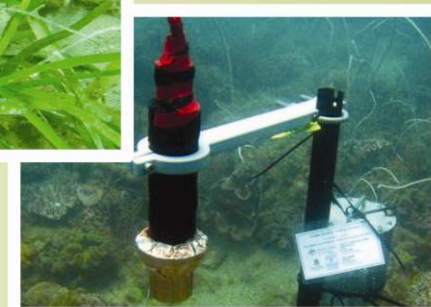
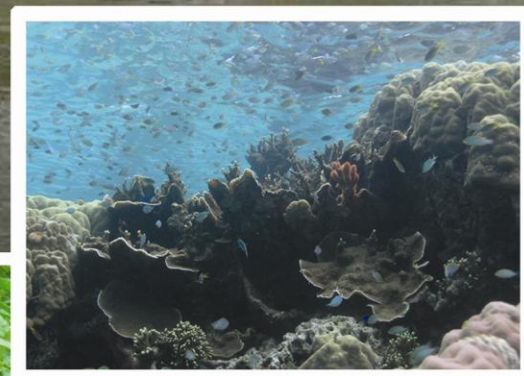




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Reef Rescue Marine Monitoring Program: 2008/2009 Synthesis Report



Compiled by the
Reef & Rainforest Research Centre Ltd
for the Great Barrier Reef Marine Park Authority



Australian Government
Great Barrier Reef
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March 2010

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Acronyms and Abbreviations

AIMS	Australian Institute of Marine Science
ANN	Artificial neural network
C	Carbon
CDOM	Coloured Dissolved Organic Matter
Chl	Chlorophyll
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEEDI	Queensland Department of Employment, Economic Development and Innovation
DERM	Queensland Department of Environment and Resource Management
Entox	National Research Centre for Environmental Toxicology, the 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
HEq	Herbicide Equivalency
JCU	James Cook University
MA	Macroalgae
ML	Mega-litres
MMP	Marine Monitoring Program
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
QLD	Queensland
RRRC	Reef and Rainforest Research Centre Ltd
RT	Radiative transfer
SC	Soft coral
SE	Standard Error
SS	Suspended solids
TCPP	Tris(1-chlor-2-propyl) phosphate

About this report

This report provides a synthesis of information collected as part of the Reef Rescue Marine Monitoring Program during 2008/2009. The information provided had been extracted from the following reports, also available for download from the RRRC website:

- **Schaffelke**, B., Thompson, A., Carleton, J., Davidson, J., Doyle, J., Furnas, M., Gunn, K., Skuza, M., Wright, M. and Zagorskis, I. (2009) *Reef Rescue Marine Monitoring Program. Final Report of AIMS Activities 2008/2009*. Report submitted to the Reef and Rainforest Research Centre. Australian Institute of Marine Science, Townsville.
- **Devlin**, M., Brodie, J., Lewis, S. and Bainbridge, Z. (2009) *Reef Rescue Marine Monitoring Program: Flood plumes in the GBR – Case studies for Marine Monitoring Program, Tully and Burdekin. Final Report for 2008/2009 activities JCU*. ACTFR Catchment to Reef Group, James Cook University, Townsville.
- **McKenzie**, L. and Unsworth, R. (2009) *Reef Rescue Marine Monitoring Program: Intertidal Seagrass, Final Report for the Sampling Period 1 September 2008 to 31 May 2009*. Fisheries Queensland, Cairns.
- **Paxman**, C., Dunn, A., O'Brien, J., Kennedy, K., Mueller, J. (2009) *Reef Rescue Marine Monitoring Program: Monitoring of organic chemicals in the Great Barrier Reef Marine Park and selected tributaries using time integrated monitoring tools (2008/2009)*. EnTox National Research Centre for Environmental Toxicology, University of Queensland, Brisbane.
- **Brando**, V.E., Schroeder, T., and Dekker, A.G. (2010) *Reef Rescue Marine Monitoring Program: Using Remote Sensing for GBR wide water quality*. Final Report for 2008/2009 Activities, CSIRO Land & Water, Canberra.
- **Waycott**, M. (2010) *Reef Rescue Marine Monitoring Program: Intertidal Seagrass. Project 1.1.3 ext (a): Reproductive Health 2008/2009*. Draft Report, March 2010. James Cook University, Townsville.

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1. Executive Summary

The Reef Rescue Marine Monitoring Program (herein referred to as the 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, including the Reef Rescue initiative. The MMP was established in 2005 to help assess the long-term status and health of GBR ecosystems and is a critical component in the assessment of regional water quality as land management practices are improved across GBR catchments. The program forms an integral part of the Reef Plan Paddock to Reef Integrated Monitoring, Modelling and Reporting Program. This Synthesis Report presents the results of the 2008/2009 MMP monitoring period as well as trend analysis for the four years of the program where possible. The data and information presented in this Synthesis Report also provides the foundation for the development of the Great Barrier Reef Water Quality and Ecosystem Health component of the Reef Plan Baseline Water Quality Report.

The 2008/2009 MMP assessed the condition of water quality in the inshore GBR lagoon and the health of key GBR marine ecosystems – inshore coral reefs and intertidal seagrass meadows – for the 2008/2009 sampling period. The MMP has two core programs: (i) inshore GBR water quality monitoring, and (ii) inshore GBR biological monitoring of seagrass meadows and coral reefs, including biological indicators. The main water quality constituents and pollutants of concern (suspended solids, nutrients and pesticides) are monitored at fourteen inshore sites along the GBR during both ambient and flood conditions, and herbicides were monitored in sediments at seagrass sites. The MMP uses the traditional monitoring techniques of grab sampling, automated water quality loggers, passive sampling of pesticides and remote sensing (for inshore and offshore waters), in combination with biological indicators. These biological indicators include seagrass abundance, reproductive potential, tissue nutrients, and epiphyte cover; reef benthic cover; and coral demographics, diversity and recruitment.

Water quality and ecosystem health in the GBR is influenced by an array of factors including land-based runoff and river flow, point source pollution, and extreme weather conditions. The roles these factors play in influencing the quality of inshore waters have been considered using a comparative analysis of the last four years of MMP water quality data. The data showed that there are significant high-level interactions between sampling year, season and geographic Region – meaning that none of these individual factors can be considered in isolation as an overarching driving factor for influencing GBR water quality. The data also showed that there is a clear water quality gradient away from river mouths and that flood events and resuspension are significant driving factors in influencing lagoon water quality. Other factors affecting lagoon water quality include the quantity of sediment, nutrients and pollutants entering from adjacent catchments, regional sediment grain size and tidal and wind forcing. The quantification of these factors will now allow for a greater capacity to predict the benefits derived from improvements in land management, highlighting the critical role of supporting research in optimisation of the MMP.

The past two years has seen exceptional river flows in the GBR catchment. In 2007/2008, both the dry tropical Burdekin and Fitzroy Rivers experienced extensive flooding, and this unusual situation was repeated for the Burdekin River in the 2008/2009 wet season. During the same two year period, the Wet Tropics (except for the Herbert River) and Mackay Whitsunday Regions experienced either just above average flow or in fact below-average flow for the Russell/Mulgrave River. Freshwater discharge from the GBR catchment in 2008/2009 was 2.2 times the long-term annual median flow, with the Burdekin River experiencing more than five times the annual median flow, and the Herbert River more than three times the annual median flow. Flow peaked in all GBR rivers between mid-February and mid-March 2009.

The water quality data collected in the MMP for 2008/2009 was considered against the Water Quality Guidelines for the Great Barrier Reef Marine Park (the 'Guidelines', GBRMPA 2009) and a preliminary Pesticide Index based on five ranges of Herbicide Equivalency (HEq). Targeted flood monitoring campaigns collected nutrient, chlorophyll and turbidity data, *in situ* water quality loggers collect chlorophyll and turbidity data, and remote sensing techniques collected chlorophyll and suspended solids proxy (non-algal particulate matter) data in inshore and offshore waters. A simple comparison across the Regions for the 2008/2009 year, indicates that the highest rate of exceedances of the chlorophyll Guidelines were measured in the Mackay Whitsunday and Burdekin Regions in both the dry and the wet seasons, and elevated turbidity concentrations were most frequently measured (using the *in-situ* logger data) in the Fitzroy Region (Pelican Island which is a naturally turbid site) and at one site in the Wet Tropics Region (Dunk Island).

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. Presently, the wet season is defined as January to March, and the dry season as July to September each year. Interannual variations in the extent of the actual wet and dry seasons will have implications for compliance with the Guidelines when considering seasonal means.

During the initial four years of the MMP (2005/2006 to 2008/2009), pesticides have been detected at all fourteen inshore reef monitoring sites with some clear differences between Regions. Routine monitoring showed the pesticide profile at inshore reef sites is dominated by diuron, atrazine and hexazinone, herbicides used to control weeds in sugar cane, cotton, broadacre crops and some horticultural crops. Other chemicals that can be detected regularly included tebuthiuron, a herbicide used to control woody weeds in grazing lands and simazine, a herbicide used on cropping land. For most sites diuron was detected at the highest concentrations.

Pesticide concentrations were generally higher in the wet season than the dry season at all sampling sites, often increasing by one to two orders of magnitude. All Regions that were monitored for pesticides were assessed to have average pesticide ratings in the lower ranges (generally 1-10 ng/L) and the Cape York Region had an average pesticide rating in the range less than 1 ng/L. There were no exceedances of the Guidelines values for pesticides.

Intertidal seagrass abundance was significantly lower (>20% difference) in the 2008/2009 monitoring period compared to 2007/2008 at two thirds of the locations examined across the GBR. These locations were all south of the Wet Tropics Region and half showed an overall decline in seagrass abundance since 2005.

Seagrass species dominance varies between habitats (reef, coastal and estuary) and latitude, and trends for each habitat suggest water quality and environmental conditions could be a major influence upon the degree of this variability. The indicator of light availability explained 58% of the variability in percent seagrass cover between coastal and estuarine sites, suggesting light availability (linked to turbidity) is a major factor influencing inter-site variability in these habitats.

Over the entire period of the currently available data (2006-2009) all seagrass monitoring sites showed some evidence of reproductive effort (measured as the number of seeds per square metre). However, the sites at Green Island (Cairns), Lugga Bay (Tully River/Mission Beach) and Urangan (Mary River/Hervey Bay) showed virtually no production of reproductive structures across the entire sampling period. A continued absence of flowering and fruiting in

these sites will result in poor capacity to recover from disturbance. Inter-annual differences in sexual reproduction are evident and these differences principally relate to the decline of meadows. The status of the sites listed in poor reproductive health, where little evidence of seed set over the entire monitoring period has been seen, is such that careful attention should be paid as to the cause of their failure to sexually reproduce.

Seagrass epiphyte cover appears to be increasing in coastal areas. Combined with evidence from tissue nutrient ratios, data indicates that some sites, particularly coastal sites within the Wet Tropics and Burdekin Regions are becoming nutrient saturated environments. Seagrass ecosystems can survive under nutrient saturated conditions until they reach a point of extreme stress, when the ecological balance changes and decline happens quickly. Macroalgal abundance in seagrass meadows is generally low but variable in coastal and reef habitats.

Within-canopy temperatures of seagrass meadows were warmer at northern locations and cooler at southern locations compared to previous monitoring years. Temperatures above 40°C were recorded at Picnic Bay, Magnetic Island; these temperatures are known to be detrimental to seagrass health. No herbicides were detected in the sediment of seagrass monitoring sites.

At the spatial scales of locations and sites, there is considerable variability in seagrass cover. Seagrasses as bioindicators of the environmental conditions of the GBR indicate a general trend of reducing light availability and nutrient enrichment. Tissue nitrogen levels within the Wet Tropics and Burdekin Regions coastal and mid-shelf reef habitats have increased over the last fifteen years and further increased from 2005 to 2008. The implications of this are that in these Regions many of the sites are becoming nutrient saturated.

Locations where seagrasses are growing in generally low light environments (C:N ratio is low, <20), with a relatively large phosphorus pool (C:P ratio <500) and an even larger nitrogen pool (N:P is high, >30 or replete (abundant), 25-30) would indicate relatively poor water quality. Three coastal locations met these criteria in the 2008/2009 monitoring period: Lugg Bay and Yule Point (both Wet Tropics Region) and Townsville (Burdekin Region). Flood plume modelling estimates indicate that Yule Point is within a zone impacted annually (Devlin *et al.* 2001) by the Barron River. During major flood events, plumes from the Mulgrave-Russell and Johnstone Rivers could also impact Yule Point. In the southern section of the Wet Tropics, the coastal seagrass meadows of Lugg Bay would be influenced primarily by the Tully and Murray Rivers (approximately 8km and 15km south of Lugg Bay respectively) which experience regular flood events (Devlin and Schaffelke 2009). The Townsville monitoring sites are located in the zone of influence of the Burdekin River, which experienced significant flow events in the last two years. It is estimated that the inshore areas north of the Burdekin River (including Magnetic Island) receive riverine waters on a less frequent basis, perhaps every two to three years (Wolanski *et al.* 1981; Maughan *et al.* 2008).

In conclusion, the health of inter-tidal seagrasses in the GBR are variable across locations and sites, and there is concern about declining abundance and light availability, lower reproductive potential, higher nutrient enrichment, and the development of nutrient saturated conditions at a number GBR monitoring sites.

The completion of the fourth inshore coral reef survey under the MMP allows the first temporal assessment of the status of coral reef communities using four years of data. Estimates of coral community status were calculated as an aggregate score for four indicators: coral cover, macroalgal cover, juvenile hard coral density, and settlement of coral spat.

Of the reefs surveyed in 2007 and 2008, there was no overall change in hard coral cover (mean cover for all Regions was 36% in both years). On reef sites, the average density of juvenile colonies per square metre has reduced from a high of 5.8 in 2005 to a low of 3.9 in 2008. This decline has been observed in all Regions. It is possible that such variation occurs naturally. However, as there are no previous studies of this nature and only future data from this project can provide estimates of the scales and magnitudes of variation in juvenile abundances. Possible explanations for these declines include a combination of variation in river flows and response to disturbance events. Numbers of juvenile colonies are the result of settlement and survival over the preceding three years. Recent disturbances (e.g. Tropical Cyclone *Larry* and associated flooding in 2006, and coral bleaching in 2006) may explain the subsequent effect of these events in the lower density of juvenile colonies observed during this last year.

Over the period 2005-2008 the average number of hard coral genera recorded in this monitoring program on core reef sites remained relatively stable, and increased slightly in 2008. At the level of genus there is no evidence for a loss of diversity.

Inshore coral community composition also showed a relationship with water column chlorophyll levels at ten of the fourteen reef sites. At sites where the annual mean Guideline value for chlorophyll in the water column was exceeded, reefs had high cover of macroalgae. Where annual means were below the Guideline value, macroalgal cover was very low. The exceptions to this pattern were Barren and Humpy Islands in the Fitzroy Region, which had high cover of the brown macroalga *Lobophora variegata* despite low chlorophyll concentrations, and Pelorus Island (Burdekin Region) and Double Cone Island (Mackay Whitsunday Region) which exceeded the chlorophyll trigger value but currently have only low macroalgal cover.

The key findings for each Region are summarised below, followed by implications of the results.

Cape York Region

- Freshwater discharge from the Normanby River was below the annual long-term median flow.
- Monitoring of water column pesticides detected diuron and hexazinone in the water column, although their concentrations did not exceed the Guidelines. All samples collected in the Cape York Region had pesticide ratings in the lower ranges, generally less than 3 ng/L, with most below 1 ng/L and an average rating of <1 ng/L.
- Seagrass cover is seasonal and has remained stable during the 2008/2009 monitoring period. Seagrass species composition has varied since 2003 but stabilised over the 2008/2009 year. Reproductive health status over the period 2006-2009 was variable, with variable seed count in 2008/2009. .
- During 2008, seagrasses were subject to potentially low light availability. Tissue nutrients show the Region to be nutrient rich. Epiphyte cover has declined.
- Coral monitoring is not undertaken in the Cape York Region.

Wet Tropics Region

- Freshwater discharge from the Herbert River was more than three times the annual median flow. Flow conditions in the Barron, Johnstone and Tully Rivers were slightly above long-term annual median levels (1.1 to 1.3 times).
- Water quality parameters were below Guideline values except at the Snapper Island and Dunk Island sites, where annual and seasonal suspended solids means exceeded the Guidelines for suspended solids, likely due to flood events and resuspension.

- Seasonal means of chlorophyll and suspended solids for the four years of monitoring did not exceed Guideline values, except at Dunk Island, which generally had the highest seasonal means of all sites in this Region.
- Results for the Cairns coastal transect indicate that flood events and resuspension events at the time of sampling are the most prominent drivers of water quality variables. The highest concentrations of chlorophyll and suspended solids were measured in periods with above median flow.
- Pesticides were detected in water column samples from all sites, and included diuron, simazine, atrazine, hexazinone and tebuthiuron. The maximum water concentrations of individual pesticides ranged from 0.26 to 15 ng/L. Diuron, hexazinone and tebuthiuron were detected in all locations; diuron was generally found at the highest concentrations. There were no exceedances of the Guidelines.
- The pesticide profile in the Tully River was dominated by diuron and atrazine, with mean concentrations of 32 ng/L and 31 ng/L respectively.
- Seagrass cover, although seasonal, has generally increased or stabilised over the past year and is naturally lower at coastal habitats compared to reef habitats. Seagrass reproductive health status over the period 2006-2009 was poor at Green Island (reef) and Lugger Bay (coastal), and variable at other sites. In 2008/2009, seed counts were generally lower than in previous years.
- Seagrass epiphytes and tissue nutrients at coastal habitats suggest nutrient saturated conditions, with potentially low light availability. Seagrass in reef habitats are growing in clearer waters (higher light environments) and are nitrogen limited.
- Coral community status scores were negative for reefs in the Herbert/Tully sub-Region. On average, reefs in these locations had relatively high cover of macroalgae and moderate to low coral cover with no signs of recovery from past disturbances (e.g. Cyclone *Larry*). This may be an indication of local environmental conditions hindering recruitment. However, more surveys over time are required to detect any consistent trend.
- A positive score of coral community status was returned for the Daintree and Johnstone-Russell/Mulgrave sub-Regions with on average high coral cover, low macroalgae cover and high juvenile colonies densities.

Burdekin Region

- Median freshwater discharge from the Burdekin River was more than five times the long-term annual median flow.
- Guideline values were exceeded at all sites for wet and dry season means of chlorophyll and suspended solids. Geoffrey Bay (Magnetic Island) generally had the highest seasonal means of all sites in this Region, and the means of all variables, except for particulate nitrogen in the wet season, exceeded Guideline values.
- High values for chlorophyll and turbidity coincided with discharge from the Burdekin River.
- Spatial representation of the exceedances for chlorophyll and suspended solids identifies the area between Magnetic Island and the Palm Islands as being highest risk.
- Pesticides were detected in water samples from all sites, and included diuron, simazine, atrazine, hexazinone, tebuthiuron and ametryn. Atrazine was generally found at the highest concentrations. The maximum water concentrations of individual pesticides ranged from 0.25-10 ng/L, with no exceedances of the Guidelines recorded.
- Seagrass abundance declined in the latter part of the 2008/2009 sampling period at coastal habitats and was variable at reef habitats. Seagrass reproductive health status over the period 2006-2009 was assessed to be good at the Townsville coastal site, and variable at Magnetic Island. Seagrass tissue nutrients indicate a potentially low light

environment at all sites. Decreasing C:N ratios at coastal sites since 2006 indicate decreasing light availability.

- Coastal and reef habitats were found to be nutrient rich (large phosphorus pool), with nutrient availability to the plant phosphorus limited at the coastal site and replete at the reef site. However, epiphytes declined at the Townsville coastal site and were variable at Magnetic Island, following similar patterns as seagrass abundance.
- Coral community status had a negative score, with overall status lower than the Wet Tropics Region to the north and the Mackay Whitsunday Region to the south because of the high occurrence of disturbance events in the Region, including significant bleaching events in 1998 and 2002, and several major flood events since 1990.
- Coral recruitment had a negative score which could also be related to disturbances and large flood events in the last two years.

Mackay Whitsunday Region

- Freshwater discharges from the Proserpine, O'Connell, Pioneer and Pine Rivers were above long-term annual median flows, with the greatest relative difference in the Proserpine River.
- Chlorophyll Guideline values were exceeded for the annual and dry season means at all sites, and wet season means exceeded the Guidelines at Pine Island. Between 65 and 100% of the dry season chlorophyll values were above the Guidelines at all locations, which is more than in any other monitored Region.
- Most of the turbidity maxima were associated with flood influences during the 2008 and 2009 wet seasons, however, the turbidity records show a regularity that implies a strong tidal influence and high turbidity values are associated with the summer king tides.
- A minor flow event was sampled in the Pioneer River for pesticide concentrations. A range of polar pesticides were detected with diuron and atrazine dominating the chemical profile, followed by hexazinone, and ametryn.
- Diuron, atrazine and tebuthiuron were detected in the water column at all sites, with diuron generally found in the highest concentrations. Pesticide water concentrations ranged from 0.15 to 4.1 ng/L, with one higher diuron concentration from the Inner Whitsundays (120 ng/L). There were no exceedances of the Guideline values.
- The pesticide profile in the Pioneer River was dominated by diuron and atrazine, with mean concentrations of 230 ng/L and 180 ng/L respectively, exceeding the Guidelines in at least one wet season sampling period.
- Coastal and estuarine seagrass abundance was variable over time, but reef seagrass continued to decline. Seagrass reproductive health status was variable over the period 2006-2009. In 2008/2009, seed counts declined from previous years at the Pioneer Bay (coastal) and Sarina Inlet (estuarine) site.
- Seagrass tissue ratios indicated that all sites were low light environments, and levels were at their lowest since monitoring began in 2006. All habitats were nutrient rich (large phosphorus pool). Nutrient availability to the plant was nitrogen limited at the Pioneer Bay site and replete at the estuarine and reef sites.
- Although sediment nutrient data was generally highly variable, levels found at reef and coastal sites were high, particularly for sediment phosphorus which was the highest of any GBR site indicating a potential issue of nutrient enrichment in the Region. Seagrass epiphyte cover was highly variable at inshore coastal and estuarine sites and is seasonal, with higher abundance in the dry season. Epiphyte cover declined at the reef habitat sites over the monitoring period.
- Coral community status was positive with average coral cover high but it did not increase despite a lack of acute disturbance. Macroalgae cover was low and the relative density of juvenile colonies and spat settlement to tiles was moderate relative to other Regions.

Fitzroy Region

- Freshwater discharge from the Fitzroy River was below the annual long-term median flow.
- For the 2008/2009 period, the highest values for all four water quality parameters (chlorophyll, suspended solids, secchi depth and particulate nutrients) were found at Pelican Island, the most inshore location with naturally turbid waters. High values for both chlorophyll and suspended solids at all three locations coincided with discharge from the Fitzroy River in 2008.
- High marine chlorophyll and suspended solids values during the wet season are likely to be associated with wind-driven resuspension.
- Pesticide sampling of the Fitzroy River during peak flow (February 2009) detected atrazine (polar pesticide) with a maximum water concentration of 254 ng/L. Tebuthiuron was the second highest polar pesticide, with a maximum concentration of 64 ng/L.
- Inshore marine water column pesticides detected included diuron and tebuthiuron; diuron was found at the highest concentration, with the maximum water concentrations of individual pesticides ranged from 0.18 to 1.1 ng/L. There were no exceedances of the Guidelines recorded.
- Coastal and estuarine seagrass meadow cover remained highly variable, but reef seagrass at Great Keppel Island declined in abundance since 2007. Over the period 2006-2009, reef and estuarine sites had variable seagrass reproductive health status and the coastal site had stable reproductive health status. However, no seeds were measured in all locations in 2008/2009.
- Estuarine and reef seagrass habitats had potentially low light environments, whilst the coastal site had moderate light availability. The estuarine and reef habitats were rich in nutrients (larger phosphorus pool) except for the coastal site that was nutrient poor. Nutrient availability to the plant was replete at all locations. Seagrass epiphytes were variable at all sites.
- Coral community status was marginally positive with high average coral cover, high settlement of spat but also high macroalgal cover and low densities of juvenile colonies. The strong gradient in turbidity between inshore locations and the more offshore islands is expected to account for the variation in coral diversity between these sites with lower diversity at inshore locations.

Burnett Mary Region

- Freshwater discharge from the Burnett-Mary River was well below the long-term annual median flow.
- Seagrass abundance has varied greatly across the Region, and significant declines occurred in 2009. Over the period 2006-2009, the seagrass reproductive health status at Rodds Bay was assessed to be good, but poor at Urangan. No seeds were measured in these locations in 2008/2009.
- Seagrass leaf tissue ratios indicate seagrass at Urangan to be growing in a low light environment, whilst seagrass in Rodds Bay are growing in a moderate light environment. Seagrass habitats were nutrient rich (larger phosphorus pool) and nutrient availability to the plant was N limited at Rodds Bay and replete at Urangan. Epiphyte cover was low.
- Coral surveys and water column pesticide monitoring are not undertaken in this Region.

Implications

The ecological consequences of degraded water quality (particularly low light and elevated nutrient, suspended solids and pesticide concentrations) reported at some seagrass locations have not been fully quantified within the GBR. Increased seagrass growth could be expected in response to low level nutrient enrichment, but as nutrients increase a comparable increase is likely to occur in epiphyte and phytoplankton abundance. These conditions can result in light limitation and subsequent seagrass decline, ultimately resulting in habitat loss. The low light availability observed throughout the GBR in 2008 could indicate high turbidity, however in intertidal environments it is generally understood that epiphyte shading is a more likely source of this reduced light, particularly in shallow sites (Pollard and Greenway 1993). Such interactions are poorly understood and require further investigation. Seagrasses also respond to nutrient enrichment at the meadow scale, with shifts in seagrass dominance reported in tropical seagrass, where species with higher elemental requirements may have a competitive advantage. Elevated plant nutrient content can also increase rates of herbivory.

Environmental conditions clearly influence the benthic communities found on coastal and inshore coral reefs of the GBR with these reefs differing markedly from those found in clearer, offshore waters. Coral reef monitoring results indicate that the particulate components of marine water quality – suspended solid and particulate nutrients and carbon – are important drivers of coral reef communities. Specific indicators of environmental stress to coral reef communities have been monitored to document change over time for example, reef sediment composition and juvenile corals.

Inshore reefs are regularly exposed to pesticides during flood plumes and concentrations at inshore reefs are detectable during both the wet and dry seasons. Whilst the concentrations did not exceed the current Guidelines, the ecological consequence of this chronic exposure is currently unknown. However, chronic stress due to poor water quality is likely to manifest as decreased resilience: either in an increase in the susceptibility of corals to disturbance events such as thermal bleaching or inhibition of their recovery following disturbance.

