Russell Mulgrave, Tully, Burdekin, O'Connell and Pioneer Rivers. Diuron was the dominant pesticide found in all locations, except for the Burdekin where only tebuthiuron was detected. Atrazine and hexazinone were also detected in the Mackay Whitsunday plume waters. Concentrations of all pesticides were highly dependent on timing of the sample in relation to event flows. As has been observed in monitoring from other rivers (Lewis *et al.* 2009), the herbicides typically displayed conservative mixing behaviour, becoming progressively diluted as the river water is mixed with seawater. The PSII-HEq concentrations did not exceed Guideline values although the samples collected near the mouth of the Russell-Mulgrave River, near High Island and the mouth of the O'Connell River exceeded effect (photosynthetic inhibition LOEC) concentrations for seagrass (100 ng/L) and diatoms (>50 ng/L). Herbicide residues detected by the passive samplers at the mouth of the Tully River and at Bedarra Island included diuron, atrazine, hexazinone, simazine and tebuthiuron.

To identify the spatial extent of areas in the GBR that are most likely to be exposed to high concentrations of pollutants, Devlin *et al.* (2010b) completed an assessment of pollutant exposure in the GBR. Using pollutant load estimations from Brodie *et al.* (2009a), Natural Resource Management (NRM) regions were ranked according to the volume of pollutant loading for dissolved nutrients (DIN), total suspended sediments and PSII herbicides (Table 3.5).

Table 3.5: GBR regions ranked by pollutant load for DIN, TSS and PSII herbicides (where 1 is the lowest volume and 6 is the highest volume). Derived from Brodie *et al.* (2009a).

Region	TSS	Dissolved Nutrients	PSII herbicides
Cape York	1	1	1
Wet Tropics	3	5	5
Burdekin	6	6	2
Mackay Whitsunday	2	4	6
Fitzroy	5	3	4
Burnett Mary	4	2	3

Exposure to contaminants was then identified by combining information from the ranked catchment loads and the frequency of exposure of GBR ecosystems to these contaminants. The frequency of exposure was determined using remote sensing images of plume extent and categorised in a range between high and low. ‘High’ exposure is identified as areas which receive plume waters ‘at least’ two to five times per year from land use activities specific to that pollutant (i.e. grazing contributes TSS in the Burdekin region). ‘Moderate’ exposure is identified as areas which receive plume waters ‘at least’ once or twice per year. It is important to recognise that periods of flow and plume extent vary between catchments. Generally wet tropical systems receive high-flow periods from a period of days to weeks intermittently, while dry tropical systems are usually associated with much longer flow periods, and recent events in both Burdekin and Fitzroy Rivers have sustained high flow for periods of four to six weeks.

The exposure mapping was then used to identify the number of seagrass and coral reef ecosystems which are located in the ‘high to moderate’ exposure areas using spatial analysis. Comparison of the number of seagrass and coral reef ecosystems within the ‘high to moderate’ category for each pollutant is shown in Figure 3.6. The number of coral reefs and seagrass beds which are located within each exposure category depends on the proximity of the ecological systems to the riverine influence gradient. For example, in the Mackay Whitsunday region there are a large number of reefs within the ‘high’ exposure category due to the close proximity of the reefs to the coast (and hence river mouths), and the large flood extent measured from remote sensing imagery. For seagrass beds, the highest number within the ‘high to moderate’ exposure categories for all pollutants is in the Fitzroy region.

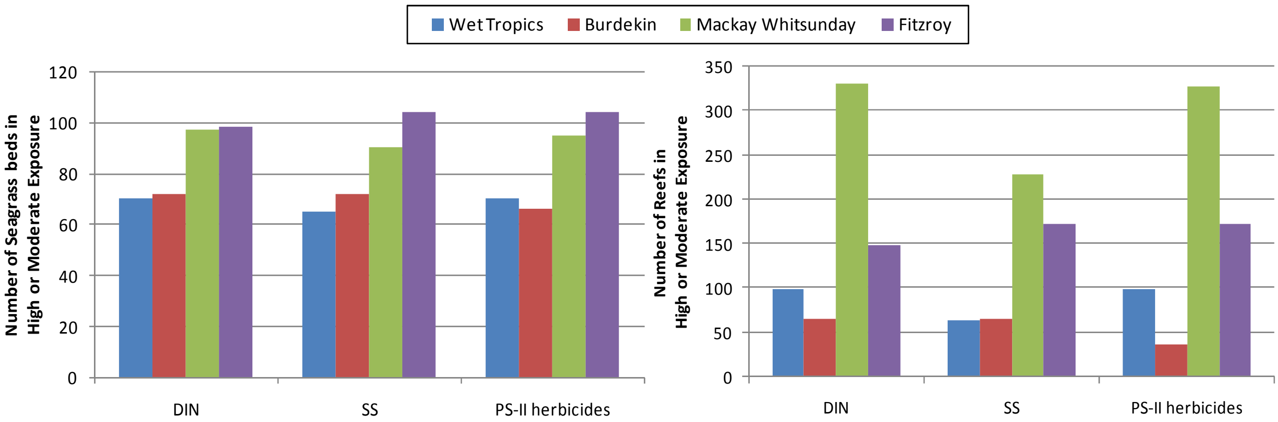


Figure 3.6: Number of seagrass beds (left) and coral reef (right) ecosystems located within areas of '*high to moderate' exposure* to specific pollutants in flood plume waters (calculated by spatial mapping of plume extent and catchment loads). Source: derived from Devlin *et al.* (2010b).

The exposure mapping focused on the movement, extent and presence of individual pollutants. However, during high flow periods, these pollutants move together to contribute combined exposure pressures. The actual movement, dispersion and uptake of the individual pollutants varies depending on the mixing properties however, the areas regularly exposed to plume waters would see 'high' exposures to all three pollutants at the same time. Figure 3.7 identifies the spatial extent of the combined exposure for the three pollutants. The combination rules identify 'high' exposure as TSS/DIN, TSS/PSII or DIN/PSII scoring high and the other pollutant scoring moderate. This exposure score then identifies different combinations of exposure rankings down to the three pollutants all being 'low' exposure (Figure 3.7).

In considering these results, it is important to recognise that exposure does not indicate certainty of an ecological effect on the plants and animals present within the plume. The probability of actually exceeding the Guidelines is limited to a smaller area contained within the 'high to moderate' exposure area. The areas identified as 'high to moderate' exposure will receive plume waters which contain elevated concentrations of pollutants (the pollutant dependent on the adjacent landscape) which may potentially impact on the ecology. In particular, the exposure maps for PSII herbicides show the herbicides are detectable at concentrations that can cause measurable effects on marine organisms in the laboratory (e.g. Haynes *et al.* 2000a, 2000b; Negri *et al.* 2005). Despite elevated concentrations being measured across these exposure areas in periods of high flow, it is not sufficient to ascribe certainty that water quality values will exceed thresholds based on Guidelines and/or be linked to a measurable ecological impact. These exposure areas represent areas which could be identified as potential areas for impact relative to terrestrial discharge. Continuing research, monitoring and mapping could be used to resolve the extent of probable impact over these exposure areas.

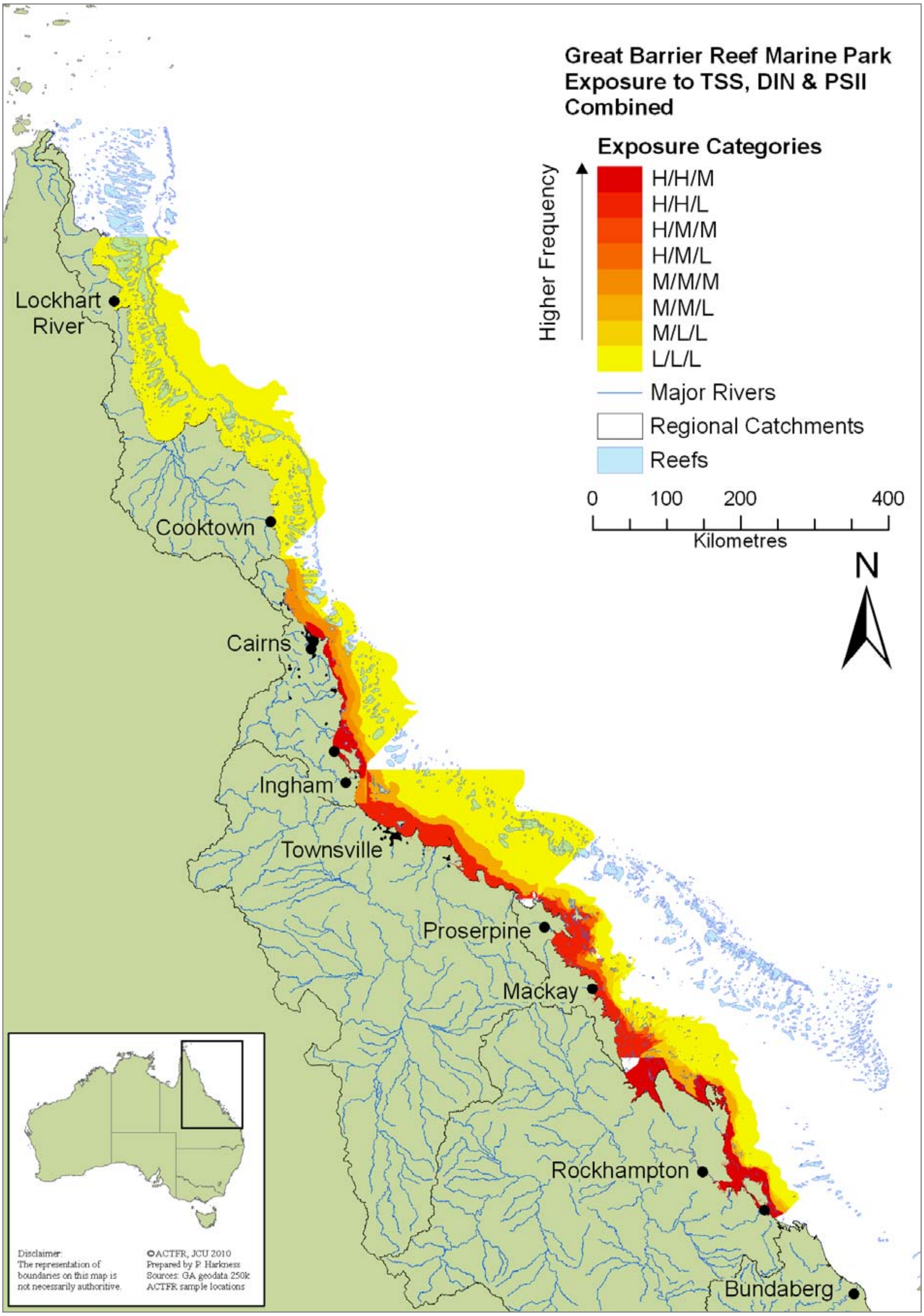
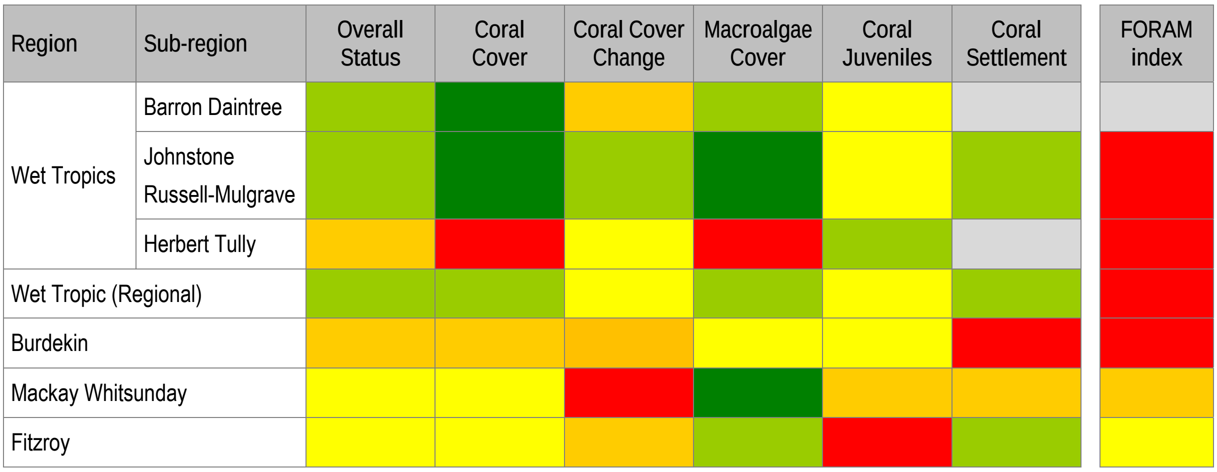


Figure 3.7: Exposure map to combined pollutants of inshore GBR waters. Exposure categories are H = high, M = moderate and L = low.

3.4 GBR inshore ecosystem status

GBR-wide estimates of coral reef community status were derived based on the observed dynamics of benthic communities over the period 2005–2010 (Table 3.6) by aggregating reef level status scores within each region and sub-region. The indicators selected consider the values of the key community variables monitored, in terms of their support toward a broad concept of resilience (Thompson *et al.* 2010b; Thompson and Dolman 2010), and include current reef status (hard coral, soft coral and macroalgae cover), and recovery potential (rate of coral cover increase, juvenile coral density and larval settlement). The underlying assumption is that a 'healthy' community should show clear signs of recovery after acute disturbances, such as cyclones and coral bleaching events, or in the absence of disturbance, maintain high coral cover and demonstrated supply of larvae and high survival rates of juveniles. This current approach uses five assessment indicators, all equally weighted. The FORAM index was also included this year as a bioindicator of coral reef water quality. Future research will need to incorporate the FORAM index into this group of bioindicators, and develop a weighting approach.

Table 3.6: Regional and sub-regional estimates of coral community condition. Overall condition for five indicators; regional estimates of these indicators are derived from the aggregation of assessments from the reefs within each region (Section 3.2). The FORAM index is included as a separate indicator of current environmental conditions and does not influence the 'Overall Condition' assessment for each region. The colour scheme reflects relative condition of reef communities: red (very poor), orange (poor), yellow (fair), light green (good), dark green (very good). Grey shading indicates regions where indicators were not sampled or assessed. Source: Thompson *et al.* (2011).



Region	Sub-region	Overall Status	Coral Cover	Coral Cover Change	Macroalgae Cover	Coral Juveniles	Coral Settlement	FORAM index
Wet Tropics	Barron Daintree	🟢	🟩	🟧	🟢	🟨	⬜	⬜
	Johnstone Russell-Mulgrave	🟢	🟩	🟢	🟩	🟨	🟢	🟥
	Herbert Tully	🟧	🟥	🟨	🟥	🟢	⬜	🟥
Wet Tropic (Regional)		🟢	🟢	🟨	🟢	🟨	🟢	🟥
Burdekin		🟧	🟧	🟧	🟨	🟨	🟥	🟥
Mackay Whitsunday		🟨	🟨	🟥	🟩	🟧	🟧	🟧
Fitzroy		🟨	🟨	🟧	🟢	🟥	🟢	🟨

Averaged over all GBR reefs surveyed, hard coral cover has remained stable since 2008 at around 35%, however with notable variations between regions (Figure 3.8). Hard coral cover substantially declined from 2009 to 2010 in the Mackay Whitsunday region – attributed to Tropical Cyclone *Ului* – and to a lesser degree in the Burdekin and Fitzroy regions. These declines were balanced by increased coral cover in the Wet Tropics region, where coral communities continued to recover from past disturbance events.

The average cover of soft corals remained stable on core reefs between 2005 and 2010 in both the Wet Tropics and Mackay Whitsunday regions. In the Fitzroy region, a slight decline was observed in 2008 as the result of storm damage at Barren Island and by 2009 soft coral cover had largely recovered before further storm damage in 2010. There was a decrease in average soft coral cover in the Burdekin region since 2007, reflecting a decline at sites in the Palm Islands, with soft coral cover elsewhere in the region remaining consistently low.

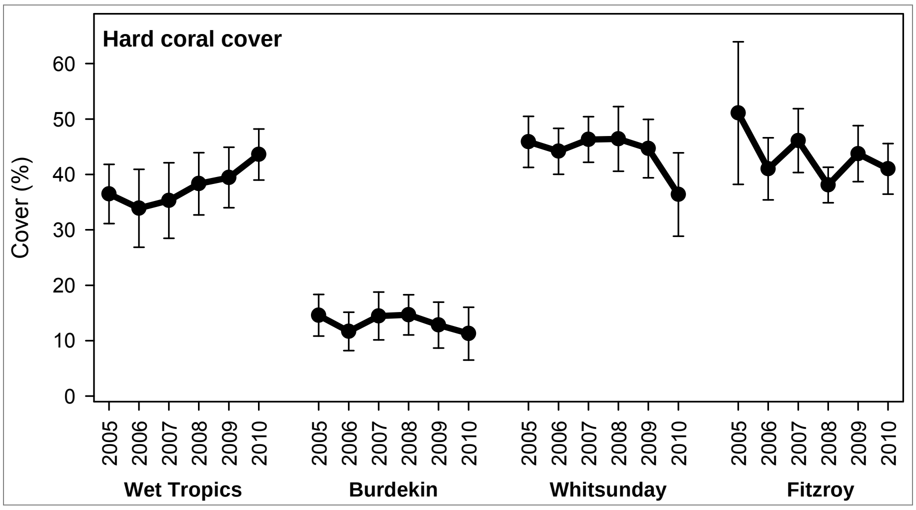


Figure 3.8: Regional change in average hard coral cover from 2005 to 2010 for each region (+/- standard error). Only reefs sampled in all years were included to ensure consistency among annual averages.

Macroalgae cover varied between regions and between reefs across the GBR. Average cover of macroalgae on core reefs declined from 2007 to 2009 (13.6% to 8.5%), remaining stable at about 8.5% in 2010. This overall lack of change, however, masks the variable profiles of algae cover at the regional level and at individual reefs within each region.

The average density of juvenile hard coral colonies on core reefs declined annually from 5.2 m^{-2} in 2005 to a low of 3.5 m^{-2} in 2009 and remained stable at 3.7 m^{-2} in 2010. This decline was most notable in the Wet Tropics, Burdekin and Mackay Whitsunday regions. The decline in the Fitzroy region was less pronounced where the density of recruits has been consistently low since monitoring began in 2005. In the Mackay Whitsunday region, the density of juvenile hard corals continued to decline in 2010 due to the effect of Tropical Cyclone *Ului* and by 2010 was only 36% of that observed in 2005. In contrast, densities of juvenile colonies rose in both the Wet Tropics and Burdekin regions in 2010, although these increases were not consistent across all core reefs within each region.

Reef-wide community composition (average number of hard coral genera) remained relatively stable or showed slight increases between 2005 and 2010. While diversity has remained stable at the genus level, this result cannot be used to infer diversity at the species level with the data not able to resolve changes in species richness within genera that have a large number of species, such as Acropora. One possible point of concern was a slight decline of richness in the Burdekin region in 2010, where lower richness was due to declines in the number of genera observed at Pandora Reef and Pelorus Island/Orpheus Island west. At these locations coral cover was very low, and in the case of Pelorus Island/Orpheus Island west, declined in 2010. There were no obvious indications of declining diversity of juvenile corals. It must be noted, however, that generic richness is a very coarse assessment of diversity, as observations of single individuals are weighted the same as those of highly abundant taxa. Variation among years is largely due to the presence or absence of individuals of rare genera.

Fluctuations in coral larval settlement between 2006 and 2009 followed a similar pattern in three of the four regions (Wet Tropics, Burdekin and Mackay Whitsunday), with a distinct peak in settlement in 2007 followed by a return to lower levels in 2008 and 2009. This pattern was reversed in the Fitzroy region, with a drop in settlement in 2007 following the highest settlement unexpectedly in 2006, in the reproductive season directly following a major bleaching event that saw up to 95% of adult corals bleached (Jones *et al.* 2008). Relative to previous observations, settlement in 2009 was low in both the Wet Tropics and Burdekin regions and similar to past observations in both the Mackay Whitsunday and Fitzroy regions. Five years of data reveals that coral larval settlement is highly variable within and among reefs within each region with a range emerging within which settlement fluctuates in each region. Notable is the consistently lower settlement in the Burdekin region, compared to the other three regions.

Foram index values observed in 2010 were consistently below those observed from 2005 to 2007, and relatively similar among the Wet Tropics, Burdekin and Fitzroy regions, but distinctly lower in the Mackay Whitsunday region. The Foram index has declined in all regions, with the exception of the Fitzroy region, however this region was only sampled twice. It appears likely that higher numbers of heterotrophic species, as observed in the Mackay Whitsunday region, reflect the higher food availability as a result of higher concentrations of organic carbon and nitrogen in the sediments, facilitated by extreme wet seasons in past years and recent flood events.

Results from the seagrass monitoring in 2009/10 across the GBR are summarised in Table 3.7 and indicate that seagrass meadows are in a state of decline (see Appendix 5 for further detail). The indicators of this decline are:

- 67% of sites had reduced seagrass abundance (below the seagrass abundance sub-regional guidelines, see Appendix 4, McKenzie *et al.* 2010);
- 50% sites exhibited shrinking meadow area;
- 60% sites had limited seed banks or are not producing seeds that would enable rapid recovery;
- 63% of sites were light limited;
- 33% sites were nutrient enriched; and
- 90% of sites had either high or elevated nitrogen.

There was also evidence of long-term increases of seagrass nutrient content (in tissues) in coastal and reef seagrasses, particularly in the Wet Tropics and Burdekin regions. Elemental ratios of tissue nutrients indicate some locations in the Wet Tropics and Mackay Whitsunday regions have degraded water quality with an excess of nutrients compared to light availability. Increased epiphyte loads, possibly stimulated by nutrient loading, further exacerbate light limitation on the surfaces of slower-growing seagrass leaves in coastal and estuarine habitats. It is not clear if this decline can be reversed with a shift in water quality status or climatic factors.

Other interactions are also important to consider. Under limiting light levels, elevated nutrient levels saturate the seagrass more rapidly. As seagrass reproduction is positively correlated with nutrient saturation in some circumstances, seagrasses experiencing low light but elevated nutrients may be expected to have increased reproductive effort – until light levels result in compromised survival due to respiration demands being greater than photosynthesis. This association was observed at the Bushland Beach and Shelley Beach sites in the Burdekin region. The capacity of seagrass meadows to naturally recover community structure following disturbance is dependent on the interaction between light availability, nutrient loads and the availability of seeds to form the foundation of new populations. At present, the recovery potential of seagrass meadows appears to be spatially and temporally variable due to variability in light levels and seed availability.

Table 3.7: Seagrass status *(community and environment)* GBR-wide and for each region, September 2009 to May 2010. Values are indexed scores scaled from 0-100. Green = good, yellow = fair, red = poor. ^=Paddock to Reef colour scheme where yellow = moderate, gold = fair. Source: McKenzie *et al.* (2010).

Region	Seagrass Abundance	Reproductive Effort	Nutrient Status (C:P and N:P ratios)	Light availability (C:N ratio)	Seagrass Index
Cape York	58	67	33	33	48
Wet Tropics	50	0	33	33	29
Burdekin	12	33	67	33	36
Mackay Whitsunday	31	0	33	33	24
Fitzroy	52	33	33	67	46
Burnett Mary	31	0	33	33	24
GBR	39	38	38	35	37

4. Regional results

4.1 Cape York region

The Cape York Peninsula is the northernmost extremity of Australia, extending south from the tip at Cape York for eight hundred kilometres, widening to its base from Cairns in the east to the Gilbert River in the west. The largest rivers in the Cape York region empty into the Gulf of Carpentaria, however the catchments of the Normanby, Endeavour and Lockhart Rivers empty into the GBR. The region has a monsoon climate with wet and dry seasons with mean annual rainfall ranging from 1,715 mm (Starke River) to 2,159 mm (Lockhart River). The majority of the land is undeveloped.