The MMP is revealing trends between inshore GBR water quality and the status of key GBR ecosystems. In particular, there is information regarding seasonal patterns, high risk areas and pollutants of concern in relation to ecological impacts that can inform future management decision-making. As changes in land management practices in the catchments under Reef Plan lead to decreased loads of sediments and nutrients to GBR coastal and inshore waters, associated changes in seagrass and coral reef communities are expected to be detected by the MMP after an initial lag period. High frequency water quality monitoring and improved system understanding will enhance this assessment.

In conclusion, the data suggest that elevated nutrients and high suspended solids levels are generally the main water quality issues in the GBR throughout the year and that elevated pesticide concentrations are largely correlated with low salinity (flood plume) waters and wet season delivery. Based on exceedances of Guideline values, suspended solids are of greatest concern in the Fitzroy and Wet Tropics Regions however, continued monitoring of these parameters will provide information to determine the ecological veracity of the Guideline values, the specific delivery pathways of these pollutants and whether targeted management interventions may be required for some Regions that continue to show high concentrations of these pollutants. While water quality indicators of nutrients and suspended solids are likely to take extended periods to respond to land management improvements, reductions in pesticide runoff to the GBR should be detectable in shorter timeframes. Therefore, intensive pesticide sampling at end of catchment locations is likely to provide useful indicators of water quality improvement in response to land management practice change when coupled with an event-monitoring program in the catchment that can identify

pollutant sources and delivery pathways. In addition, further work in designing reporting metrics for inshore water quality data, and ways to integrate the assessment of all variables is needed to provide a higher degree of integration of, and confidence in monitoring results.

2. Introduction

Water quality is a key issue for the health of the Great Barrier Reef (GBR), its catchments and for the communities, industries and ecosystems that rely on good water quality in North Queensland. Substantial investment is being undertaken to halt and reverse the decline of water quality entering the GBR lagoon.

The Reef Rescue Marine Monitoring Program (herein referred to as the MMP) is a component of the Reef Plan Paddock to Reef Program and is undertaken in the Great Barrier Reef (GBR) lagoon. The MMP assesses the long-term effectiveness of the Australian and Queensland Government's Reef Water Quality Protection Plan (Reef Plan) and Reef Rescue initiative. Reef Plan was released by the Australian and Queensland Governments in October 2003, and was updated in 2009. It focuses on identifying and implementing solutions to improve water through sustainable natural resource management, with the ultimate goal to 'halt and reverse the decline in water quality entering the Reef within ten years'. The update of Reef Plan in 2009 added a long-term goal to ensure that by 2020 the quality of water quality entering the Reef from adjacent catchments has no detrimental impact on the health and resilience of the GBR, with specific end of catchment pollutant load reduction targets.

As part of Reef Plan, the MMP was established in 2005 to help assess the long-term status and health of GBR ecosystems. The MMP is a critical component in the assessment of any long-term improvement in regional water quality that will occur as best land management practices are adopted across GBR catchments. The program forms an integral part of the Reef Plan Paddock to Reef Integrated Monitoring, Modelling and Reporting Program supported through Reef Plan and Reef Rescue initiatives, which will produce annual reports that detail improvements in land management practices and catchment, end of catchment and inshore marine water quality. This Synthesis Report presents the results of the 2008/2009 MMP monitoring period as well as trend analysis for the four years of the program where possible. The data and information presented in this Synthesis Report will provide the foundation for the development of the Great Barrier Reef Water Quality and Ecosystem Health component of the Reef Plan Baseline Water Quality Report.

A consortium of monitoring providers in partnership with the North Queensland based Reef and Rainforest Research Centre (RRRC) implemented the MMP in 2008/2009, overseen by the Great Barrier Reef Marine Park Authority (GBRMPA) (refer to Figure 2.1).

The 2008/2009 MMP assessed the condition of water quality in the inshore GBR lagoon and the health of key GBR marine ecosystems – inshore coral reefs and intertidal seagrass meadows – for the period July 2008 to June 2009. The MMP has two core programs: (i) inshore GBR water quality monitoring, and (ii) inshore GBR biological monitoring of seagrass meadows and coral reefs, including biological indicators (Figures 2.1 and 2.2). The main water quality constituents and pollutants of concern (suspended solids, nutrients and pesticides) are monitored at fourteen sites along the GBR within twenty kilometres of the coast line (Figure 2.3), during both ambient and flood conditions. 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 indicators. These biological indicators include seagrass abundance, reproductive potential (seed bank and flowering), epiphyte cover, tissue nutrients (C:P, P:N), light availability (C:P); reef benthic cover; and coral demographics, diversity and recruitment.

The data from the water quality monitoring is complemented with biological monitoring of seagrass and coral reef ecosystems to determine the ecological relevance of these pollutants.

The data collected is considered against the Water Quality Guidelines for the Great Barrier Reef Marine Park (GBRMPA 2009) and a preliminary Pesticide Index. 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 season and dry seasons. For example, chlorophyll is estimated to be twenty percent higher than the annual mean in the wet season, and twenty percent lower than the annual mean in the dry season. Presently, the wet season is defined as January to March, and 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 compliance with the Guidelines when considering seasonal means. Therefore, it is recommended that further work is undertaken to consider defining the wet season and dry season 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 including the remote sensing.

This information is presented at a GBR-wide scale and at a Regional scale. Synthesised information from the full four years of the MMP (2005 to 2009) is also presented where available. Additional water quality trend information has been derived from long-term monitoring data in the Cairns Region, with the Cairns Coastal Transect ongoing since 1989.

The MMP is strongly linked to research under the Australian Government's Marine and Tropical Sciences Research Facility (MTSRF), which provides critical knowledge and information for the continued improvement of water quality and ecosystem health indicators and ecosystem processes.

For an overview of each of the monitoring sub-programs, including objectives and detailed methods, refer to Appendix 1. Detailed documentation of the methods for the MMP are provided in the *Reef Rescue Marine Monitoring Program Quality Assurance/Quality Control Methods and Procedures Manual* (RRRC Consortium, 2009) (http://www.rrrc.org.au/mmp/mmp_pubs.html).

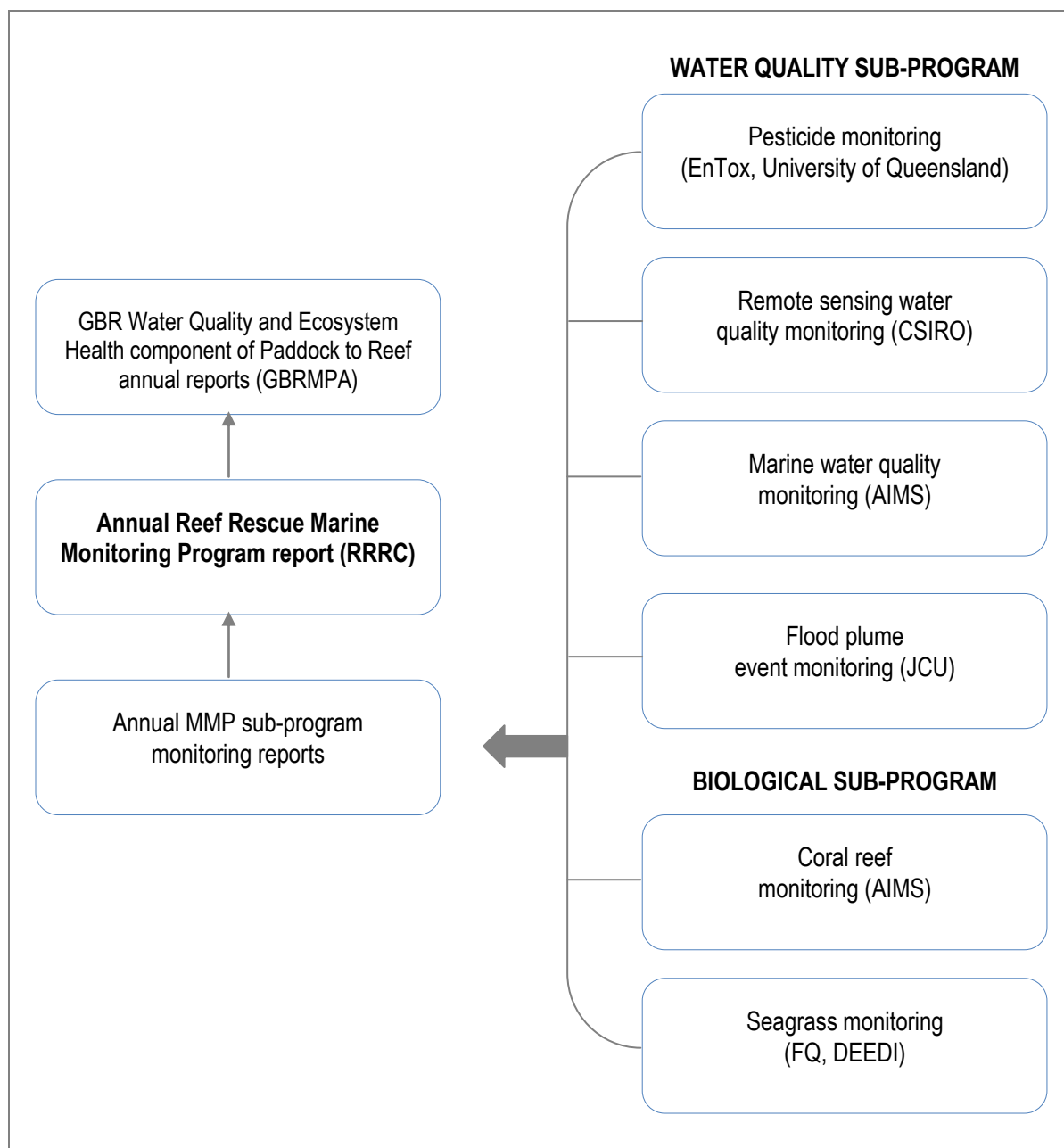


Figure 2.1: Diagrammatic representation of all components of the Reef Rescue Marine Monitoring Program.

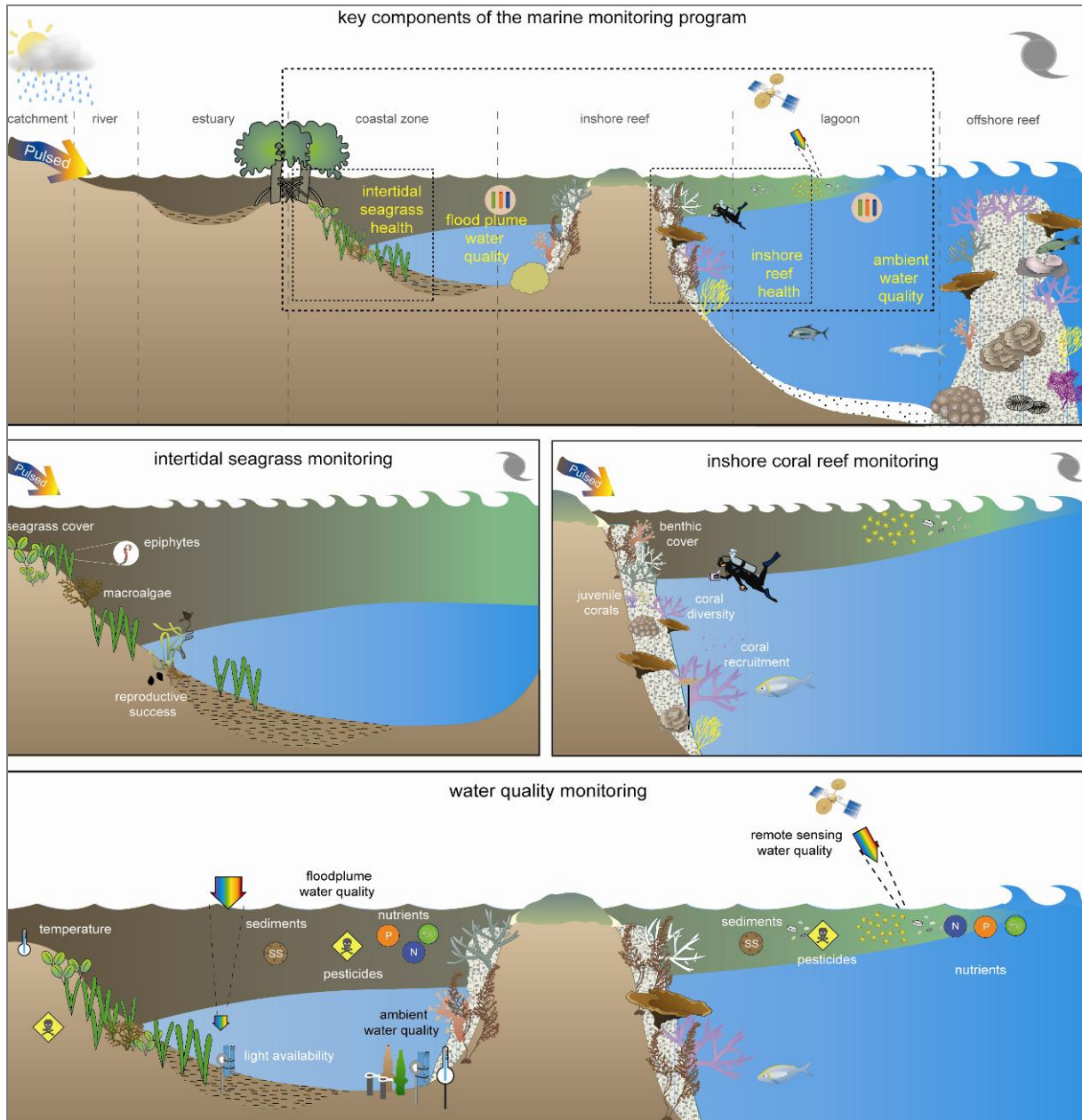


Figure 2.2: Conceptual representation of the Reef Rescue Marine Monitoring Program. See Key provided on page 14 (Source: GBRMPA).



Key to conceptual diagrams used in Figure 2.2.

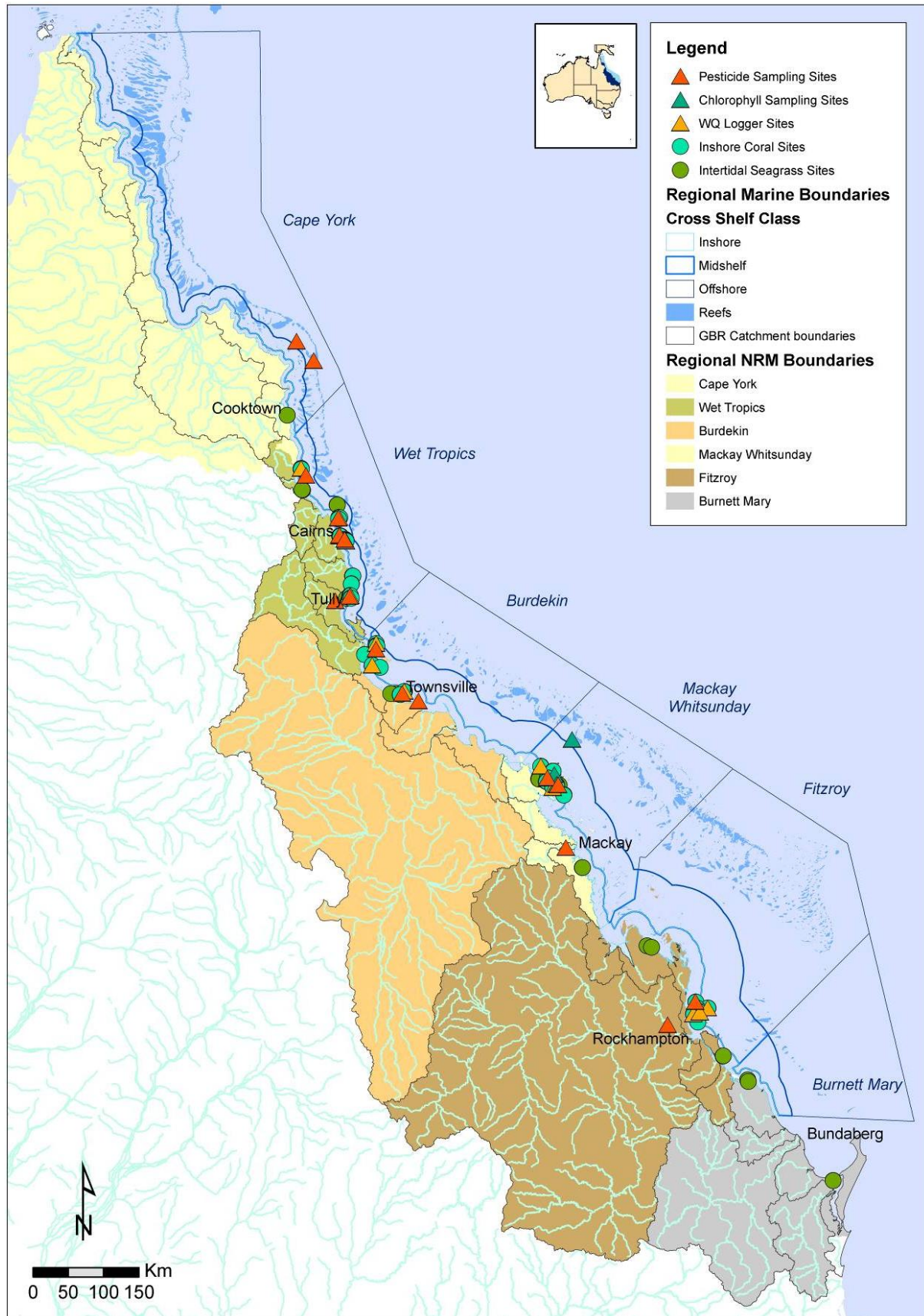


Figure 2.3: Location of all monitoring sites for the Reef Rescue Marine Monitoring Program.

Reporting framework

The key driver for monitoring and reporting in the Great Barrier Reef and its catchments is Reef Plan 2009. The Reef Plan is a joint commitment of the Queensland and Australian Governments to minimise the risk to the Reef ecosystem from a decline in the quality of water entering the Reef from the adjacent catchments. The Reef Plan is underpinned by a suite of targets linking land management, water quality and ecosystem health from the paddock to the reef. Achieving these targets will help achieve the long-term goal. A key action of the Reef Plan is the development and implementation of the Paddock to Reef Integrated Monitoring, Modelling and Reporting 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 will be released in 2010. The subsequent annual Reef Plan Water Quality Reports will report on progress towards the Reef Plan goals and targets.

The annual report will have links to several other reports, in particular the Australian Government's Caring for Our Country Annual Report, State of the Environment reporting and the Outlook Report for the Great Barrier Reef. A Reef Water Quality Summary Report will communicate GBR-wide progress towards targets supported by Regional summary inserts. In addition there will be a Management Response Report. The Management Response Report will communicate the progress made in implementation of the priority work areas and actions within the updated Reef Plan.

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 Reef Plan Baseline Water Quality Report.

Reporting boundaries

Reporting boundaries have been defined for the MMP as shown in Figure 2.4 and described as follows:

- **Regional boundaries:** The Regional boundaries have been defined in accordance with the NRM boundaries for the catchment and marine extensions of these have been agreed by the GBRMPA; and
- **Cross-shelf boundaries:** The cross shelf boundaries are defined in accordance with the Water Quality Guidelines for the Great Barrier Reef Marine Park 2009 (GBRMPA 2009). The Guidelines specify five distinct water bodies:
 1. Enclosed coastal;
 2. Open coastal;
 3. Midshelf;
 4. Offshore; and
 5. 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 2.4. The approximate distances of the water body delineations for each of the Regions is discussed in the Guidelines (GBRMPA 2009, p. 11-13).

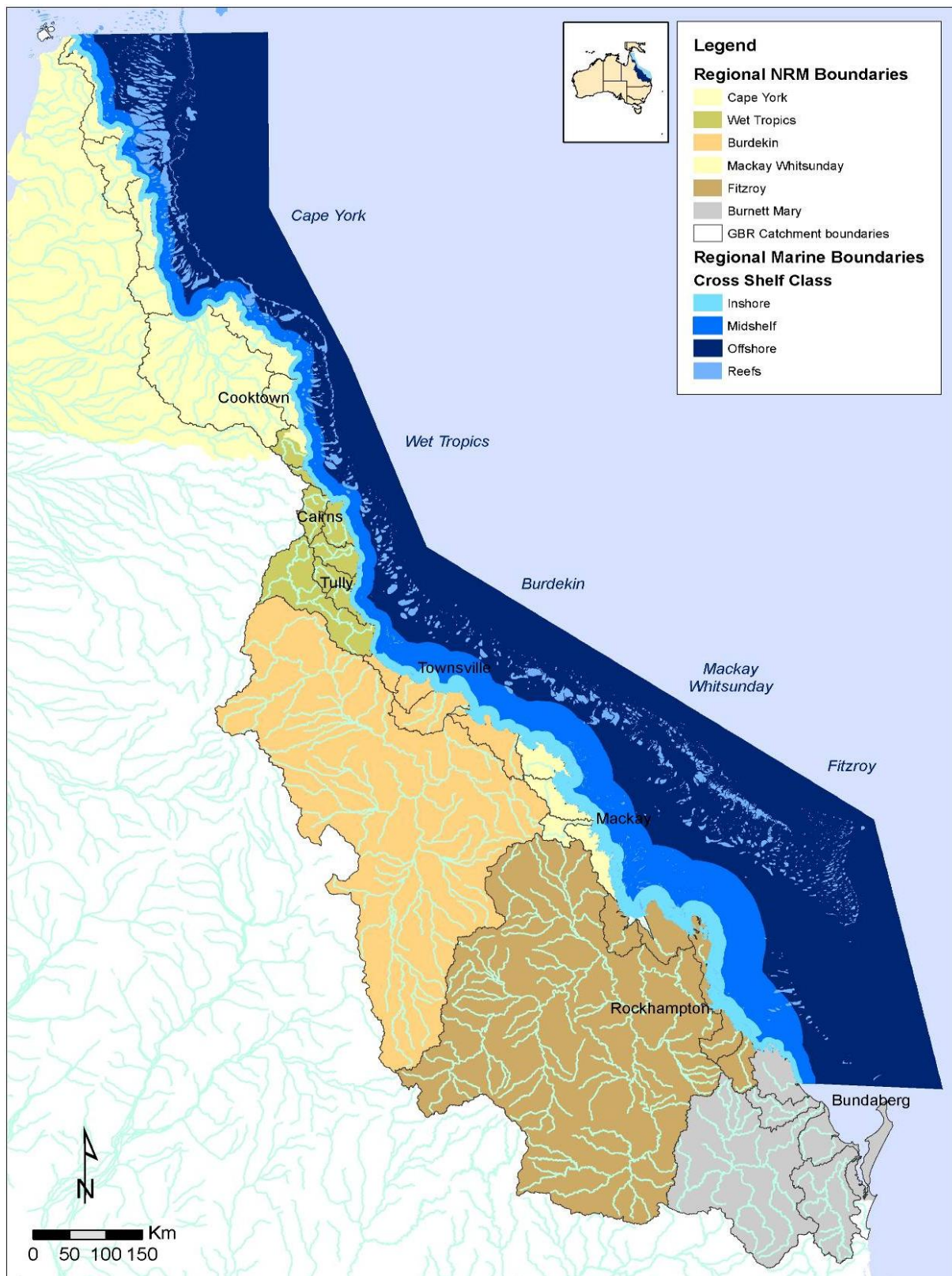


Figure 2.4: Regional and cross-shelf boundaries defined for the Reef Rescue Marine Monitoring Program 2008/2009 reporting.

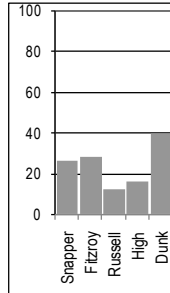
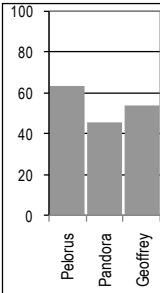
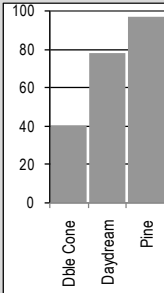
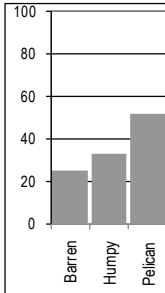
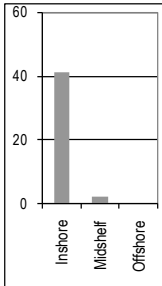
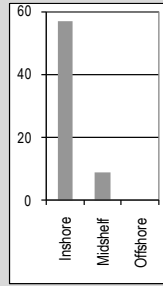
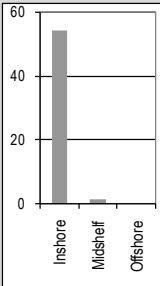
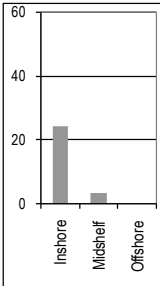
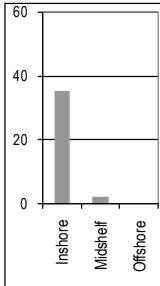
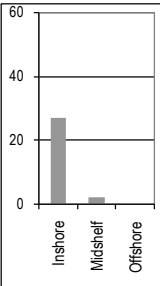
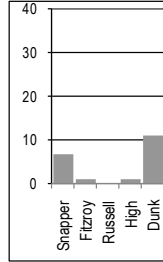
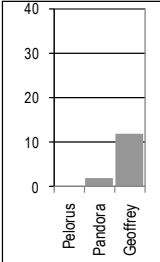
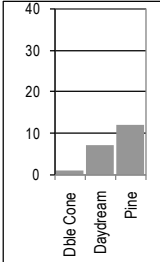
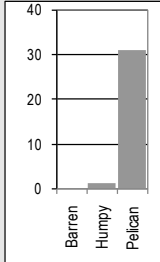
3. GBR-wide overview for 2008/2009

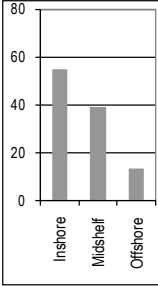
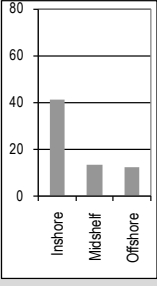
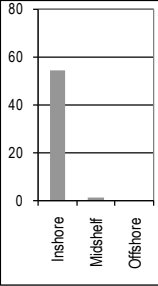
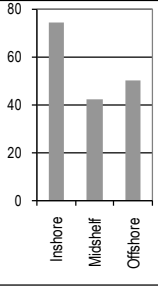
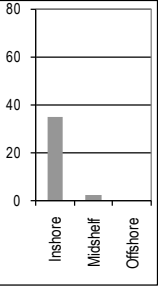
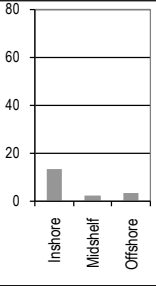
This section provides an overview of the results of the 2008/2009 Reef Rescue MMP in the context of the whole GBR. The results are presented in two primary categories: GBR marine water quality, and inshore biological monitoring. Table 3.1 provides a summary of the key indicators by Region, and where available, GBR wide. The parameters presented in the table follow the logic of the overview below.

Summarised results are included for each key indicator in the MMP, and for explanation of the data, it is important to note that the parameter, period, data source and unit shown in the first four columns. The cells highlighted in grey indicate higher and/or negative results compared to the results for other Regions. Text highlighted in bold indicate higher and/or negative results compared to the results for other locations in the Region. Where data was difficult to provide a quantitative result, or there was considerable regional variability (e.g. seagrass monitoring), descriptive text is included. Further discussion of the key findings are presented in the Discussion (Section 5).

Table 3.1: Synthesis of Reef Rescue Marine Monitoring Program results for 2008/2009, by Region. Grey shaded cells highlight results that indicate poor water quality or ecological status relative to the other Regions. Text in bold type indicates higher and/or negative results compared to the results for other locations in the Region.

Parameter	Period	Data Source	Unit	GBR-wide	Region					
					Cape York	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
River flow	Annual (continuous monitoring) Flood events are defined as periods where flow exceeds 95 th percentile (1 Jan 2009 – 30 April 2009)	DERM flow data	Relative difference of 2008/2009 median annual flow compared to long term median annual flow/ <i>rivers > median flow (# of events)</i>	2.2	0.66	0.96-3.1 <i>Barron (4)</i> <i>Russell (2)</i> <i>Nth Johnstone (4)</i> <i>Sth Johnstone (n/a)</i> <i>Tully (4)</i> <i>Herbert (2)</i>	5.1 <i>Burdekin (1)</i>	1.1-1.8 <i>Proserpine (3)</i> <i>O'Connell (n/a)</i> <i>Pioneer (4)</i> <i>Plane (n/a)</i>	0.81 <i>Fitzroy (0)</i>	0.08 <i>Burnett (0)</i>

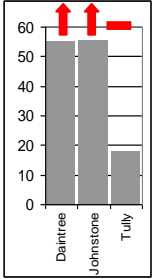
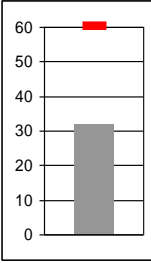
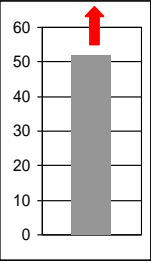
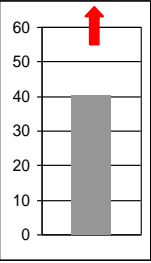
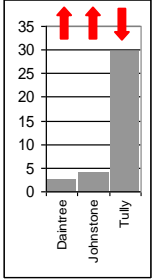
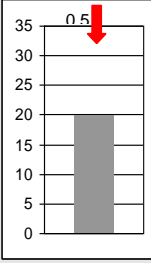
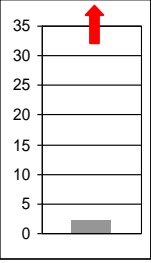
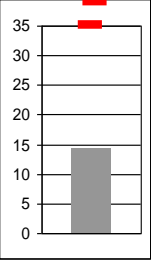
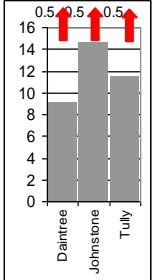
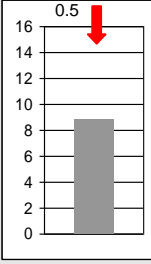
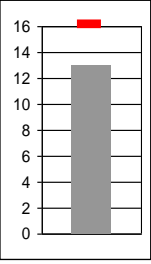
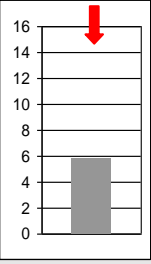
Parameter	Period	Data Source	Unit	GBR-wide	Region					
					Cape York	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
GBR Water Quality										
Chlorophyll	Annual mean n=259-505; mean n per site = 452	WQ loggers (AIMS)	n % of days with daily mean values > Guideline / <i>Locations where annual mean > Guideline</i>		n/a	<i>Mean n=450</i>  <i>Dunk Is</i>	<i>Mean n=439</i>  <i>All locations</i>	<i>Mean n=449</i>  <i>All locations</i>	<i>Mean n=472</i>  <i>Pelican Is</i>	n/a
	Annual mean (daily observations for valid data)	Remote sensing (CSIRO)	Relative area (%) for each water body where the annual mean exceeded the Guideline	Mean n of valid observations (millions): Inshore = 0.39 Midshelf = 1.2 Offshore = 3.0						
Suspended solids (turbidity)	Annual mean n=259-505; Mean n per site = 452	WQ loggers (AIMS)	% of days with daily mean values > 5 NTU ¹		n/a	<i>Mean n=450</i> 	<i>Mean n=439</i> 	<i>Mean n=449</i> 	<i>Mean n=472</i> 	n/a

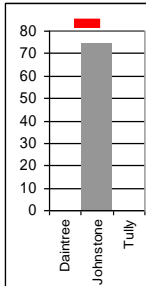
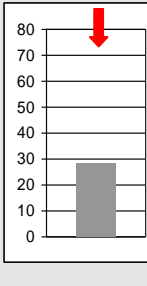
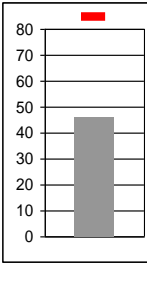
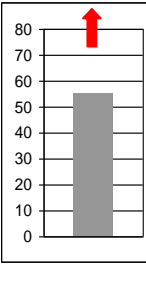
Parameter	Period	Data Source	Unit	GBR-wide	Region					
					Cape York	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
Suspended solids (turbidity)	Annual mean (daily observations for valid data)	Remote sensing (CSIRO)	Relative area (%) for each water body where the annual mean exceeded the Guideline	Mean n of valid observations (millions): Inshore = 0.39 Midshelf = 1.2 Offshore = 3.0						
Pesticides	Monthly during wet season and over two-month periods in dry season	Passive samplers (UQ)	Detected pesticides (highest concentration shown in bold)	Diuron Simazine Atrazine Hexazinone Tebuthiuron Ametryn	Diuron Hexazinone	Diuron Simazine Atrazine Hexazinone Tebuthiuron	Diuron Simazine Atrazine Hexazinone Tebuthiuron Ametryn	Diuron Atrazine Hexazinone Tebuthiuron	Diuron Tebuthiuron	n/a
	Herbicide equivalency (Refer to p29 for explanation)	Passive samplers (UQ)	Range ng/L	0-1 ng/L to 1-10 ng/L	0-1 ng/L to 1-10 ng/L	1-10 ng/L	1-10 ng/L	1-10 ng/L	1-10 ng/L	n/a
	Flood events	Flood monitoring (JCU)		n/a	n/a	Tully: Jan/Feb 2009 - Diuron (max 0.19µg/L), hexazinone (max 0.05 µg/L) & atrazine simazine (both max 0.4 µg/L) detected offshore from Tully River at Dunk Is, the Nth Barnards, Bedarra Is & King Reef.		Jan 09: Highest concentrations near the mouth of the O'Connell River: diuron 0.15 µg/L, atrazine (0.06 µg/L) & hexazinone (0.4 µg/L) . Feb 09: Diuron (0.01 µg/L) at Edward Island & bromacil (0.02	Feb 09: Atrazine dominated the polar pesticides, max 254 ng/L. Tebuthiuron max 64 ng/L.	n/a

Parameter	Period	Data Source	Unit	GBR-wide	Region					
					Cape York	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
								µg/L) at Deloraine Island. No pesticide residues were detected at the inshore sites.		
Plume exposure		Flood monitoring (JCU)		n/a	n/a	Tully Region: 37 reefs & 14 seagrass beds exposed to riverine plume waters; 11 flood events; 1994 to 2007. Likely that at least 1/3 reefs are exposed to plume waters with elevated WQ concentrations every year.	Variable between years. <i>High:</i> between Cape Upstart & Cape Cleveland. <i>Medium to high:</i> Offshore of the Burdekin River past Magnetic Is. <i>Medium to low:</i> Beyond Palm Is group & towards offshore reefs.	n/a	n/a	n/a
Inshore Biological Monitoring										
Seagrass status		Seagrass-Watch & Fisheries Queensland (DEEDI)								
Community status										
	Late dry and wet seasons		% Cover ³ (long-term mean) <i>Trend</i>		Reef: 17±2 (18) <i>stable</i>	Coast: 18±0.7 (13) Reef: 27±0.9 (33) <i>stable</i>	Coast : 14.3±1.3 (19) Reef: 30.6±1.0 (36) <i>declining</i> ↓	Estuary: 16.8±1.2 (15) Reef: 4.7±0.7 (7) Coast: 21.1±1.2 (20) <i>variable</i>	Estuary: 23.8±1.4 (18) Reef: 1.4±0.3(3) Coast: 24.4±0.9 (23) <i>variable</i>	Estuary: 6.2±0.8 (14) <i>declining</i> ↓

Parameter	Period	Data Source	Unit	GBR-wide	Region					
					Cape York	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
			Seed reserve (per m ²)		Reef: 150±42 (140) <i>Increasing</i> ↑	Coast: 260±37 (270) Reef: nil (0.4) <i>variable</i>	Coast: 1829±268 (2113) Reef: 34±17 (41) <i>stable</i>	Estuary: 0 (41) Reef: nil Coast: 71±17 (247) <i>declining</i> ↓	Estuary: nil Reef: nil Coast: nil <i>absent</i>	Estuary: nil (1) <i>declining</i> ↓
			Repro effort (structures per node) ⁴		Reef: 2.5 (15.4) <i>declining</i> ↓	Coast: 39.3 (25.8) Reef: 10.6 (3.6) <i>increasing</i> ↑	Coast: 541.3 (195.7) Reef: 20.9 (16.7) <i>increasing</i> ↑	Estuary: 11.2 (33.5) Reef: nil (4.0) Coast: 5.6 (20.8) <i>declining</i> ↓	Estuary: 79.3 (91.4) Reef: 1.0 (1.0) Coast: 100.1 (73.2) <i>variable</i>	Estuary: 177.7 (69.7) <i>increasing</i> ↑
Environmental status										
<i>Light</i>	Late dry season		Leaf tissue C:N		Reef: low <i>low light availability & decreasing</i> ↓	Coast : low Reef: low <i>low light availability & variable</i>	Coast : low Reef: low <i>low light availability & decreasing</i> ↓	Estuary: low Reef: low Coast: low <i>low light availability & decreasing</i> ↓	Estuary: low Reef: low Coast: moderate <i>low light availability & decreasing</i> ↓	Estuary: low/moderate <i>low light availability & variable</i>
<i>Nutrients</i>	Late dry season		Leaf tissue C:P		Reef: rich <i>high nutrients & variable</i>	Coast : rich Reef: poor <i>moderate nutrients & variable</i>	Coast: rich Reef: rich <i>high nutrients & increasing</i>	Estuary: rich Reef: rich Coast: rich <i>high nutrients & variable</i>	Estuary: rich Reef: rich Coast: poor <i>moderate nutrients & variable</i>	Estuary: rich <i>high nutrients & variable</i>
	Late dry season		Leaf tissue N:P		Reef: replete <i>nitrogen replete & decreasing</i> ↓	Coast: P limited Reef: replete <i>nitrogen elevated & increasing</i> ↑	Coast: P limited Reef: Replete <i>nitrogen replete & increasing</i> ↑	Estuary: replete Reef: replete Coast: N limited <i>nitrogen replete & variable</i>	Estuary: replete Reef: replete Coast: replete <i>nitrogen replete & increasing</i> ↑	Estuary: replete <i>nitrogen replete & decreasing</i> ↓

Parameter	Period	Data Source	Unit	GBR-wide	Region					
					Cape York	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
	Late dry and wet seasons		Epiphytes (%) <i>Trend</i>		Reef: 16.8±2.2 (26) <i>declining</i> ↓	Coast : 28.1±1.5 (15) Reef: 26.0±1.4 (23) <i>increasing</i> ↑	Coast: 14.7±1.6 (17) Reef: 40.5±2.1 (42) <i>declining</i> ↓	Estuary: 29.3±3.0 (14) Reef: 14.4±2.3 (17) Coast: 9.2±1.6 (14) <i>variable</i>	Estuary: 25.9±2.7 (27) Reef: 19.3±2.8 (31) Coast: 14.4±1.6 (13) <i>variable</i>	Estuary: 7.3±1.0 (15) <i>variable</i>
<i>Pesticides</i>	Late wet season	Rhizosphere sediment passive sampling (DEEDI)	Diuron (µg/kg) ⁵ <i>Trend</i>		ND (reef: 0) <i>never detected</i>	ND (coast: 0.42, reef: 0.37) <i>variable (acute)</i>	ND (coast: 0.13, reef: 0.11) <i>variable (acute)</i>	ND (estuary: 0.32, reef: 0, coast: 0.48) <i>decreasing (chronic)</i> ↓	ND (estuary: 0.4, reef: 0, coast: 0) <i>variable (acute)</i>	ND (estuary: 0.17) <i>variable (acute)</i>
Inshore Coral Reefs ⁶		AIMS								
Community status										
	Overall status 2005-2009	Inshore coral reef monitoring (AIMS)	Refer to Table 3.9 & associated text		n/a					n/a

Parameter	Period	Data Source	Unit	GBR-wide	Region					
					Cape York	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
Coral			Cover (%) / Status		n/a					n/a
Macroalgae			Cover (%) / Status		n/a					n/a
Juveniles			Density (m ⁻²) / Status		n/a					n/a

Parameter	Period	Data Source	Unit	GBR-wide	Region					
					Cape York	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
Settlement			# per Tile / Status		n/a					n/a

Notes:

¹ Suggested turbidity threshold for coral light limitation of 5 NTU as defined in Cooper *et al.* (2008).

² Note that seagrass data is highly variable between sites (within and between Regions) and cannot be grouped within a Region with sufficient confidence at this stage.

³ Percent cover = mean percent cover for sampling period \pm SE, with long-term mean in parenthesis and trend in bold.

⁴ Reproductive health = reproductive structures per node $\times 10^3$ with trend in seed reserves in parenthesis and overall trend in bold.

⁵ Pesticides = diuron with maximum reported since 2005 in parenthesis. ND=below limits of detection (0.1 $\mu\text{g/kg}$).

⁶ Regional estimates of coral community status based on the aggregate assessment of four indicators: 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 (upward arrow), neutral (dash), or negative (downward arrow) score for any of the indicators are outlined in Table 3.9.

3.1. Drivers of GBR inshore 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, and extreme weather conditions, as well as natural nutrient pools and nitrogen fixation by organisms. The roles these factors play in influencing the quality of inshore waters have been considered using a comparative analysis of the last four years of MMP water quality data (autonomous loggers and grab samples). The data showed that there are 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 did show that there is 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. Along with flood events and resuspension, geographical location, river flow and climatic variation between years accounted for forty percent of the variation in water quality between Regions. This indicates that there are other factors also affecting water quality such as the quantity and quality of sediment, nutrients and pollutants entering from adjacent land use, Regional sediment grain size and tidal forcing. Quantification of these factors will allow for a greater capacity to predict the benefits derived from improvements in land use management, highlighting the critical role of supporting research in optimisation of the MMP.

3.1.1. River flow

The past two years have seen unusual river flows in the GBR catchment. In 2007/2008, both the dry tropical Burdekin and Fitzroy Rivers experienced extensive flooding, and this situation was repeated for the Burdekin River in the 2008/2009 wet season. During the same two year period, the Wet Tropics and Mackay Whitsunday Regions (with the exception of the Herbert River) experienced slightly above-average flow conditions without a significant flood event (Table 3.2). Freshwater discharge from the GBR catchment in 2008/2009 was 2.2 times the annual median flow, with the flow in the Burdekin River more than five times the annual median flow, and the Herbert River was more than three times the annual median flow. Flow peaked in all GBR rivers between mid-February and mid-March 2009.

Figure 3.1 shows the high flow periods (daily flow >95th percentile of the daily flow hydrograph) for 2009 in a number of GBR rivers. The 95th percentile was calculated using tens years' flow data for each river, except the Normanby where only four years of flow data was available for the assessment. It highlights the extended period of event flows in the Normanby, Tully, Burdekin and Proserpine Rivers in particular, however, it is important to note that the Normanby assessment is only based on four years of data, providing a relatively low 95th percentile value. Using this information, it is possible to define the extent of the wet season for the GBR rivers in 2008/2009 which is estimated to be from mid-January to March 2009.

Table 3.2: Annual freshwater discharge (ML) for major GBR catchment rivers in 2008/2009. The median and mean annual flow is estimated from available long-term time series for each river. Data supplied by the Queensland Department of the Environment and Resource Management. Long-term medians were estimated from annual total flows (October to October) available at <http://www.nrw.qld.gov.au/precomp>.

Region	River	Long-term river discharge median (ML)	Long-term river discharge mean (ML)	Total year discharge 2008/2009 (ML)	Difference between 2008/2009 flow and long-term median (ML)	Relative difference between 2008/2009 flow and long-term median
Cape York	Normanby	3,550,421	3,707,007	2,338,784	-1,211,637	0.66
Wet Tropics	Barron	692,447	795,275	779,456	87,009	1.13
	Mulgrave	719,625	743,399	688,515	-31,110	0.96
	Russell	1,049,894	1,051,743	1,212,230	162,337	1.16
	North Johnstone	1,845,338	1,797,648	1,986,776	141,438	1.08
	South Johnstone	810,025	801,454	1,043,893	233,868	1.29
	Tully	3,128,458	3,175,298	3,759,051	630,593	1.20
	Herbert	3,122,768	3,492,135	9,606,409	6,483,641	3.08
Burdekin	Burdekin	5,957,450	9,575,660	30,110,062	24,152,612	5.05
Mackay Whitsunday	Proserpine	35,736	70,568	63,263	27,527	1.77
	O'Connell	148,376	201,478	167,586	19,211	1.13
	Pioneer	731,441	648,238	931,808	200,367	1.27
	Plane	112,790	154,092	188,195	75,405	1.67
Fitzroy	Fitzroy	2,708,440	4,461,132	2,193,040	-515,400	0.81
Burnett	Burnett	147,814	217,511	12,079	-135,735	0.08
Total		24,761,023	30,892,638	55,081,147	30,320,124	2.22

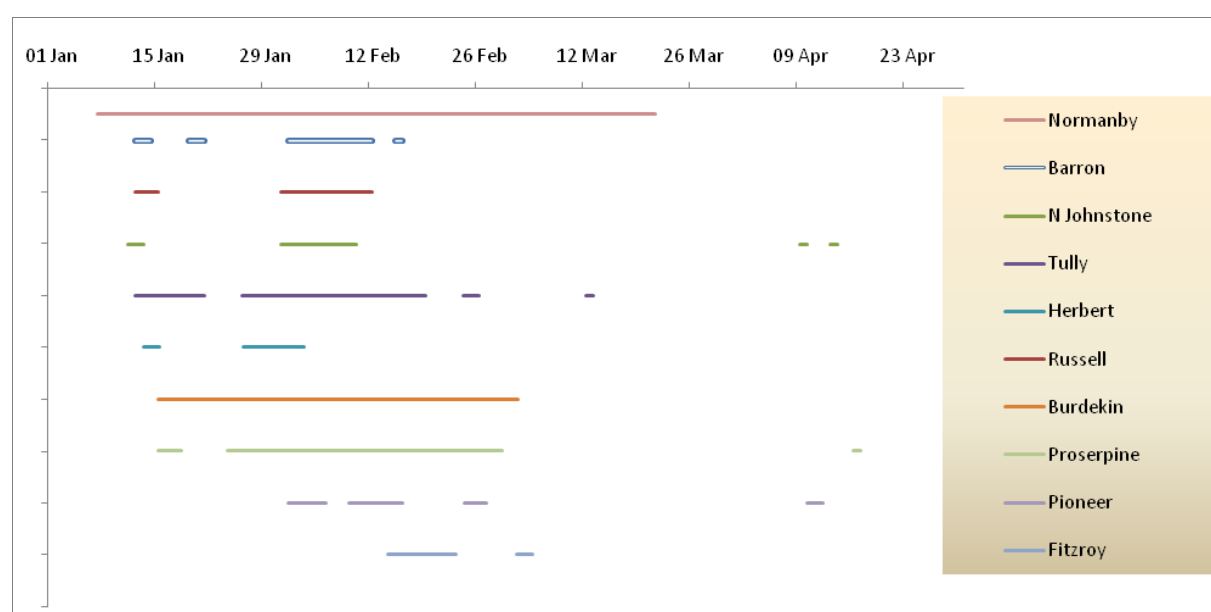


Figure 3.1: High flow periods (daily flow > 95th percentile) for 2009 in a selection of GBR rivers.

The extent of river plumes in the GBR (along the GBR and cross shelf) is a consequence of several factors including river flow (volume and duration), wind direction and velocity and currents and tidal dynamics. Remote sensing techniques are currently being trialled to map flood extent using Colour Dissolved Organic Matter (CDOM). Figure 3.2 shows a compiled Regional map of maximum CDOM concentrations in the 2008/2009 wet seasons as a proxy for estimated flood extent. It is compiled by defining a threshold of CDOM of 0.12nm^{-1} that represents the maximum influence of freshwater due to the strong relationship between CDOM and the adsorption curve, with a distinct marine signal. The map indicates the full extent of the freshwater plume for the 2008/2009 wet season.

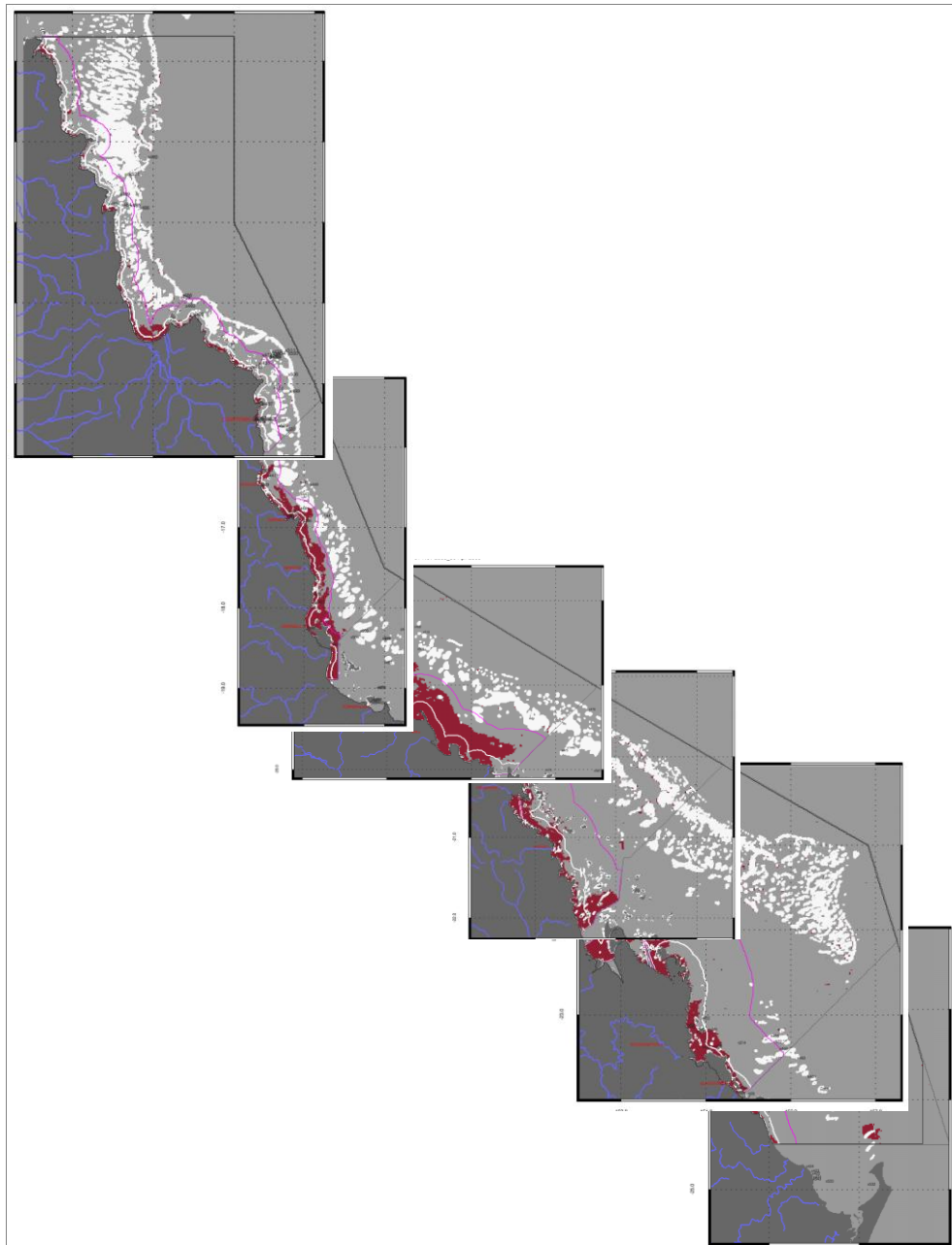


Figure 3.2: Estimated spatial extent (red areas) of freshwater discharge in the GBR during the 2008/2009 wet season. Each Regional flood extent map is also provided in Section 4. The white line represents Inshore boundary; pink line represents Midshelf boundary. Source: CSIRO.

The acute impact of flood plumes on inshore coral reefs and seagrass meadows can result from exposure to low salinities, the effects of sedimentation and low light conditions, and exposure to elevated levels of pesticides and nutrients. The extent of freshwater discharge into the GBR during the 2008/2009 wet season (represented in Figure 3.2) can be compared to the surface salinity Exceedance Probabilities modelled by King *et al.* (2001) to establish whether this was a significant incursion into the inshore GBR.

The ecological consequences associated with exposure of coral reefs and seagrasses 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). The need to develop a metric for the MMP that integrates these drivers is recognised as an important need for future reporting.

3.1.2. Sea temperature monitoring

Water temperature data are reported for the period of January 2005 to June 2008 (Figure 3.3). Prolonged exposures to sea temperatures above the local mean have been shown to cause stress to corals resulting in bleaching and in severe cases mortality (Berkelmans 2002). Seasonal average temperatures were exceeded for prolonged periods in the summer of 2005/2006 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 (Ray Berkelmans, AIMS, pers. comm., 2010). Fluctuations about the long-term averages in the period April 2006 to June 2008 have been relatively minor and unlikely to have caused stress to the corals in any Regions.