In situ water quality monitoring, flood event monitoring and coral reef monitoring are not undertaken in the Cape York region.

4.1.1 Water quality results

Estimates of water quality concentrations in the Cape York region was undertaken using remote sensing however, limited *in situ* data for data validation gives relatively low confidence in the results. Analysis of the remote sensing data show that the annual mean values of chl *a* exceeded the Guideline trigger value (0.45 µg/L) for 56% percent of the inshore area, 4% of the midshelf and none of the offshore areas (Table 4.1). Exceedance of TSS Guideline values in the inshore and midshelf areas (2 mg/L) were recorded in 45% of inshore area and 44% of the midshelf area. Offshore Guideline values (0.7 mg/L) were exceeded in 26% of the offshore area (Table 4.1).

For the Cape York region, the estimated freshwater extent using CDOM values from satellite imagery in 2009/10 was 4,167 km^2, while in the 2008/09 wet season it was 1,775 km^2. The annual flow data for the Normanby River for 2009/10 indicated discharges comparable to the previous three years. Caution should be used when interpreting the results for this region as limited field information was used for the parameterization and validation on the remote sensing retrievals.

Table 4.1: Summary of the annual exceedance of Guideline values for chl *a* and TSS in the Cape York region.

			Chl *a*: Relative area (%) of the water body where annual mean value exceeds the Guideline value (inshore and midshelf = 0.45 µg/L; offshore = 0.4 µg/L)		TSS: Relative area (%) of the water body where annual mean value exceeds the Guideline value (inshore and midshelf = 2 mg/L; offshore = 0.7 mg/L)	
Waterbody	Surface Area (km^2)	Number valid obs.	Mean > trigger	Median > trigger	Mean > trigger	Median > trigger
Inshore	4,295	1	56%	49%	45%	20%
Midshelf	10,544	2	4%	2%	44%	10%
Offshore	62,344	4	0%	1%	26%	4%

Note: ‘Surface Area’ is the surface area in square kilometres for each of the three reporting water bodies for this region. The rating of valid observations is classified as: 1= <500,000 valid observations; 2 = 500,000-1,000,000 valid observations; 3 = 1,000,000-2,000,000 valid observations; 4 = >2,000,000 valid observations. A greater number of valid observations should provide greater confidence in the results. ‘Mean > trigger’ and ‘Median > trigger’ report the relative area for each water body where the mean or the median exceeded the trigger value. Values higher than 50% are shaded grey.

Pesticides were monitored in one location in the region, Pixies Garden, until January 2010 when the site was discontinued. No PSII herbicides were detected in the 2009/10 monitoring period. Other PSII herbicides detected in the region in previous years (2006–2009) include atrazine (and breakdown product desthylatrazine), hexazinone, and simazine, with an evident spike in the concentration of PSII-Heq in the wet season, mainly due to high concentrations of the dominant herbicide diuron. The Pesticide Index for the Cape York region based on the Pixies Garden site (2006–2010) was 5, with all PSII-HEq ≤ 10 ng/L across all years. All PSII-HEq were typically within the lower range of category 5 with maximum values in the wet seasons typically < 2 ng/L.

4.1.2 Biological monitoring results

Only one seagrass location (two sites) was monitored in the Cape York region in 2009/10, at Archer Point in the southern part of this remote region. This location has a fringing reef seagrass meadow that has remained stable in terms of seagrass abundance (Figure 4.1) and extent, and had increasing seed banks indicating high recovery potential to disturbances. Leaf tissue nutrient ratios suggest the seagrass habitat had 'moderate to fair' light availability, was nutrient poor and the plants nitrogen-limited. Epiphyte fouling of seagrass leaves increased above the GBR long-term average of 27% for reef habitats. Overall the status of seagrass condition in the region was rated as 'moderate'.

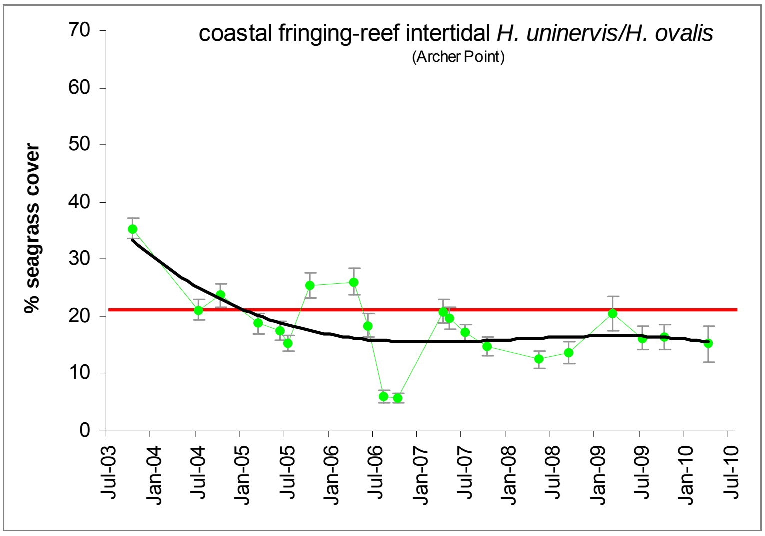


Figure 4.1: Seagrass abundance (% cover ± Standard Error) in the Cape York region (Archer Point sites), inshore intertidal fringing-reef habitat (sites pooled) from 2003 to 2010. Red line = GBR long-term average for reef habitats (the average of all sites pooled).

4.2 Wet Tropics region

Agricultural land use within the Wet Tropics catchment include primary production such as sugar cane and banana farming, dairy, beef, cropping and tropical horticulture. Other activities in the region include fisheries, mining and tourism. Declining water quality, due to sedimentation combined with other forms of pollutants, the disturbance of acid sulphate soils, and point source pollution have been identified as a major concern to the health of coastal and marine ecosystems adjacent to this region. Major environmental controls in the Wet Tropics region include pulsed terrestrial runoff, salinity and temperature extremes.

All components of the MMP are measured in the Wet Tropics region.

4.2.1 Water quality results

Using *in situ* water quality monitoring results, the Water Quality Index at seven out of the eleven Wet Tropics region sites were rated as ‘good’ or ‘very good’ (Table 4.2). 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 five year means of Secchi depth (and PP concentration at Dunk Island) exceeded the Guidelines. At two 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.

Table 4.2: Water quality status in the Wet Tropics region sampled in 2009/10. Water quality index rating: red (very poor), orange (poor), yellow (fair), light green (good), dark green (very good). Measurements marked with an asterisk (*) indicate that direct water sampling data was used.

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

The longest time series of water quality data for the GBR, the Cairns Transect undertaken by AIMS, 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.

Analysis of the remote sensing data in the Wet Tropics region show that the annual mean values of chl *a* exceeded the Guideline value (0.45 µg/L) in 81% of the inshore area and followed a gradient to the offshore area (Table 4.3). When the median was used for the assessment, almost no exceedance of TSS was recorded for the midshelf and offshore areas in both seasons and over the year, and the exceedance of the median values for the inshore area were also relatively low (<20%). The significant difference observed when assessing exceedance of the Guidelines for TSS by using the mean and median values could be due by the effect of outliers in the remote sensing data. A series of really high values TSS retrievals could skew the estimate of the mean while not affecting the median.

Table 4.3: Summary of annual exceedance of Guideline values for chl *a* and TSS in the Wet Tropics region.

			Chl *a*: Relative area (%) of the water body where annual mean value exceeds the Guideline value (inshore and midshelf = 0.45 µg/L; offshore = 0.4 µg/L)		TSS: Relative area (%) of the water body where annual mean value exceeds the Guideline value (inshore and midshelf = 2 mg/L; offshore = 0.7 mg/L)	
Waterbody	Surface Area (km²)	Number valid obs.	Mean > trigger	Median > trigger	Mean > trigger	Median > trigger
Inshore	2,044	1	81%	76%	23%	7%
Midshelf	5,859	1	16%	14%	3%	1%
Offshore	19,906	3	0%	3%	30%	0%

Note: 'Surface Area' is the surface area in square kilometres for each of the three reporting water bodies for this region. The rating of valid observations is classified as: 1= <500,000 valid observations; 2 = 500,000-1,000,000 valid observations; 3 = 1,000,000-2,000,000 valid observations; 4 = >2,000,000 valid observations. A greater number of valid observations should provide greater confidence in the results. 'Mean > trigger' and 'Median > trigger' report the relative area for each water body where the mean or the median exceeded the trigger value. Values higher than 50% are shaded grey.

The estimated freshwater extent for the Wet Tropics region using CDOM values from satellite imagery for the 2009/10 wet season (November 2009 to April 2010) was 3,786 km^2 while in the 2008/09 wet season it was 4,898 km^2. The reduced freshwater extent was due to the to the lower flow conditions in the Russell, Johnstone, Tully and Herbert Rivers that were below long-term median levels (0.6–0.8 times median levels).

In the Wet Tropics region, estimates of chlorpyrifos concentrations (0.56–0.72 ng/L) exceeded the Guideline trigger value (0.5 ng/L) at several inshore reef sites (Green Island, Fitzroy Island, Normanby Island and Dunk Island) in 2009/10. Chlorpyrifos was only detected during January 2010 at these sites while ANZECC and ARMCANZ Freshwater Guidelines (99% and 95%) were consistently exceeded in the Tully River (2.4-12 ng/L) with the maximum concentration occurring in the December 2009 to January 2010 sampling period. Diazinon concentrations in the Tully River (46-55 ng/L) also exceeded ANZECC and ARMCANZ Guidelines.

A limited range of less common pesticides (herbicides, insecticides and fungicides) were detected at inshore reef and coastal sites in the Wet Tropics region (Table 4.4). These included chlorpyrifos (0.56-0.72 ng/L) at four sites, and the herbicide pendimethalin (1.1 ng/L) at Normanby Island. There are no Guideline trigger values for pendimethalin. The concentrations of chlorpyrifos exceeded the Guideline trigger value of 0.5 ng/L (as well as

ANZECC and ARMCANZ Guidelines) for 99% species protection in marine waters, and occurred in January 2010 which is consistent with the timing of maximum concentrations of chlorpyrifos in the Tully River (estimated concentrations of 2.4–12 ng/L). A broad range of other pesticides were detected in the Tully River for which no Guidelines are available. These include an aryloxyphenoxypropionic herbicide (haloxyfop-methyl: 0.63 ng/L), a dinitroaniline herbicide (pendimethalin: 0.85–5.4 ng/L), two conazole fungicides (propiconazole: 11–19 ng/L and tebuconazole: 13–22 ng/L), and another organophosphate insecticide (prothiofos: 0.19–2.0 ng/L).

The Tully-Murray River experienced a number of moderate flooding events in 2009/10, and sampling spanned almost a three month period, with a peak of almost 41,000 ML (see Table 3.4). Sampling was undertaken four times during this period providing a comprehensive dataset to assess material behaviour and plume dynamics. The Tully River plume waters travelled north past Dunk and Bedarra Island, and north to the Barnard Islands. Satellite images showed extensive areas of green coloured water moving offshore, possibly due to due to phytoplankton (as shown by chl *a* concentrations) and hence indicative of the extent of the algal bloom. Further assessment of available images allowed definition of water types within the plume waters, validated with *in situ* water quality monitoring results.

Using a compilation of plume extents, the water types have been defined for the Wet Tropics, shown in Figure 4.2. TSS and chl *a* concentrations from 2009/10 sampling are also shown on the water type maps in Figure 4.2.

Over 90% of all samples taken exceeded the Guidelines for chl *a* and TSS. For the two sites with repeated sampling (Dunk Island and Tam O'Shanter Point), the chl *a* Guideline value was exceeded for the first three sampling times and TSS was exceeded all four sampling times. The frequency of elevated concentrations imply that there were long periods during which chl *a* and TSS concentrations were elevated for extended period of times relative to the high flow periods.

The characteristics and transformation of materials in the plume were assessed using mixing curves for four water quality parameters (chl *a*, TSS, DIN and DIP), with results showing contrasting responses between parameters along the salinity gradient over spatial and temporal scales. Further interpretation of the results are presented in Devlin *et al.* (2010a) and indicate that the impacts of the fertilized agriculture has typically been seen and measured in elevated concentrations of DIN, and that elevated levels of DIP measured in the plume may require some more thought on the nutrient priorities. As expected, lower measurements of TSS were recorded in the Tully River samples as sediment erosion on the Tully-Murray catchment is not seen as one of the main land use issues.

Using a combination of information from catchment loads of TSS, DIN and PSII herbicides, the frequency and exposure of plume waters and long-term information on the water quality characteristics of water types most commonly found within the marine regions, the areas most likely to exceed Guidelines for TSS and chl *a* in the Wet Tropics region has been defined and is shown in Figure 4.3 (refer to Devlin *et al.* (2010b) for a detailed description of the methods used to produce these maps). The 2010 sampling results for TSS and chl *a* are reasonably well correlated with the predicted areas of exceedance of Guideline values.

Table 4.4: Pesticide concentration ranges (ng/L) detected in the inshore waters and reefs of the GBR in 2009/10; herbicides (triazine, phenyl urea, triazinone, dinitroaniline, chloracetanilide) and organophosphate insecticide (chlorpyrifos). The PSII-HEq range for these sites and the Pesticide Index rating are also provided. Sites where no monitoring is undertaken for chemicals other than PSII herbicides are shaded light grey.

Region / Site		Triazine-PSII Herbicide	Triazine- PSII Herbicide	Urea-PSII Herbicide	Triazinone-PSII Herbicide	Triazine-PSII Herbicide	Urea-PSII Herbicide	PSII-HEq		Organophosphate Insecticide	Dinitroaniline Herbicide	ChloracetanilideHerbicide
		Ametryn	Atrazine	Diuron	Hexazinone	Simazine	Tebuthiuron	Range	Index	Chlorpyrifos	Pendimethalin	Metolachlor
Cape York	Pixies Garden[D]	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	5			
Wet Tropics	Low Isles	n.d	n.d.-0.90	n.d.-5.7	n.d.-2.6	n.d.	n.d.-0.30	n.d.-6.7	5			
	Green Island[N]	n.d	n.d.-1.6	n.d.-6.2	n.d.-2.2	n.d.	n.d.-0.90	n.d.-7.4	5	n.d-0.69	n.d.	n.d.
	Fitzroy Island	n.d	n.d.-2.6	0.90-12	n.d.-9.5	n.d.	n.d.-1.9	0.94-16	4	n.d.-0.56	n.d.	n.d.
	Normanby Island	n.d	n.d.-1.5	n.d.-3.6	n.d-1.9	n.d.	n.d.-0.93	n.d.-4.0	5	n.d.-0.72	n.d.-1.1	n.d.
	Dunk Island	n.d	n.d.-3.0	0.57-5.9	n.d.-2.6	n.d.	n.d.-1.6	0.57-7.1	5	n.d.-0.69	n.d.	n.d.
Burdekin	Orpheus Island	n.d.	n.d.-2.2	1.5-100*	n.d.-0.86	n.d.	n.d.-2.8	2.1-100	3			
	Magnetic Island	n.d.	n.d.-5.1	n.d.-6.9	n.d.-1.8	n.d.-1.5	n.d.-4.7	0.88-8.8	5	n.d.	n.d.	n.d.
	Cape Cleveland	n.d.-0.10	n.d.-13	n.d.-6.7	n.d.-0.61	n.d.-0.36	n.d.-2.2	0.036-9.1	5	n.d.	n.d.	5.8
Mackay -Whitsunday	Outer Whitsunday	n.d.	n.d.-11	n.d.-27	n.d.-15	n.d.	n.d.-0.64	n.d.-35	4	n.d.	n.d.	n.d.
	Daydream Island – Inner Whitsunday[D]	n.d.	0.59-3.1	1.5-51	0.50-15	n.d.	n.d.-2.2	1.7-57	3			
	Pioneer Bay – Inner Whitsunday[N]	n.d.	n.d.-1.1	3.6-43	n.d.-11	n.d.	n.d.-0.90	3.6-43	4			
	Sarina Inlet[N]	n.d.-2.3	n.d.-170	n.d.-429	n.d.-91	n.d.	n.d.-0.71	0.58-495	2			
Fitzroy	North Keppel Island	n.d.	n.d.-8.4	n.d.-6.4	n.d.-2.1	n.d.	n.d.-14	n.d.-8.7	5			

[D] Sites discontinued in 2009/10

[N] New sites added in 2009/10

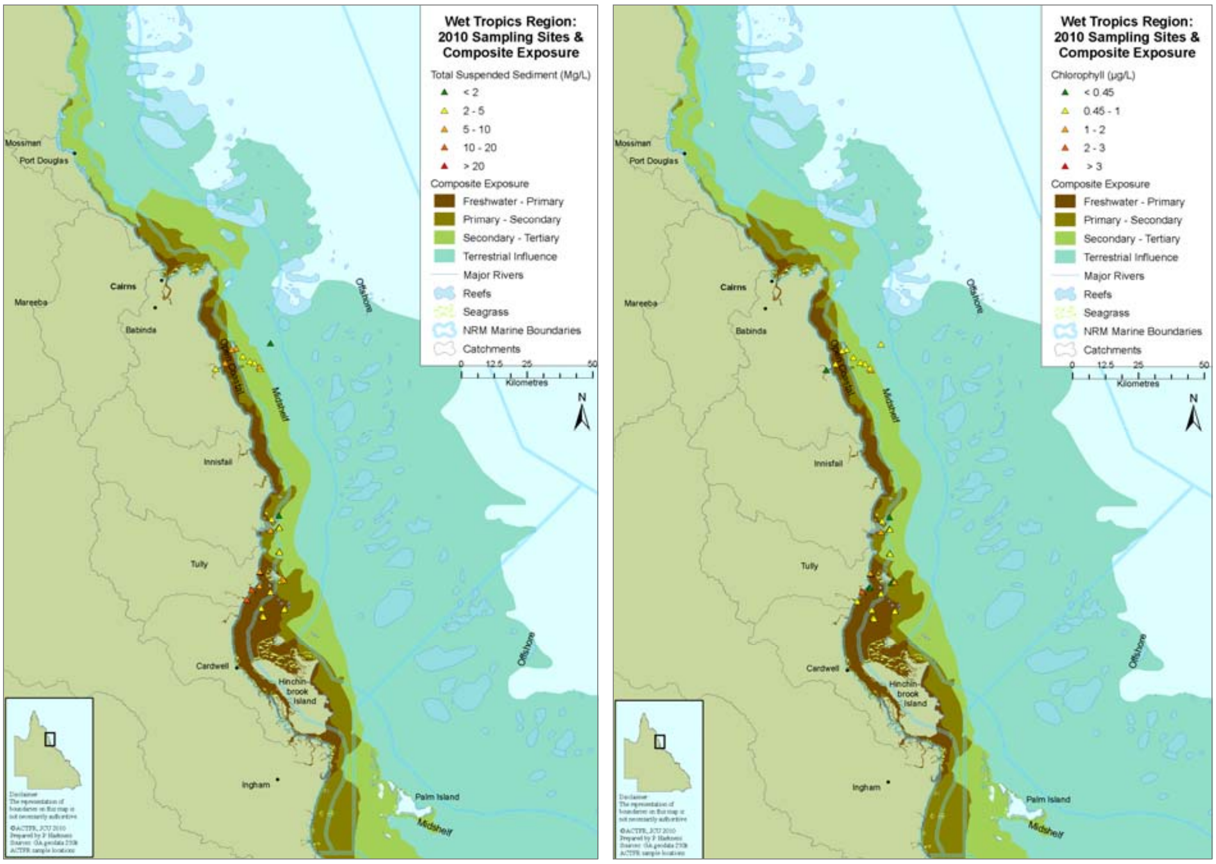


Figure 4.2: Classification of the water types commonly found within the Wet Tropics region during riverine flood events: TSS (*left*) and chl *a* (*right*) concentrations sampled over the 2009/10 wet season.

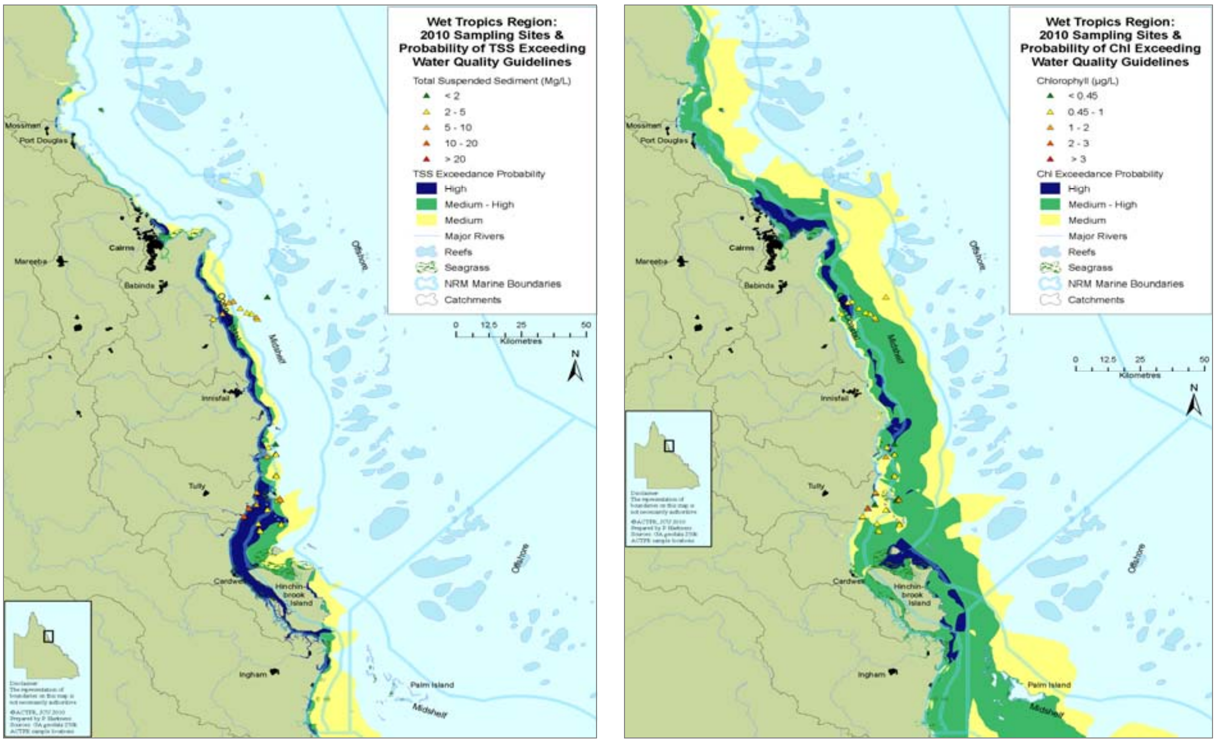


Figure 4.3: Definition of areas in the Wet Tropics region that are most likely to exceed Guideline trigger values based on catchment load information, movement and extent of flood plume waters and the extent and frequency of the common water types for TSS (*left*) and Chl *a* (*right*) concentrations.