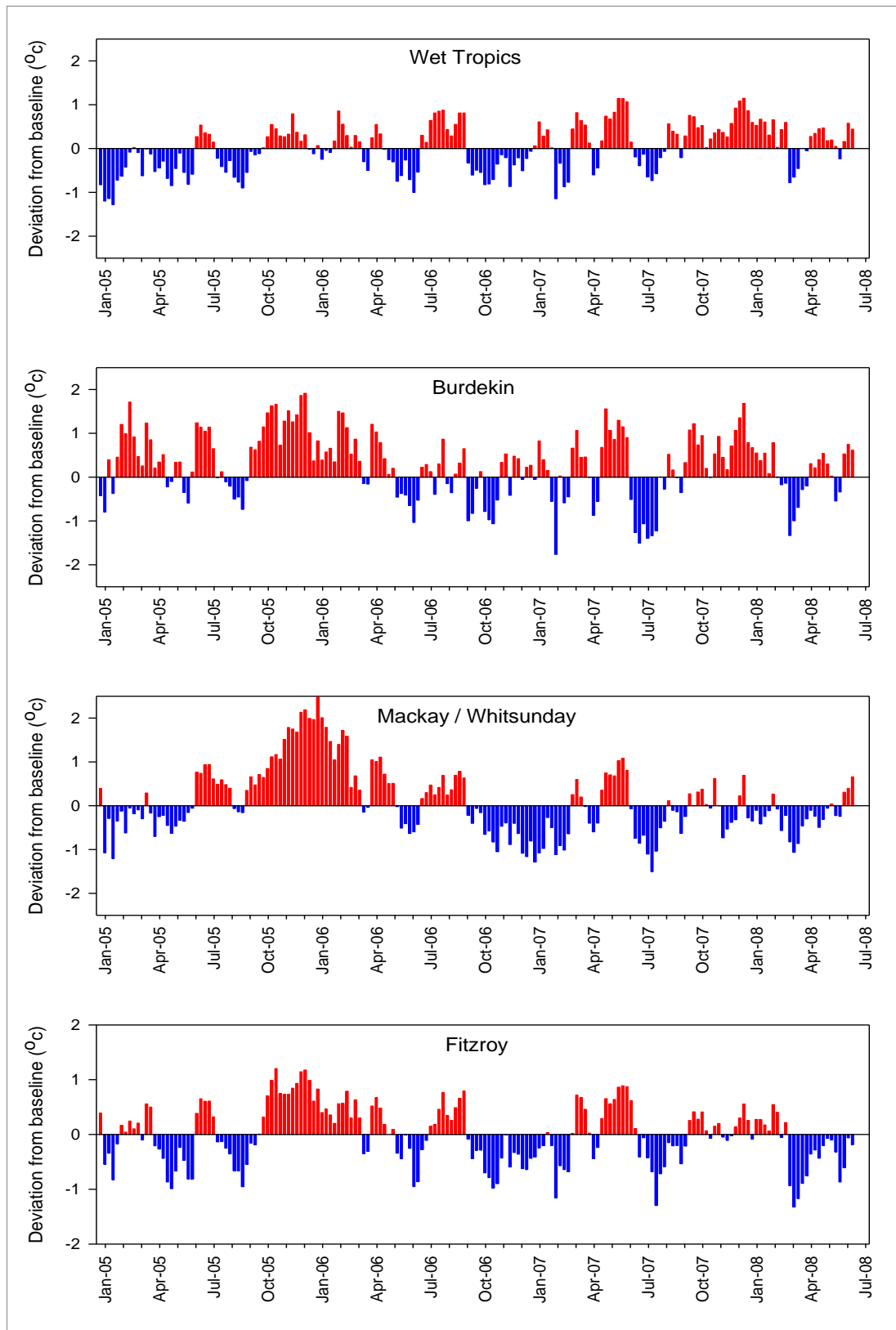


Figure 3.3: Sea temperature monitoring 2005 to 2008. Deviation from ten year mean weekly temperature records (based on records from July 1998 to June 2008). Weeks above the long-term average are represented as red bars and the magnitude of their deviation from the mean represented by the length of the bars. Blue bars represent weeks with lower than average temperatures and are plotted as negative deviations.

3.2. GBR-wide water quality monitoring

The biological productivity of the GBR is supported by nutrients (e.g. nitrogen, phosphorus, silicate, iron), which are supplied by a number of processes and sources (Furnas *et al.* 1997; Furnas 2003). These include upwelling of nutrient-enriched subsurface waters from the Coral Sea, rainwater, fixation of gaseous nitrogen by cyanobacteria and runoff from the adjacent catchment from point and diffuse sources.

Land runoff is the largest source of new nutrients to the GBR (Furnas 2003). However, most of the inorganic nutrients used by marine plants and bacteria on a daily basis come from recycling of nutrients already within the GBR ecosystem (Furnas *et al.* 2005). Extensive water sampling throughout the GBR over the last 25 years has established the typical concentration range of nutrients, chlorophyll and other water quality parameters and the occurrence of persistent latitudinal, cross-shelf and seasonal variations in these concentrations (summarised in Furnas 2005, De'ath & Fabricius 2008). While concentrations of most nutrients, suspended particles and chlorophyll *a* are normally low, water quality conditions can change abruptly and nutrient levels increase dramatically for short periods following disturbance events (wind-driven re-suspension, cyclonic mixing, river flood plumes). Trigger values from the Guidelines for these parameters are outlined in Table 3.3.

Table 3.3: Trigger values from the *Water Quality Guidelines for the Great Barrier Reef Marine Park* (GBRMPA 2009). Seasonal adjustments have been calculated according to the information provided in the Guidelines (to two significant figures).

Parameter	Water body			
	Enclosed coastal	Inshore	Midshelf	Offshore
Chlorophyll (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 *1.4 ¹ /2.0 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 (ng/L)^{***}	Reliability		99% species protection	
Diuron	Moderate		900	
Atrazine	Moderate		600	
Ametryn	Moderate		500	
2,4-D	Moderate		800	
Endosulfan	Moderate		5	
Chorpyrifos	High		5	
Simazine	Low		200	
Hexazinone	Low		1200	
Tebuthiuron	Low		20	
MEMC	Low		0.2	
Diazinon	Low		0.03	

Notes:

* Seasonal adjustment: Summer¹/Winter². Note: Chlorophyll 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.

Table 3.4: Summary of **(a)** chlorophyll ($\mu\text{g/L}$) data and **(b)** turbidity (NTU) data from deployments of WET Labs Eco FLNTUSB Combination Fluorometer and Turbidity Sensors at fourteen inshore reef sites (October 2007 to February 2009). Grey shaded cells indicate data that exceed the Guideline value.

(a)

NRM Region	Location	Chlorophyll a Annual mean	SE	N	> trigger value	Chlorophyll a Wet season mean	SE	Chlorophyll a Dry season mean	SE
Wet Tropics	Snapper Island	0.375	0.011	502	26	0.435	0.016	0.286	0.009
	Fitzroy Island	0.365	0.011	259	28	0.442	0.012	0.235	0.010
	Russell Island**	0.327	0.010	504	12	0.367	0.016	0.269	0.004
	High Island	0.336	0.007	503	16	0.379	0.010	0.273	0.006
	Dunk Island	0.456	0.013	484	40	0.549	0.018	0.322	0.012
Burdekin	Pelorus Island**	0.574	0.015	404	64	0.710	0.025	0.443	0.011
	Pandora Reef**	0.463	0.008	503	46	0.480	0.012	0.437	0.012
	Geoffrey Bay	0.526	0.014	410	54	0.627	0.021	0.393	0.012
Mackay Whitsunday	Double Cone Island	0.497	0.024	342	40	0.568	0.036	0.370	0.012
	Daydream Island	0.567	0.007	501	78	0.620	0.010	0.494	0.007
	Pine Island	0.690	0.008	505	97	0.687	0.012	0.695	0.009
Fitzroy	Barren Island**	0.371	0.007	504	25	0.437	0.009	0.281	0.005
	Humpy Island	0.423	0.010	408	33	0.506	0.017	0.345	0.007
	Pelican Island	0.549	0.017	503	52	0.654	0.026	0.404	0.014

(b)

NRM Region	Location	Turbidity Annual mean	SE	N	> trigger value	> 5 NTU	Turbidity Wet season mean	SE	Turbidity Dry season mean	SE
Wet Tropics	Snapper Island	2.109	0.114	502	40	7	1.861	0.163	2.478	0.145
	Fitzroy Island	0.849	0.044	259	5	1	0.834	0.066	0.875	0.036
	Russell Island**	0.543	0.018	504	3	0	0.539	0.028	0.548	0.017
	High Island	0.821	0.028	503	7	1	0.840	0.044	0.793	0.028
	Dunk Island	2.244	0.134	484	36	11	2.427	0.205	1.983	0.137
Burdekin	Pelorus Island**	0.686	0.039	404	6	0	0.893	0.077	0.489	0.008
	Pandora Reef**	1.205	0.104	503	15	2	1.363	0.171	0.980	0.061
	Geoffrey Bay	2.660	0.238	411	44	12	3.318	0.401	1.781	0.126
Mackay Whitsunday	Double Cone Island	1.163	0.052	342	17	1	1.294	0.076	0.931	0.040
	Daydream Island	1.962	0.076	501	44	7	2.261	0.123	1.547	0.052
	Pine Island	2.748	0.118	505	62	12	3.166	0.192	2.167	0.077
Fitzroy	Barren Island**	0.352	0.016	504	2	0	0.396	0.021	0.291	0.026
	Humpy Island	0.839	0.052	408	15	1	1.147	0.081	0.550	0.059
	Pelican Island	4.701	0.282	503	53	31	5.951	0.422	2.987	0.296

Note:

'Guideline' refers to the percentage of days with mean values above the chlorophyll and suspended solid Guideline values (see Table 3.3). Turbidity is converted from suspended solids (2.0 mg/L = 1.54 NTU, see report text for details); '> 5 NTU' refers to the percentage of days with mean values above the suggested turbidity threshold for coral light limitation of 5 NTU (Cooper *et al.* 2008). Shading highlights the locations with annual means above the Guideline value.

Table 3.5: Area exceedance of mean annual chlorophyll and non-algal particulate matter (as a proxy of suspended solids) using remote sensing data (retrieved from MODIS AQUA) for the inshore, midshelf and offshore waterbodies 1 May 2008 to 30 April 2009. Values higher than 50% are shaded grey.

Region	Number of valid observations			Chlorophyll: Relative area (%) of the waterbody where the annual mean value exceeds the Guideline value (Inshore and Midshelf = 0.45µg/L; Offshore = 0.4µg/L)			Suspended solids: Relative area (%) of the waterbody where annual mean value exceeds the Guideline value (Inshore and Midshelf = 2mg/L; Offshore = 0.7 mg/L)		
	Inshore	Midshelf	Offshore	Inshore	Midshelf	Offshore	Inshore	Midshelf	Offshore
Cape York	222,281	705,210	2,829,184	41	2	0	55	39	13
Wet Tropics	153,380	518,460	1,320,487	57	9	0	41	13	12
Burdekin	532,814	1,509,959	2,156,319	54	1	0	65	5	3
Mackay Whitsunday	575,561	1,429,099	2,526,710	24	3	0	74	42	50
Fitzroy	742,478	2,529,946	5,118,440	35	2	0	35	2	0
Burnett Mary	103,684	552,733	4,282,628	27	2	0	13	2	3

Targetted flood monitoring campaigns collect nutrient, chlorophyll, suspended solids and pesticide data, and *in-situ* water quality loggers and remote sensing techniques collect chlorophyll and suspended solids data. A simple comparison across the Regions indicates that the highest rate of exceedances of the chlorophyll Guidelines were measured in the Mackay Whitsunday and Burdekin Regions in both the dry and the wet seasons, and elevated suspended solids concentrations were most frequently measured (using the *in-situ* logger data, Table 3.4) in the Fitzroy Region (Pelican Island which is a naturally turbid site) and in the Wet Tropics Region at one site (Dunk Island; Table 3.4). The sites that are on average (over all available data) above the Guideline value also have the highest percentage of days exceeding the Guideline value higher than 50%. This means they are not driven by large flood events, but are indeed high throughout the year.

Remote sensing data (Table 3.5) shows similar patterns for chlorophyll and suspended solids, with the greatest Guideline exceedances in the inshore areas in the Wet Tropics and Burdekin Regions. The data also show cross shelf differences, with almost all of the exceedances for chlorophyll recorded in the inshore area along the GBR. However, the patterns for suspended solids are quite different, with high exceedances in the inshore area along the GBR, but around forty percent of the midshelf areas of the Cape York and Mackay Whitsunday Regions exceeded the Guideline. Some exceedances were also recorded in offshore areas with a high value of 50% for the Mackay Whitsunday Region.

Pesticide monitoring in 2008/2009 detected low concentrations of pesticides at all inshore reef sites, with clear differences between Regions. Overall, water concentrations of pesticides were lowest in the Cape York and Fitzroy Regions (typically below 2 ng/L). In the Wet Tropics Region the maximum water concentrations of individual pesticides ranged from 2-15 ng/L (Table 3.6). Maximum and median water concentrations in the Burdekin Region were relatively similar. Monitoring in the Mackay Whitsunday Region showed that water concentrations for individual pesticides were generally higher at the Inner Whitsundays (Table 3.6) including one very high diuron concentration in a sample collected in September 2008 (120 ng/L). This level is nonetheless below the Guideline value for diuron (refer to Table 3.3), and most sites had pesticide toxicity ratings above those known to cause ecological impacts, with one site having pesticide levels below, there were no exceedances of the Guideline values for pesticides.

Pesticide concentrations were generally higher in the wet season than the dry season at all sampling sites, often increasing by one to two orders of magnitude. All Regions that were monitored for pesticides were assessed to have average Herbicide Equivalency (combined toxicity) levels of 1-10 ng/L, with only the Cape York Region have an overall rating less than 1 ng/L. There were no exceedances of the Guideline values for pesticides.

Pesticide results were considered against a preliminary pesticide index (see p. 35) that assesses the ecological consequences of pesticide concentrations detected. During the initial four years of the MMP (2005/2006 to 2008/2009), pesticides have been detected at all 14 inshore reef monitoring sites with some clear differences between Regions. Routine monitoring showed the pesticide profile at inshore reef sites is dominated by diuron, atrazine and hexazinone. Other chemicals that can be detected regularly included simazine and tebuthiuron. For most sites diuron was detected at the highest concentrations.

Flood plume monitoring at the Tully and Pioneer Rivers detected a wider range of pesticides and elevated water concentrations compared to inshore reef sites, particularly in the Pioneer River. Water concentrations for dominant chemicals during flow events monitored at the Pioneer and Fitzroy Rivers in 2008/2009 exceeded 500 ng/L, which is significantly less than levels during 2007/2008. However, the passive sampling flood monitoring for 2008/2009 was limited due to some logistical problems with sampler deployment and retrieval. Flow events monitored were later in the wet season and less intense than in 2007/2008, therefore lower concentrations of pesticides are to be expected. As in 2007/2008, atrazine was the most dominant chemical detected at the river sites.

Table 3.6: Concentrations of pesticides at all of the study sites during 2008/2009 (ng/L). Maximum concentrations are shown for both the wet and dry seasons. The median includes all samples pooled from both the dry and wet seasons.

Region	Site		Diuron	Simazine	Atrazine	Hexazinone	Tebuthiuron	Ametryn
Cape York	Lizard Island	Max Wet	-	-	-	-	-	-
		Max Dry	2.5	-	-	-	-	-
		Median	2.1	-	-	-	-	-
	Pixies Garden	Max Wet	1.7	-	-	0.34	-	-
		Max Dry	0.43	-	-	nd	-	-
		Median	0.22	-	-	nd	-	-
Wet Tropics	Low Isles	Max Wet	5	0.8	2	1.8	0.61	-
		Max Dry	3.5	nd	1.5	0.89	0.61	-
		Median	0.56	nd	nd	nd	nd	-
	Fitzroy Island	Max Wet	15	1.3	3.7	3	0.32	-
		Max Dry	3	nd	1.8	0.29	0.13	-
		Median	1.8	nd	0.6	0.14	0	-
	High Island	Max Wet	2.3	-	-	0.26	0.29	-
		Max Dry	2.3	-	-	0.26	0.29	-
		Median	0.8	-	-	0.13	0.15	-
	Normanby Island	Max Wet	7.8	0.74	3.5	1.5	1.5	-
		Max Dry	3	nd	3.8	1.1	1.5	-
		Median	1.7	nd	0.76	0.13	nd	-
	Dunk Island	Max Wet	3.2	-	1.1	2.3	0.46	-
		Max Dry	nd	-	nd	nd	nd	-
		Median	2.2	-	nd	0.56	0.16	-
Burdekin	Orpheus Island	Max Wet	1.7	-	1.4	0.26	0.8	-
		Max Dry	1.7	-	1.4	0.26	0.8	-
		Median	0.95	-	nd	nd	0.07	-
	Magnetic Island	Max Wet	4.4	0.36	6.3	0.25	1.2	-
		Max Dry	4	0.36	6.3	0.25	0.82	-
		Median	1.8	nd	1.7	nd	0.58	-
	Cape Cleveland	Max Wet	4.5	-	10	0.59	1.3	0.49
		Max Dry	0.92	-	5.4	0.4	0.78	nd
		Median	0.85	-	2.7	nd	0.49	nd
Mackay Whitsunday	Inner Whitsunday	Max Wet	120*	-	1.2	2.8	0.15	-
		Max Dry	120*	-	nd	nd	nd	-
		Median	8.5	-	0.79	1.4	nd	-
	Outer Whitsunday	Max Wet	3.9	-	2.7	-	4.1	-
		Max Dry	3.9	-	2.7	-	4.1	-
		Median	0.8	-	2.2	-	0.57	-
	North Keppel Island	Max Wet	1.1	-	-	-	0.18	-
		Max Dry	1.1	-	-	-	0.18	-
		Median	0.91	-	-	-	nd	-

* Note: Further investigation of this result is required,

Pesticide index

Herbicide (PSII) equivalencies (HEq) were calculated for the inshore GBR and river sampling sites from relative potency factors for herbicides that are routinely found in the environment, to estimate the inhibition of photosystems due to the suite of chemicals present. Herbicides are assumed to act additively and the HEq concentration can be predicted by multiplying the concentration of the chemical in the water to its relative potency (Paxman *et al.* 2009). The relative potencies were collated from relevant laboratory studies and are provided in Table 3.7.

The HEq data are interpreted using a preliminary Pesticide Index with five ranges that are based on the relative potency factor. The ranges for the pesticide index are:

HEq > 900 ng/L:	Concentration that would inhibit growth of algae based on just diuron which is the most commonly detected pesticide.
HEq 100 – 900 ng/L:	Concentration causing measurable PSII response to diuron.
HEq 10 – 100 ng/L:	Concentration at the lower end of potential measurable PSII inhibition in sensitive species using PSII inhibition (noted in the Guidelines).
HEq 1 – 10 ng/L:	PSII pesticides clearly detectable using modern sampling tools but time averaged concentrations are below those that can be expected to cause measurable inhibition of PSII.
HEq < 1 ng/L:	Concentrations are below those that can be expected to cause measurable inhibition of PSII and are near or below the limit of detection.

Table 3.7: Potency factors for different pesticides: summary of available data used for calculating HEq concentrations. EC= effective concentrations.

Herbicides	Relative potency (range)			Relative potency (mean based on various EC)			Mean/ Preliminary consensus value
	Zooxanthellae (Corals) ^a	<i>P. tricornutum</i> ^{bcd}	<i>C. vulgaris</i> ^{bde}	Zooxanthellae (Corals) ^a	<i>P. tricornutum</i> ^{bcd}	<i>C. vulgaris</i> ^{bde}	
diuron	1	1	1	1	1	1	1
ametryn	1.2-1.35	0.94	0.9-2.7	1.28	0.94	1.71	1.31
hexazinone	0.2-0.26	0.27-0.82	0.17-0.95	0.23	0.46	0.44	0.38
atrazine	0.05-0.06	0.1-0.4	0.15-0.3	0.05	0.22	0.21	0.16
simazine	0.02	0.03-0.05	0.02-0.26	0.02	0.04	0.14	0.07
tebuthiuron	0.01	0.07	0.11-0.2	0.01	0.07	0.15	0.08
promertyn			1-1.1			1.05	1.05
terbuthylazine			0.3			0.3	0.3
desethylatrazine			0.01-0.2			0.105	0.11
desisopropylatrazine			0.003			0.003	0.003
flumeturon			0.04			0.04	0.04

^a Jones and Kerswell (2003)

^b Muller *et al.* (2008)

^c Benston Nash *et al.* (2005)

^d Schmidt (2005)

^e Macova *et al.* (unpublished data, EnTox).

At most sites diuron was the pesticide that was found most frequently and at the highest mean concentrations (a notable exception is the Cape Cleveland site where the mean and median concentration of atrazine was higher than that of diuron). In combination with its high relative potency, diuron is the key contributor to the overall HEq in water on the GBR, contributing typically to more than 90% of the HEq concentration.

3.3. Seagrass monitoring

Inter-tidal seagrass in the GBR are generally in a healthy state, but concern exists about declining light availability, nutrient enrichment and the development of nutrient saturated conditions at a number of sites. Table 3.8 summarises seagrass data. Seagrass tissue ratios are used as an indication of environmental conditions at the monitored locations (see McKenzie and Unsworth, 2009 for further explanation). Plant elemental C:N is a surrogate for light where moderate = adequate light availability on average required for growth ($C:N > 20:1$), low = less available light on average than required for growth ($C:N < 20:1$); C:P is a surrogate for nutrient status of the habitat where, rich = relatively large P pool ($C:P < 500:1$), poor = relatively small P pool ($C:P > 500:1$); N:P is the overall nutrient availability to the plant, where N limited = $N:P < 25$, replete (abundant) $N:P = 25$ to 30 ; P limited = $N:P > 30$. Locations where seagrass are growing in generally low light environments (C:N is low), with a relatively large P pool (C:P is rich) and an even larger N pool (N:P is P limited) would indicate relatively poor water quality. The results for the seagrass monitoring have been considered in the context of the environmental conditions.

Intertidal seagrass abundance was significantly lower (>20% difference) in the 2008/2009 monitoring period compared to 2007/2008 at two thirds of the locations examined across the GBR. These locations were all south of the Wet Tropics Region and half have an overall decline in seagrass abundance since 2005.

Seagrass species dominance varies between habitats (reef, coastal and estuary) and latitude, and trends for each habitat suggest water quality and environmental conditions could be a major influence upon this variability. The indicator of light availability (C:N ratio) explained 58% of the variability between coastal and estuarine sites in terms of seagrass cover, suggesting light is a major factor influencing inter-site variability in these habitats.

At the scale of locations and sites, there is considerable variability in seagrass cover, but at a GBR-wide scale there is no evidence of sustained losses or gains where monitoring has occurred. Seagrass as bioindicators of the environmental conditions of the GBR indicate a general trend of reducing light availability and nutrient enrichment. Tissue nitrogen levels within the Wet Tropics and Burdekin Regions coastal and mid-shelf reef habitats have increased from 2005 to 2008, and over the last fifteen years, again indicating a nutrient saturated environment.

Over the entire period of the currently available data (2006-2009) all seagrass monitoring sites showed some evidence of reproductive effort (measured as the number of seeds per square metre). However, the sites at Green Island (Cairns), Lugga Bay (Tully River/Mission Beach) and Urangan (Mary River/Hervey Bay) showed virtually no production of reproductive structures across the entire sampling period. A continued absence of flowering and fruiting in these sites will result in poor capacity to recover from disturbance. Inter-annual differences in sexual reproduction are evident and these differences principally relate to the decline of meadows. The status of the sites listed in poor reproductive health, where little evidence of seed set over the entire monitoring period has been seen, is such that careful attention should be paid as to the cause of their failure to sexually reproduce.

The average seagrass percent cover (over the past ten years of *Seagrass Watch* monitoring) at each of the intertidal seagrass habitats within the GBR are relatively similar: 20% for intertidal, 19% for coastal and 24% for reef (see Figure 3.4).

Seagrass epiphyte cover appears to be increasing in coastal areas and when considered in combination with the tissue nutrient ratios the data indicate that some sites, particularly coastal sites within the Wet Tropics and Burdekin Regions, are becoming nutrient saturated environments with reduced light availability. Seagrass ecosystems can survive under nutrient saturated conditions until they reach a point of extreme stress, when the ecological balance changes and decline happens quickly. Macroalgal abundance is generally low and variable in coastal and reef habitats.

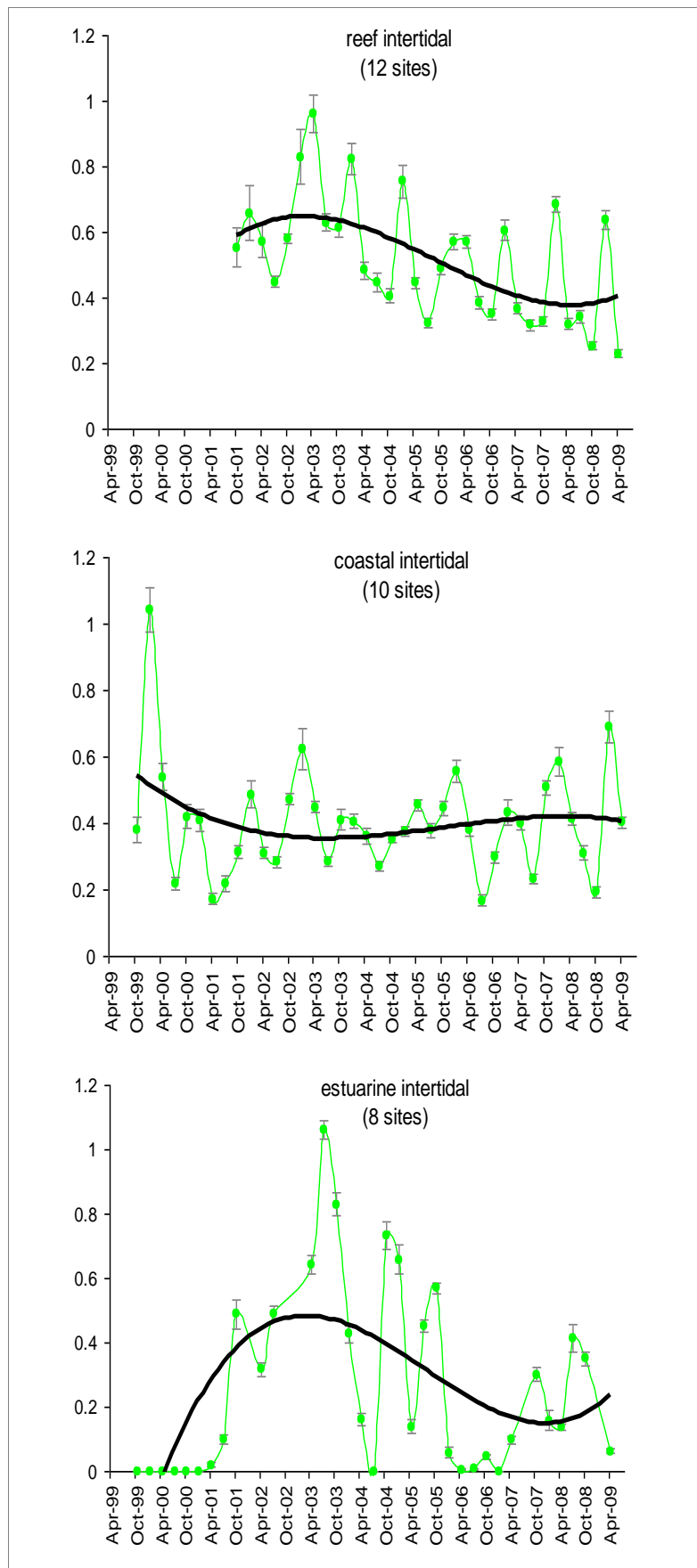


Figure 3.4: Generalised trends in seagrass abundance (y-axes) for each habitat type (sites pooled) relative to the 95th percentile (black line). The 95th percentile is calculated for each site across all data.