Pesticide sampling was undertaken in plume waters in the Wet Tropics region adjacent to the Russell-Mulgrave and Tully Rivers. Sampling adjacent to the Russell-Mulgrave Rivers showed that the highest diuron (260 ng/L) and herbicide equivalent (284 ng/L, sample contained diuron, atrazine, hexazinone and also the insecticide imidachloprid) concentration was at the river mouth before being diluted at the offshore sites (including out to the Frankland Island Group). These samples were all below the Guidelines (900 ng/L) but samples from the Russell River mouth and near High Island exceeded effect (photosynthetic inhibition LOEC) concentrations for seagrass (100 ng/L) and diatoms (>50 ng/L). Note that these samples were collected at the tail end of a moderate flow event and that the concentrations during the initial rise and peak of this event were probably much higher. As has been observed in monitoring from other rivers (Lewis *et al.* 2009), the herbicides display conservative mixing behaviour becoming progressively diluted as the river water is mixed with seawater.

Pesticide sampling adjacent to the Tully River was conducted in December 2009, collected from the mouths of the Tully and Hull Rivers prior to any large event flows; pesticide residues were not detected at this time. Further sampling in early February 2010 was towards the end of a moderate flow event in the Tully River. Diuron was the only herbicide detected in three of the seven samples from this event and concentrations were below Guidelines and PSII effect levels (≤20 ng/L). As with the samples collected off the Russell-Mulgrave River, the concentrations during the early-peak stages of the flow were probably much higher. The passive samplers recorded flow-averaged herbicide equivalent concentrations of 10 ng/L at the mouth of the Tully River during a 38 day deployment (3 March to 1 April, 2010) while the site at Bedarra Island recorded average concentrations of 30 ng/L over the first 29 day deployment (1 January to 8 February, 2010) and 4 ng/L over the second 38 day deployment (3 March to 1 April, 2010). Herbicide residues detected by the passive samplers at these sites included diuron, atrazine, hexazinone, simazine and tebuthiuron.

4.2.2 Biological monitoring results

The assessment of coral community status for the Wet Tropics region is summarised in Table 4.5. The assessment gave a positive score for reefs monitored in the Daintree and Johnstone-Russell/Mulgrave sub-regions of the Wet Tropics region. The condition of these coral communities was assessed as ‘good’ due to their high coral cover that increased rapidly during periods free from acute disturbance, low cover of macroalgae, and moderate to high (but variable) densities of juvenile colonies relative to other regions. The Johnstone-Russell/Mulgrave sub-region also had high settlement of coral larvae to deployed settlement tiles. Levels of chlorophyll and turbidity at core reefs in the Johnstone-Russell/Mulgrave sub-region were generally below Guideline values, in contrast to Snapper Island, in the Daintree sub-region, where turbidity was highly variable and on average exceeded the Guidelines.

Coral reef community condition was assessed as ‘poor’ for reefs in the Herbert Tully sub-region. On average, reefs in this sub-region had relatively high cover of macroalgae and low coral cover due to physical damage and mortality caused by Tropical Cyclone *Larry* in 2006. An improvement in the rate of increase in coral cover and continued ‘good’ assessment of the density of juvenile colonies, however, indicate some recovery potential for these communities, despite the continued high cover of macroalgae. Water quality in this region was only assessed at one site, Dunk Island, where mean levels of turbidity exceeded the Guidelines.

Foram samples from the Barron-Daintree sub-region were collected from two locations at Snapper Island north where the richness of foram increased between 2007 and 2010. This is mainly due to an increase in the number of heterotrophic species, which have also increased in abundance. This change lead to a strong decline in the FORAM index to ~4 in 2010 (FORAM index values of between 2 and 4 reflect environmental conditions that are marginal for coral reef growth; Hallock *et al.* 2003). No assessment of condition based on the FORAM index was carried out for this sub-region because there was only one year (2007) available during the baseline period for comparison. In the Johnstone-Russell/Mulgrave sub-region, there has been a decline in the relative abundance of symbiotic species at all sites leading to a reduced FORAM index and subsequently a ‘very poor’ assessment of foram assemblage condition in 2010 (compared to baseline FORAM index values from 2005 to 2007). In the Herbert Tully sub-region, the FORAM index (only Dunk Island north sampled in 2010) indicated a slight but steady decline since 2005, resulting in a negative rating.

Table 4.5: Regional and sub-regional assessment of benthic reef community condition in the Wet Tropics region. Overall status for five indicators; regional estimates of these indicators are derived from the aggregation of assessments from the reefs within each region (Section 3.2). The colour scheme reflects relative condition of reef communities ranging from red (very poor), orange (poor), yellow (fair), light green (good), dark green (very good). Grey indicates no sampling. Source: Thompson *et al.* (2011).

Reef	Depth (m)	Overall Condition	Coral cover	Change in hard coral cover	Macroalgae cover	Juvenile density	Settlement	FORAM index
Fitzroy Island East	2	+	neutral	neutral	+	-	+	
	5	+++	+	neutral	+	neutral	+	
Frankland Group East	2	+	neutral	neutral	+	neutral	neutral	
	5	+++	neutral	neutral	+	+	+	
Frankland Group West	2	+	+	+	neutral	neutral	-	
	5	- -	+	-	neutral	-	-	-
Fitzroy Island West	2	+++++	+	+	+	+	+	
	5	+++++	+	+	+	+	+	neutral
High Island East	2	+	+	neutral	+	-	neutral	
	5	+++	+	neutral	+	neutral	+	
High Island West	2	+	+	neutral	+	-	neutral	
	5	+	neutral	+	+	-	neutral	-
Sub-regional assessment		🟩	🟩	🟩	🟩	🟨	🟩	🟥

Seagrass meadows were monitored at reef and coastal sites at four locations (8 sites) in the Wet Tropics region. In 2009/10, seagrass cover in the north of the region was consistently high and either expanded or stabilised, however cover in the south declined (Figure 4.4). Seagrass in the region was growing in low light and nutrient enriched (elevated nitrogen) environments. Seed banks and reproductive effort across the region decreased below the GBR long-term average of twenty percent, indicating lower recovery potential to disturbances. Leaf tissue nutrient ratios indicated a potentially higher light environment in reef habitats than coastal habitats. Leaf tissue nutrient ratios also indicated high and increased nitrogen availability at both coastal locations and Dunk Island. Epiphytic fouling of seagrass leaves increased at most locations and was well above the GBR long-term average. Overall the status of seagrass in the region was rated as ‘fair’.

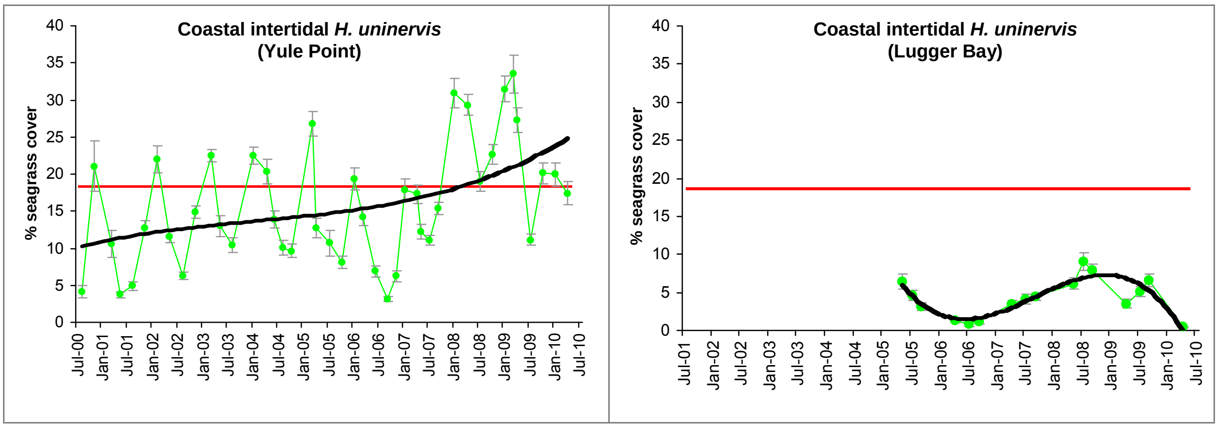


Figure 4.4: Changes in seagrass abundance (% cover) of coastal intertidal *Halodule uninervis* meadows monitored in the Wet Tropics region from 2000 to 2010. Red line = GBR long-term average for coastal habitats (the average of all sites pooled).

4.3 Burdekin region

The Burdekin region includes the Black, Burdekin, Don, Haughton and Ross River catchments as well as several smaller coastal catchments, all of which discharge into the GBR lagoon. The dominant land use in the region is cattle grazing with sugar cane in the coastal catchments. Rainfall in the region is lower than other regions within tropical Queensland because of its geographical location, although there is considerable year to year variation, with 75% of the annual rainfall received during December to March. River discharge, especially from the Burdekin River, can be quite high due to the size of the catchment.

All components of the MMP are measured in the Burdekin region.

4.3.1 Water quality results

The *in situ* Water Quality Index rated two sites located in the mid-shelf as ‘good’, while the Magnetic Island site (closer to the mainland and to riverine influence) had a ‘very poor’ rating (Table 4.6). 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.

Table 4.6: Water quality status in the Burdekin region sampled in 2009/10. Water quality index rating: red (very poor), orange (poor), yellow (fair), light green (good), dark green (very good).

Region	Location	Turbidity/ SS	Chlorophyll	PN	PP	Secchi
Burdekin	Pelorus / Orpheus Island	2	1	2	2	0
	Pandora Reef	2	1	2	2	0
	Magnetic Island	0	2	0	0	0

Analysis of the remote sensing data in the Burdekin region showed that the annual mean values of chl *a* exceeded the Guideline value (0.45 µg/L) in 65% of the inshore area with low exceedances in the midshelf and offshore areas (Table 4.7). Exceedance of the annual mean TSS Guideline value (2 mg/L) in the inshore and midshelf areas occurred in thirty percent of the inshore area and none of the midshelf area. Thirty-nine percent of the offshore areas exceeded the TSS Guideline value for offshore areas (0.7 mg/L). This result is considered to be unusual and may be related to delineation of the cross shelf boundaries and Guideline values in the offshore area, but warrants further investigation (refer also to discussion in Section 5). In contrast, when the median was used for the assessment no exceedance was recorded for the midshelf and offshore areas in both seasons.

Table 4.7: Summary of the annual exceedance of Guideline values for chl *a* and TSS in the Burdekin region.

			Chl *a*: Relative area (%) of the water body where annual mean value exceeds the Guideline value (inshore and midshelf = 0.45 µg/L; offshore = 0.4 µg/L)		TSS: Relative area (%) of the water body where annual mean value exceeds the Guideline value (inshore and midshelf = 2 mg/L; offshore = 0.7 mg/L)	
Waterbody	Surface Area (km^2)	Number valid obs.	Mean > trigger	Median > trigger	Mean > trigger	Median > trigger
Inshore	3,971	1	65%	64%	39%	19%
Midshelf	11,065	2	2%	2%	0%	0%
Offshore	26,560	3	0%	0%	30%	0%

Note: 'Surface Area' is the surface area in square kilometres for each of the three reporting water bodies for this region. The rating of valid observations is classified as: 1= <500,000 valid observations; 2 = 500,000-1,000,000 valid observations; 3 = 1,000,000-2,000,000 valid observations; 4 = >2,000,000 valid observations. A greater number of valid observations should provide greater confidence in the results. 'Mean > trigger' and 'Median > trigger' report the relative area for each water body where the mean or the median exceeded the trigger value. Values higher than 50% are shaded grey.

In the Burdekin region, the estimated freshwater extent using CDOM values from satellite imagery for the 2009/10 wet season (November 2009 to April 2010) was 3,599 km^2 while in the 2008/09 wet season it was 9,733 km^2. This reflects the high freshwater discharge from the Burdekin River that was ~1.3 times the median value while the 2008/09 flow was more than five times the annual median flow.

Pesticide monitoring was conducted at three sites in the Burdekin region. Atrazine was frequently the dominant PSII-herbicide at both Cape Cleveland and Magnetic Island in the Burdekin region, which is indicative of the dominance of atrazine in loads from rivers in this region. The highest maximum concentrations of tebuthiuron are observed in the Burdekin region (2.2–4.7 ng/L) and at North Keppel Island (Fitzroy region), and was the only PSII herbicide detected in Burdekin River plumes. Metolachlor (5.8 ng/L) was also detected at Cape Cleveland and no Guideline trigger value exists to assess the ecological consequences of this concentration of metolachlor. An interim working level for marine waters from ANZECC and ARMCANZ exists for metolachlor and the detected concentration was below this working level.

The Burdekin River experienced a moderate flood event in 2009/10, with a peak of almost 281,442 ML (see Table 3.4) on 22 February 2010. In 2010, sampling in the Burdekin plume took place at only one time on the 24 February 2010; samples were collected only at the mouth and slightly north. Due to the low number of samples collected in the Burdekin plume, the data was combined with results from the 2007/08 and 2008/09 sampling period.

Three samples for pesticide analysis were collected in the vicinity of the Burdekin River mouth during the peak of a moderate flow event on 24 February 2010. Tebuthiuron was the only herbicide detected in all three samples at 10 ng/L.

Figure 4.5 shows the water types that have been defined for Burdekin River flood waters using a compilation of plume extents. The very turbid inshore plume can be seen moving north and offshore from the Burdekin mouth, almost reaching the offshore reefs. There is also a secondary plume visible from the Burdekin River, moving north. Field sampling was used to validate the water type areas. TSS and chl *a* concentrations from 2010 sampling are also shown on the water type maps.

The overall patterns of the salinity profiles versus TSS, DIN and chl *a* concentrations for the Burdekin River plume from 2007/08 to 2009/10 are consistent, with TSS falling out rapidly in the lower salinity ranges, and DIN concentrations reducing rapidly in the middle salinity ranges corresponding to the higher chl *a* measurements and indicating the zone of higher biological activity.

Using a combination of information from catchment loads of TSS, DIN and PSII herbicides, the frequency and exposure of plume waters and long-term information on the water quality characteristics of water types most commonly found within the marine regions, the areas most likely to exceed Guidelines for TSS and chl *a* in the Burdekin region have been defined and are shown in Figure 4.6 (refer to Devlin *et al.* (2010b) for a detailed description of the methods used to produce these maps).

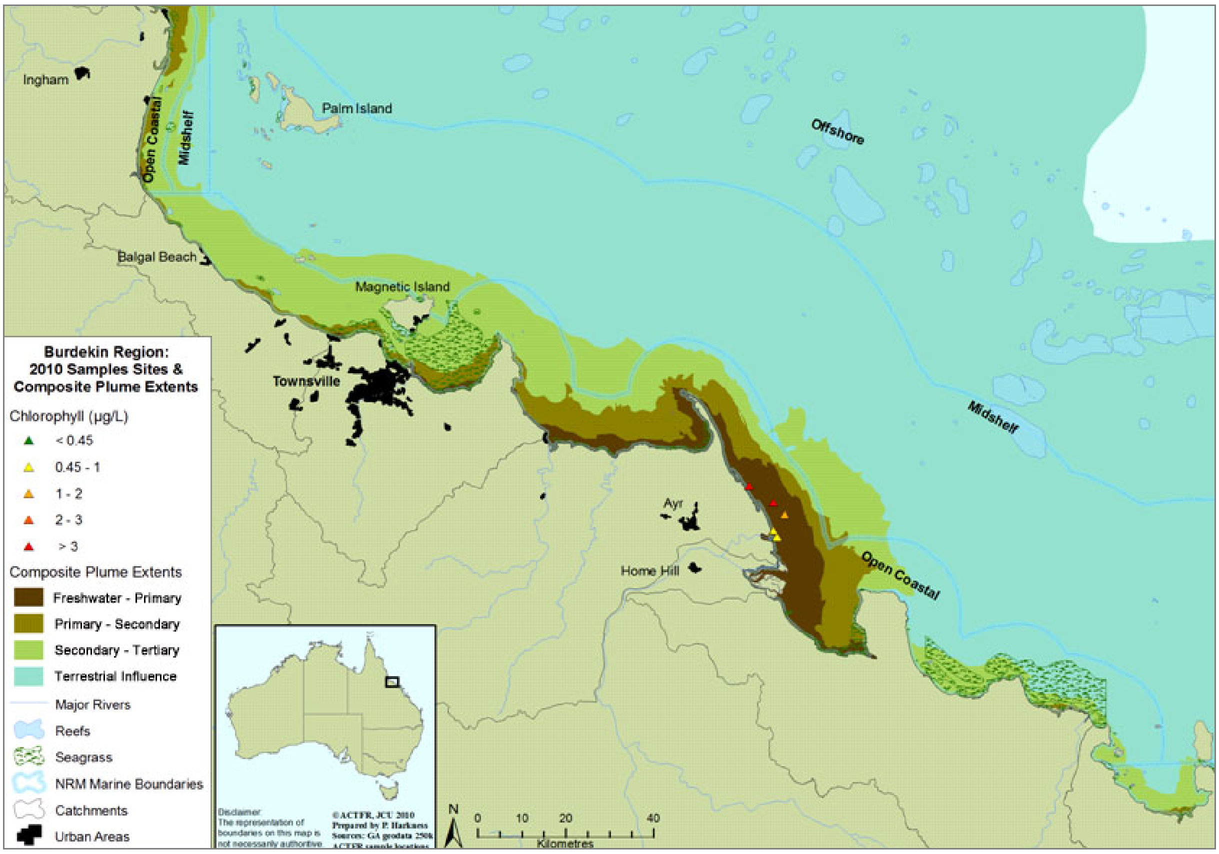


Figure 4.5(a): Classification of the water types commonly found within the Burdekin region: TSS sampled over the 2009/10 wet season.

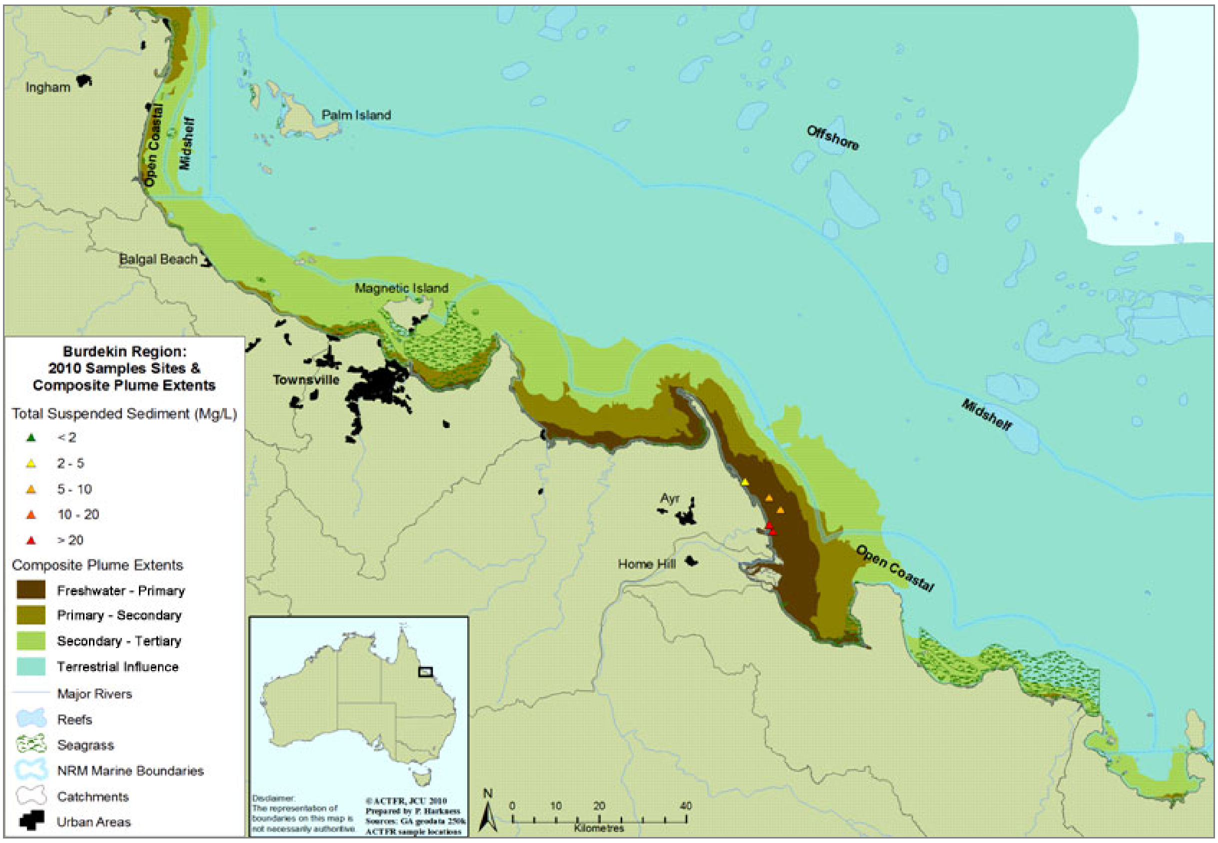


Figure 4.5(b): Classification of the water types commonly found within the Burdekin region: chl *a* concentrations sampled over the 2009/10 wet season.

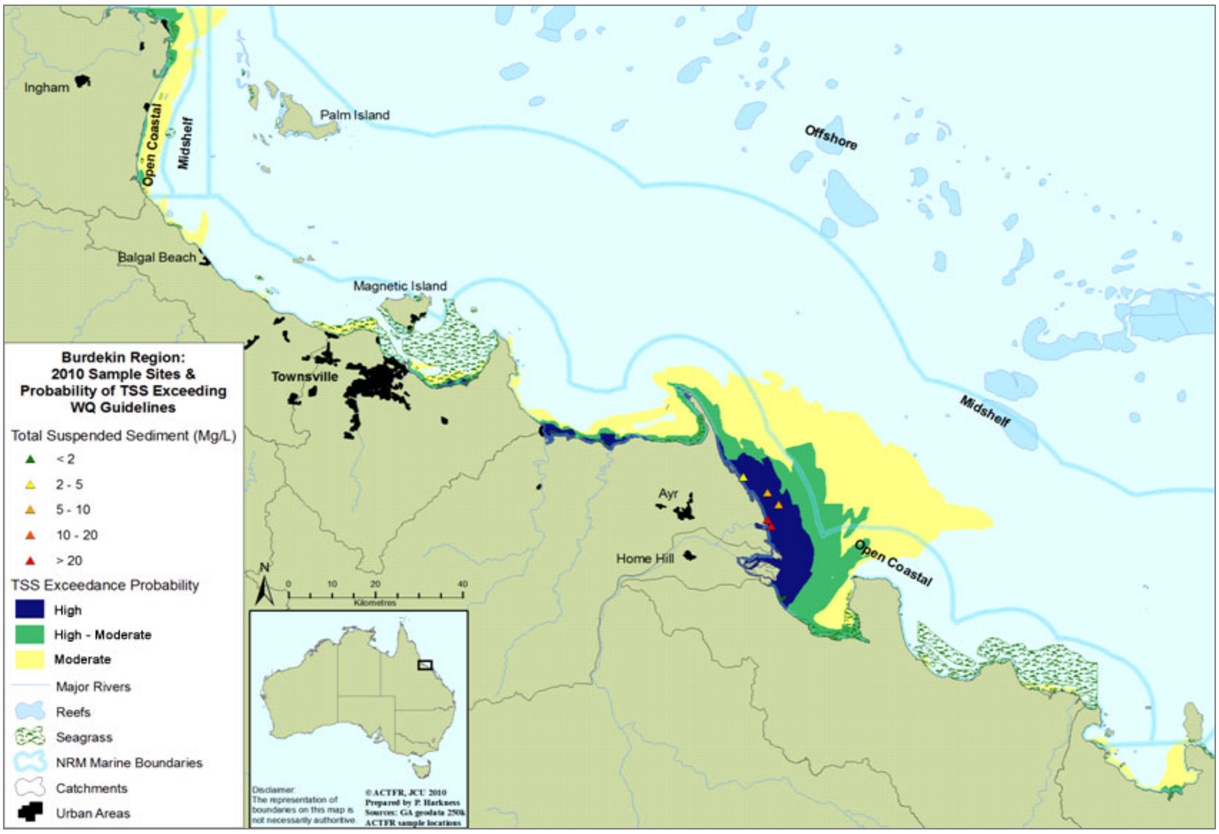


Figure 4.6(a): Definition of areas in the Burdekin region that are most likely to exceed Guideline trigger values based on catchment load information, movement and extent of flood plume waters and the extent and frequency of the common water types for TSS.

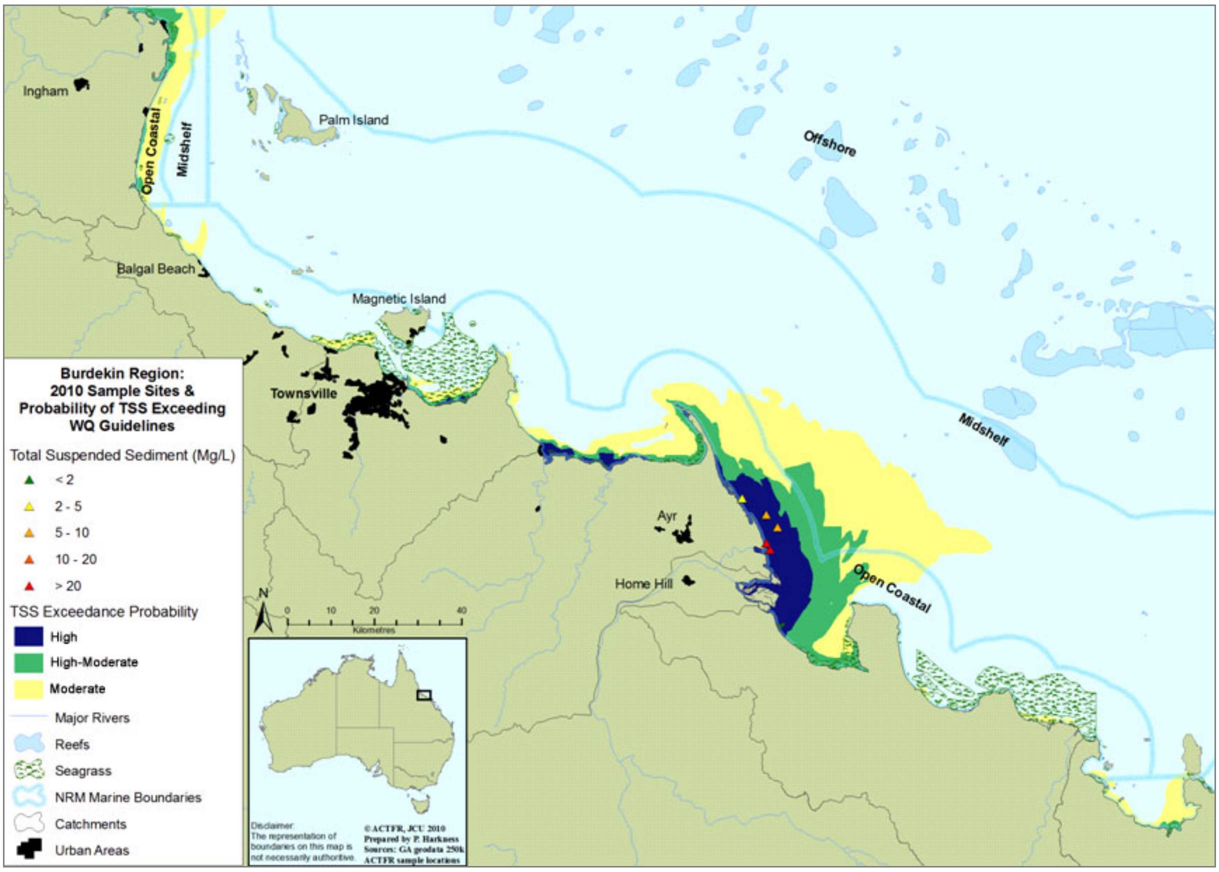


Figure 4.6(b): Definition of areas in the Burdekin region that are most likely to exceed Guideline trigger values based on catchment load information, movement and extent of flood plume waters and the extent and frequency of the common water types for chl *a* concentrations.

4.3.2 Biological monitoring results

Coral reef community condition was assessed as ‘poor’ for reefs in the Burdekin region (Table 4.8). On average, reefs in this region had relatively high cover of macroalgae and low coral cover, that is increasing at a rate below modelled expectations (Thompson and Dolman 2010). The lack of reef recovery is of concern as there have been no obvious disturbances since coral bleaching impacted reefs in this region in 2002. Settlement of spat to tiles and numbers of juvenile colonies continue to be low. The regionally low coral cover may be limiting the availability of coral larvae, which may explain the regionally low density of juvenile colonies. Water quality in this region is characterised by high chl *a* values that on average exceed the Guidelines however, with relatively low turbidity at some reef sites, implying some degree of eutrophication.

In the Burdekin region, the density and richness of foraminifera and values of the FORAM index were variable amongst reefs and times. Increases in the proportion of heterotrophic species resulted in a negative condition rating of the communities of foraminifera (Table 4.8), indicating possible environmental stress in this region over recent years, similar to the coral communities.

Seagrass meadows were monitored at reef and coastal habitats at two locations (four sites) in the Burdekin region. Seagrass abundance (Figures 4.7 and 4.8) and meadow extent declined at both habitats and was in a ‘poor’ state throughout the 2009/10 monitoring period. Seagrass leaf tissue nutrient concentrations indicated potential light limitation with elevated phosphorus and nitrogen in coastal habitats. In reef habitats, tissue nutrient concentrations indicated more available light, with a high nitrogen pool but the plants are limited by a smaller phosphorus pool. Seed banks also declined across the region and reproductive effort at reef habitats was ‘poor’, raising concerns about the ability of reef meadows to recover from disturbance. Low epiphyte abundance may be a consequence of the seagrass loss experienced across this region. Extreme canopy water temperatures of 43°C were experienced by seagrass meadows in this region and were the hottest measured across the entire GBR in 2009/10. Overall the status of seagrass condition in the region was rated as ‘moderate’.

Table 4.8: Assessment of benthic reef community condition for the Burdekin region. Overall status for five indicators; regional estimates of these indicators are derived from the aggregation of assessments from the reefs within each region (see Section 3.2). The colour scheme reflects relative condition of reef communities ranging from red (very poor), orange (poor), yellow (fair), light green (good), dark green (very good). Grey indicates no sampling. Source: Thompson *et al.* (2011).

Reef	Depth (m)	Overall Condition	Coral cover	Change in hard coral cover	Macroalgae cover	Juvenile density	Settlement	FORAM index
Orpheus Island East	2	neutral	neutral	neutral	+	-		
	5	neutral	neutral	neutral	+	-		
Pelorus Island and Orpheus Island West	2	neutral	-	-	+	+		
	5	-	neutral	-	+	neutral	-	-
Havannah Island	2	-	-	neutral	+	-		
	5	-	-	+	-	neutral		
Pandora Reef	2	- - - -	-	-	-	-		
	5	- - - -	-	neutral	-	-	-	neutral
Lady Elliot Reef	2	-	neutral	-	-	+		
	5	neutral	neutral	-	+	neutral		
Middle Reef		+	neutral	-	+	+		
Geoffrey Bay	2	- - -	-	-	-	neutral		
	5	- -	neutral	-	-	+	-	-
Regional assessment		🟧	🟧	🟧	🟨	🟨	🟥	🟥

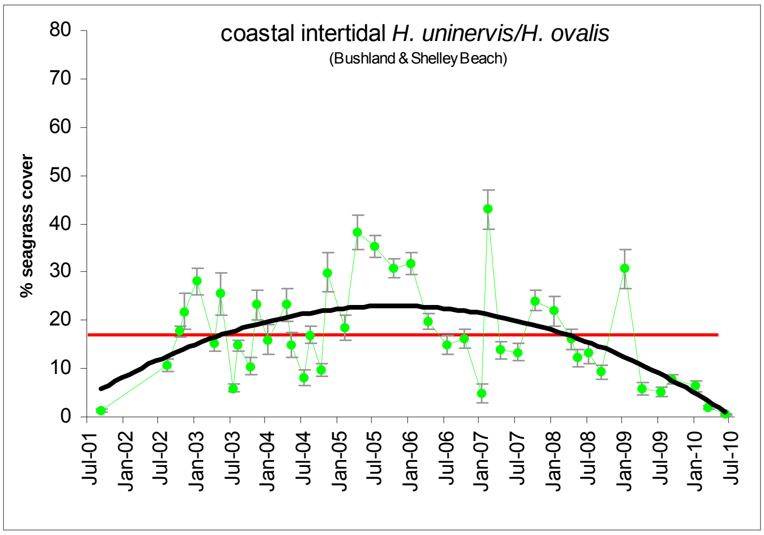


Figure 4.7: Change in seagrass abundance (percentage cover) at coastal intertidal meadows in the Burdekin region from 2001 to 2010. Red line = GBR long-term average for coastal habitats (average of all sites pooled).

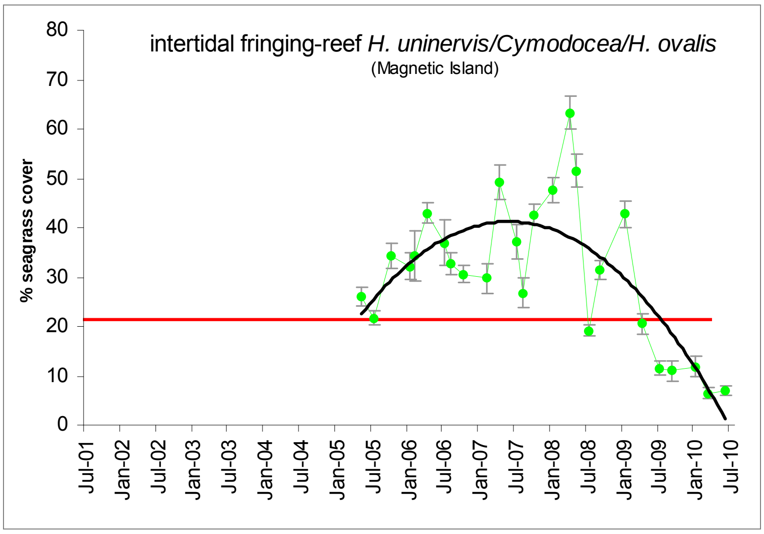


Figure 4.8: Change in seagrass abundance (percentage cover) at intertidal meadows on fringing reef platforms in the Burdekin region from 2001 to 2010. Red line = GBR long-term average for reef habitats (average of all sites pooled).

4.4 Mackay Whitsunday region

The Mackay Whitsunday region comprises of 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 grazing and cropping (mainly sugar cane on coastal plains), and minor urbanisation. The adjacent coastal and inshore marine areas have a large number of high continental islands with well-developed fringing reefs.

All components of the MMP are measured in the Mackay Whitsunday region.

4.4.1 *Water quality results*

The *in situ* Water Quality Index for the three sites in the Mackay Whitsunday region was rated 'fair' for two sites (Daydream and Double Cone Islands) and 'poor' at one site (Pine Island; Table 4.9). 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 2007/08 and 2008/09 at Daydream Island.

Table 4.9: Water quality status in the Mackay Whitsunday region sampled in 2009/10. Water quality index rating: red (very poor), orange (poor), yellow (fair), light green (good), dark green (very good).

Region	Location	Turbidity/ SS	Chlorophyll	PN	PP	Secchi
Mackay Whitsunday	Double Cone Island	1	1	2	2	0
	Daydream/West Molle Island	0	1	2	2	0
	Pine Island	0	0	2	2	0

Analysis of the remote sensing data in the Mackay Whitsunday region shows that the annual mean values of chl *a* exceeded the Guideline value (0.45 µg/L) in 32% of the inshore area with a gradient to the offshore areas with no exceedances (Table 4.9). Similar exceedance values were retrieved if the median was used for the assessment. Exceedances of the mean TSS Guideline values of the inshore and midshelf areas (2 mg/L) were exceeded in 69% and 40% of the areas respectively (Table 4.10). The offshore TSS Guideline value (0.7 mg/L) was exceeded in 64% of the offshore area. These relatively high results may be due to high river flows in the region over an extended period. However, this result warrants closer examination as *in situ* results for TSS in this region were also elevated at some sites at different times of the year and the annual mean turbidity levels at Pine and Daydream Islands exceeded the Guidelines in all three years of monitoring. The mean and median values for the TSS concentration differed substantially (for all water bodies and seasons) with the mean values were ~2–3 times higher than medians.

Table 4.10: Summary of the annual exceedance of Guideline values for chl *a* and TSS in the Mackay Whitsunday region.

			Chl *a*: Relative area (%) of the water body where annual mean value exceeds the Guideline value (inshore and midshelf = 0.45 µg/L; offshore = 0.4 µg/L)		TSS: Relative area (%) of the water body where annual mean value exceeds the Guideline value (inshore and midshelf = 2 mg/L; offshore = 0.7 mg/L)	
Waterbody	Surface Area (km^2)	Number valid obs.	Mean > trigger	Median > trigger	Mean > trigger	Median > trigger
Inshore	4576	1	32%	21%	69%	30%
Midshelf	11389	2	3%	0%	40%	10%
Offshore	25580	3	0%	2%	64%	3%

For the Mackay Whitsunday region, the estimated freshwater extent using CDOM values from satellite imagery for the 2009/10 wet season (November 2009 to April 2010) was 5,557 km^2 while in the 2008/09 wet season it was 3,507 km^2. The larger freshwater extent in 2009/10 correlates with freshwater discharges from the Proserpine, O'Connell, Pioneer and Plane Rivers above median flows.

Pesticide monitoring was conducted at five sites in the Mackay Whitsunday region in 2009/10. The Sarina Inlet site had the highest concentrations of most PSII herbicides of all sampling sites, including ametryn (2.3 ng/L), atrazine (170 ng/L), diuron (429 ng/L) and hexazinone (91 ng/L), reflecting its proximity to the coast and riverine inputs from significant areas of sugar cane production. The relative proportions of PSII herbicides are consistent with previous monitoring results in both Plane Creek and Sandy Creek (Rhode *et al.* 2008), which may influence concentrations at this site that show the same relative abundance of diuron > atrazine > hexazinone >> ametryn and tebuthiuron. Atrazine concentrations detected at the Outer Whitsundays site were also high (11 ng/L), and comparable with other high concentrations in the Burdekin (Cape Cleveland) and Fitzroy (North Keppel Island) regions. The Mackay Whitsunday region has previously been identified as a high risk region in terms of pesticide loads (Brodie and Waterhouse 2009) and in terms of PSII herbicides this is reflected in higher PSII-HEq than all other regions in the current monitoring year.

The PSII herbicide profiles in the Pioneer River in the Mackay Whitsunday region were similar to that of the Tully River in the Wet Tropics region, with diuron > atrazine > hexazinone > simazine > ametryn. However the maximum concentrations of each individual PSII herbicide are higher in the Pioneer River by factors of between 3 and 41, with a narrower range of pesticides detected than in the Tully River. Chlorpyrifos was detected in the Pioneer River (0.25–0.69 ng/L) as well as pendimethalin (0.36–7.3 ng/L) and the organochlorine insecticide dieldrin (0.87–2.9 ng/L) the latter which was only detected only in the Pioneer River. The only inshore GBR site in the Mackay Whitsunday region monitored for other pesticides was Outer Whitsunday and no pesticides were detected at this location in 2009/10. The maximum chlorpyrifos concentration in the Pioneer River (0.69 ng/L) exceeded the 99% species protection ANZECC and ARMCANZ Freshwater Guideline. The maximum concentration of the PSII herbicide atrazine (690 ng/L) in the Pioneer River is equivalent to the 99% species protection freshwater ANZECC and ARMCANZ Guideline. The ANZECC and ARMCANZ Interim Working Level for diuron was also exceeded by the maximum diuron concentration (761 ng/L) in the Pioneer River.

Plume waters of three rivers were sampled during the 2009/10 wet season in the Mackay Whitsunday region during multiple flow events that had exceptional flow for all rivers; the Pioneer, Proserpine and O'Connell Rivers (see Table 3.4). Total annual discharges for all four rivers in the region were greater than the long-term river discharge median. The movement of the plume north and offshore was observed using remote sensing images, as well as a vivid green water colour moving offshore, most likely due to phytoplankton (and indicative of the extent of the plume waters).

Figure 4.9 identifies the water types for Mackay Whitsunday river flood waters defined using a compilation of plume extents over the period 2001 to 2010. A turbid inshore plume can be seen in Repulse Bay and in the receiving waters of several small coastal streams. There is also a large secondary plume almost covering the entire coastline of the region, and a tertiary plume extending beyond the outer reef. Field sampling was used to validate the water type areas. TSS and chl *a* concentrations from 2010 sampling are also shown on the water type maps.

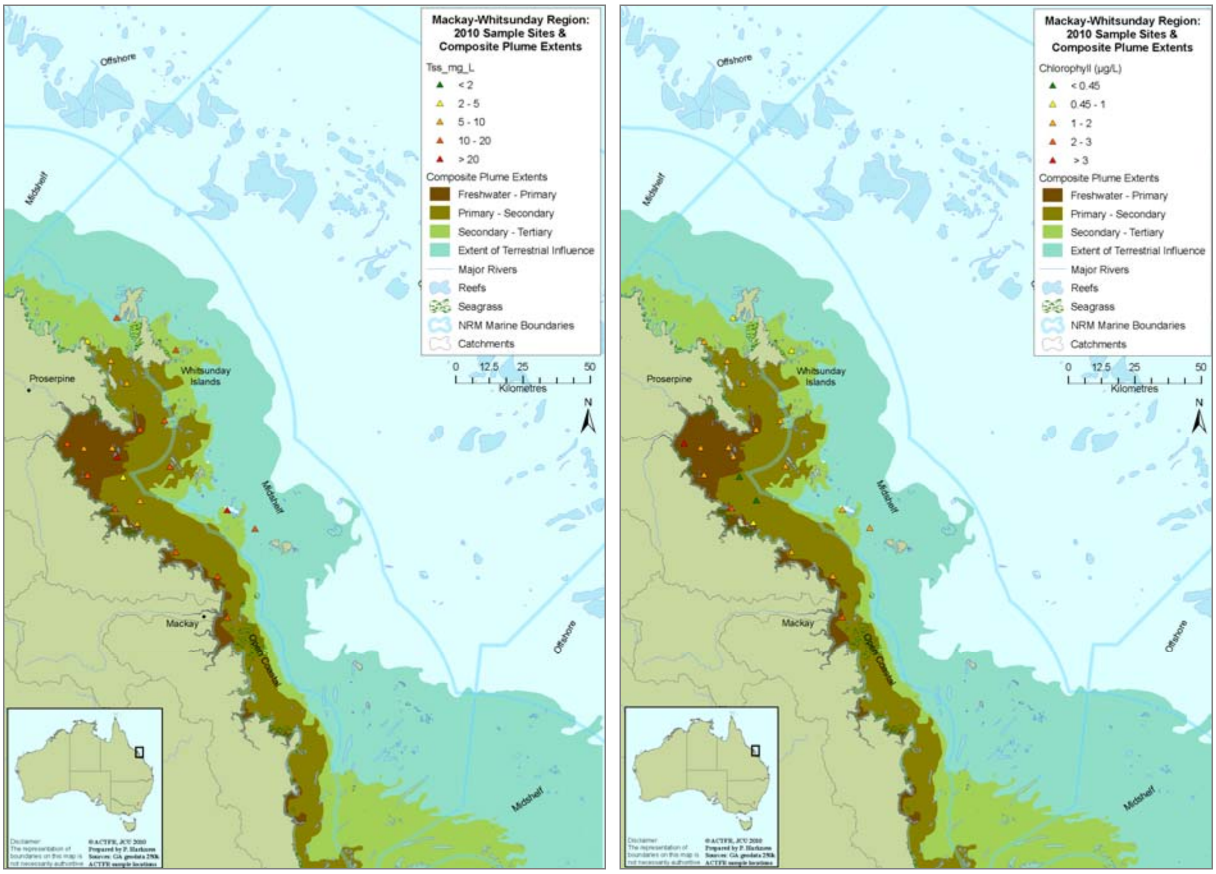


Figure 4.9: Classification of the water types commonly found within the Mackay Whitsunday region: TSS (*left*) and chl *a* (*right*) concentrations sampled over the 2009/10 wet season.

Two sites in the Mackay Whitsunday region with repeated sampling in 2009/10 had chl *a* concentrations that exceeded the Guideline values in two thirds of samples, and TSS concentrations that exceeded the Guideline values in all samples. The frequency of elevated concentrations imply that there were long periods during which chl *a* and TSS concentrations were elevated for extended period of times relative to the high flow periods.

At the time of sampling, river flow rates had reduced slightly and thus the event peak was not measured. All samples were taken in the later stages of the plume in higher salinity waters. The focus was on understanding the extent, temporally and spatially, of plume waters and their longer term impact on the water quality in GBR inshore waters. In all samples, the nutrient concentrations were elevated 2–10 times above baseline levels (Furnas *et al.* 2005).

TSS and chl *a* were all elevated with TSS concentrations ranging 4–26 mg/L, chl *a* concentrations ranging 0.2–3.5 µg/L, and all other water quality parameters also elevated.

These elevated concentrations, in particular chl *a* and CDOM, indicate the spatial and temporal extent of the potentially eutrophic conditions of high nutrients, high phytoplankton biomass and other secondary effects persisting over days to weeks. Initial flood plume sampling occurred about fourteen days after the peak flow for the Pioneer River (see Table 4.2). The second event sampled was four days after peak flow in the Proserpine River but still before the largest event for all rivers (see Table 3.4). Thus the Mackay Whitsunday region would have experienced the highest concentrations in water quality parameters for up to 7–10 weeks over the multiple flow peaks. This is an area of high ecological significance and the number of coral reefs and seagrass meadows impacted by these multiple flood events ranged 1–16% of these ecosystems in the region.

Using a combination of information from catchment loads of TSS, DIN and PSII herbicides, the frequency and exposure of plume waters and long-term information on the water quality characteristics of water types most commonly found within the marine regions, the areas most likely to exceed Guidelines for TSS and chl *a* in the Mackay Whitsunday region has been defined and is shown in Figure 4.10 (refer to Devlin *et al.* (2010b) for a detailed description of the methods used to produce these maps). The number of reefs and seagrass beds located in areas with a high probability of exceeding the Guideline trigger values vary according to the water quality parameters: TSS (28 reefs and 44 seagrass beds) and chl *a* (93 reefs and 306 seagrass beds). The large number of reefs and seagrass beds likely to be exposed to chl *a* exceedances reflects the high DIN concentrations sourced from Mackay Whitsunday catchments and the close proximity of the inshore reef system.