Table 3.8: Summary of condition and overall trend of seagrass at GBR monitoring locations for each season. Values are October 2008 to April 2009 with the long-term average in parentheses. Red = poor; green = good; yellow = fair; white = ambiguous or insufficient data.

NRM	Catchment	Location	% cover Long Term Average	% cover late-Dry		% cover late- Monsoon		Overall trend since late-Dry 2005				
				2008	% Difference 2008 to 2007	2009	% Difference 2009 to 2008	Seagrass Cover	Seagrass Seeds	Meadow	Epiphytes	Macro-Algae
Cape York	Endeavour	Archer Point	18.5 ±1.8	13.7 ±2.0	similar	20.6 ±3.0	>20% increase	stable	76 - 229 (138) increase	variable	19 - 14 (26) decline	3 - 1 (10) decline
Wet Tropics	Barron Russell / Mulgrave Johnstone	Yule Point	15.6 ±1.2	22.7 ±1.4	>20% increase	27.2 ±1.7	similar	increase	170 - 679 (424) increase	increase	30 - 53 (20) increase	2 - 1 (2) decline
		Green Is	41.1 ±2.3	28.0 ±1.4	>20% decrease	35.9 ±1.8	similar	stable	nil	stable	27 - 63 (26) increase	3 - 4 (4) stable
	Tully – Murray	Lugger Bay	4.3 ±0.6	7.9 ±0.7	>20% increase	3.5 ±0.5	>20% decrease	variable	0 - 0 (4) variable	variable	2 (3) variable	0 (<1) stable
		Dunk Is	11.8 ±1.3	15.0 ±1.5	similar	13.9 ±14.7	similar	stable	0 - 0 (1) variable	stable	27 - 70 (25) increase	7 - 7 (6) stable
Burdekin Dry Tropics	Burdekin	Townsville	18.6 ±2.2	9.2 ±1.4	>20% decrease	5.8 ±1.2	>20% decrease	decline	2348 - 1715 (2113) stable	decline	7 - 15 (17) decline	2 - 1 (4) variable
		Magnetic Is	35.8 ±2.7	31.5 ±1.8	>20% decrease	20.5 ±2.0	>20% decrease	variable	34 - 34 (41) variable	stable	38 - 2 (42) decline	13 - 4 (7) stable
Mackay Whitsunday	Proserpine	Pioneer Bay	20.2 ±1.6	27.4 ±2.0	similar	24.1 ±1.9	>20% increase	variable	59 - 136 (247) variable	increase	4 - 20 (14) stable	1 (11) stable
		Hamilton Is*	7.3 ±1.1	7.9 ±1.3	similar	1.6 ±0.5	>20% decrease	decline	nil	variable	15 - 14 (17) decline	3 - 6 (3) stable
	Pioneer	Sarina Inlet	15.2 ±1.6	23.6 ±1.9	>20% increase	4.9 ±0.7	>20% decrease	variable	0 (41) decline	variable	68 - 2 (14) variable	<1 (2) variable
Fitzroy	Fitzroy	Shoalwater	22.6 ±1.4	26.4 ±1.3	>20% decrease	22.4 ±1.0	>20% decrease	decline	nil	stable	21 - 8 (13) stable	5 - <1 (6) decline
		Great Keppel	2.7 ±0.6	1.7 ±0.4	>20% decrease	1.1 ±0.3	>20% decrease	decline	nil	variable	17 - 22 (31) variable	7 - 1 (7) decline
	Boyne	Gladstone	17.7 ±1.2	34.6 ±1.9	>20% increase	13.1 ±0.9	>20% decrease	variable	nil	variable	45 - 6 (27) variable	<1 (17) decline
Burnett Mary	Burnett	Rodds Bay	19.9 ±2.4	30.3 ±3.4	>20% decrease	1.8 ±0.4	>20% decrease	decline	0 (2) NA	decline	21 - 1 (8) variable	2 - 1 (2) stable
	Mary	Urangan	15.6 ±1.0	2.9 ±1.0	>20% increase	0.5 ±0.2	>20% decrease	variable	nil	decline	7 - 1 (20) variable	<1 (1) stable

Note: Cover = Percent seagrass cover; Seeds = Seeds/m² sediment surface; Meadow = Edge mapping within 100m of monitoring sites; Epiphytes = Percent cover on seagrass leaves; Macroalgae = Percent cover.

Within canopy temperatures of seagrass meadows were warmer at northern locations and cooler at southern locations compared to previous monitoring years. Temperatures above 40°C were recorded at Picnic Bay, Magnetic Island; these temperatures are known to be detrimental to seagrass health (Bulthuis 1987; Campbell *et al.* 2006).

The reproductive health of seagrasses across GBR sites is variable although some sites are categorised as being in 'good' health indicating a resilience to change, and all sites showed some evidence of reproductive effort. However, the sites at Green Island (Cairns), Lugga Bay (Tully River/Mission Beach) and Urangan (Mary River/Hervey Bay) showed very low production of reproductive structures during the 2008/2009 sampling period. A continued absence of flowering and fruiting in these sites will result in poor capacity to recover from disturbance and inter-annual differences in sexual reproduction are evident.

3.4. Coral reef monitoring

The completion of the fourth inshore coral reef survey under the MMP allows the first temporal assessment of the status of coral reef communities using four years of data. Estimates of coral community status were calculated as an aggregate score for four indicators: coral cover, macroalgal cover, juvenile hard coral density, and settlement of coral spat (see Table 3.9 for community status and Schaffelke *et al.* (2009) AIMS report for detailed calculation of these scores).

Over the period 2005-2008 the average number of hard coral genera recorded in this monitoring program on the fourteen core reef sites has remained relatively stable or increased slightly in 2008. At the level of genus there is no evidence for a loss of diversity.

Inshore coral community composition also showed a relationship to water column chlorophyll levels at ten of the fourteen reef sites. Where the annual mean Guideline value for chlorophyll was exceeded, reefs have high cover of macroalgae. Where annual means were below the Guideline value, macroalgal cover was very low. The exceptions to this pattern were Barren and Humpy Islands in the Fitzroy Region, which had high cover of the brown macroalga *Lobophora variegata* despite low chlorophyll concentrations, and Pelorus Island (Burdekin Region) and Double Cone Island (Mackay Whitsunday Region) which exceeded the chlorophyll Guideline value but currently have only low macroalgal cover. It would be of interest to observe how these communities change after an acute disturbance increases available substratum for algal colonisation.

Wet Tropics Region: Daintree and Johnstone-Russell/Mulgrave sub-Regions

For the 2008/2009 monitoring period, a positive score of coral community status was indicated for the Daintree and Johnstone-Russell/Mulgrave sub-Regions of the Wet Tropics Region. Coral communities on average showed high coral cover that increased during periods without acute disturbance, low macroalgae cover and relatively high densities of juvenile colonies (Table 3.9). There were no major flood events in this sub-Region during 2008/2009, which may explain increasing coral cover during this period.

Wet Tropics Region: Herbert Tully sub-Region and Burdekin Region

A negative status was assigned for reefs in the Herbert Tully sub-Region of the Wet Tropics Region and also the Burdekin Region (Table 3.9). On average, reefs in these areas had relatively high cover of macroalgae and moderate to low coral cover with no clear evidence of increase. Limited recovery of coral cover was observed in the Herbert Tully sub-Region since the impacts of Cyclone *Larry* in 2006, which may be due to the fact that more time is required to observe recovery but may also be a consequence of riverine influence from regular flood events. Chronic poor water quality can affect coral fertilisation and larval

recruitment (Hoegh-Guldberg *et al.* 2007), as well as increase competition with macroalgae that overgrow available recruitment substrate (McCook *et al.* 2001; Diaz-Pulido *et al.* 2009). The negative attributes are partly offset by moderate juvenile colony densities. No historical time series exists for these reefs to infer recovery potential. The lack of recovery in the Burdekin Region is concerning as there have been no obvious disturbances since coral bleaching impacted reefs in 2002. Settlement of spat to tiles was low.

Mackay Whitsunday Region

In the 2008/2009 monitoring period, coral communities in the Mackay Whitsunday Region scored positive in terms of status (Table 3.9). Here, average coral cover was high but did not increase despite a lack of acute disturbance. The cover of macroalgae was low and the relative density of juvenile colonies and settlement of spat to tiles was moderate relative to other Regions. Regional river flows were above median levels during periods of declining juvenile colony densities. In particular, flooding of the Pioneer River in 2007/2008 greatly exceeded median flow. It is plausible that increased flux of fine sediments associated with these wetter years contributed to the decline in juvenile density as the repeated re-suspension of fine material would repeatedly reduce light availability at the reef surface and when settling require energetic input from the corals for removal.

Fitzroy Region

The assessment of coral community status in the Fitzroy Region was marginally positive (Table 3.9). High average coral cover (relative to other Regions), a clear capacity to recover following disturbance events and high but variable, spat settlement were offset by high macroalgae cover and low juvenile colony densities. Corals have been repeatedly affected by bleaching in this Region with substantial declines in coral cover observed in 1998, 2002 and 2006, however, rapid recovery has also been documented (Sweatman *et al.* 2007; Diaz-Pulido *et al.* 2009). A decline in cover from 2007 to 2008 was the result of a major flood of the Fitzroy River (February 2008) and a strong northerly wind event (February 2008) affecting reefs. The slight declines associated with these recent disturbances did not affect the overall status as Regional hard coral cover started high and remained at 40%, which is still more than the GBR-wide average for hard coral cover of 36%.

Of the reefs surveyed in both 2007 and 2008 there was no overall change in the cover of hard corals (mean hard coral cover for all Regions was 36% in both years). On reef sites, the average density of juvenile colonies per square metre has reduced from a high of 5.8 in 2005 to a low of 3.9 in 2008. This decline has been observed in all Regions. It is possible that such variation occurs naturally. However, as there are no previous studies of this nature, only future data from this project can provide estimates of the scales and magnitudes of variation in juvenile abundances. Possible explanations for these declines include a combination of variation in river flows and response to disturbance events. Numbers of juvenile colonies are the result of settlement and survival over the preceding three years. It is plausible to infer that the lower density of juvenile colonies during the last monitoring period is a consequence of the adult corals being impacted by recent disturbances (e.g. Cyclone *Larry* and associated flooding in 2006, and coral bleaching in the Keppel Island sub-Region in 2006).

Table 3.9: Regional estimates of coral community status, based on performance (level, rate and direction of change) of four indicators from 2004-2008: 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 listed below the table showing overall status estimates.

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

Cover of corals (combined HC and SC) considered as

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

Cover of macroalgae

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

Density of Juveniles colonies (averaged over years)

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

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

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

4. Regional reports

The MMP assesses water quality and ecosystem condition for each of the six Natural Resource Management Regions of the GBR (Figure 2.4). The information collected complements Regional monitoring of land management practices and catchment water quality.

4.1. Cape York Region

Regional context and drivers

Cape York Peninsula is the northernmost extremity of Australia. It extends south from its tip at Cape York for 800 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 large 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.

The annual river flow of the Normanby River in 2008/2009 (October 2008 to October 2009) was less than the long term median flow, with a relative difference of 0.66 (refer to Table 3.2) and no major flood events were recorded in the Region.

Monitoring activities conducted in the Cape York Region are pesticide sampling, the application of remote sensing techniques and seagrass sampling. Other water quality parameters, flood plumes and coral reefs are not directly monitored in the Region.

4.1.1. Inshore water quality

Nutrients, chlorophyll and turbidity

Water Quality Guideline exceedances

The exceedance of the Guidelines were assessed in the Cape York Region for chlorophyll and suspended solids (retrieved from MODIS AQUA images). The annual mean values of chlorophyll exceeded the Guideline values (0.45 µg/L) for 41% percent of the inshore area, 2% of the midshelf and none of the offshore areas (Figure 4.1). Exceedance of suspended solids Guideline values were recorded in 55% of inshore, 39% of midshelf and 13% of offshore areas.

Guideline exceedances for chlorophyll and suspended solids (using non-algal particulate matter as a proxy) were calculated for dry season (winter months) data, along with the Exceedance Probability for that period. The mean and the median values of chlorophyll exceeded the Guideline values for the inshore area, and the mean values of suspended solids exceeded the Guideline values for the inshore, midshelf and offshore areas (Table 4.1).

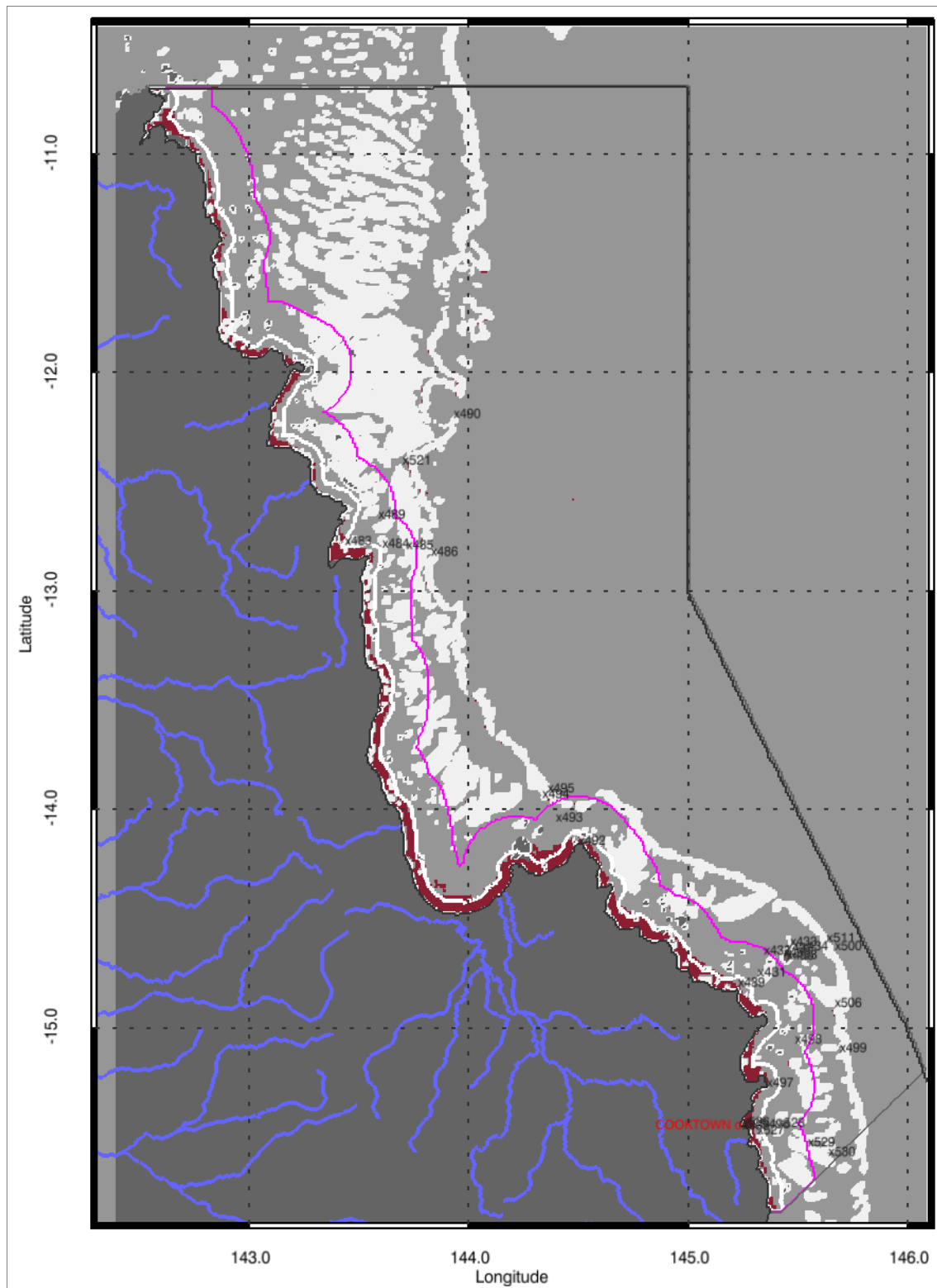


Figure 4.1: Annual mean chlorophyll Guideline exceedance map for the Cape York Region, 1 May 2008 to 30 April 2009. Pixels are mapped in dark red when annual mean values exceed the threshold. The white line represents Inshore boundary; pink line represents Midshelf boundary(Source: CSIRO).

Table 4.1: Summary of chlorophyll and suspended solids (using non-algal particulate matter as a proxy) Guideline exceedances for the dry season (winter months) in the Cape York Region.

	Surface Area (km ²)	Chlorophyll (µg/L): 01-May-2008-31-Oct-2008			Suspended solids (mg/L): 01-May-2008-31-Oct-2008		
		Mean	Median	Exceedance Probability	Mean	Median	Exceedance Probability
Inshore	6,001	0.60	0.47	57%	4.11	1.96	49%
Midshelf	15,603	0.34	0.31	20%	3.48	1.23	38%
Offshore	78,347	0.26	0.20	13%	1.16	0.22	26%

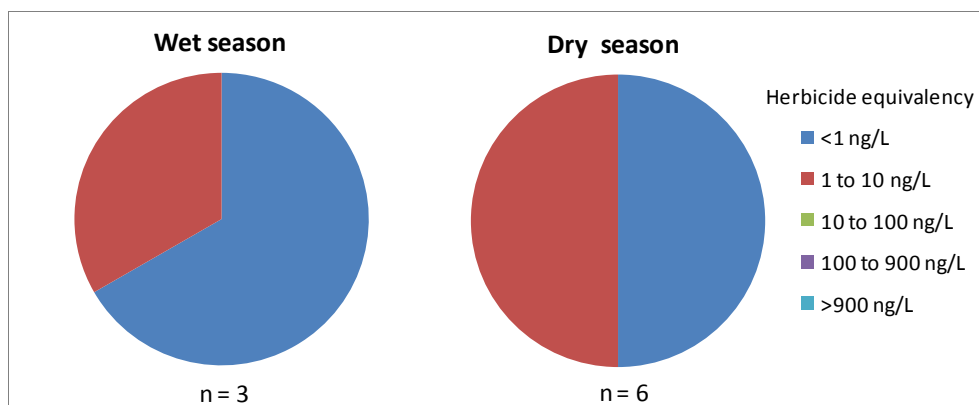
Note: Mean and Median report the mean and median concentrations calculated from all valid observations (i.e. number of cloud-free and error-free pixels – included in Brando *et al.* 2010). Exceedance Probability is the number of observations where the concentration exceeded the Guideline value divided by number of observation with (error-free) data for that period. Mean and median are presented in red and bold if they exceed the Guideline value.

Pesticide concentrations

The results for pesticide sampling in the Cape York Region are summarised below.

Location:	Lizard Island (3 deployments, dry season)
Detections:	• Diuron in each deployment, range 1.1-2.5 ng/L
Location:	Pixies Garden (6 deployments, wet and dry season)
Detections:	• Diuron (3/6) (nd-1.7 ng/L), hexazinone (1/6) (0.34 ng/L) • DEET, galaxolide, pendimethalin and Tris(1-chlor-2-propyl) phosphate (TCPP) detected during the wet season. However, concentration estimates are preliminary and therefore not reported here.

All samples collected in the Cape York Region had Herbicide Equivalency (HEq) indices in the ranges less than 10 ng/L (Figure 4.2), and none exceeded the Guideline values.

**Figure 4.2:** HEq index of all samples collected in Cape York Region in wet and dry seasons 2008/2009.

4.1.2. Inshore biological monitoring

Status of Intertidal seagrass habitats

One location with two sites containing intertidal fringing reef seagrass habitat is monitored within the Cape York Region. At this location, Archer Point, physical disturbance from waves and swell and associated sediment movement control seagrass growth in the area. Key results from 2008/2009 and from comparisons with previous years' data show:

- Seagrass cover, although seasonal, has remained stable and appears to have recovered from previous declines;
- Seagrass species composition has varied since 2003 but has stabilised over the 2008/2009 year;
- Reproductive health status over the period 2006-2009 was variable, with variable seed count in 2008/2009. Epiphyte cover has declined.
- Seagrass tissue ratios (C:N) were within previous levels recorded and indicative of low light availability;
- Seagrass tissue nutrient ratios (C:P and N:P) were lower than previous years, with N:P ratios being the lowest recorded, suggesting that the habitat is nutrient rich;
- The spatial extent of seagrass habitat in the area declined slightly during 2008/2009 and remained below the 2005 baseline; and
- No pesticides were detected in sediments within the seagrass habitats.

Seagrass community status

Over the 2008/2009 sampling period, the meadow remained stable at one site but declined seaward at the other, decreasing the overall area of seagrass present within the location. The sites were dominated by *Halodule uninervis* and *Halophila ovalis*, and the long-term average of seagrass cover was 16-19% in the dry season (Figure 4.3). The meadows within the area appear to have recovered from the declines reported in the previous monitoring period and have stabilised within documented long-term ranges of abundance in this type of habitat.

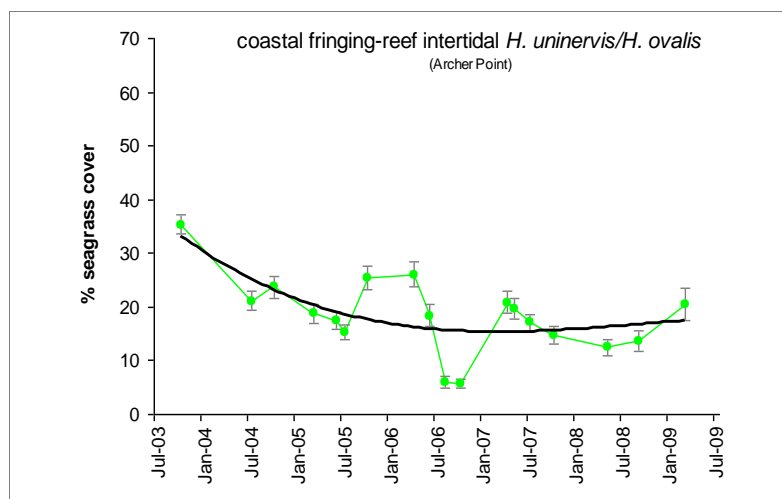


Figure 4.3: Seagrass abundance, expressed as percent cover, at Archer Point (sites pooled).

Seagrass environment status

Light environment (indicators of light availability): Seagrass species in Archer Point all had low molar C:N ratios late in the 2008 dry season, where values of 20 or less indicate light availability may be low. Although C:N values in 2008 were lower than in 2007, they were still within the range of previously observed levels and not significantly different from previous years (Figure 4.4).

Nutrient environment: C:P ratios were lower in 2008 relative to all previous years and all values were below 500, indicative of the presence of a relatively large phosphorus pool. This suggests that the habitat is nutrient rich. N:P ratios were the lowest since commencement of monitoring (below 30 for all species), indicating that some plants were nutrient replete, while many others were nitrogen limited (Figure 4.4).

Epiphyte cover on seagrass leaf blades at Archer Point was variable over the monitoring period, although a gradual decline is evident since the monitoring began in 2003; abundances were low in 2008/2009. The percentage cover of macro-algae is also variable between years for this location, with increases in abundance recorded in 2006 and 2007, followed by a decline. Overall, macro-algae has declined in abundance at Archer Point.

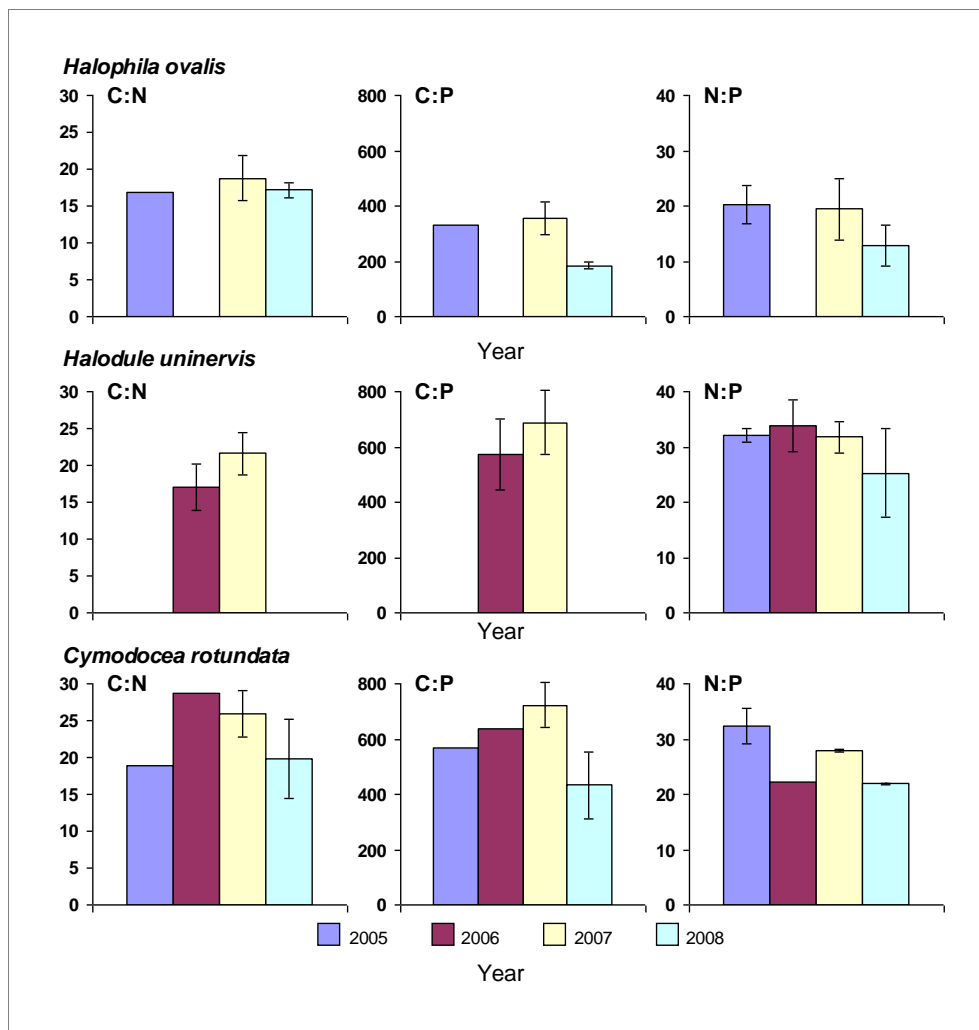


Figure 4.4: Plant tissue ratios C:N, C:P and N:P for seagrass species in the Cape York Region at Archer Point for all sampling years (mean and SD displayed).