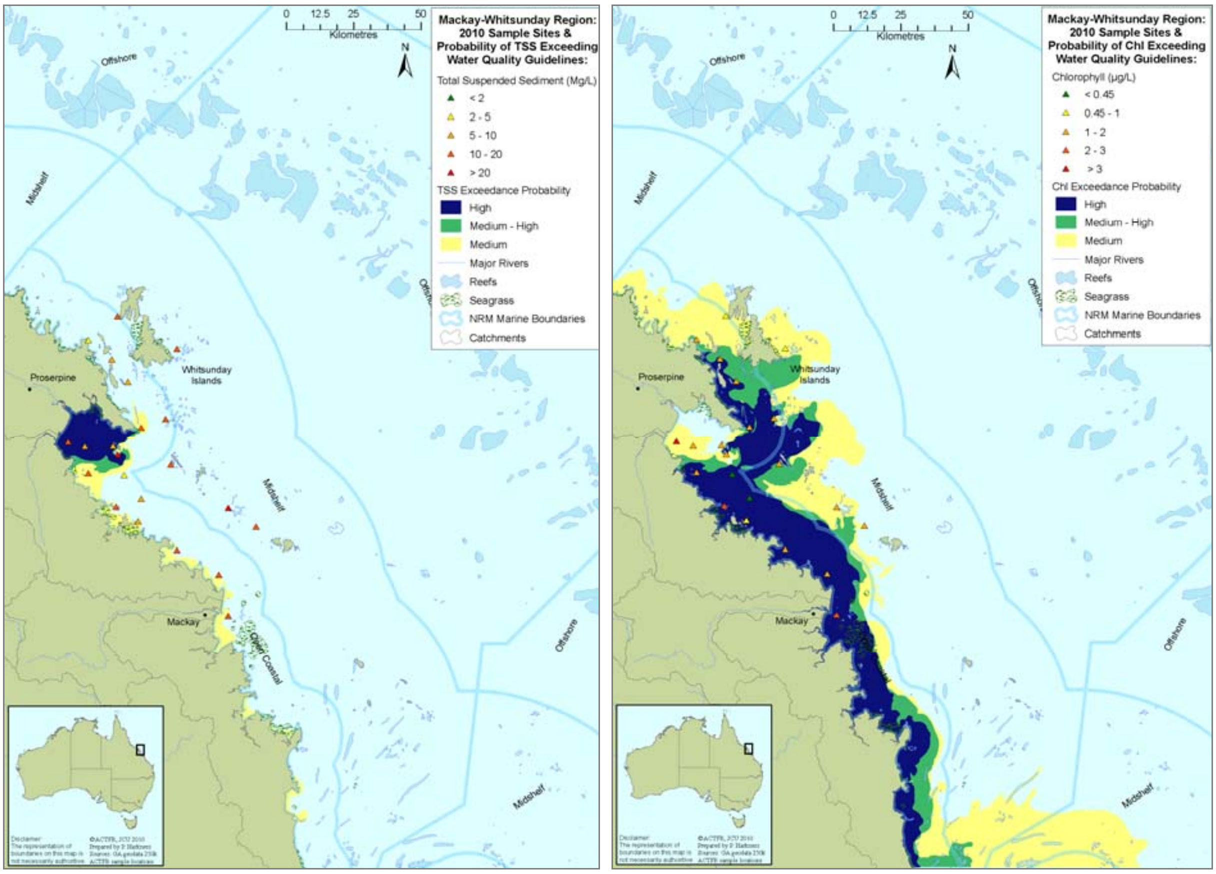


Figure 4.10: Definition of areas in the Mackay Whitsunday region that are most likely to exceed Guideline trigger values based on catchment load information, movement and extent of flood plume waters and the extent and frequency of the common water types for TSS (*left*) and chl *a* (*right*).

Pesticide sampling off the mouth of the O'Connell River was conducted following two separate flow events on 8 February 2010 (moderate flow) and 5 March 2010 (peak flow). The samples from February 2010 were collected at the very end of a small to moderate flow event and as such only diuron residues were detected at very low concentrations (range below detection – 20 ng/L) in two of the five samples collected. Diuron was detected near South Repulse Island (10 ng/L) and from Rabbit Island in the Newry Island Group (20 ng/L). The samples collected in March 2010 followed moderate flows in the O'Connell River. Diuron was detected in seven of the eight collected samples (range 10–50 ng/L) and atrazine (5 of 8 samples) and hexazinone (5 of 8 samples) were also detected. The herbicide equivalent concentrations did not exceed the Guidelines although the sample collected near the mouth of the O'Connell River exceeded effect (photosynthetic inhibition LOEC) concentrations for seagrass (100 ng/L) and diatoms (>50 ng/L).

Samples from the mouth of the Pioneer River were collected in March 2010 following moderate flows, around five days after the event peak. Diuron was detected in all four samples which were collected along a transect from the mouths of the Pioneer River and Sandy Creek out to Keswick Island, but the concentrations were below the Guidelines and known effect concentrations (range 10–20 ng/L). No other herbicides were detected in these samples.

4.4.2 Biological monitoring results

Overall coral reef community condition in the Whitsunday Mackay region was assessed as 'moderate' despite a substantial decline in coral cover at Daydream Island due to Tropical Cyclone *Ului* in March 2010 (Table 4.11). The cover of macroalgae remained low, offsetting declines in the relative density of juvenile colonies and coral cover. The settlement of coral larvae to tiles was low relative to other regions, and the rate of increase in coral cover in the absence of disturbance events was well below modelled expectations (Thompson and Dolman 2010). In combination, these poor results raise concerns over the long-term resilience of local coral communities in this region. The sediment at these reefs consists of a high proportion of fine particles (silt and clay), which increased after repeated flood events in 2007/08 and 2008/09. Water quality monitoring showed relatively high chl *a* and turbidity levels, with averages at all three core reef sites near or above the Guideline trigger values.

Foram communities in the Mackay Whitsunday region are distinct from those in other regions, as the diversity of symbiont bearing forams is generally lower resulting in lower FORAM indices. Over the period 2005 to 2007 the density, richness and composition of foram assemblages remained relatively stable on most reefs however, the density of heterotrophic species increased significantly at some sites (e.g. Daydream Island, Pine Island). These findings resulted in neutral or negative assessments of condition for this region (Table 4.11).

Intertidal seagrass meadows were monitored at reef, coastal and estuarine sites at three locations (six sites) in the Mackay Whitsunday region in 2009/10. Seagrass abundance declined significantly at all intertidal habitats throughout the region and by late in the 2009/10 wet season the condition of seagrass meadows at all but one site was rated as poor (Figures 4.11, 4.12 and 4.13). Seagrass tissue nutrient concentrations indicate continued light limitation and elevated nutrients (particularly nitrogen). Although nitrogen concentrations remained high in reef and coastal habitats, the plants were limited by a decreasing phosphorus pool (i.e. phosphorus limited). Low epiphyte abundance was observed and appears to be the consequence of seagrass decline experienced across the region. Seed banks and reproductive effort also declined at reef and coastal sites, raising concerns about the ability of local seagrass meadows to recover from disturbance. Overall the status of seagrass condition in the region was rated as 'fair'.

Table 4.11: Assessment of benthic reef community condition for the Mackay Whitsunday region. Overall status for five indicators; regional estimates of these indicators are derived from the aggregation of assessments from the reefs within each region (see Section 3.2). The colour scheme reflects relative condition of reef communities ranging from red (very poor), orange (poor), yellow (fair), light green (good), dark green (very good). Grey indicates no sampling. Source: Thompson *et al.* (2011).

Reef	Depth (m)	Overall condition	Coral cover	Change in hard coral cover	Macroalgae cover	Juvenile density	Settlement	FORAM index
Double Cone Island	2	- -	neutral	-	+	-	-	
	5	neutral	+	-	+	-	neutral	neutral
Daydream Island	2	- -	neutral	-	+	-	-	
	5	-	neutral	-	+	-	neutral	-
Hook Island	2	neutral	neutral	neutral	+	-	N/A	
	5	neutral	neutral	-	+	neutral	N/A	
Dent Island	2	+++	+	neutral	+	+	N/A	
	5	-	neutral	-	+	-	N/A	
Shute Island and Tancred Island	2	+++	+	neutral	+	+	N/A	
	5	+	neutral	-	+	+	N/A	
Pine Island	2	- - - -	neutral	-	-	-	-	
	5	-	neutral	-	+	-	neutral	neutral
Seaforth Island	2	neutral	neutral	-	neutral	+	N/A	
	5	neutral	-	-	+	+	N/A	
Regional assessment		🟨	🟨	🟥	🟩	🟧	🟧	🟧

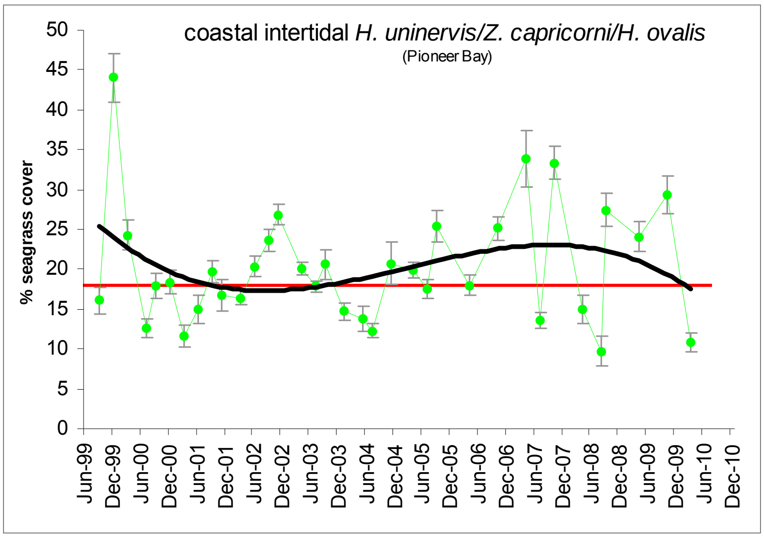


Figure 4.11: Change in seagrass abundance (percentage cover) at the coastal intertidal meadows (Pioneer Bay) in the Mackay Whitsunday region from 1999 to 2010. Red line = GBR long-term average for coastal habitats (average of all sites pooled).

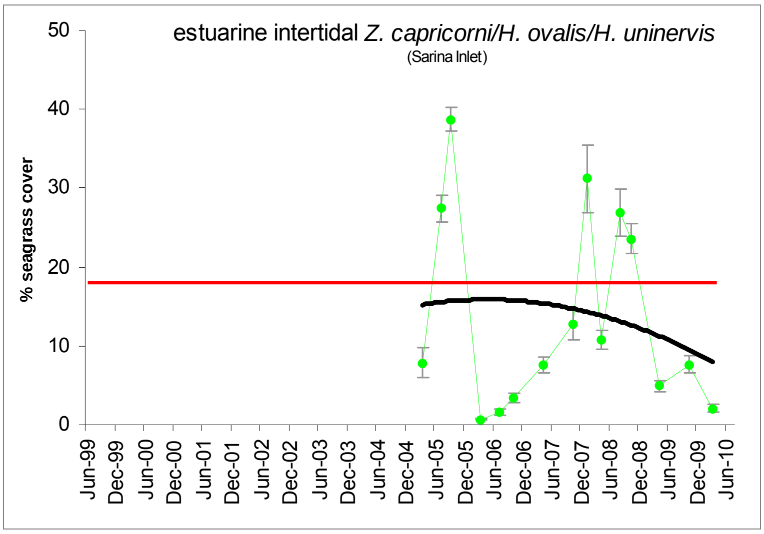


Figure 4.12: Change in seagrass abundance (percentage cover) at intertidal meadows located in estuaries in the Mackay Whitsunday region from 1999 to 2010. Red line = GBR long-term average for estuarine habitats (average of all sites pooled).

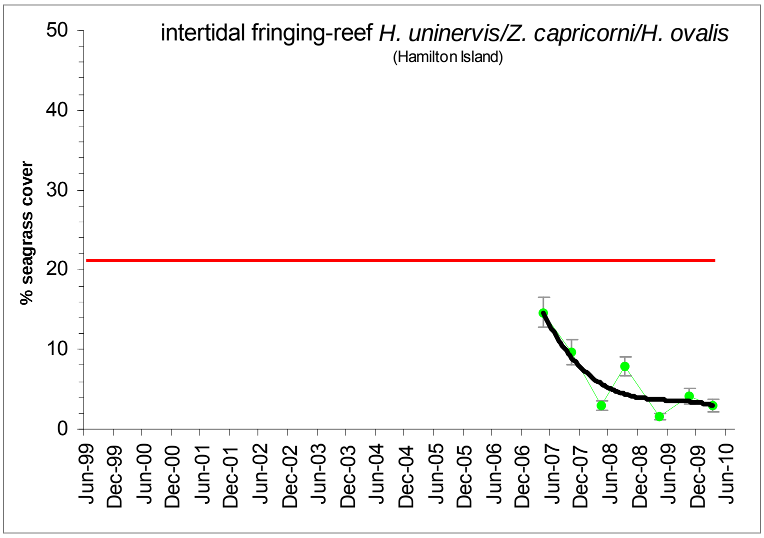


Figure 4.13: Change in seagrass abundance (percentage cover) at intertidal meadows located on a fringing reef in the Mackay Whitsunday region from 1999 to 2010. Red line = GBR long-term average for reef habitats (average of all sites pooled).

4.5 Fitzroy region

The Fitzroy region is a large dry tropical catchment with cattle grazing as the primary land use. 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 sediments and associated nutrients. The main river system influencing the region is the Fitzroy River. Intensive cropping of grains exists in the upper catchment areas.

All components of the MMP are measured in the Fitzroy region.

4.5.1 Water quality results

The *in situ* Water Quality Index rated as 'very poor' in only the most inshore site, Pelican Island.. At this site, the annual means of turbidity and chlorophyll exceeded the Guidelines, and long-term means of particulate phosphorus and Secchi depth also did not comply. The Water Quality Index at Barren and Humpy Islands was rated 'very good' (Table 4.12).

Table 4.12: Water quality status in the Fitzroy region sampled in 2009/10. Water quality index rating: red (very poor), orange (poor), yellow (fair), light green (good), dark green (very good).

Region	Location	Turbidity/ SS	Chlorophyll	PN	PP	Secchi
Fitzroy	Barren Island	2	1	2	2	2
	Humpy Island	2	1	2	2	2
	Pelican Island	0	0	2	0	0

Analysis of the remote sensing data in the Fitzroy region showed that the annual mean values of chl *a* exceeded the Guideline value (0.45 µg/L) in 66% of the inshore area with a gradient to the offshore area where there were no exceedances (Table 4.13). Similar exceedance values were retrieved when the median was used for the assessment. The TSS Guidelines values in the inshore and midshelf areas (2 mg/L) were exceeded in 43% of the Inshore area and 7% of the midshelf area. Fifty percent of the offshore area exceeded the TSS Guideline value for offshore areas (0.7 mg/L) (Table 4.13). When the median was used for the assessment low exceedance was recorded for the midshelf and offshore areas in both seasons. The mean and median values for the TSS concentration differed for all regions and seasons. Only the mean values of TSS exceeded the Guidelines values for the inshore area for both seasons.

For the Fitzroy region, the estimated freshwater extent using CDOM values from satellite imagery for the 2009/10 wet season (November 2009 to April 2010) was 7,882 km^2, 4,770 km^2 for the 2008/09 wet season, while the 2007/08 wet season was 8,080 km^2. Freshwater discharge was four times above the long-term median flow for the Fitzroy River, and comparable with the flows of the 2007/08 wet season when the largest flood since 1991 occurred.

Table 4.13: Summary of the annual exceedance of Guideline values for chl *a* and TSS in the Fitzroy region.

			Chl *a*: Relative area (%) of the water body where annual mean value exceeds the Guideline value (inshore and midshelf = 0.45 µg/L; offshore = 0.4 µg/L)		TSS: Relative area (%) of the water body where annual mean value exceeds the Guideline value (inshore and midshelf = 2 mg/L; offshore = 0.7 mg/L)	
Waterbody	Surface Area (km^2)	Number valid obs.	Mean > trigger	Median > trigger	Mean > trigger	Median > trigger
Inshore	5,919	1	66%	55%	43%	34%
Midshelf	18,421	3	5%	4%	7%	2%
Offshore	48,664	4	0%	12%	50%	0%

Note: 'Surface Area' is the surface area in square kilometres for each of the three reporting water bodies for this region. The rating of valid observations is classified as: 1= <500,000 valid observations; 2 = 500,000-1,000,000 valid observations; 3 = 1,000,000-2,000,000 valid observations; 4 = >2,000,000 valid observations. A greater number of valid observations should provide greater confidence in the results. 'Mean > trigger' and 'Median > trigger' report the relative area for each water body where the mean or the median exceeded the trigger value. Values higher than 50% are shaded grey.

Pesticide monitoring was conducted at one site (North Keppel Island) in the Fitzroy region. The maximum concentrations of both atrazine (8.4 ng/L) and tebuthiuron (14 ng/L) exceed the maximum concentration of diuron (6.4 ng/L) in 2009/10. However, this is still the highest diuron concentration that has been detected at this site over the five years of monitoring and has contributed significantly to the observed increase in the Pesticide Index at this site. It is also important to note that hexazinone (1.6–2.1 ng/L) has been reported at this site for the first time since monitoring commenced in 2005.The time averaged concentration estimated for tebuthiuron approached the Guideline value for this PSII herbicide which indicates that acute exposures (short duration, high concentration) within this period may have exceeded the Guideline.

In 2009/10, sampling in the Fitzroy River plume took place during two field trips in April several days (15–25) past the peak flow period. The total volume of freshwater moving into the marine environment was significant, with over 2,193,040 ML of water discharging from the Fitzroy catchment over the 2009/10 wet season. Note that the delay in sampling reflects both the inclement weather that was experienced during the latter part of March and early April, and importantly, the shift in focus of the flood plume monitoring program to extend the sampling for days to weeks following peak flow to capture the full extent of both the secondary and tertiary water types, and to identify the longer term impact of the less visible plume constituents.

Figure 4.14 identifies the water types that have been defined for Fitzroy River flood waters using a compilation of plume extents over the period 2001 to 2010. These maps identify a small area out of the Fitzroy and local rivers that would be dominated by primary water characteristics during the wet seasons. There is a much larger area characterised by the occurrence of secondary waters, extending north for at least one hundred kilometres, and offshore past and around the Keppel Island reefs.

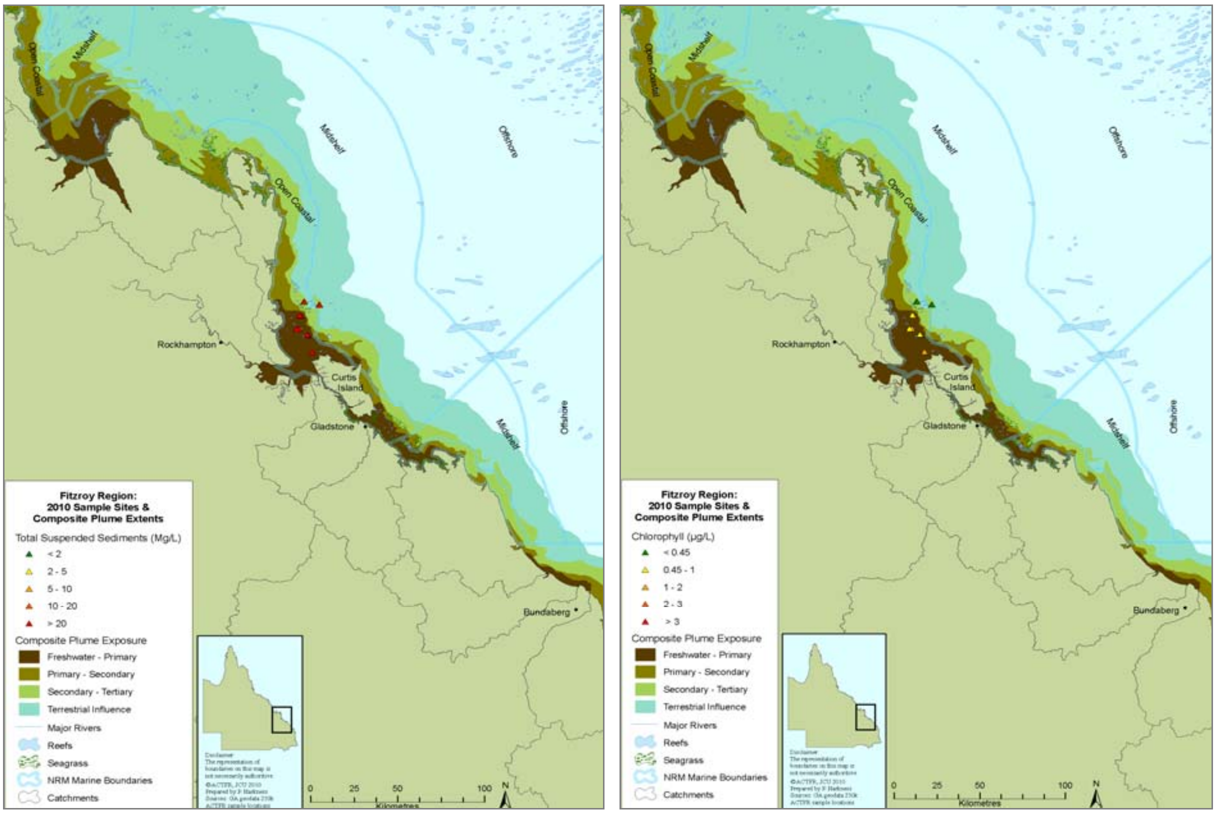
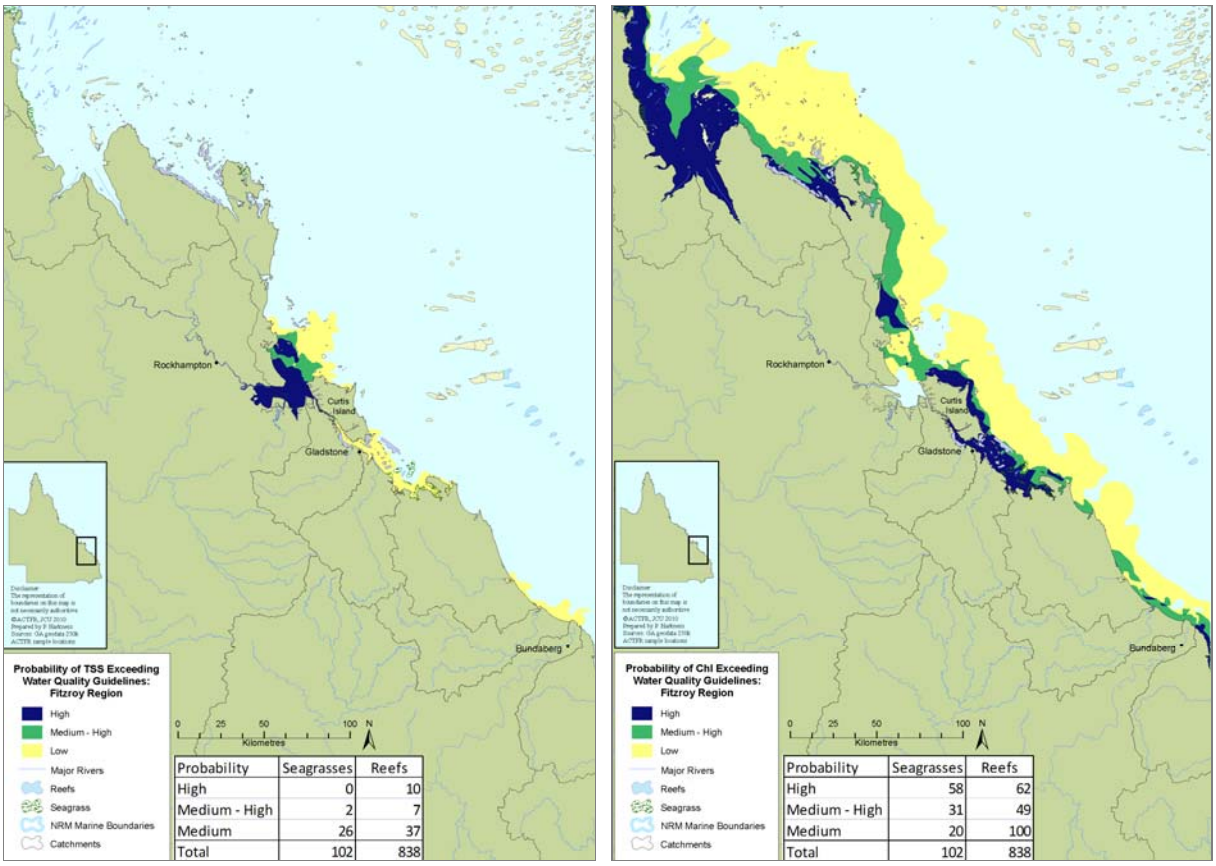


Figure 4.14: Classification of the water types commonly found within the Fitzroy region: TSS (*left*) and Chl *a* (*right*) concentrations sampled over the 2009/10 wet season.