4.2. Wet Tropics Region

Regional context and drivers

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.

The annual river flow of all of the Wet Tropics rivers in 2008/2009 (October 2008 to October 2009) exceeded the long term median flow with the exception of the Mulgrave River which was just below median flow conditions (refer to Table 3.2) The river flow from the Herbert River was more than three times the annual median flow. Flow conditions in the the Barron, Russell, Johnstone and Tully Rivers were slightly above median levels.

In the context of temporal data analysis, the major rivers in the Wet Tropics Region had above median discharge since the start of the MMP, whereas flow in 2004/2005 was below the long-term median. Noteworthy were major flood events of the Barron River in 2007/2008 and the Herbert River in 2008/2009.

In the Wet Tropics Region water quality, flood plumes, seagrass habitats, and coral reefs are all monitored as part of the MMP. Overviews of the results of each of these are below.

4.2.1 Inshore water quality

Spatial and temporal patterns

The 'Cairns Coastal Transect' (Figure 4.5), has been regularly sampled since 1989 and is the only long-term data set for a comprehensive range of water quality parameters in the GBR lagoon with which to conduct temporal trend analyses (Schaffelke *et al.* 2009a). The water quality parameters measured include the full suite of nutrients at all fixed lagoon sampling locations. The analysis of temporal trends used a subset of six parameters, chlorophyll, particulate nitrogen, particulate phosphorus, suspended solids, total dissolved nitrogen and total dissolved phosphorus, the concentrations of all of which are expressed as μgL^{-1} .

These six parameters have shown temporal trends over sampling years in previous analysis (De'ath 2005; CRC Reef Consortium 2006; Schaffelke *et al.* 2007). All parameters, except chlorophyll, showed significant long-term patterns. Long-term trends in particulate nitrogen and suspended solids were nonlinear, while particulate phosphorus showed a linear trend of declining values over time (Figure 4.6). Suspended solid concentrations increased in the early to late 1990s, peaked around 1999 and then declined.

Particulate nitrogen and chlorophyll levels fluctuated over years, possibly an indication of multi-year cycling, had high values in 1999 but generally decreased over time. An analysis of driving factors is underway and results so far indicate that flood events and resuspension events at the time of sampling are the most prominent drivers of the water quality variables (Schaffelke *et al.* 2009b). The highest concentrations were measured in periods with above median flood events over several years (e.g. 1989-1991 and 1999-2001). There is currently no indication that the temporal pattern is related to changes in land use. Modelled suspended sediment and nutrient loads for the Barron River do not indicate a change over the period of time the Cairns Coastal Transect was sampled and are predominantly related to river flow variability (John Armour, pers. comm.). However, more catchment-related data are sought to include in the analysis. In addition to the long-term trends, some variables had recurring

seasonal trends. Suspended solids steadily increased from January to September 2009 and then declined. Chlorophyll increased from January to April 2009 and then steadily declined. Particulate nitrogen, particulate phosphorus, total dissolved nitrogen and total dissolved phosphorus showed no significant variation across months.

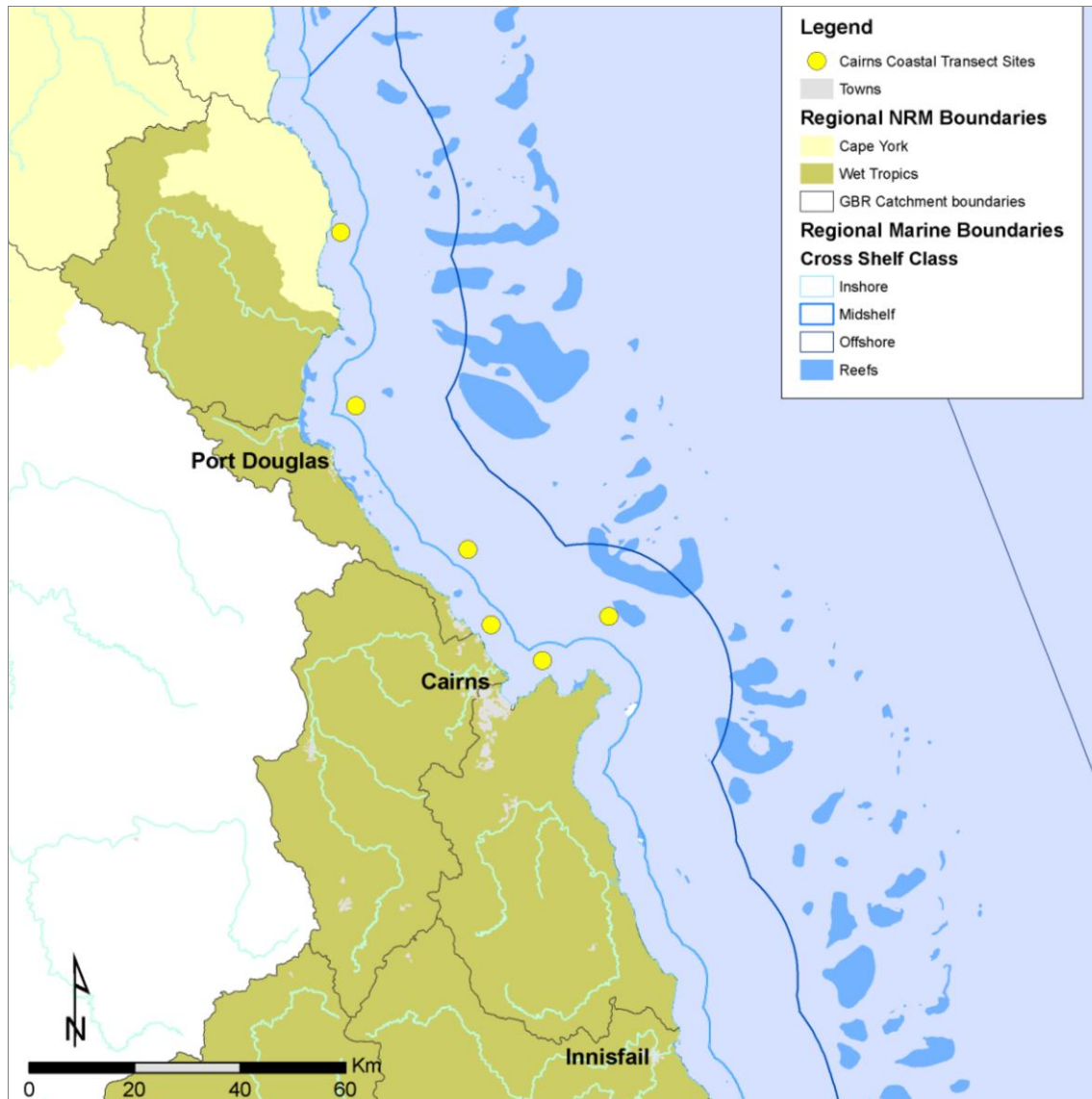


Figure 4.5: Location of the Cairns Coastal Transect (yellow symbols) sampled from 1989-2008. (Source: AIMS).

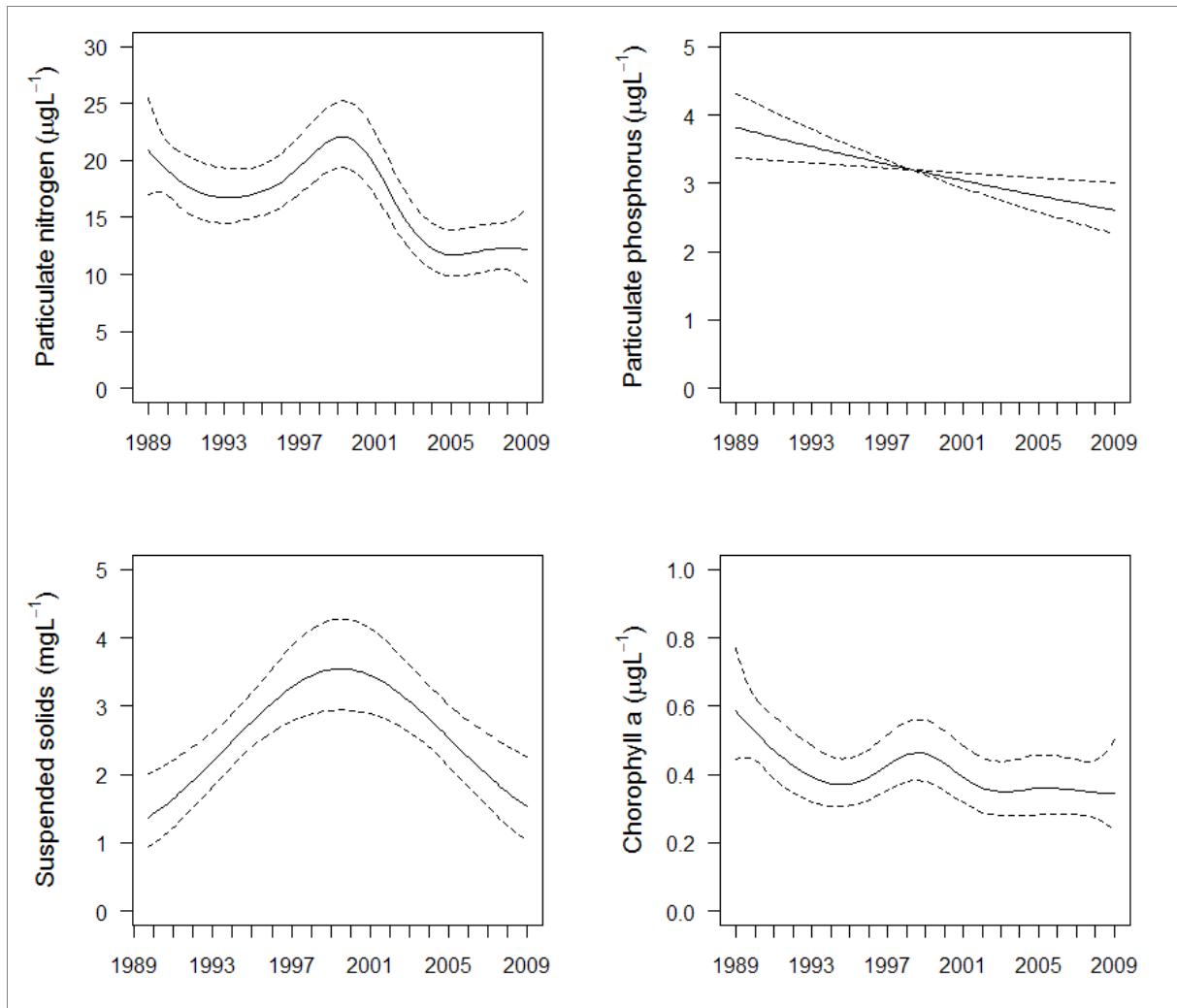


Figure 4.6: Smooth trends of long-term time series of Carins Coastal Transect over sampling years from 1989 to 2008 for the water quality parameters: particulate nitrogen and phosphorus, suspended solids and chlorophyll. Solid line represents fitted trend line.

Nutrients, chlorophyll and turbidity

Seasonal means of chlorophyll, suspended solids, particulate nutrients and turbidity (secchi depth) over four years of monitoring were mostly below the Guideline values. An exception is Dunk Island, which generally had the highest seasonal means of all locations in this Region, and all means, except for particulate nitrogen, exceeded Guideline values. Russell Island (Frankland Island Group) had the lowest concentrations of all four variables and the highest secchi depth readings. All other Wet Tropics locations had secchi readings above the Guideline value for this parameter (10 m).

Annual and seasonal turbidity means for Snapper and Dunk Islands were above the Guideline value for suspended solids (after conversion to NTU; see Table 3.4). This is also reflected in these two sites having the lowest secchi depth readings in the manual water sampling. At Snapper and Dunk Islands, the turbidity readings were above the suggested 5 NTU limit for severe coral photo-physiological stress (Cooper *et al.* 2007; 2008) for 7% and 11% of daily records over the whole period (October 2007 to February 2009), respectively, indicating nominal light limitation of corals at these two locations. This light limitation is not limited to flood events but the data record indicates that resuspension throughout the year during strong winds lead to frequent high turbidity events.

Water Quality Guideline exceedances

The exceedance of Guidelines were assessed in the Wet Tropics Region for chlorophyll and suspended solids (retrieved from MODIS AQUA images). The annual mean (2008/2009) values of chlorophyll exceeded the Guideline value (0.45 µg/L) for 57% of the inshore area, 9% of the midshelf and none of the offshore areas (Figure 4.7). Exceedance of suspended solids Guideline values were recorded in 41% of the inshore, 13% of the midshelf and 12% of offshore areas.

Guideline exceedances for chlorophyll and suspended solids (using non-algal particulate matter as a proxy) were calculated for dry season (winter months) data, along with the Exceedance Probability for that period. The mean and the median values of chlorophyll exceeded the Guideline values for the inshore area, and the mean values of suspended solids exceeded the Guideline values for the inshore and offshore areas (Table 4.2). The mean and median values for the suspended solids concentration differed substantially for all areas. The mean values were two to three times higher than the medians.

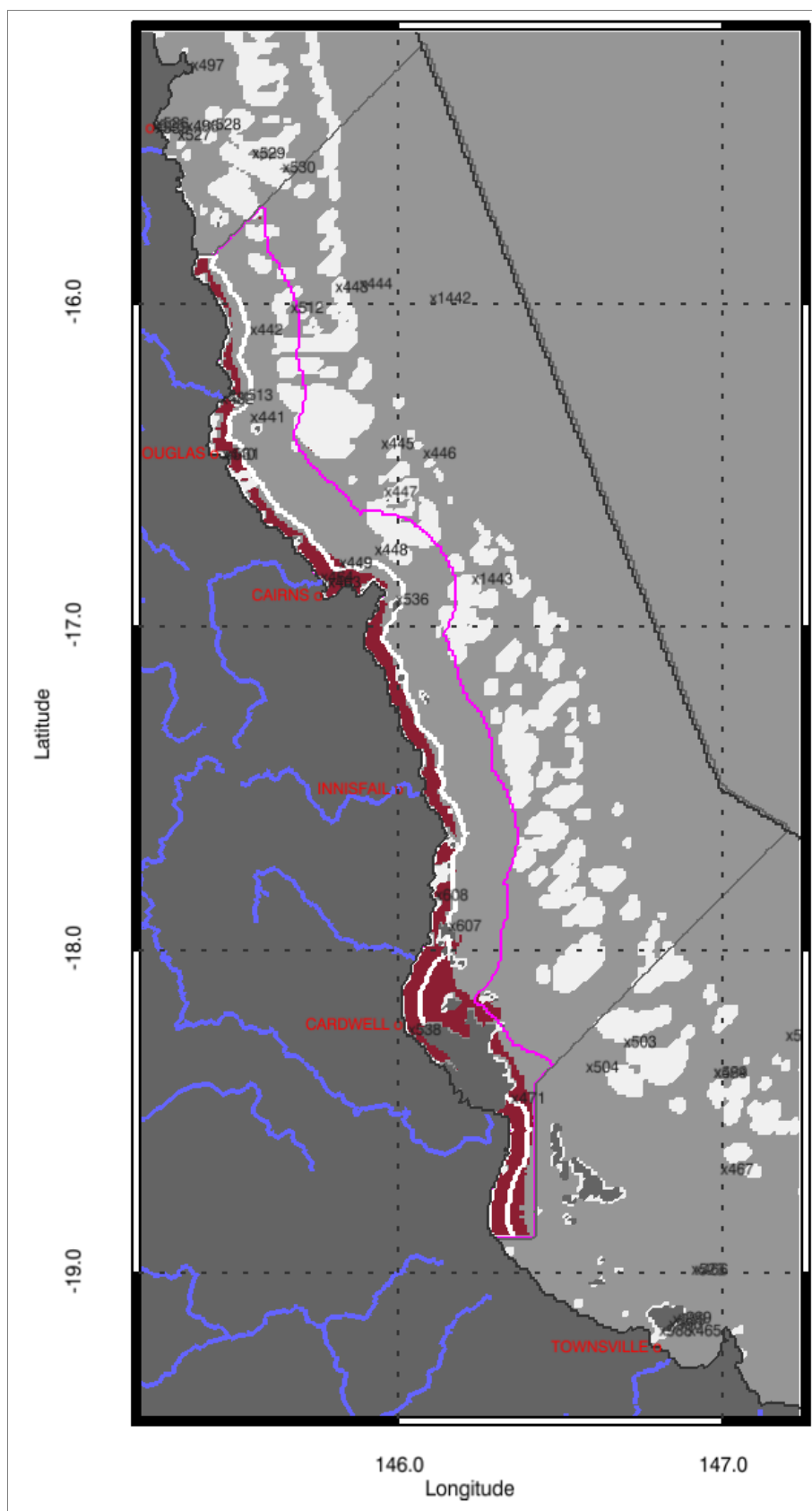


Figure 4.7: Annual mean chlorophyll Guideline exceedance map for the Wet Tropics Region, 1 May 2008 to 30 April 2009. Pixels are mapped in dark red when annual mean values exceed the Guideline value ($0.45\mu\text{g/L}$). The white line represents Inshore boundary; pink line represents Midshelf boundary(Source: CSIRO).

Table 4.2. Summary of chlorophyll and suspended solid (using non-algal particulate matter as a proxy) exceedances for the dry season (winter months) in the Wet Tropics Region.

	Surface Area (km ²)	Chlorophyll (µg/L): 01-May-2008-31-Oct-2008			Suspended solids (mg/L): 01-May-2008-31-Oct-2008		
		Mean	Median	Exceedance Probability	Mean	Median	Exceedance Probability
Inshore	2723	0.73	0.54	72%	2.83	1.35	32%
Midshelf	6920	0.37	0.36	24%	1.74	0.61	22%
Offshore	24295	0.26	0.21	11%	0.87	0.15	22%

Note: Mean and Median report the mean and median concentrations calculated from all valid observations (i.e. number of cloud-free and error-free pixels – included in Brando *et al.* 2010). Exceedance Probability is the number of observations where the concentration exceeded the Guideline value divided by number of observation with (error-free) data for that period. Mean and median are presented in red and bold if they exceed the Guideline value.

Pesticide concentrations

The results for pesticide sampling in the Wet Tropics Region are summarised below.

Location:	Low Isles (9 deployments, wet and dry season)
Detections:	<ul style="list-style-type: none"> • Pesticides were detected consistently through the wet and dry seasons • Diuron was most consistently detected – mean concentration 1.8 ng/L; maximum concentration 5 ng/L • A series of other pesticides were detected in the polar passive samplers with hexazinone and atrazine dominating
	Trends (4 years)
	<ul style="list-style-type: none"> • Pesticide concentrations increased during the wet season and are correlated to river flows • No significant long-term decrease in the concentration of pesticides in the water at Low Isles
Location:	Fitzroy Island (8 deployments, wet and dry season)
Detections:	<ul style="list-style-type: none"> • Diuron in all samples - mean concentration 3.8 ng/L; maximum concentration 15 ng/L • Atrazine and hexazinone were detected in 4 of 8 sampling periods, typically at concentrations lower than those of diuron • Data in the same range as data obtained by Shaw <i>et al.</i> (2005; 2010) from inshore reefs including Fitzroy Island • A series of other pesticides were detected in the non-polar passive samplers including galaxolide, pendimethalin and TCP
	Trends (4 years)
	<ul style="list-style-type: none"> • Pesticide concentrations typically increased during the wet season associated with river flows • No significant long term decrease of the pesticide concentration in the water at Fitzroy Island
Location:	High Island (2 deployments, dry season, discontinued 2008)
Detections:	<ul style="list-style-type: none"> • Diuron in both samples – mean concentration 1.8 ng/L

Location:	Normanby Island (10 deployments, wet and dry season)
Detections:	<ul style="list-style-type: none"> • Diuron most consistently detected (8/10 samples) and at the highest concentrations with a mean concentration of 2.2 ng/L • Atrazine, hexazinone and tebuthiuron were detected but usually at lower concentrations than diuron • A series of other pesticides were detected in the non-polar passive samplers including galaxolide, TCPP, phosphate tri-n-butyl, chlorpyrifos and DEET
	Trends (4 years)
	<ul style="list-style-type: none"> • High variability between years; concentrations are often higher in the wet season, however there is no long-term trend discernable at this stage
Location:	Dunk Island
Detections:	<ul style="list-style-type: none"> • Diuron and hexazinone detected (3/4 samples) – mean concentration 1.9 ng/L and 0.85 ng/L respectively • A series of other pesticides were detected in the non-polar passive samplers including galaxolide, TCPP, chlorpyrifos, fipronil and pendimethalin

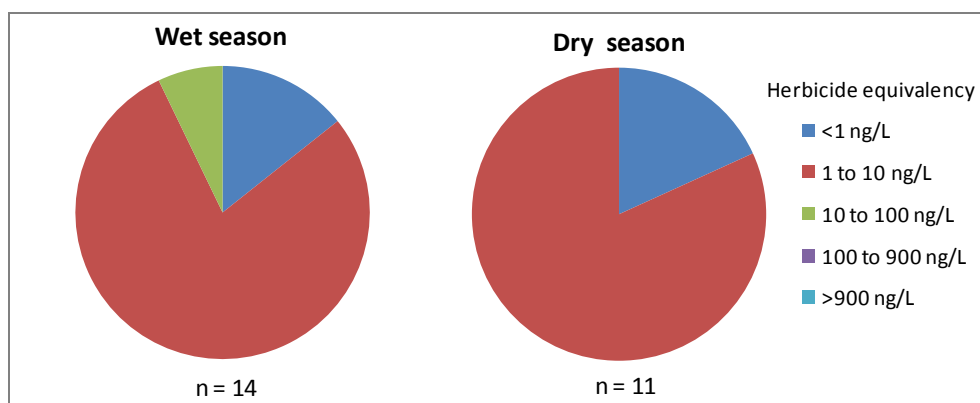


Figure 4.8: HEq index of all samples collected in the Wet Tropics Region in wet and dry seasons 2008/2009.

All five inshore reef sites sampled in the Wet Tropics Region had average HEq of 1-10 ng/L, with only one sample in the range 10-100 ng/L (Figure 4.8). There were no exceedances of the Guideline values.

4.2.2 Flood plume monitoring

Sampling

Sampling in the Tully River plumes occurred on 6 occasions between 3 January and 17 March 2009 following medium to high peak flows in the Tully River (Figure 4.9).

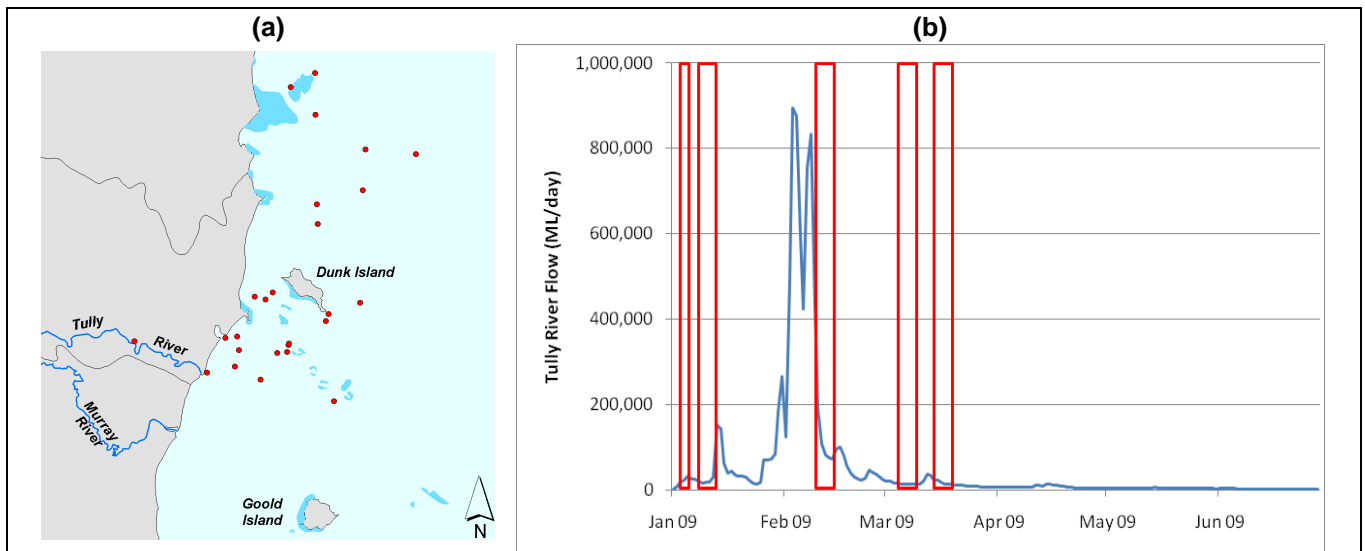


Figure 4.9: (a) Sampling sites offshore from the Tully River sampled January to March 2009; (b) Flow hydrograph for the Tully River in early 2009. Red boxes denote the periods of time in which sampling took place.

Water quality characteristics

The concentrations of chlorophyll and suspended solids in plume waters were higher than the wet season Guideline values in over 90% of all samples collected in the Tully River plume. The elevated concentrations measured across the wet season imply that there were long periods when these concentrations were elevated above Guideline values, however, given the sampling interval, it is not possible to accurately determine the persistence of the elevated concentrations.

Measurements of suspended solids were relatively constant over the whole salinity range. Sediment erosion on the Tully-Murray catchment is not seen as a significant land management issue and this may be reflected in the lower measurements of suspended solids in the Tully River samples. However, the suspended sediment does not fall out in low salinities, implying that it is the finer particulate matter that may be able to travel beyond the coastal zone and thus further impact on inshore ecosystems. There is also the combined effect of the Herbert River plume, which may be bringing fine suspended solids into the Tully River plume, influencing the higher measurements in those higher salinity zones.

Chlorophyll measurements showed low concentrations in the early stages of the Tully River plume, most likely related to growth limitation caused by low light levels and freshwater, with significant increases in the concentrations in the higher salinity zones, corresponding to secondary plume characteristics.