Due to the limited number of samples taken in the 2010 sampling year, concentrations for four water quality parameters (chl *a*, TSS, DIN and DIP) were overlaid on the salinity scatter plots with 2008 and 2010 data (refer to Devlin *et al.* (2010a) for more detail). In both years, the overall patterns are clear, with TSS falling out rapidly in the lower salinity ranges, with DIN concentrations reducing rapidly in the middle salinity ranges, corresponding to the higher chl *a* measurements, indicating the zone of higher biological activity. The other nitrogen species, particularly DON, do not reduce linearly along the salinity gradient. DON is the largest contribution to the N pool, and stays elevated, with reduction in the higher salinities. PN is variable, and potentially reflects transformation between the inorganic particulate matter to phytoplankton.

Data analysis also illustrates the spatial patterns within the Fitzroy plume waters. Suspended particulate matter (SPM) is low compared to the Burdekin data, with elevated concentrations, but not the high values that would be expected in the very low salinity waters. Land use activities and time and location of sampling may affect the TSS measurements. In the 2008 and 2010 sampling events (and particularly in 2010), sampling occurred a number of days to weeks after the peak flow which is reflected in the TSS concentrations. However, all values were higher than 2.0 mg/L, thus still indicating an ongoing source of particulate matter. At later stages in the plume, it is also possible that the TSS is incorporating a significant proportion of phytoplankton cells and by-products. Further work on sediment particle size and composition is ongoing in Burdekin and Tully catchments and may help define the sources of TSS in plume waters (see for example Bainbridge *et al.* 2010, Wolanski *et al.* 2008). Pesticide samples were not collected in plume waters of the Fitzroy River in 2009/10.

Using a combination of information from catchment loads of DIN, TSS and PSII herbicides, the frequency and exposure of plume waters and long-term information on the water quality characteristics of water types most commonly found within the marine regions, the area most likely to exceed Guidelines for TSS and chl *a* in the Fitzroy region has been defined and is shown in Figure 4.15 (refer to Devlin *et al.* (2010b) for a detailed description of the methods used to produce these maps).



Probability	Seagrasses	Reefs
High	0	10
Medium - High	2	7
Medium	26	37
Total	102	838

Probability	Seagrasses	Reefs
High	58	62
Medium - High	31	49
Medium	20	100
Total	102	838

Figure 4.15: Definition of areas in the Fitzroy region that are most likely to exceed Guideline trigger values based on catchment load information, movement and extent of flood plume waters and the extent and frequency of the common water types for TSS (*left*) and chl *a* (*right*).

4.5.2 Biological monitoring results

Coral reef community condition in the Fitzroy region was assessed as 'moderate' in 2010 (Table 4.14). Average coral cover was moderate and the rate of increase of coral cover from 2008 to 2010 was lower than model expectations (Thompson and Dolman 2010). Monitoring again recorded high coral larval settlement but low density of juvenile corals and this discrepancy coupled with low coral growth rates if it continues will be of concern for coral community resilience in this region. One positive result was the observed decline in macroalgae cover between 2009 and 2010. It is possible that the chronic influences of increased turbidity and nutrient levels resulting from the major floods of the Fitzroy River in both 2008 and 2010 may be temporarily influencing the condition assessment of coral reef communities in this region. The water quality at Pelican Island exceeded Guidelines and along with the reef at Peak Island (situated in similarly turbid waters) had a clearly different benthic reef community composition at depth compared to the other monitoring locations in Keppel Bay.

Foram monitoring results supported the strong environmental gradient detected between Pelican Island and Peak Island and then the islands further offshore, with low densities on the nearshore reefs and very low species richness at Peak Island. At the two locations with good temporal data (Humpy and Halfway Islands and Pelican Island), the richness of forams in 2010 was similar to that observed over the period 2005 to 2007 and densities in 2010 were the lowest recorded with declines in both heterotrophic and symbiotic groups. The values of the FORAM index remained unchanged leading to the neutral ranking of foram assemblages in this region (Table 4.14) despite substantial declines in density.

Intertidal seagrass meadows were monitored at reef, estuarine and coastal habitats at three locations (six sites) in the Fitzroy region. Coastal and estuarine meadows remained stable in extent and abundance with continued condition improvement ('good to fair' status) during 2009/10 (Figures 4.16 and 4.17). Whereas, abundance of reef seagrass at Great Keppel Island continued to decline ('poor' status; Figure 4.18). Although there were no seed banks, the high reproductive effort at the reef sites suggests the meadows have high capacity to recover through the recruitment of new plants. Reproductive effort remained low at coastal and estuarine habitats. Seagrass tissue nutrient concentrations indicate an improved light environment in estuarine habitats, but low light at reef and coastal habitats in this region. Reef sites remain saturated in tissue nutrients (both nitrogen and phosphorus) however decreased phosphorus and elevated nitrogen levels were present at coastal and estuarine habitats, respectively. Epiphyte cover has changed little, and remains below the GBR long-term average for each habitat. Overall the status of seagrass condition in the region was rated as 'moderate'.

Table 4.14: Assessment of benthic reef community condition for the Fitzroy region. Overall status for five indicators; regional estimates of these indicators are derived from the aggregation of assessments from the reefs within each region (see Section 3.2). The colour scheme reflects relative condition of reef communities ranging from red (very poor), orange (poor), yellow (fair), light green (good), dark green (very good). Grey indicates no sampling. Source: Thompson *et al.* (2011).

Reef	Depth (m)	Overall condition	Coral cover	Change in hard coral cover	Macroalgae cover	Juvenile density	Settlement	FORAM index
Barren Island	2	-	neutral	neutral	+	-	-	
	5	neutral	+	+	neutral	-	-	
North Keppel Island	2	- - - -	-	-	-	-		
	5	- - - -	-	-	-	-		
Humpy Island and Halfway Island	2	+	+	-	+	-	+	
	5	neutral	neutral	-	+	-	+	neutral
Middle Island	2	-	neutral	neutral	neutral	-		
	5	-	neutral	-	+	-		
Pelican Island	2	++	neutral	neutral	+	neutral	+	
	5	++	neutral	neutral	+	neutral	+	neutral
Peak Island	2	- - - -	-	-	-	-		
	5	+	neutral	neutral	+	neutral		
Regional assessment		🟨	🟨	🟧	🟩	🟥	🟩	🟨

Figure 4.16: Change in seagrass abundance (percentage cover) at coastal intertidal meadows (Shoalwater Bay) in the Fitzroy region from 1999 to 2010. Red line = GBR long-term average for coastal habitats (average of all sites pooled).

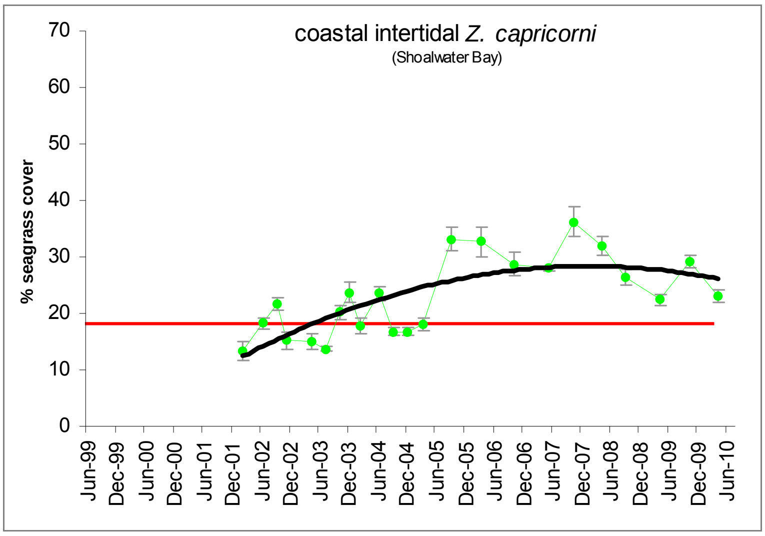


Figure 4.17: Change in seagrass abundance (percentage cover) at estuarine intertidal meadows (Gladstone Harbour) in the Fitzroy region from 1999 to 2010. Red line = GBR long-term average for estuarine habitats (average of all sites pooled).

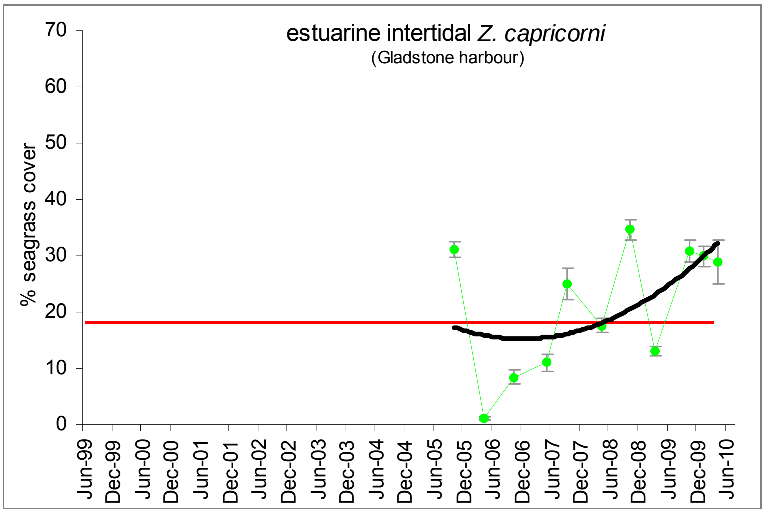
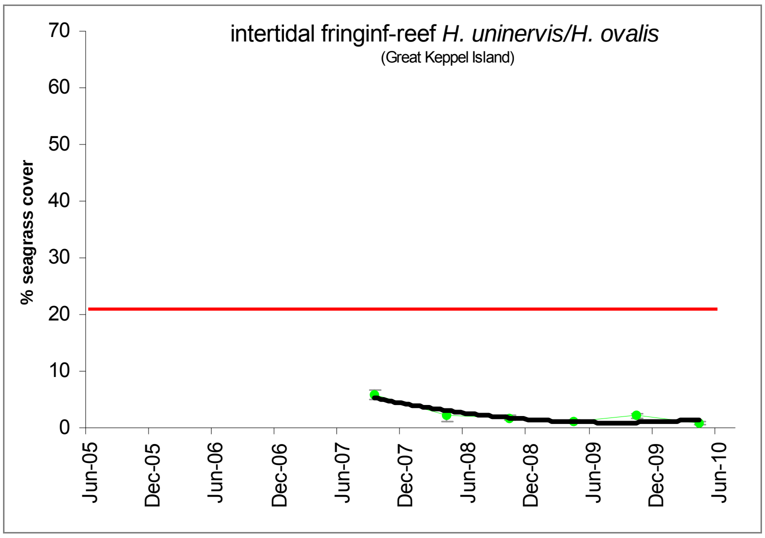


Figure 4.18: Change in seagrass abundance (percentage cover) at intertidal fringing reef meadows (Great Keppel Island) in the Fitzroy region from 2005 to 2010. Red line = GBR long-term average for reef habitats (average of all sites pooled).



4.6 Burnett Mary region

The Burnett Mary region is the southernmost in the GBR and is comprised of a number of catchments, though only the northernmost catchment, the Baffle Basin, discharges into the GBR. The dominant land uses in the coastal areas are intensive cropping including sugar cane and horticultural crops, while grazing dominates the upper catchment areas.

In situ water quality monitoring, flood event monitoring, coral reef monitoring and pesticide monitoring are not undertaken in the Burnett Mary region.

4.6.1 Water quality results

Estimates of water quality concentrations in the Burnett Mary region were undertaken using remote sensing, however, limited *in situ* data for validation gives relatively low confidence in the results. Analysis of remote sensing data in the Burnett Mary region showed that the annual mean values of chl *a* exceeded the Guideline value (0.45 µg/L) in 83% percent of the inshore area with a gradient to no exceedances in the offshore area (Table 4.15). Similar exceedance values were retrieved when the median was used for the assessment. The exceedance of mean TSS Guideline values in the inshore and midshelf areas (2 mg/L) were recorded in 12% of the inshore area and none of the midshelf area. The offshore TSS Guideline value (0.7 mg/L) was exceeded in 48% of the offshore area (Table 4.15). The high occurrence of exceedances in the offshore area requires further investigation and may be associated with a number of factors including delineation of the offshore boundary or insufficient validation of the algorithm in this region (refer also to discussion in Section 5 and Appendix 1). The estimated exceedance for the all areas was zero for the median values.

Table 4.15: Summary of the annual exceedance of Guideline values for chl *a* and total suspended solids in the Burnett Mary region.

			Chl *a*: Relative area (%) of the water body where annual mean value exceeds the Guideline value (inshore and midshelf = 0.45 µg/L; offshore = 0.4 µg/L)		TSS: Relative area (%) of the water body where annual mean value exceeds the Guideline value (inshore and midshelf = 2 mg/L; offshore = 0.7 mg/L)	
Waterbody	Surface Area (km^2)	Number valid obs.	Mean > trigger	Median > trigger	Mean > trigger	Median > trigger
Inshore	753	1	83%	60%	12%	0%
Midshelf	3,401	1	4%	3%	0%	0%
Offshore	33,928	4	0%	1%	48%	0%

Note: 'Surface Area' is the surface area in square kilometres for each of the three reporting water bodies for this region. The rating of valid observations is classified as: 1= <500,000 valid observations; 2 = 500,000-1,000,000 valid observations; 3 = 1,000,000-2,000,000 valid observations; 4 = >2,000,000 valid observations. A greater number of valid observations should provide greater confidence in the results. 'Mean > trigger' and 'Median > trigger' report the relative area for each water body where the mean or the median exceeded the trigger value. Values higher than 50% are shaded grey.

In the Burnett Mary region, the estimated freshwater extent using CDOM values from satellite imagery for the 2009/10 wet season (November 2009 to April 2010) was 1,170 km^2, 399 km^2 for the 2008/09 wet season, while in the 2007/08 wet season it was 1,549 km^2. Freshwater discharge was eight times above the annual median flow in the region in 2009/10 (the median flow was calculated using annual flow from 2001 to 2009, refer Table 3.1).

4.6.2 Biological monitoring results

Seagrass meadows were monitored at two estuarine locations (four sites) in the north and south of the Burnett Mary region respectively. Seagrass meadows in the south continued to recover from the effects of flooding in 2006, from aggregated patches to form continuous meadows. Whereas, meadows in the north at Rodds Bay declined and were absent by late in the 2009/10 wet season. Seagrass abundances declined in the region were rated as poor throughout 2009/10 (Figure 4.19). Seagrass tissue nutrient concentrations indicate light environments across the region remain low (limited), but have improved in the south. Tissue nutrient status indicated that although locations were nutrient poor (small phosphorus pool), nitrogen concentrations remained high (replete) in the south but increased at Rodds Bay indicating nitrogen enrichment. Declining seed banks and reproductive effort raise concerns about the ability of local seagrass meadows to recover from environmental disturbances. Epiphytes remained variable at the Rodds Bay site, but at the Urangan site they increased above the GBR long-term average of 18% for estuarine habitats. Within canopy temperatures were warmer at all habitats than in previous monitoring years, with extreme temperatures of 38.2°C being reached at Rodds Bay in February 2010. Overall the status of seagrass condition in the region was rated as ‘fair’.

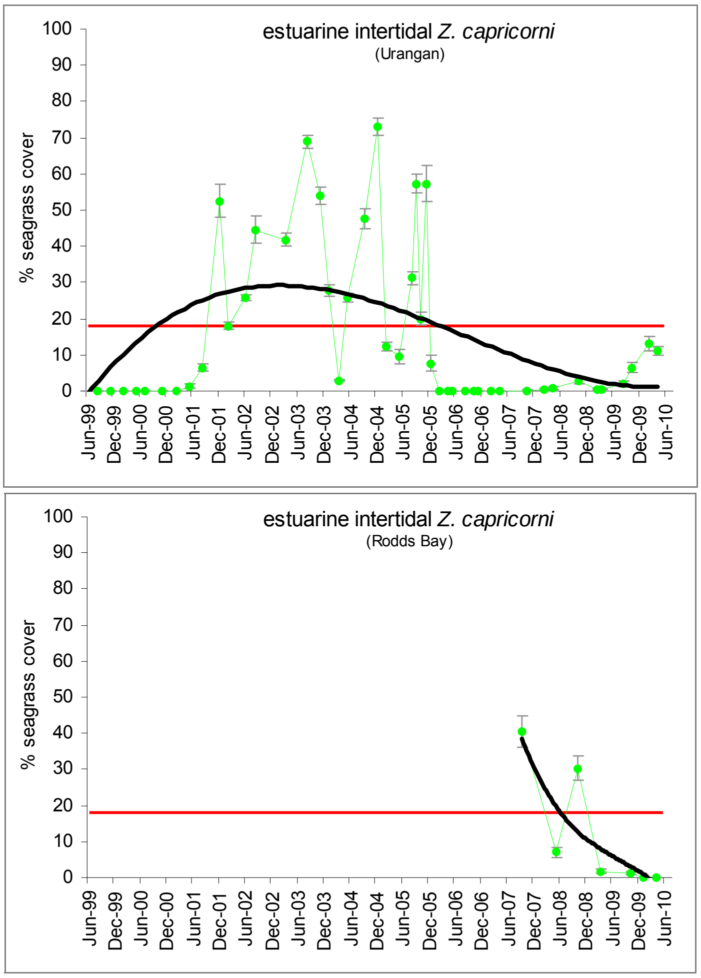


Figure 4.19: Change in seagrass abundance (percentage cover ± Standard Error) at estuarine (Urangan [*top*] and Rodds Bay [*bottom*]) intertidal seagrass meadows in the Burnett Mary region from 1999 to 2010. Red line = GBR long-term average for estuarine habitats (average of all sites pooled).

5. Discussion and Conclusions

As described in previous sections of this report, the monitoring of water quality and inshore biological communities was successfully continued throughout 2009/10 as part of the MMP. The findings for this time period are contributing to our understanding of the status of GBR ecosystems, and in some cases, the relationships between ecosystem health and water quality conditions. The state of water quality in the inshore GBR shows clear gradients away from river mouths and is influenced over short time periods by flood events and sediment resuspension. Heavy and persistent flooding occurred in many rivers draining into the GBR between January and April 2010, with the largest flows occurring in the southern catchments, particularly the Mackay Whitsunday catchment and the Fitzroy River.

The water quality *in situ* instrumental data provides an accurate measure of water quality at the fourteen core reef sites, and continued instrumental monitoring of chlorophyll and turbidity will deliver information essential for determining which locations continually exceed the Water Quality Guidelines, and whether further management actions may be required at these specific locations or regions.

With the exception of the Mackay Whitsunday region, regional remote sensing results in the inshore area water body showed high areas of exceedance of the Guidelines for chl *a* (>0.45 µg/L in 56-83% of the relative area of each water body). Results from the 2008/09 MMP monitoring period presented a similar pattern of exceedance (51–84%). The spatial patterns of chl *a* Guideline exceedance reflected the gradient in water quality from inshore to offshore water bodies, and the difference in Guideline values between midshelf (0.45 µg/L) and offshore (0.4 µg/L) waters. However, the exceedance of TSS Guidelines in all offshore areas (>0.7 mg/L) warrants further investigation. It is proposed that the relatively high occurrence of exceedances in the offshore areas may be related to several factors, including (a) the effect of outliers in the remote sensing data, given a series of high value TSS retrievals could skew the estimate of the mean while not affecting the median, (b) the delineation of the cross-shelf boundary between the midshelf and offshore water bodies, (c) the difference in the Guideline value between midshelf and offshore areas (2 mg/L and 0.7 mg/L), or potentially, (d) a shift in the long-term turbidity in offshore waters (measured as TSS). Supporting research is required to resolve these uncertainties as a matter of urgency if remote sensing results for TSS continue to be reported. In addition, outstanding concerns regarding limited validation data and model parameterisation for remote sensing results in several locations, and particularly in the Cape York and Burnett Mary regions (where there is no other water quality monitoring undertaken as part of the MMP), need to be addressed as a matter of priority if remote sensing data is to continue being an essential part of the MMP integrated reporting process. Further discussion of the limitations and future needs for remote sensing applications in the MMP is provided in Appendix 1.

Assessment of the water quality data against the Guidelines highlighted areas that require further consideration with regard to regional and seasonal variations in the data. The Guidelines are defined for annual mean values and estimates are made for seasonal variation of chlorophyll, suspended solids and particulate nutrient values for the wet and dry seasons. For example, chlorophyll is estimated to be twenty percent higher than the annual mean during the wet season, and twenty percent lower than the annual mean during the dry season. Presently, the wet season is defined as the period January to March, while the dry season is defined as July to September each year. Interannual variations in the extent of the actual wet and dry seasons will have implications for measuring exceedance of the Guidelines when considering seasonal means. It is therefore recommended that further work is undertaken to consider defining the wet and dry seasons for each year for the MMP and that the Guidelines are applied only within those periods. This is relevant to all water quality data collected in the MMP, but particularly the high frequency remote sensing data.

PSII herbicides are present in both inshore and midshelf waters of the GBR. The risks to reef ecosystems from exposure to mixtures of PSII herbicides and the potential for synergistic effects with con-committant changes in other water quality parameters remain largely uncharacterised. Pesticide Index results for all sampling sites in the 2009/10 monitoring period indicate regional differences in the exposure of inshore waters of the GBR. However, concentrations of individual herbicides did not exceed the Guidelines at inshore reef and nearshore sites. However, biologically relevant concentrations of PSII herbicides expressed as PSII-HEq (>10 ng/L) were measured at inshore reef sites in the Wet Tropics, Burdekin and Mackay Whitsunday regions in 2009/10.

The dominant pesticide at all sites monitored in 2009/10 was the phenyl urea herbicide diuron. Hexazinone (a triazinone herbicide) and atrazine (chlorotriazine herbicide) were also detected at concentrations that were high but lower than that of diuron, and their relative contribution varied on a regional basis. Diuron is a herbicide widely used in sugarcane production and some tropical fruit crops to control pre- and post-emergent weeds. It is also found in antifoulant paints.

The concentrations of PSII herbicides can increase between 1 and 2 orders of magnitude between wet and dry season sampling periods, and in many cases are only detected during the wet season. Any assessment of long-term trends within regions is complicated by observed relationships between peak discharge events (i.e. flow variability; Bainbridge *et al.* 2009) within specific monitoring years which may influence PSII-HEq maximum concentration. Where rainfall is concentrated in specific sub-catchments where dominant land use differs within the region, variability in loads is likely (Packett *et al.* 2009). Specific sub-catchment events such as these, and gaps in the monitoring record, will need to be considered in order to properly assess both short-term variation and long-term trends in pesticide monitoring results.