A total of 31 samples (over six field campaigns) were collected for pesticide analysis from the Tully sub-Region in the 2008/2009 wet season (Figure 4.10a). Pesticide residues were

detected offshore from the Tully River at sites off Dunk Island, North Barnard Islands (the Triplets), Bedarra Island and King Reef. Diuron, atrazine, hexazinone and simazine residues were all detected in the January 2009 plume and diuron and hexazinone residues were detected in the samples collected in February 2009. While the concentrations in February were considerably lower (e.g. see Figure 4.10b), the fact the residues were still detectable following high river flows in both January and February 2009 suggests longer-term persistence.

In addition, imidacloprid residues (an insecticide) were below detection in the January 2009 samples but were detected in four of eight samples collected in February 2009 (concentrations range from below detection to 0.03 $\mu\text{g/L}$). This result suggests that this insecticide was applied to paddocks following the January 2009 rains.

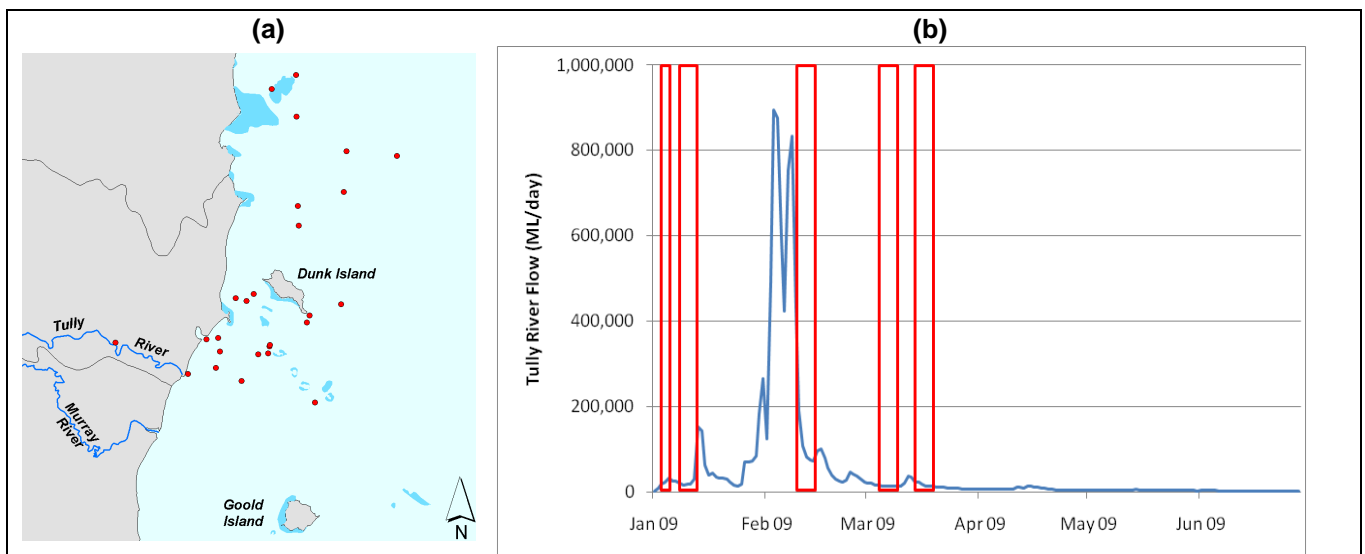


Figure 4.10: (a) Sampling sites offshore from the Tully River in January and February 2009; (b) Diuron residues detected offshore from the Tully River in January and February 2009 over the salinity gradient.

Three additional samples were collected from islands further north of the Tully Region in February 2009: Green, Russell and High Islands. No pesticide residues were detected at Green or Russell Islands, while atrazine (0.01 $\mu\text{g/L}$) and diuron (0.03 $\mu\text{g/L}$) residues were detected at High Island. The residues detected at High Island are probably sourced from the nearby Russell River which had a flow at the time of sampling (L. McKinna, pers. comm., 2009).

Remote sensing of flood plume extent

Tully and Herbert River plume extents have been identified using remotely sensed images derived on 14 January 2009 (Figure 4.11). The top image illustrates the primary and secondary plumes associated with the Herbert and Tully River floods, and shows that chlorophyll levels were high along the coast in the primary and secondary plumes. The very turbid inshore plume can be seen south of the Herbert River and extending north of Dunk Island. The lower images show the calculated CDOM and chlorophyll images for 14 January 2009. These images indicate that the influence of terrestrial discharge may extend a considerable distance beyond the outer reefs as tertiary plumes.

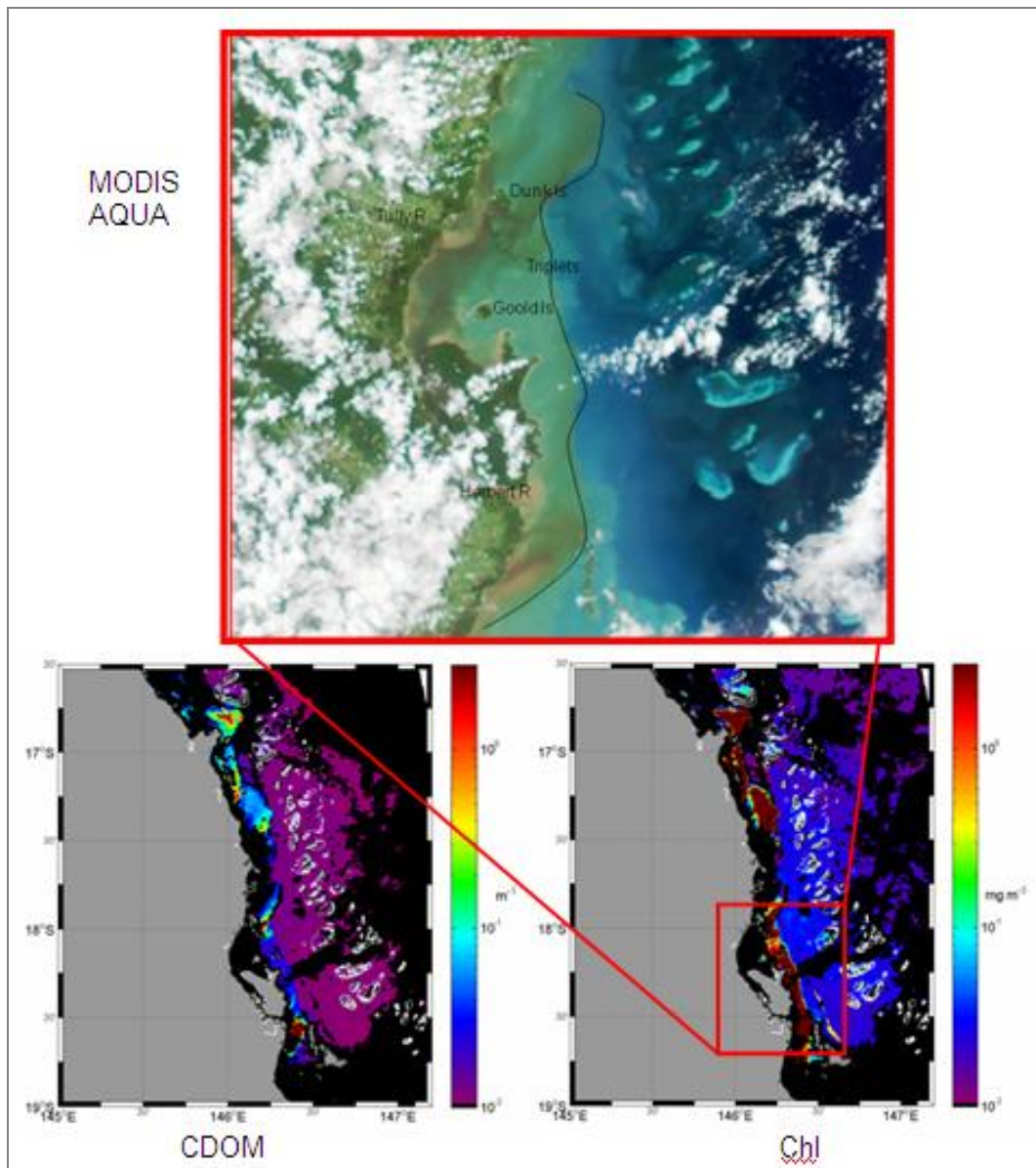


Figure 4.11: Remotely sensed images of the Tully and Herbert River flood plumes showing MODIS AQUA (comparable to true colour) NASA images, CDOM and chlorophyll on 14 January 2009 (Source: JCU).

Flood plume exposure

The flood plume exposure map for the Tully River (Figure 4.12) was calculated from the intersection of the plume image and category from the aerial surveys (1995-2000) and remote sensing images (2003-2009) for the Tully sub-Region. Thirty-seven reefs and fourteen seagrass beds in the Tully Region were exposed to some degree to riverine plume waters during eleven flood events from the period 1994 to 2007. Over the eleven years, a minimum of eleven reefs (30%) and a maximum of 37 reefs (100%) were inundated by either a primary or secondary plume, indicating that it is likely that at least a third of the reefs are exposed to plume waters every year. In years with data to validate plume type (1998, 2003-2008), it is estimated that six to fifteen reefs were inundated by primary plume waters carrying high sediment loads, which is up to 41% of the inshore reefs in the Tully sub-region and five to sixteen reefs (43%) were inundated by secondary plumes with elevated nutrient and chlorophyll concentrations. These exposure rates have significant implications for the transport of sediments and nutrients onto inshore reefs, and on the settlement and survival of corals, and growth of macroalgae.

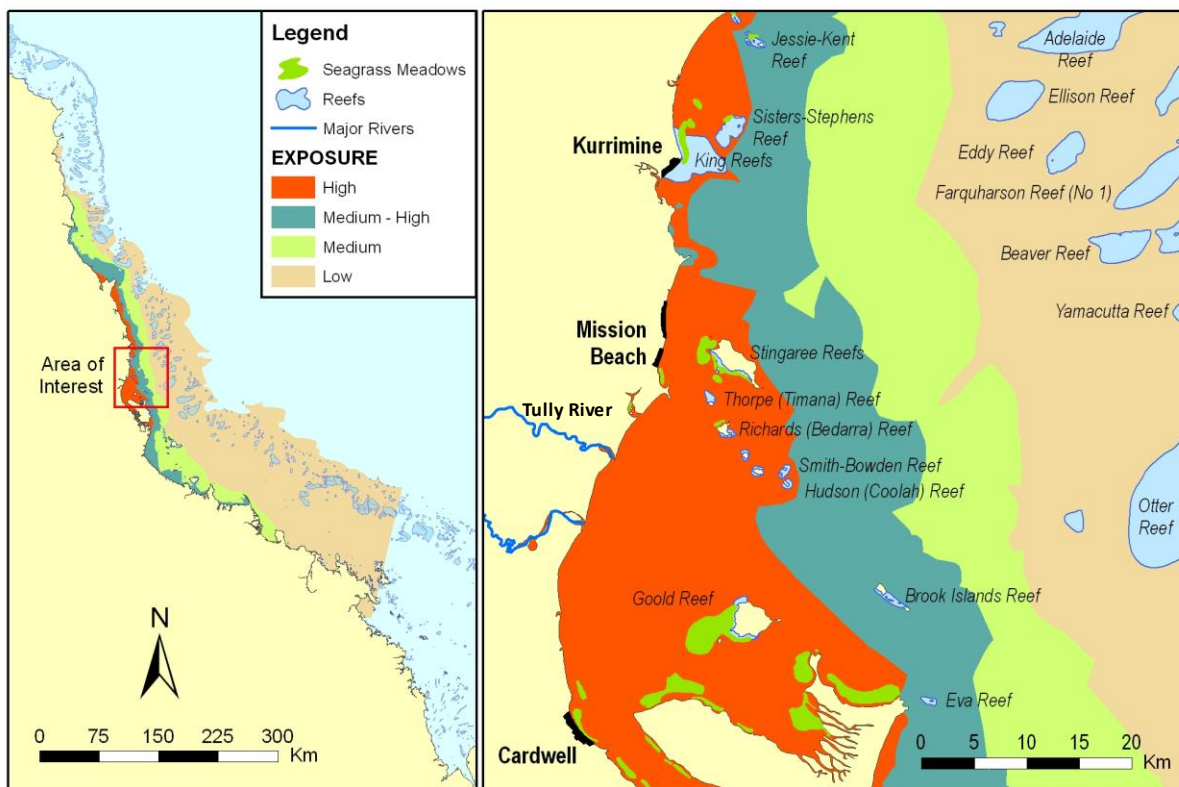


Figure 4.12: Flood plume exposure map for the Tully sub-Region, constructed from GIS imagery of plume extents from 1994 to 2009.

4.2.3 Inshore biological monitoring

Status of intertidal seagrass habitats

In the Wet Tropics Region, seagrass monitoring is undertaken at two coastal (Yule Point and Lugger Bay) and two reef habitats (Green Island and Dunk Island). The sediments in these locations are relatively unstable (due to their regular resuspension by prevailing winds), which restricts seagrass growth and distribution. The Barron, Tully and Hull Rivers are a major source of pulsed sediment and nutrient input to these meadows.

Key results from 2008/2009 and comparisons of data from previous years indicates:

- Seagrass cover, although seasonal, has generally increased or stabilised over the past year and is naturally lower at coastal habitats compared to reef habitats;
- Reproductive health status over the period 2006-2009 was poor at Green Island (reef) and Lugger Bay (coastal), and variable at other sites. In 2008/2009, seed counts were generally lower than in previous years;
- Seagrass tissues in reef habitats had higher C:N ratios than those in coastal habitats, indicating a potentially higher light environment in reef habitats. Decreasing C:N ratios at Green Island since 2006 indicate decreasing light availability at this location;
- Seagrass tissue nutrients suggest high levels of nutrients at coastal habitats with low light availability and elevated nitrogen (nutrient saturated);
- Seagrass spatial extent was stable at reef habitats and variable at coastal habitats; and
- No pesticides were detected in seagrass sediments in 2009.

Seagrass community status

Coastal habitats: The seagrass at Yule Point and Lugger Bay were representative of coastal (inshore) seagrass communities in the Region, and dominated by *Halodule uninervis* and *Halophila ovalis*. A meadow dominated by *Zostera capricorni* has continued to expand at Yule Point and is now mixed with a shoreward meadow dominated by *H. uninervis*. At Lugger Bay the meadow is only exposed at very low tides (0.4 m) and seagrass cover was generally low (<10%), which is similar to observations in the early 1990s at this location (Mellors *et al.* 2005; Figure 4.13). The decline of seagrass at Lugger Bay in 2006 is likely to be a consequence of the passage of Tropical Cyclone *Larry* (March 2006). No significant changes in species composition were observed at Lugger Bay (Figure 4.13).

Reef habitats: The Green Island and Dunk Island sites are on offshore reef-platforms. Seagrass species at Dunk Island sites included *H. uninervis*, with some *C. rotundata*, *H. ovalis*, and *C. serrulata*. In contrast, Green Island sites are dominated by *C. rotundata*, and *T. hemprichii* with some *H. uninervis* and *H. ovalis*. The sites appear to follow a seasonal pattern in abundance with high cover in the summer and low cover in the winter. No significant changes in species composition were noted during this last year (Figure 4.14).

Seagrass environment status

Light environment (indicators of light availability): Seagrasses in reef habitats had higher C:N ratios than those in coastal habitats in most years, indicating that reef habitats may have higher light (Figure 4.15). Seagrasses at the coastal intertidal site at Yule Point had C:N ratios below 20 (indicative of low light), as did some at the more turbid reef site at Dunk Island. C:N ratios were below 20 for all four species sampled at Green Island and values for *H. ovalis* at Green Island have declined since 2006 suggesting that light has become increasingly limited in this habitat.

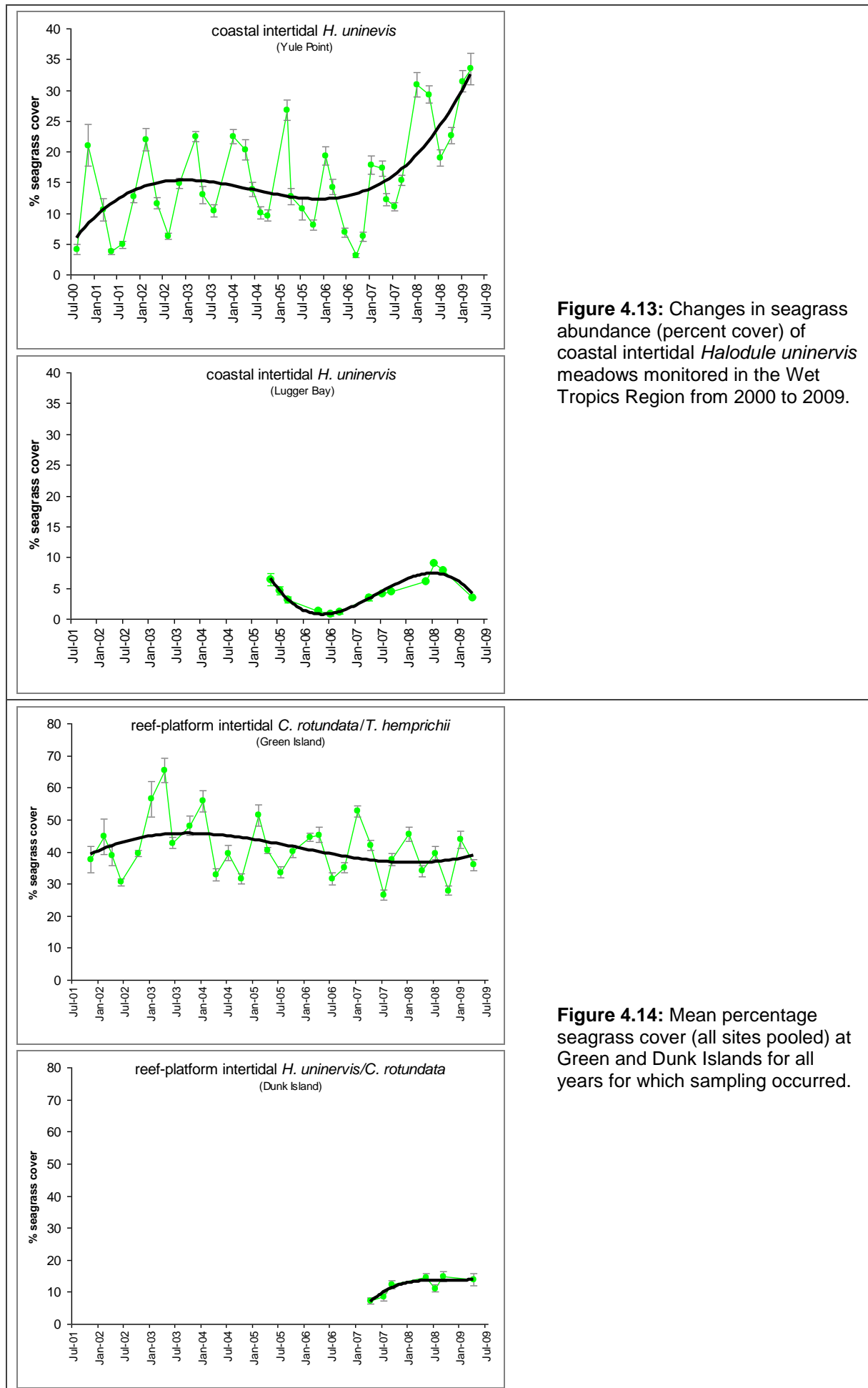


Figure 4.13: Changes in seagrass abundance (percent cover) of coastal intertidal *Halodule uninervis* meadows monitored in the Wet Tropics Region from 2000 to 2009.

Figure 4.14: Mean percentage seagrass cover (all sites pooled) at Green and Dunk Islands for all years for which sampling occurred.

Nutrient environment. Tissue nutrient ratios (C:P and N:P) show increasing nutrient saturation at coastal sites (phosphorus limitation; Figure 4.15). At Green Island (reef site), there were also significant differences in N:P in some species between years however, these differences were not in a consistent direction and levels in 2008 were within the variability of previous years. Levels in 2008 of N:P at Green Island were replete.

Epiphyte cover on seagrass leaf blades at coastal sites was highly variable and appears correlated with seagrass abundance. Epiphyte cover has continued to increase at Yule Point over the past twelve months and has remained low at Lugger Bay. Percentage cover of macro-algae at coastal sites is also variable, however at Yule Point abundance has declined over the last four years. Epiphyte cover at reef sites is highly variable and although not significant, it appears to be increasing. Macro-algae at both reef locations were predominately composed of *Halimeda* spp. and abundance is relatively stable, with mean covers less than ten percent.

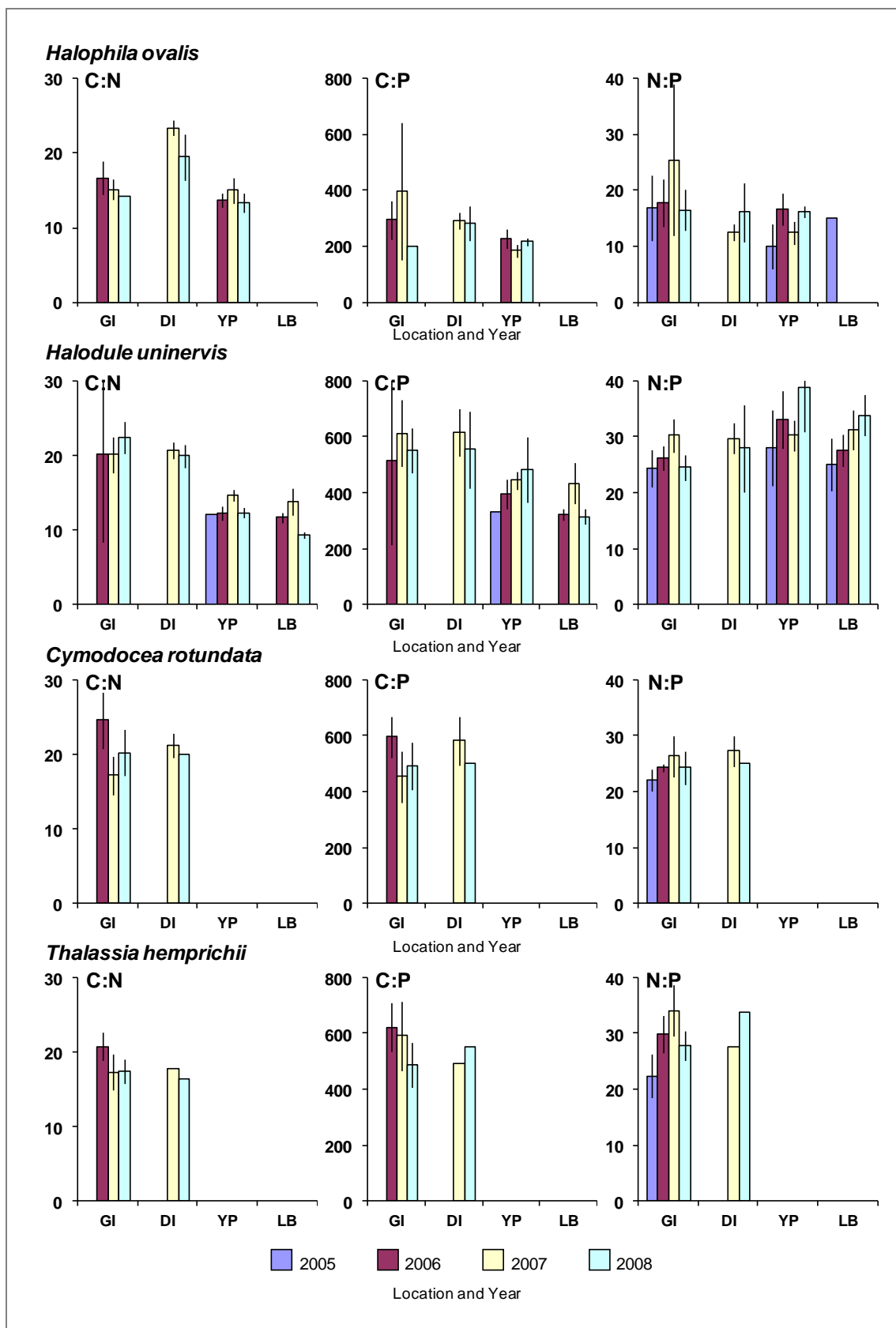


Figure 4.15: Plant tissue ratios C:N, C:P and N:P for each seagrass species examined in the Wet Tropics Region. GI=Green Island, DI=Dunk Island, YP=Yule Point, LB=Lugger Bay (mean and SD displayed).

Coral habitats

Coral reef sites monitored within the Wet Tropics Region are grouped into three sub-regions based on river catchments: the Barron Daintree, Johnstone and Russell/Mulgrave, and Herbert Tully sub-regions. Assessments of 'status' were determined for each of the reef sites by aggregating scores for three indicators: coral cover, macroalgae cover, and juvenile hard coral density. Nine sites are monitored in the region and status assessments were positive for six of the nine. Status assessments were negative for: Frankland Group west in the Johnstone and Russell/Mulgrave sub-region, and King Reef and Dunk Island south in the Herbert Tully sub-region. Overviews are provided below of the key results from monitoring at coral reef sites within each of the sub-regions. Further detailed results and analysis are presented in Schaffelke *et al.* (2009a).

Barron-Daintree sub-region

Reefs at Snapper Island north and Snapper Island south are sampled annually and historical data (Sea Research since 1995) showed that while the benthic communities have experienced several disturbances, resilience is evident with coral cover tending to increase in inter-disturbance periods (Figure 4.16). The reefs in this sub-region have been subject to disturbance from floods (1996 and 2004) and cyclones (1999; Ayling and Ayling 2005). Over the period 2005 to April 2009, the only disturbance to have impacted these reefs was an unidentified storm event (possibly associated with Tropical Cyclone *Hamish* in March 2009) that caused physical damage to corals at Snapper Island north. This potential for recovery was also observed in the data presented here.