Water quality sampling of GBR flood plumes showed high concentrations of all water quality parameters moving offshore with plume waters. Concentrations of water quality parameters remained high (relative to ambient values) for days to weeks after peak flow in the Mackay Whitsunday and Fitzroy regions, and are indicative of the long-term influence of flood plume conditions on inshore marine environments. Pesticide sampling in flood plume waters revealed elevated concentrations of a range of herbicides, with the herbicides displaying conservative mixing behaviour. The highest pesticide concentrations were found closest to river mouths during the peak of flood events, indicating that ecosystems closest to rivers are most at risk of herbicide exposure.

The status of the GBR catchments that deliver pollutants to the river systems, and ultimately the inshore GBR environment, plays a role in determining risk to inshore ecosystems from flood plumes and the ecological consequences of any exposure. Each GBR catchment is characterised by different topography, rainfall, land use patterns and practices, and therefore the exposure of ecosystems to particular pollutants in adjacent waters is specific to these catchment characteristics (see Table 3.5). This information, coupled with knowledge of plume movement and composition, can be used to target management actions in areas that are delivering the highest loads of sediments, nutrients and pesticides to the GBR, and where the greatest number or area of inshore ecosystems are at risk of exposure. The ecological consequences associated with this exposure of coral reefs and seagrass meadows to flood plumes is dependent upon a number of parameters including the time and severity of exposure, the status of the ecosystem prior to exposure and other concurrent disturbance events (Fabricius 2005).

Consideration of the biological monitoring results for the five years of MMP data indicates that the condition of many inshore marine ecosystems is ‘poor’ or declining. In particular, some coral reefs in the Tully-Herbert sub-region of the Wet Tropics as well as the Burdekin and Fitzroy regions are showing signs of impacts from a combination of turbidity, sedimentation and recent disturbances, such as cyclones and coral bleaching. A negative change in coral cover in the Mackay Whitsunday region is also of concern, with indicators of recovery (rate of coral cover increase and settlement of coral larvae) not progressing as models would predict (Thompson and Dolman 2010). The condition of seagrass meadows across the whole GBR has declined since 2008 to a 'moderate' state, with particularly poor results for seagrass abundance in coastal habitats in the Burdekin, Mackay Whitsunday and Burnett Mary regions. Reproductive effort was 'very poor' in all regions except Cape York, and particularly in coastal habitats.

Monitoring carried out over five years has revealed differences in coral reef communities in the inshore GBR, and provides a useful starting point for the detection of long-term trends in coral reef status. The assessment of coral reef status focuses on areas of the GBR where certain indicators of status appear to be compromised and has highlighted likely correlations with water quality parameters. At present, the uniform, abundance-based criteria for the assessment of coral cover, macroalgae cover, juvenile density and settlement do not differentiate between reefs with different community composition. However, it is well documented that both susceptibility to disturbance and environmental condition, as well as growth and mortality rates, vary among coral taxa (see Sweatman *et al.* 2007). Thompson and Dolman (2010) use GBR inshore reef community data to model expected growth rates (increases in cover) based on broad differences in community composition. This analysis forms the basis of the condition estimate 'coral cover change' presented in this synthesis report. As the time-series extends, it is expected that condition indicators will evolve to incorporate community composition. For example, lower numbers of juvenile colonies in a community dominated by large colonies of resilient taxa (*Porites*, for example) may be adequate for replacing colonies lost to mortality, whereas far greater levels of recruitment may be required to maintain the *status quo* if more susceptible taxa (*Acropora*, for example) suffer high mortality. The current relative assessment among reefs may point towards those that are most at risk of decline.

Local environmental conditions clearly influence the benthic communities found on coastal and inshore reefs of the GBR. These reefs differ markedly from those found in clearer, offshore waters (e.g. Done 1982, Wismer *et al.* 2009, De'ath and Fabricius 2010). Water quality results suggest that particulate components of inshore marine waters (suspended sediment and particulate nutrients and carbon) are the most important drivers of coral reef communities (Uthicke *et al.* 2010, Thompson *et al.* 2010b). As a consequence, inshore coral reef communities vary along steep environmental gradients that occur with distance from the coast and from major rivers (van Woesik and Done 1997, van Woesik *et al.* 1999, Fabricius *et al.* 2005, De'ath and Fabricius 2008, Thompson *et al.* 2010a, 2010b). Coral reef communities will therefore be susceptible to any deterioration in environmental conditions such as increases in the rates of sedimentation, levels of turbidity, nutrient concentrations or other anthropogenic pressures. Conversely, if improvements under the Reef Plan and Reef Rescue initiatives lead to better inshore water quality, coral reef communities are expected to change over time to reflect the changed environmental conditions (De'ath and Fabricius 2008, 2010).

The general responses of coral reef communities to turbidity and nutrients are relatively well understood (e.g. Fabricius 2005, 2010, Brodie *et al.* 2008, De'ath and Fabricius 2010, Thompson *et al.* 2010b, Uthicke *et al.* 2010). In simple terms, species that are tolerant to environmental stresses are advantaged, and hence more likely to be in abundance, compared to less-tolerant species (e.g. Stafford-Smith and Ormond 1992, Anthony and Fabricius 2000, Anthony and Connolly 2004, Anthony 2006). However, the processes shaping biological communities are complex and spatially and temporally variable, and are likely to include interactions between various environmental factors, past disturbance regimes and a degree of stochasticity in the demographic processes of individual species. As a result, different communities may be present at any one time in very similar environmental settings. Conversely, gradually changing environmental conditions may allow existing colonies to adapt due to the inherent physiological (Anthony and Fabricius 2000) and morphological (Anthony *et al.* 2005) plasticity of corals. Colonies then persist in conditions unlike those into which they recruited, forming relic communities. This variability makes it difficult to assess status and resilience of GBR inshore coral reef communities based on their composition.

A new conceptual approach to estimating and ranking status and resilience of reef communities considers their potential to recover from disturbance events. This assessment uses the observed levels of community attributes against estimates of expected change derived from a coral growth model (Thompson and Dolman 2010), which is based on our understanding of community dynamics. The underlying assumption is that a healthy community will show resilience to disturbances by recovering lost cover through the recruitment and growth of new colonies or the re-growth of surviving colonies and fragments. These status assessments are therefore based on indicators of ‘recovery potential’ thereby removing the shortcomings and ambiguities associated with using composition-based indicators. Importantly, it allows communities across naturally occurring environmental gradients to be considered within a uniform framework.

The current coral reef status assessment indicates that reefs in the Burdekin region are showing the least capacity to recover from disturbance events. In this region, coral cover is low and only increasing at a slow rate; some reefs have very high cover of macroalgae and the density of juvenile colonies and the settlement of coral larvae are both low. The ‘poor’ status of coral reef communities in this region almost certainly reflects the high mortality of corals during the 1998 mass bleaching event (Berkelmans *et al.* 2004, Sweatman *et al.* 2007) and poor larval supply (Box 5.1).

Box 5.1: Recovery from coral bleaching

One GBR inshore site (Pandora Reef) has been studied since 1981 and initially showed high resilience to disturbances despite proximity to land runoff (Done *et al.* 2007). However, it appears that such resilience has declined over the last decade because certain reef zones have not recovered since the 1998 mass bleaching event, which was interpreted as a result of reduced larval availability (Done *et al.* 2007). Hydrodynamic modelling indicates that over a period of one to two weeks (which is generally long enough for coral larvae to settle), particles released in Halifax Bay remain within the bay with some movement to the north or south depending on the prevailing winds, however, they do not move to reefs further offshore (Luick *et al.* 2007). This indicates that larvae originating in Halifax Bay will predominantly settle within the bay. The mortality of a high proportion of adult corals in the Burdekin region during the 1998 bleaching event implies a substantial reduction in local larval supply, leading to low juvenile densities and limited recovery rate, as observed in the MMP surveys. The reduced availability of larvae results in low recovery of coral communities, even without considering post-settlement stress to coral recruits due to extremes in environmental conditions at some of the reefs, such as high turbidity and chl *a* concentrations.

The overall status of coral communities in the Mackay Whitsunday region is positive, however there are three aspects of the community dynamics that are a cause for concern. Despite high coral cover and low levels of macroalgae, the rate of coral cover increase is low, settlement of coral larvae is low and there has been a substantial decline in the density of juvenile colonies. This trajectory can be interpreted as a response to regional environmental stresses. Benthic community composition has been shown to respond to the proportion of fine grained components in sediments (silt and clay sized particles) (Thompson *et al.* 2010b, 2011), which has noticeably increased on reefs in the Mackay Whitsunday region since 2005. This increase in fine grained sediment particles corresponds to changes in the flows of the nearest rivers (Proserpine, O'Connell and Pioneer Rivers). River flows were below long-term medians for several years prior to 2005, and since 2006 were substantially higher than the median flow. Further evidence that increased sediment loads from the catchment have led to observed changes in sediment composition at reef sites is that during surveys in 2009 the proportion of the substrate categorised as 'silt' was the highest recorded over the five years of observation at four of five reefs. Changes in sediment composition toward finer grained particles would logically lead to increased levels of turbidity and sedimentation, which are likely to have influenced the lower than expected rate of coral cover increase and low settlement of coral larvae to tiles in this region (Box 5.2). Recent MTSRF funded research set out to understand how long fine particulate matter discharged from rivers remains in inshore waters through continued resuspension, and how water quality in the GBR lagoon changes throughout the year, especially after floods. Results indicate that fine sediment imported by floods remains in the coastal zone for long after the event, leading to recurring high turbidity by resuspension (Wolanski *et al.* 2008, Lambrechts *et al* 2010).

Box 5.2: Turbidity and sedimentation stress on coral reefs

Turbidity and sedimentation have the potential to stress corals by reducing light availability for photosynthesis, with sedimentation also incurring an energy cost when active removal is required. Juvenile corals are generally more susceptible to turbidity and sedimentation than adult colonies (Fabricius *et al.* 2003, Fabricius 2005). Declining densities of juvenile colonies may reflect reduced survivorship or declines in the number of larvae settling to the reef. Although not quantified, it is readily observed that settlement tiles deployed in the Mackay Whitsunday region accumulate a substantially thicker covering of 'silt' than those deployed in other regions. Larvae settlement is enhanced by chemical cues arising from the biological characteristics of the settlement substrate (e.g. biofilms; Negri *et al.* 2002). A thick layer of sediments will limit settlement both chemically, by precluding the development of appealing biofilms, and physically, by not providing a suitably stable substrate for attachment (Birrell *et al.* 2005). Accumulation of sediments on tiles almost certainly influences the low settlement rates but, importantly, also mirrors the accumulation of sediments to the reef substrate.

Monitoring of reef communities since 2005 has improved our understanding of the functioning of inshore communities, with new recognition that reef community composition will vary depending on position along a multidimensional environmental gradient, and exposure to past disturbance events (Box 5.3). The assessment approach can now make 'predictions' of a reef's recovery potential rather than present condition alone. For example, growth models for inshore reef hard coral communities that incorporate differences in community composition and initial coral cover (derived from Thompson and Dolman 2010) have been developed. However, it has not been possible to similarly conceptualise and predict other aspects important to the resilience of coral reef communities. For example, the number of coral larvae settling to tiles and density of juvenile colonies that would be sufficient to sustain a coral community needs to be defined, or cover of macroalgae that represents a resilience threshold beyond which coral recovery is impeded. It is intended that the program continues to improve this protocol for coral community assessment, such as a greater capacity to estimate critical values of community and environmental variables that promote community resilience.

Another important inshore ecosystem in the GBR that is frequently exposed to flood plumes and poor water quality is seagrass meadows. Seagrasses form critical coastal ecosystems in northeast Australia and play a significant role in fisheries production, sediment accumulation and stabilization, food and shelter provision for a range of marine species, filtering nutrients from the water, and carbon sequestration (Spalding *et al.* 2003). They are also susceptible to ecological impacts from exposure to elevated concentrations of sediment, nutrients and pesticides.

Box 5.3: Coral reefs, water quality and climate change

The status of coral communities in the Burdekin region illustrates a key issue facing inshore GBR coral reefs in general, that is, the proposed synergy between nutrient loads and susceptibility of corals to thermal bleaching (Wooldridge 2009). Higher sea temperatures have increased the frequency of mass coral bleaching events globally, often resulting in broad-scale severe mortality (Hoegh-Guldberg 1999, Wilkinson 2004). Although coral bleaching affected large areas of coral reef in the GBR in 1998, only five percent suffered severe mortality (Johnson and Marshall 2007). That reefs in the Burdekin region show little evidence of recovery potential after ten years illustrates the long-term susceptibility of some inshore coral reef communities to such regional scale disturbance. A similar lack of resilience was shown in a long-term study of a GBR offshore reef at Lizard Island and was attributed to an increased frequency of disturbance (Wakeford *et al.* 2008). With frequency and severity of disturbance events projected to increase in response to continuing rises in greenhouse gases (Hoegh-Guldberg *et al.* 2007a, Steffen 2009) any increase in susceptibility as a result of local anthropogenic nutrient loads may be catastrophic for GBR inshore reef communities. Corals exposed to nutrients, turbidity, sedimentation, or pathogens have been shown to be more susceptible to bleaching, or less able to survive a bleaching episode (Hoegh-Guldberg *et al.* 2007b). Furthermore, chronic local stressors – such as poor water quality – can affect the recovery potential of reef communities (Hoegh-Guldberg *et al.* 2007a). This is because fertilization and larval recruitment in corals are particularly sensitive to environmental conditions.

Seagrasses monitored in all GBR regions in the 2009/10 season were evaluated as being of ‘moderate’ or ‘fair’ status. The estimates of reproductive effort were ‘poor’ for all regions except Cape York, indicating the limited production of reproductive structures and a reduced capacity to recover from large-scale meadow losses. These results indicate an overall decline in seagrass status from the 2008/09 monitoring period, particularly along the agricultural and urban GBR coast, which could be a result of the delivery of water quality pollutants from river discharge in flood plumes.

At a regional and GBR-wide scale seagrass meadows are showing signs of being in a state of decline (based on indicators of seagrass abundance, meadow area, seed production, light availability, nutrient enrichment and nitrogen levels). There is also evidence of long-term increases of seagrass nutrient content (in leaf tissues) in coastal and reef seagrasses, particularly in the Wet Tropics and Burdekin regions. Elemental ratios of tissue nutrients indicate some locations in the Wet Tropics and Mackay Whitsunday regions have degraded water quality, with an excess of nutrients compared to light availability. Increased epiphyte loads, possibly stimulated by nutrient loading, further exacerbate light limitation on the surfaces of slower-growing seagrass leaves in coastal and estuarine habitats. Reproductive status has also declined in many locations, suggesting that there may be inhibition of meadow recovery from their current state due to limited recruitment capacity. Continued monitoring of trends in seagrass status could indicate whether improvements in water quality have translated into improvements in ecosystem health.

Interactions between stressors also play an important role in seagrass health (Box 5.4). For example, under limited light conditions, elevated nutrient levels will saturate seagrasses more rapidly (Collier *et al.* 2009). While seagrass reproduction is positively correlated with nutrient saturation, in some circumstances seagrasses experiencing low light but elevated nutrients may be expected to have increased reproductive effort. That is until light levels result in compromised survival due to respiration demands being greater than photosynthesis. This association was observed at two sites in the Burdekin region. A high level of seagrass resilience involves the interaction between light availability, nutrient loads and availability of seeds to form the foundation of new populations. At present, the resilience of GBR seagrass meadows appears to be varied, both spatially and temporally, due to changeable light levels and seed availability both spatially and temporally. The capacity of seagrass meadows to recover from significant losses following disturbance is a critical component of ecosystem resilience and understanding of these processes remains poor in the GBR.

Box 5.4: Synergistic effects on seagrasses

Future climate change projections for the GBR region indicate that rainfall patterns are likely to change, possibly resulting in fewer but more intense rainfall events. This may have implications for the delivery of terrestrial water quality pollutants to the inshore GBR. If longer dry spells eventuate, and catchment management adoption rates increase, some of the ecological pressures associated with catchment loads may be alleviated. However, further evaluation of the relationships between water quality parameters and a range of climate disturbances that influence the health and productivity of seagrass meadows are required. In addition, further research is required on the synergistic effects between high nutrient availability and exposure to pollutants, particularly given that increasing urban and catchment development is introducing higher levels of different pollutants into GBR waters.

Although the 2009/10 water quality monitoring results are not directly correlated with observed fluctuations in biological communities, several potential relationships between water quality and ecosystem health can be identified. Water quality status at two of the coral monitoring sites was rated as ‘very poor’ (Magnetic Island in the Burdekin region and Pelican Island in the Fitzroy region), and one site (Pine Island in the Fitzroy region) was rated as having ‘poor’ water quality. The areas where water quality was ‘very poor’ also returned a neutral or negative rating for coral status, although the relationship between coral reef health and water quality is not necessarily linear (Thompson *et al.* 2010b, Uthicke *et al.* 2010). The health of seagrasses in proximity to these locations also showed negative results in terms of health indicators. Comparison of pesticide results across monitoring years showed some indication of increasing PSII-HEq concentrations at Fitzroy Island (Wet Tropics region), Magnetic Island (Burdekin region) and North Keppel Island (Fitzroy region). There are some correlations between these pesticide results and ecosystem status, with the Burdekin and Fitzroy region sites in close proximity to the biological communities showing negative results for most bioindicators, as discussed above.

While these relationships have been identified through observation of the results across the sub-programs, caution should be exercised in drawing absolute conclusions identifying water quality as the only cause of these measured declines, as there are many factors that may influence the health of the ecosystem. The results of the other components of the Paddock to Reef Program for 2009/10 include management practice adoption and effectiveness, catchment condition and catchment loads, and will assist to interpret the results when they become available (the overall Program is reported in an annual Report Card and supporting Technical Report; see www.reefplan.gov.au). Despite these uncertainties, the MMP results do indicate areas where targeted responses by managers of water quality in the GBR may be required.

The results of mapping plume exposure illustrate how a combination of *in situ* and remote sensing monitoring information can be used to maximise the usefulness of monitoring data and how they are used to inform catchment and GBR management. However, further information on the physical and biogeochemical processes transporting and transforming land-derived materials in the marine environment, as well as the influence of hydrodynamics of the GBR inshore area on residence times, would improve how this information is used and the timing of management strategies. The missing links between catchment and marine processes hampers the implementation of management options for specific water quality constituents. A primary use of results from this type of study will be to set targets connecting end-of-river loads of particular materials to an intermediate end point target such as chlorophyll (Brodie *et al.* 2009b) or, in the future, to an ecological end point target such as a composite indicator for coral reef health (Fabricius *et al.* 2007).

For the first time, the MMP results have been presented as a series of metrics which combine datasets at site specific and regional levels. An outstanding challenge is the development of a consolidated assessment and reporting system that integrates all three water quality sampling approaches (direct water sampling, instruments and remote sensing) for reporting of GBR lagoon water quality to provide a comprehensive evaluation of the overall status of coastal and inshore waters. This could then be correlated with the biological monitoring results to target effective management of water quality ‘hot spots’. Such an integrated water quality system will also support the Reef Plan Paddock to Reef Integrated Monitoring, Modelling and Reporting Program measuring progress towards the Reef Plan and Reef Rescue goals and targets.

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Appendix 1

Supplementary information on remote sensing applications in the Reef Rescue Marine Monitoring Program

The following information is largely derived from the report of the remote sensing component of the Marine Monitoring Program for 2009/10 (Brando *et al.* 2010b).

Introduction

Remote sensing techniques can be a cost-effective method to determine spatial and temporal variation in near-surface concentrations of suspended solids (as non-algal particulate matter), turbidity (as vertical attenuation of light coefficients Kd), chlorophyll a (chl *a*) and coloured dissolved organic matter (CDOM) for the Great Barrier Reef (GBR). This is achieved through the acquisition, processing (with regionally valid algorithms), validation and transmission of geo-corrected ocean colour imagery and data sets derived from MODIS imagery.

Since the commencement of the Reef Rescue Marine Monitoring Program (MMP), significant investment from the program has supported development of remote sensing as a monitoring tool for water quality (chlorophyll, CDOM, TSM and Kd) in the GBR. These improvements have enhanced the confidence in remote sensing estimates and it is intended that remote sensing could soon be a primary tool for detecting broad scale changes in GBR water quality. At present, MODIS Aqua represents a time series from November 2002 to present of water quality estimates with spatial coverage at 1 km resolution, nominally on a daily basis (except overcast days) for the whole GBR lagoon. The water quality estimates are retrieved from the MODIS Aqua time series using two coupled physics-based inversion algorithms developed to accurately retrieve water quality parameters for the optically complex waters of the GBR lagoon level. This is necessary because chl *a* concentrations retrieved with the MODIS standard algorithms provided by NASA are inaccurate up two-fold in GBR waters (Qin *et al.* 2007), while regionally parameterised algorithms do account for the significant variation in concentrations of CDOM and TSS and achieve more accurate retrievals.

The comparison of MODIS Aqua retrievals of chl a, CDOM and NAP with *in situ* data showed that the regional algorithm coupled with the ANN atmospheric correction is more accurate than NASA's algorithms for GBR waters. The accuracy for the retrieval of chl *a*, CDOM and TSS with the coupled physics-based inversion algorithms was 58%, 57% and 66%, respectively. The parameterization and validation on the remote sensing retrievals was mainly based on observations performed in coastal and lagoon waters during the dry season between Keppel Bay and the Wet Tropics region. The accuracy of the retrieval is likely to likely to be lower in shallow and turbid waters systems such as Princess Charlotte Bay, Broad Sound, Shoalwater Bay where there was no data available for parameterisation and validation.

Continued improvement of remote sensing techniques in the GBR has resulted in changes to the reporting metric since 2008/09. These are described below in addition to identification of future work required to continue to improve confidence in remote sensing applications for water quality monitoring in the GBR. Further detail can be found in the full report of the remote sensing component of the MMP for 2009/10 in Brando *et al.* (2010a).

Changes to the reporting metric

The metrics for the assessment of exceedance to the Guidelines have been modified compared to the 2008/09 MMP report (see Johnson *et al.* 2010). The surface area used as the basis for the relative area of exceedance now reports the actual number of pixels with valid observations for each reporting region instead of the surface area of the whole water body. Accordingly, the reported surface areas are lower than those reported in 2008/09 (10-20% lower depending on the region) affecting in turn the reported relative areas for each water body where the mean or the median exceeded the Guideline value. Also as a result of the stricter quality control of the imagery, the number of available observations for each pixel is lower than for the MMP report 2008/09. This affects the estimates of the annual and seasonal mean and median values for the reported variables. A relative rating of the number of valid observations has been developed to assist in interpretation of the information and to provide a rapid indication of variability between regions and waterbodies (Table A1.1).

To enable a comparison between the results of the 2009/10 and 2008/09 (Brando *et al*. 2010b) reporting periods, the 2008/09 values were recomputed and are presented in Table A1.1.

Table A1.1: Revised summary of the exceedance of annual mean Guideline values of chl *a* and non-algal particulate matter (as a measure of TSS) for the 2008/09 reporting period (1 May 2008 to 30 April 2009) for the inshore, midshelf and offshore water bodies. Values higher than 50% are shaded grey.

Region	Rating of the number of valid observations			Chl *a*: Relative area (%) of the water body where the annual mean value exceeds the Guideline value (inshore and midshelf = 0.45 µg/L; offshore = 0.4 µg/L)			TSS: Relative area (%) of the water body where the annual mean value exceeds the Guideline value (inshore and midshelf = 2 mg/L; offshore = 0.7 mg/L)		
	Inshore	Midshelf	Offshore	Inshore	Midshelf	Offshore	Inshore	Midshelf	Offshore
Cape York*	1	2	4	61	5	0	71	61	17
Wet Tropics	1	1	3	84	15	0	40	9	13
Burdekin	1	3	3	67	3	0	54	2	4
Mackay Whitsunday	1	2	3	33	2	0	84	42	63
Fitzroy	1	3	4	55	3	0	53	11	40
Burnett Mary *	1	1	4	51	4	0	10	0	1

* Caution should be used when interpreting the results for the Cape York and Burnett Mary as limited field information was used for the parameterisation and validation on the remote sensing retrievals. Note: The rating of valid observations is classified as follows: 1= <500,000 valid observations; 2 = 500,000-1,000,000 valid observations; 3 = 1,000,000-2,000,000 valid observations; 4 = >2,000,000 valid observations. A greater number of valid observations should provide greater confidence in the results.

Adequate validation of remote sensing data at the scale of an environment as large as the GBR continues to be a challenge for the MMP. Caution should be applied when interpreting the results for the Cape York and Burnett Mary regions and all offshore areas (where there is no other water quality monitoring undertaken as part of the MMP) as limited field information was used for the parameterization and validation of the remote sensing results. The statistical distributions of the chlorophyll concentrations retrieved with the algorithm from MODIS-AQUA data have been compared with the in situ data from the GBR Long Term Monitoring Program (AIMS) for each region for the wet and dry seasons 2005/06. In general, the measured *in situ* sample ranges were within the remotely sensed values. However, a simple comparison of the 2009/10 remote sensing inshore and midshelf chl *a* and TSS results with the *in situ* logger instrument data generally showed retrieval of higher concentrations in the remote sensing data. Further validation and comparison with *in* *situ* data would build confidence in the application of these techniques as a monitoring tool for reporting.

Future work

Further work is required to support ongoing application of remote sensing applications for water quality monitoring in the GBR. Many of the limitations and uncertainties identified in this report and detailed in Brando *et al.* (2010a) are already being progressed through further studies, or proposals have been developed to support further research. The priority areas for future work are outlined below.

Improvement of the algorithm and remote sensing techniques

Comprehensive wet season studies carried out by the CSIRO Environmental Earth Observation Group has shown that considerable differences in optical properties and concentrations are found between the dry and wet season for the GBR lagoon waters. In order to incorporate seasonal knowledge of variability in the specific inherent optical properties in the algorithms, a new comprehensive statistical analysis should be performed to include the optical characterisations carried out in the last two years, in particular those of the flood waters of the Fitzroy River in Keppel Bay (February 2008) and the wet season sampling of the Wet Tropics region (April 2008).

Other priority tasks include characterisation of the detection limits for each of the water quality variables (chl *a*, TSS, CDOM and water clarity) for environmental conditions ranging from high flow turbid river plumes to dry season wind-driven resuspension to outer reef blue waters. Improving the accuracy of chl *a* detection in the wet season in the outer lagoon and reef matrix for both sensors is also a priority. This will be based on a re-analysis of existing optical data sets for dry and wet season, combined with the data collected during at the Integrated Marine Observing System (IMOS) facilities: the Lucinda Jetty Coastal Observatory and the National Reference Station moored at the Yongala wreck.

A CDOM absorption threshold was also established for MMP reporting from visual inspection of a daily imagery; further work is needed to establish a threshold based on the relationship between measurements of salinity and CDOM absorption as proposed for the North and Baltic Seas (Astoreca *et al.* 2009; Ferrari and Dowell 1998). The high CDOM concentrations may also reflect other processes in occurring in near-shore waters, further work should also attempt to separate the plume from non-plume effects.

Further data validation

A number of programs are underway that may assist in providing more *in situ* validation data of the remote sensing results. The CSIRO Environmental Earth Observation Group has been commissioning the Lucinda Jetty Coastal Observatory (LJCO), as part of the Australian National Mooring Network, one the facilities of Australia's Integrated Marine Observing System (IMOS). LJCO aims to provide valuable data in tropical Queensland coastal waters to unravel the inaccuracies in remotely-sensed satellite ocean colour products due to the optical complexity in coastal waters and the overlying atmosphere. The LJCO data stream will increase the number of satellite versus *in situ* match-ups to assess normalized water-leaving radiances, water inherent optical properties and aerosol optical properties.

In addition, AIMS is leading the setup of the Great Barrier Reef Ocean Observing System (GBROOS) that has a number of observation moorings throughout the GBR. Several autonomous water quality loggers are being deployed in GBR waters with the support of MMP and IMOS. Water quality data is also being provided by a flow-through system installed on the AIMS vessel RV Cape Ferguson. This dataset will provide insight in the spatial variability of water quality in GBR waters. The value for remote sensing validation of the chl *a* data from this sampling and moorings should be investigated as a priority over the next 24 months.

Reporting metrics

The MMP water quality monitoring uses three complementary approaches to collect data at various spatial (site, location, region, and whole GBR lagoon) and temporal (snapshot, daily, ten-minute) scales: traditional direct water sampling from research vessels, *in situ* data loggers at a small number of selected inshore reef locations and remote sensing techniques. While data loggers provide detailed information on the local variability in water quality parameters, remote sensing observations provide extensive spatial coverage at 1 km resolution. Given the spatial and temporal complexity of the data, the development of an integrated assessment and reporting framework is needed to provide a comprehensive and more easily interpretable assessment of GBR water quality. Further work in designing the Guideline exceedance metrics and how to combine the assessment over more variables is needed to provide a high degree of confidence in the remote sensing results.

Conclusions

Managers need to be aware of the limitations and uncertainties associated with various monitoring tools applied in the MMP so that informed decisions can be made on appropriate application of the results. Despite the limitations and uncertainties associated with reporting remote sensing data for monitoring water quality in the GBR outlined here, remote sensing does show considerable promise as one of the primary tools for assessing the status of water quality in the GBR. Work has already commenced to address the current limitations and uncertainties in the application of these techniques however, continued support of remote sensing capability in the GBR will assist to overcome these issues and could be accelerated as a matter of priority given allocation of the appropriate skills and resources.

References

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Ferrari GM and Dowell MD (1998) CDOM absorption characteristics with relation to fluorescence and salinity in coastal areas of the southern Baltic Sea. *Estuarine, Coastal and Shelf Science* 47(1): 91-105.

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Appendix 2

Decision rules for the Water Quality Index

A simple water quality index was developed in 2009/10 to generate an overall assessment of water quality at each of the twenty 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). The index is considered 'interim' as further research and data analyses need to be undertaken to refine, for example, the quantification of Guideline exceedances and the weighting of the water quality parameters.

The index aggregates scores given to five indicators in comparison with the Water Quality Guidelines for the Great Barrier Reef Marine Park (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; and
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 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 score of 1 was given.

2. **Chlorophyll:**
    a. Chlorophyll measured by FLNTUSB: annual mean values 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; and

>80%.............is assessed as ‘very good’ and coloured dark green.

Appendix 3

Decision rules for categorising coral reef community status

The decision rules for categorising coral reef community attributes to make an assessment of reef status are summarised in Table A3.1. For each reef a categorical assessment was made for each community attribute and reef condition was determined by aggregation across these categories. To aggregate the condition assessment to a sub-regional or regional level, the assessments for each attribute were converted to numerical scores whereby: positive = 2, neutral = 1, and negative = 0. The attribute scores were added for each (sub-) region and then converted into an overall proportional score relative to the maximum possible score by dividing this sum by the number of assessments x 2 (i.e. the maximum rating that could be achieved if all assessments returned a positive score = 2) and multiplying by 100 (to convert into a percentage scale). The average of these regional attribute scores gave the overall (sub-) regional assessment rating. The proportional scores were expressed on a five point scale and converted to a colour scheme for reporting:

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; and

>80% ....is assessed as ‘very good’ and coloured dark green.

Table A3.1: Summary of decision rules for the assessment of coral reef condition.

Community attribute	Assessment category	Decision rule
Combined hard and soft coral cover	+	> 50%
	neutral	between 25% and 50%
	-	< 25%
Rate of increase in hard coral cover (coral cover change)	+	above upper confidence interval of model-predicted change
	neutral	within confidence intervals of model-predicted change
	-	below lower confidence interval of model-predicted change
Macroalgae cover	+	< 5%; or <10% and declining from a high cover following disturbance
	neutral	stable between 5-15%, or declining and between 10-20%
	-	> 15% or increasing
Density of hard coral juveniles	+	> 10.5 juvenile colonies per m^2 of available substratum (2m depth) > 13 juvenile colonies per m^2 of available substratum (5m depth)
	neutral	- between 7 and 10.5 juvenile colonies per m^2 of available substratum (2m depth) - between 7 and 13 juvenile colonies per m^2 of available substratum (5m depth)
	-	< 7juvenile colonies per m^2 of available substratum
Settlement of coral spat	+	> 70 recruits per tile
	neutral	between 30 and 70 recruits per tile
	-	< 30 recruits per tile

Appendix 4

Decision rules for categorising seagrass community and environment status

Four indicators were chosen as components of the seagrass reporting (seagrass guidelines), and these were divided into community and environment status in recognition of the role of seagrass as a bioindicator:

Seagrass community status

- Seagrass abundance
- Reproductive effort

Seagrass environment status

- Light availability (seagrass tissue C:N ratio)
- Nutrient status (seagrass tissue N:P and C:P ratios, and epiphyte abundance)

Seagrass abundance

The status of seagrass abundance was determined using the seagrass abundance guidelines developed by McKenzie (2009) (Table A4.1). Subregional seagrass abundance guidelines were developed based on the 50th and 20th percentiles (as recommended for the Water Quality Guidelines) of abundance data collected from reference sites (McKenzie 2009). For the 50th and 20th percentiles, error values were found to level off at around 15-20 samples, suggesting this number of samples was sufficient to provide a reasonable estimate of the true percentile value. Based on the analyses it was recommended that estimates of the 20th percentile at a reference site should be based on a minimum of 18 samples collected over at least three years. For the 50th percentile a smaller minimum number of samples (~10-12) would be adequate but in most situations it would be necessary to collect sufficient data for the 20th percentile anyway. For seagrass habitats with high variability, primarily the result of seasonal fluctuations, a more appropriate guideline may however be the 10th percentile (similar to highly disturbed systems).

Using the recommended approach, subregional guidelines were developed for each seagrass habitat types where possible (Table A4.1). If an individual site had 18 or more sampling events and no identified impacts (eg major loss from cyclone), abundance guideline was determined at the site or location level and used for the specific site.

Using the subregional guidelines, seagrass state was determined for each monitoring event at each site and allocated as poor (median abundance below 20th or 10th percentile), fair (median abundance below 50th and above 20th percentile) or good (median abundance above 50th percentile) state. Seagrass state was then scored on a scale of 0 to 3 against the abundance guidelines and relative to the previous sampling event (Table A2.2).

Scores were then rescaled from 0 to 100 to allow integration with other components of the report card (Table A4.3).

Reproductive effort

The reproductive effort of seagrasses provides an indication of the capacity of seagrasses to recover from the loss of an area of seagrass through the recruitment of new plants, i.e. the resilience of the population (Collier and Waycott 2009). Given the high diversity of seagrass species that occur in the GBR coastal zone (Waycott *et al.* 2007), their variability in production of reproductive structures (e.g. Orth *et al.* 2006b), a metric that incorporates all available information on the production of flowers and fruits per node is the most useful.

The production of seeds also reflects a simple measure of the capacity of a seagrass meadow to recover following large scale impacts (Collier and Waycott 2009). As it is well recognized that coastal seagrasses are prone to small scale disturbances that cause local losses

(Collier and Waycott 2009) and then recover in relatively short periods of time, the need for a local seed source is considerable. In the GBR, the production of seeds comes in numerous forms and assessments must capture these forms in sampling. Unfortunately, seed banks examined at Seagrass-Watch and Reef Rescue MMP sites are limited to seagrass species with larger seeds or seeds which are not targeted by consumers. As a result, seed banks have not been included in the metric for reproductive effort at this time, but methods for future incorporation are currently being explored.

Using the annual mean of all species pooled in the late Dry and comparing with the long-term (2005-2010) average for GBR habitat, the reproductive effort was scored as the number of reproductive structures per core and the overall status determined (Table A4.4).

Seagrass environment light status (light limitation)

As changing leaf C:N ratios have been found in a number of experiments and field surveys to be related to light levels (Abal *et al.* 1994; Grice *et al.* 1996; Cabaço and Santos 2007; Collier *et al.* 2009) they can be used as an indicator of the light that the plant is receiving. With light limitation, seagrass plants are unable to grow (take up carbon), hence the proportion of carbon decreases relative to nitrogen. Experiments on seagrasses in Queensland have reported that at an atomic C:N ratio of less than 20, may suggest reduced light availability (Abal *et al.* 1994; Grice *et al.* 1996). The light availability to seagrass is not necessarily an indicator if light in the water column, but an indicator of the light that the plant is receiving. This available light can be highly impacted by epiphytic growth or sediment smothering photosynthetic leaf tissue.

Using the guideline ratio of 20:1 for the foundation seagrass species (excluding Halophila ovalis), light status was scored on a scale of 0 to 3 scale and then rescaled from 0 to 100 to allow integration with other components of the report card (Table A4.5).

Seagrass environment nutrient status

The ratios of the most common macronutrients required for plant growth has been used widely as an indicator of growth status, in phytoplankton cultures this known as the familiar ‘Redfield’ ratio of 106C:16N:P (Redfield *et al.* 1963). Seagrass and other benthic marine plants possess large quantities of structural carbon, resulting in ‘seagrass Redfield ratios’ estimated to be between 550:30:1 (Atkinson and Smith 1983) and 474:24:1 (Duarte 1990). Like phytoplankton, seagrasses growing in eutrophic waters have C:N:P ratios that reflect elevated nitrogen and phosphorus levels (Duarte 1990). Plants residing in nutrient poor waters show significantly lower N:P and/or higher C:P ratios than those from nutrient rich conditions (Atkinson and Smith 1983). Comparing deviations in the ratios of carbon, nitrogen and phosphorous (C:N:P) retained within plant tissue has been used extensively as an alternative mean of evaluating the nutrient status of coastal waters (Duarte 1990).

Seagrass with an atomic N:P ratio of 25 to 30 can be determined to be ‘replete’ (Atkinson and Smith 1983; Fouqurean *et al.* 1997; Fourqurean and Cai 2001). N:P values in excess of 30 may potentially indicate P-limitation and less than 25 are considered to show N limitation (Atkinson and Smith 1983; Duarte 1990; Fourqurean *et al.* 1992; Fourqurean and Cai 2001). The median seagrass tissue ratios of C:P is approximately 500 (Atkinson and Smith 1983), therefore deviation from this value is also likely to be indicative of some level of nutrient enriched or nutrient limited conditions. A combination of these ratios can indicate seagrass environments which are impacted by nutrient enrichment. Plant tissue which has a high N:P and low C:P indicates an environment of elevated (saturated) nitrogen.

Using the guideline ratios of C:P and N:P for the foundation seagrass species (excluding *Halophila ovalis*), nutrient status was scored on a scale of 0 to 3 scale and then rescaled from 0 to 100 to allow integration with other components of the report card (Table A4.6).

Table A4.1: Subregional seagrass abundance guidelines.

NRM Region	habitat	percentile guideline		
		10th	20th	50th
Cape York	*estuarine*			
	coast			
	reef	11	16.8	18.9
Wet Tropics	*estuarine*			
	coast	5	6.6	12.9
	reef	27.5	31.9^	37.7
Burdekin Dry Tropics	*estuarine*			
	coast	11.9	15.7	21.1
	reef	22.15	26.25	34.5
Mackay Whitsunday	*estuarine*		18*	34.1*
	coast	12.1	13.15	19.1
	reef	22.2*		34.5*
Fitzroy	*estuarine*		18*	34.1*
	coast	15.85	17.5	21.6
	reef	22.2*		34.5*
Burnett Mary	*estuarine*	10.8	18	34.1
	coast			

* From nearest adjacent region

Table A4.2: Scores against abundance guideline adjusting for trends.

		Trend from previous event	
		>20% increase	>20% decrease
median	>50th percentile	3	2
	>20<50th percentile	2	1
	<10th percentile	1	0

Table A4.3: Rescaled scores to determine seagrass abundance status.

State to guidelines	Score	0-100 score	Status
Good	3	>66.7 - 100.0	Good
Fair	2	>33.3 - 66.7	Fair
Poor	1	0 -33.3	Poor
Poor	0	0	Very poor

Table A4.4: Scores for monitoring period reproductive effort average against long-term (2005–2010) GBR habitat average.

Reproductive Effort monitoring period / long-term	Score	0-100 score	Status
4.0	3	100.0	Good
2.0	2	66.7	Fair
1.0	1	33.3	Poor
<1.0	0	0.0	Very poor

Table A4.5: Scores for leaf tissue C:N against guideline to determine light availability (limitation).

C:N Ratio	Score	0-100 score	Status
> 25	3	100.0	Excellent
20-25	2	66.7	Good
15-20	1	33.3	Fair
<15	0	0.0	Poor

Table A4.6: Scores for leaf tissue N:P + C:P ratios against guideline to determine nutrient status (enrichment).

N:P ratio	Score	C:P ratio	Score
> 30	0	> 500	1
25-30	1	<= 500	0
<25	2		

FINAL score (N:P score + C:P score)	0-100 score	Status
3	100	Good
2	67	Moderate
1	33	Moderate
0	0	Poor

Increased epiphyte (the plants growing on the surfaces of slower-growing seagrass leaves (Borowitzka *et al.* 2006) loads may result in shading of seagrass leaves by up to 65%, reducing photosynthetic rate and leaf densities of the seagrasses (Tomasko and Lapointe 1991; Walker and McComb 1992; Tomasko *et al.* 1996; Touchette, 2000). In seagrass meadows, increases in the abundance of epiphytes are stimulated by nutrient loading (e.g. Silberstein *et al.* 1986; Neckles *et al.* 1994; Balata *et al.* 2008) and these increases in abundance have been implicated as the cause for declines of seagrasses during eutrophication (e.g. Cambridge *et al.* 1986).

Given the observed relationships between nutrient loading and the abundance of epiphytes observed in seagrass ecosystems from around the world, and the perceived threat to water quality owing to human population, the abundance of epiphytes in seagrass meadows may prove to be a valuable indicator for assessing both the current status and trends of the GBR seagrass meadows. However, preliminary analysis of the relationship between seagrass abundance and epiphyte cover collected by the MMP and Seagrass-Watch were inconclusive (McKenzie 2009) and further research and analysis is recommended before threshold levels for epiphyte abundances can be used as an indicator.

Seagrass index

The seagrass index is to average score (0-100) of the four seagrass status indicators chosen for the Reef Rescue MMP. Each indicator is equally weighted as we have no preconception that it should be otherwise. The overall index is rated and coloured according to the standard scheme adopted by the Paddock to Reef reporting (Table A4.7).

Table A4.7: Paddock to Reef Program index rating scheme.

80 - 100	excellent
60 - < 80	good
40 - < 60	moderate
20 - < 40	fair
0 - <20	poor

Appendix 5

Summary of seagrass condition and overall Great Barrier Reef trend

Table A5.1: Data presented for each monitoring location (sites pooled) for each season. Cover = % seagrass cover, Seeds = seeds per m^2 sediment surface, meadow = edge mapping within 100m of monitoring sites, epiphytes = % cover on seagrass leaves, macro-algae = % cover. Trend data values presented as October 2009 to April 2010 (long-term average in parenthesis) and colours represent direction of trend, where red= declining, green = stable or increasing, yellow = variable.

NRM	Catchment	Location	% cover Long Term Average	% cover late dry		% cover late monsoon		Overall trend since late dry 2005				
				2009	% Difference 2008 to 2009	2010	% Difference 2009 to 2010	Seagrass Cover	Seagrass Seeds	Meadow	Epiphytes	Macro-Algae
Cape York	Endeavour	Archer Point	18.1 ± 1.9	16.1 ± 2.1	similar	15.2 ± 3.1	>20% decrease	stable	187 - 288 (162) increase	variable	30 – 39 (27) increase	3 - 2 (9) decline
Wet Tropics	Barron Russell-Mulgrave Johnstone	Yule Point	15.7 ± 1.3	20.1 ± 1.4	similar	17.4 ± 1.6	>20% decrease	increase	611 - 459 (386) decline	variable	16 -22 (21) increase	1 (2) decline
		Green Is	40.2 ± 2.2	36.5 ± 1.7	>20% increase	36.4 ± 2.1	similar	stable	nil	stable	28 - 12 (27) increase	3 - 15 (4) increase
	Tully-Murray	Lugger Bay	4.3 ± 0.6	6.6 ± 0.8	similar	0.4 ± 0.1	>20% decrease	variable	9 - 0 (4) variable	variable	8 - 1 (3) increase	0 (<1) stable
		Dunk Is	9.7 ± 1.0	6.7 ± 0.8	>20% decrease	2.9 ± 0.3	>20% decrease	variable	8 - 0 (3) variable	stable	10 - 7 (16) decline	4 (6) variable
Burdekin	Burdekin	Townsville	16.9 ± 2.1	7.7 ± 1.0	similar	2.0 ± 0.4	>20% decrease	decline	675 – 764 (2004) decline	decline	4 - 1 (15) decline	3 - 1 (4) decline
		Magnetic Is	30.8 ± 2.5	11.0 ± 2.2	>20% decrease	6.5 ± 1.1	>20% decrease	decline	0 (16) decline	decline	43 - 6 (38) decline	8 - 9 (7) stable
Mackay Whitsunday	Proserpine	Pioneer Bay	20.2 ± 1.6	29.4 ± 2.3	similar	10.9 ± 1.1	>20% decrease	variable	71 - 161 (208) stable	increase	4 - 2 (14) decline	2 - 1 (11) decline

NRM	Catchment	Location	% cover Long Term Average	% cover late dry		% cover late monsoon		Overall trend since late dry 2005				
				2009	% Difference 2008 to 2009	2010	% Difference 2009 to 2010	Seagrass Cover	Seagrass Seeds	Meadow	Epiphytes	Macro-Algae
		Hamilton Is*	6.3 ± 1.1	1.6 ±1.5	>20% decrease	2.9 ± 0.8	>20% increase	decline	nil	variable	14 - 4 (15) decline	1 - 3 (3) stable
	Pioneer	Sarina Inlet	13.8 ± 1.5	7.6 ±1.1	>20% decrease	2.0 ± 0.5	>20% decrease	decline	0 (31) stable	decline	22 - 0 (14) stable	<1 (2) variable
Fitzroy	Fitzroy	Shoalwater	22.9 ± 1.4	29.2 ±1.1	similar	23.0 ± 1.1	similar	increase	nil	stable	10 – 8 (12) decline	4 - 1 (5) decline
		Great Keppel	2.3 ± 0.5	2.1 ±0.4	>20% increase	0.7 ± 0.2	>20% decrease	decline	nil	variable	19 - 11 (27) decline	2 - 18 (8) stable
	Boyne	Gladstone	21.0 ± 1.7	30.8 ±1.8	similar	28.9 ± 4.0	>20% increase	increase	nil	variable	16 - 4 (22) decline	2 -<1 (12) decline
Burnett Mary	Burnett	Rodds Bay	11.6 ± 1.4	1.3 ±0.5	>20% decrease	0	>20% decrease	decline	0 (1) stable	variable	5 - 0 (5) decline	1 - 6 (2) increase
	Mary	Urangan	15.0 ± 1.0	6.5 ±1.3	>20% increase	11.0 ± 1.2	>20% decrease	variable	nil	variable	5 - 39 (20) variable	4 - 0 (1) variable