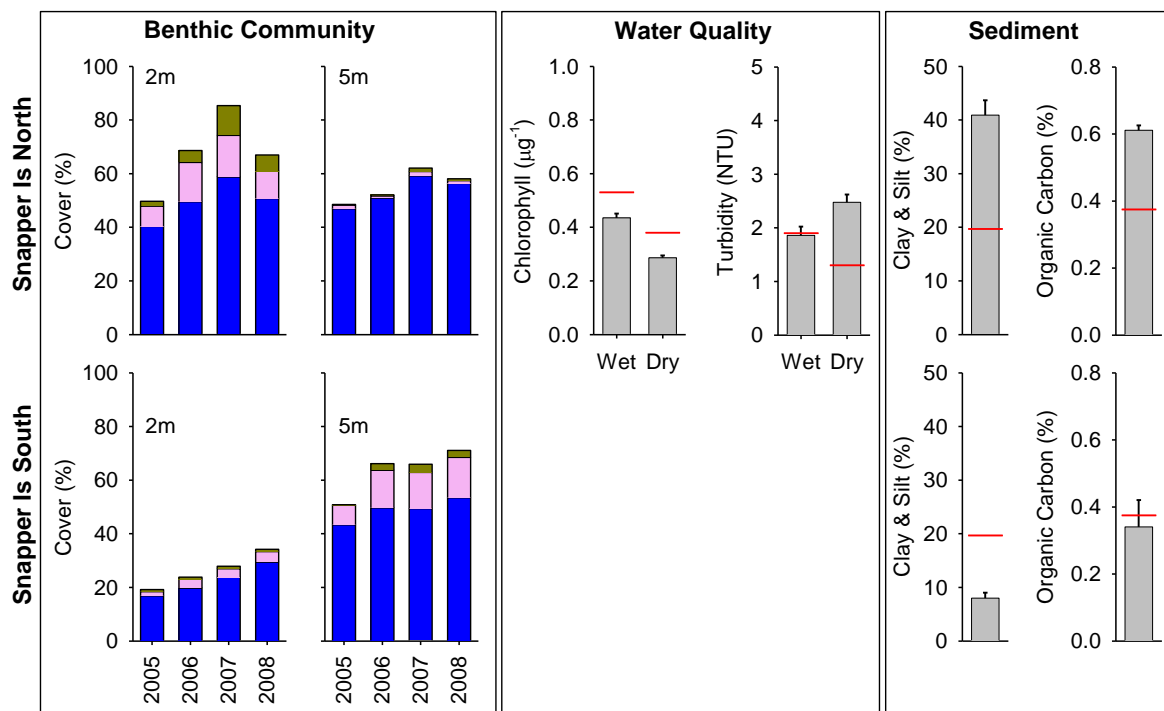


Figure 4.16: Percent cover estimates of major benthic groups: hard coral (blue), soft coral (pink) and macroalgae (green) for each sampling year and water quality and sediment quality parameters on reefs in the Barron Daintree sub-region of Wet Tropics Region. Red reference lines indicate the average values of environmental data from reef sites.

A very high density of juvenile colonies (mostly *Acropora*) was recorded at two metres at Snapper Island south in 2009 (Figure 4.17) however, the number of juveniles at five metres was low (Figure 4.17). At Snapper Island north the density of juvenile colonies has been similar to the overall average for all reefs in most years (Figure 4.17).

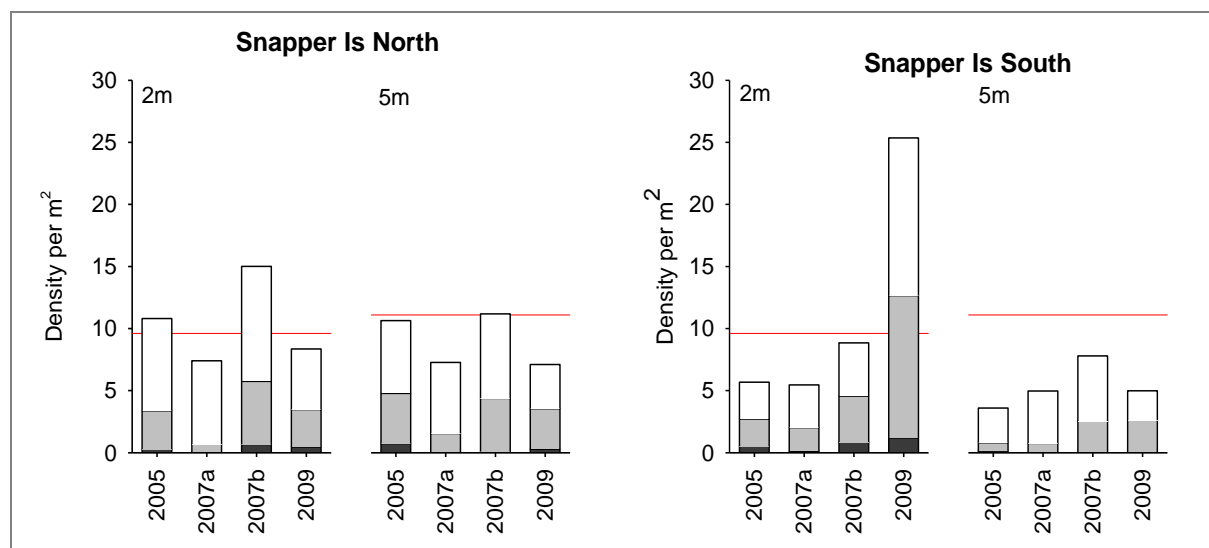


Figure 4.17. Density of juvenile hard coral colonies standardised to the area of available substrate for settlement on reefs in the Barron Daintree sub-region of the Wet Tropics. Bars are cumulative densities over the three size classes: <2 cm (dark grey), 2-5 cm (pale grey) and >5 cm to 10 cm (white). The average density over all years at each depth is indicated by the red reference line.

The overall assessment of status (Table 4.3) for both Snapper Island north and Snapper Island south is positive based on:

- High coral cover with demonstrated potential for increase during non-disturbance periods;
- Low cover of macro algae; and
- Moderate densities of juvenile colonies at two metres in general with high density at Snapper Island south in 2009.

Table 4.3: Reef by depth estimates of coral community status of reefs in the Barron Daintree sub-region of the Wet Tropics.

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

Note: The status assessments are aggregates over three indicators: coral cover, macroalgae cover, and juvenile hard coral density (see Table 3.9 for more detail). Coral cover trend indication: u= 'up', s= 'stable', d= 'decreasing'.

Johnstone and Russell/Mulgrave sub-region

Of the reefs surveyed in this sub-region those at the Frankland Group and Fitzroy Island have been monitored regularly since 1995 (Ayling and Ayling 2005) and 1992 (Sweatman *et al.* 2005), respectively. This long-term data set has documented four major disturbances responsible for substantial reductions in coral cover: coral bleaching (1998 and 2002), crown-of-thorns starfish outbreaks (1999-2000), and Tropical Cyclone *Larry* (2006).

In the period 2005 to 2008 both the western and eastern reefs of Fitzroy Island have shown marked increases in hard coral cover (Figure 4.18). This strong increase in cover along with above average densities of juveniles leads to a positive assessment of the status of benthic communities at Fitzroy Island (Figure 4.19). The cover of soft corals has remained stable over the period 2005 to 2008 with cover of this group regionally high at both depths of Fitzroy Island west.

The western reefs of both High Island and the Frankland Island Group have not shown similar increases despite avoiding substantial disturbances in the period 2005-2008 (Figure 4.18). The exception may be High Island west where cover appears to have increased in 2008 following slight declines between 2005 and 2006 and also 2006 to 2007. Slight declines in coral cover at the Frankland Island Group west at five metres have occurred since 2006. Despite this increase the cover of macroalgae remains low on all reefs in this sub-region (Figure 4.18).

The overall assessment of status for reefs in this sub-region is positive for all locations other than the Frankland Island Group west at five metres (Table 4.4). The status at this site is negative despite high coral cover due to the observed decline in coral cover and increase in the cover of macroalgae that cannot be associated with acute disturbance, along with consistently low densities of juvenile colonies.

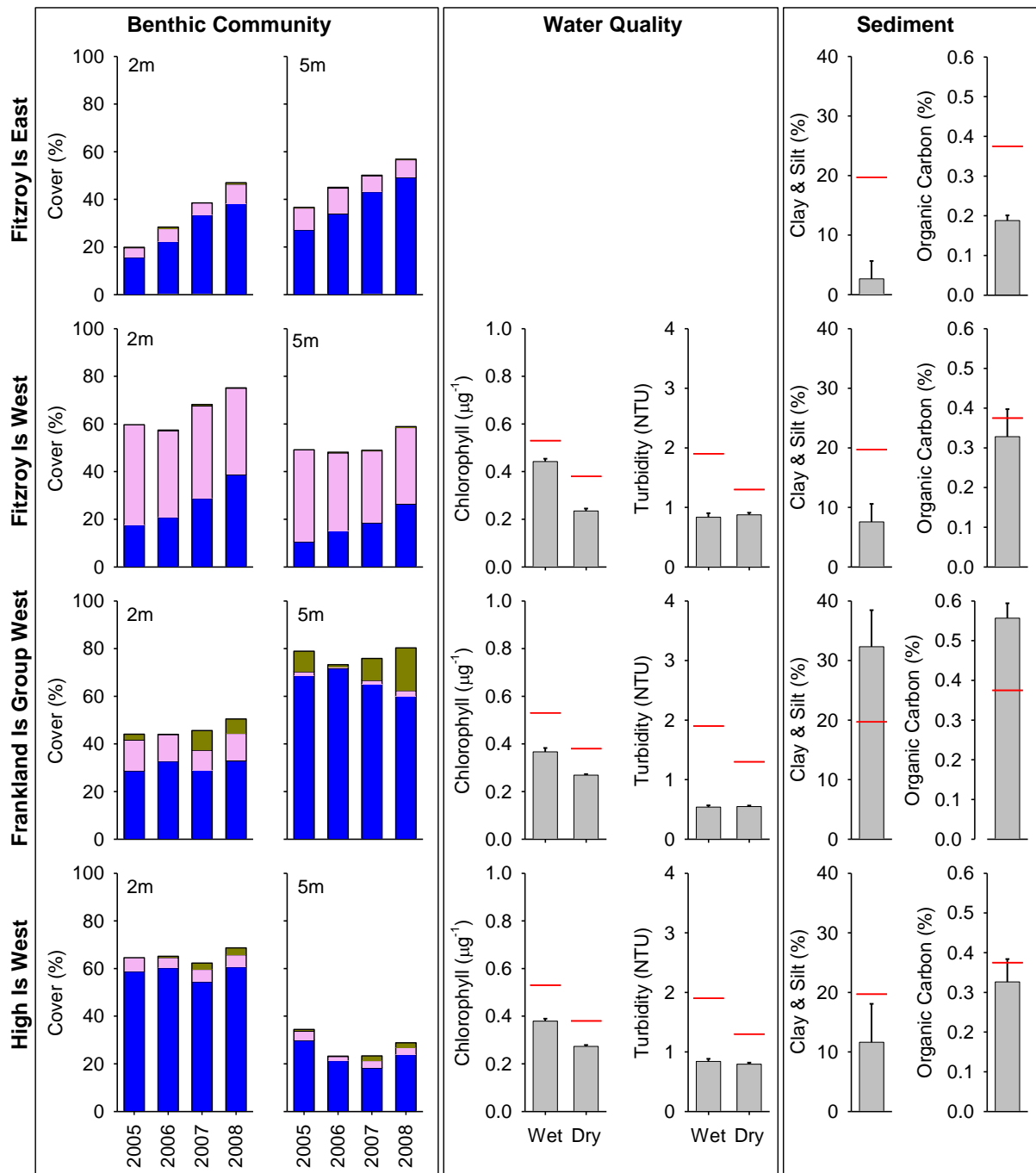


Figure 4.18: Percent cover estimates of major benthic groups: hard coral (blue), soft coral (pink) and macroalgae (green) for each sampling year and water quality and sediment quality parameters on reefs in the Johnstone Russell/Mulgrave subregion of Wet Tropics Region. Red reference lines indicate the average values of environmental data from reef sites.

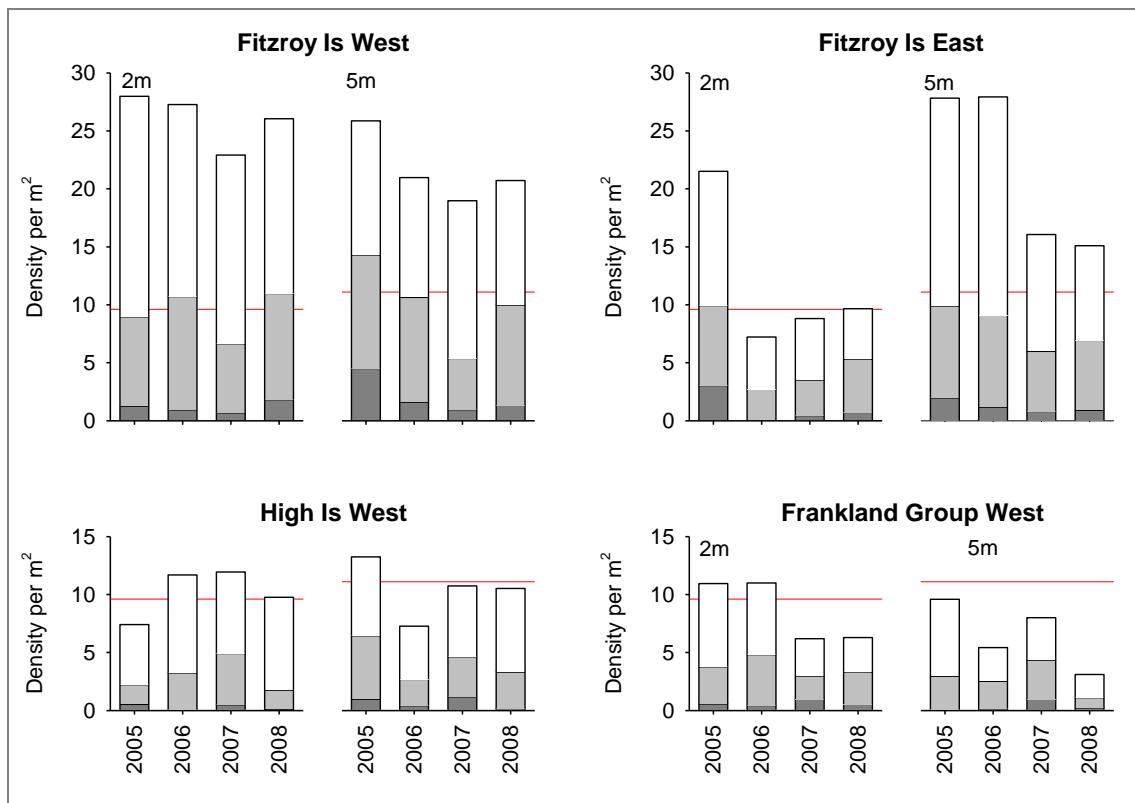


Figure 4.19: Density of juvenile hard coral colonies standardised to the area of available substrate for settlement on reefs in the Johnstone and Russel/Mulgrave sub-region of the Wet Tropics. Bars are cumulative densities over the three size classes: <2 cm (dark grey), 2-5 cm (pale grey) and >5 cm to 10 cm (white). The average density over all years at each depth is indicated by the red reference line.

Table 4.4: Reef by depth estimates of coral community status of reefs in the Johnstone and Russell/Mulgrave sub-region of the Wet Tropics.

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

Note: The status assessments are aggregates over three indicators: coral cover, macroalgae cover, and juvenile hard coral density (see Table 3.9 for more detail). Coral cover trend indication: u= 'up', s= 'stable', d= 'decreasing'.

Herbert Tully sub-region

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

Recent modelling work indicates hard coral communities in this sub-region were likely to have been impacted by coral bleaching in 1998 and 2002. These reefs are also exposed to the outflow from the Herbert and Tully Rivers, with Dunk Island only ten kilometres from the Tully River mouth. The levels of fine sediment, nitrogen, and organic carbon are lower than regional averages. This suggests a low residence time for fine sediment at these reefs.

In March 2006 Tropical Cyclone *Larry* severely impacted Dunk Island resulting in a substantial reduction in the cover of hard corals, soft corals and macroalgae in the north and a slight decline in hard coral cover in the south (Figure 4.20). King Reef was also influenced at this time however as coral cover was already very low the disturbance was most evident in the removal of macroalgae (Figure 4.20). In 2008 only minor recovery in hard coral cover had occurred at both Dunk Island sites. No recovery was evident at King Reef.

The density of juvenile colonies tended to decline over the period 2006 to 2008 with very low densities observed at King Reef and Dunk Island south at two metres (Figure 4.21). Dunk Island north at five metres was an exception where strong *Turbinaria* recruitment was observed in 2008. The cover of macroalgae increased between 2006 and 2008 at all locations with the exception of Dunk Island north at five metres, though cover here also increased between 2007 and 2008 (Figure 4.20).

The overall assessment of status for reefs in this sub-region varied among reefs (Table 4.5). The status for Dunk Island north was positive reflecting relatively high average densities of juvenile hard corals. King Reef status was negative with high cover of macroalgae at both depths and coral cover very low and showing no signs of recovery. This is especially true at two metres where the density of juveniles is also extremely low. At Dunk Island south the high cover of macroalgae at two metres strongly influences the negative status for this community.

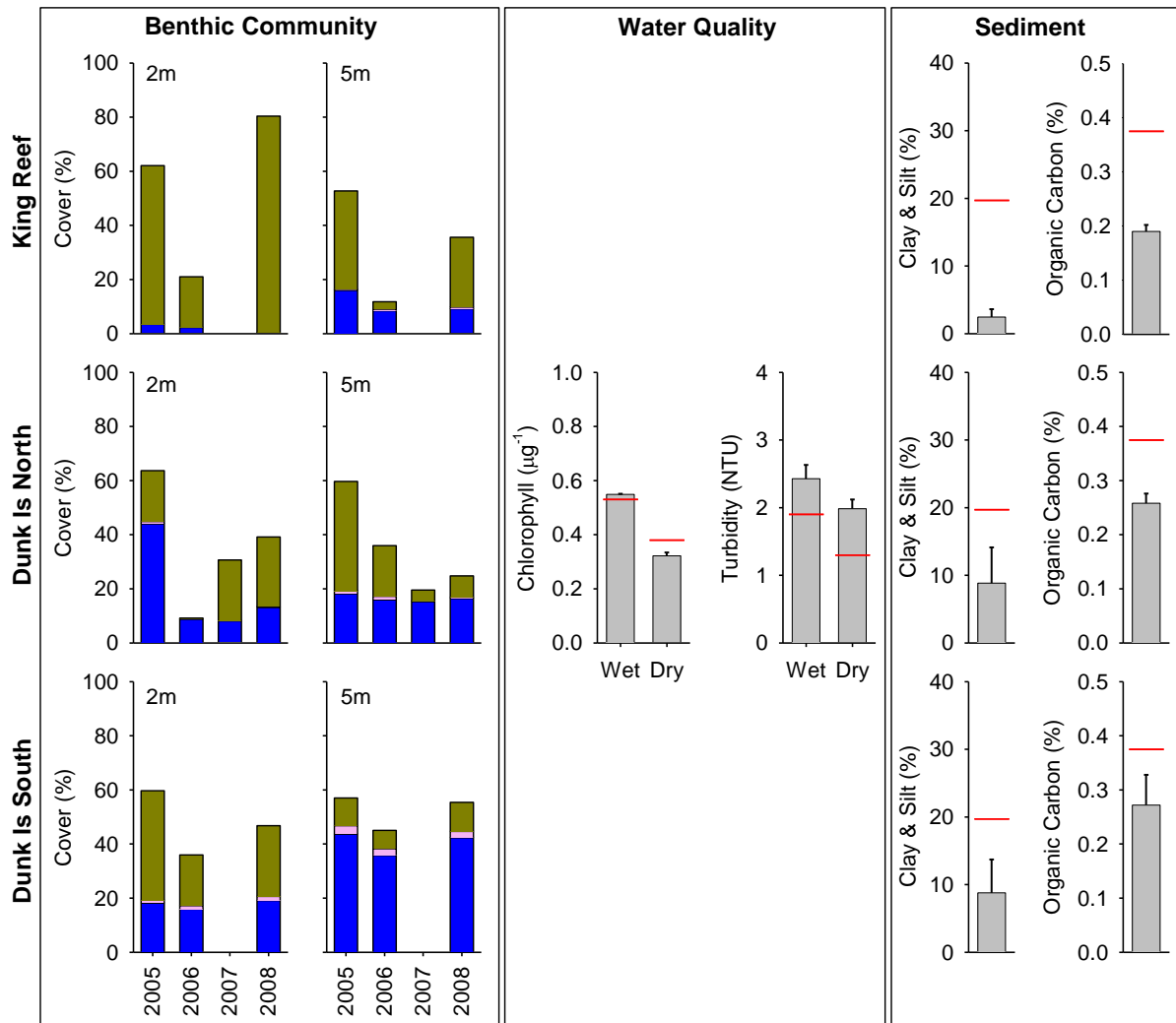


Figure 4.20: Percent cover estimates of major benthic groups: hard coral (blue), soft coral (pink) and macroalgae (green) for each sampling year and water quality and sediment quality parameters on reefs in the Herbert Tully sub-region of Wet Tropics Region. Red reference lines indicate the average values of environmental data from reef sites.

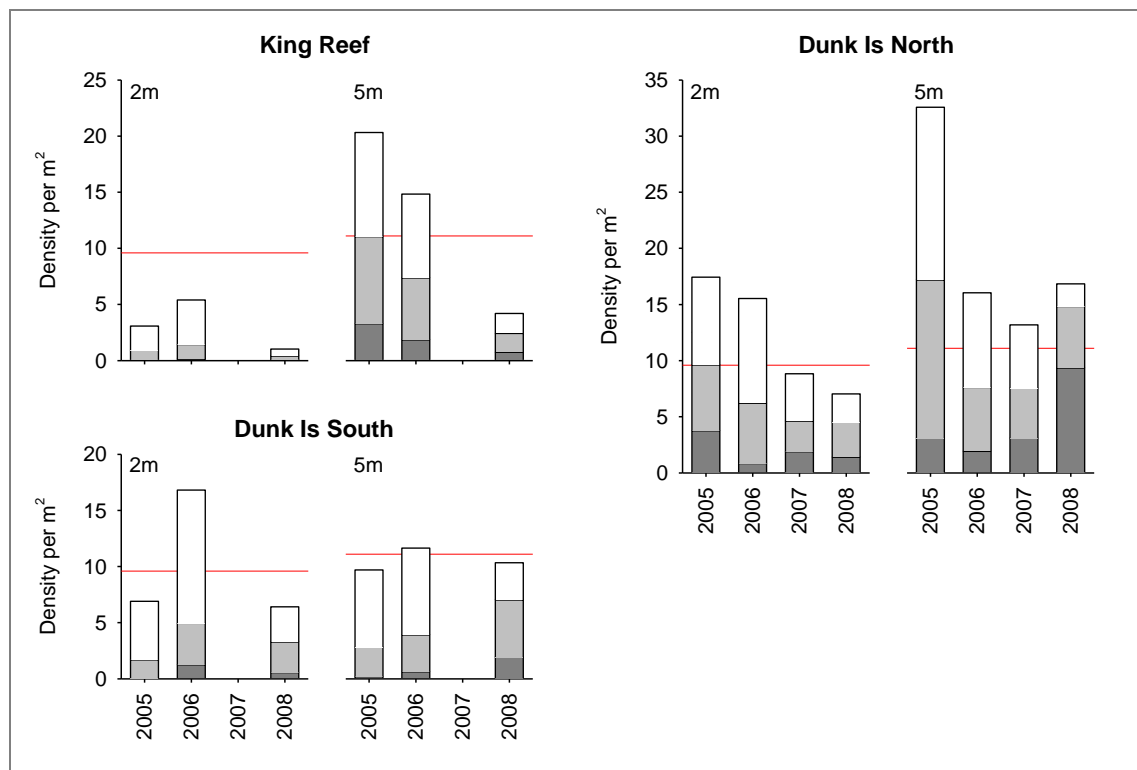


Figure 4.21: Density of juvenile hard coral colonies standardised to the area of available substrate for settlement on reefs in the Barron Daintree sub-region of the Wet Tropics. Bars are cumulative densities over the three size classes: <2 cm (dark grey), 2-5 cm (pale grey) and >5 cm to 10 cm (white). The average density over all years at each depth is indicated by the red reference line.

Table 4.5: Reef by depth estimates of coral community status of reefs in the Herbert Tully sub-region of the Wet Tropics.

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

Note: The status assessments are aggregates over three indicators: coral cover, macroalgae cover, and juvenile hard coral density (see Table 3.9 for more detail). Coral cover trend indication: u= 'up', s= 'stable', d= 'decreasing'.

4.3. Burdekin Region

Regional context and drivers

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. Because of its geographical location, rainfall in the Region is lower than other Regions within tropical Queensland, 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.

The annual river flow of the Burdekin River in 2008/2009 (October 2008 to October 2009) exceeded the long term median flow by more than five times, with peak flows recorded in February 2009 (Figure 4.22) but was only 73% of the highest flow on record in 1991.

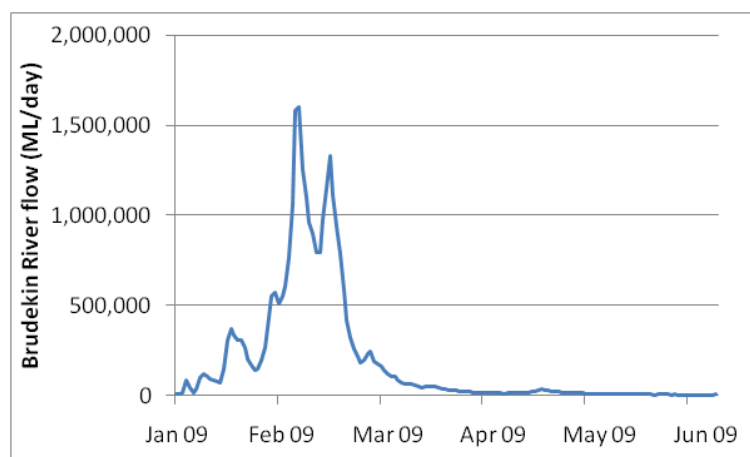


Figure 4.22: Flow rates of the Burdekin River during the wet season peak flow period within the 2008/2009 monitoring period.

In the Burdekin Region water quality, flood plumes, seagrass habitats, and coral reefs are monitored as part of the MMP. Overviews of the results of each of these areas are below.

4.3.1 Inshore water quality

Nutrients, chlorophyll and turbidity

Guideline values (see Table 3.3) were exceeded at all three locations in the Region for wet season means of chlorophyll and in both seasons for secchi depth (see Table 3.4). Geoffrey Bay, Magnetic Island generally had the highest seasonal means of all locations in this Region, and the means of all variables, except for particulate nitrogen in the wet season, exceeded Guideline values. Pelorus Island in the Palm Island Group had the lowest concentrations of all four variables and the highest secchi depth readings in the Region.

Turbidity readings were highest at Geoffrey Bay, which is closest to the Burdekin River mouth and lowest at Pelorus Island, the location furthest away. Annual and seasonal turbidity means for Geoffrey Bay were above the Guideline value for suspended solids (see Table 3.4) and 12% of daily records (October 2007 to February 2009) were above the suggested 5 NTU limit for severe coral photo-physiological stress (Cooper *et al.* 2007; 2008). Most of the turbidity maxima were associated with flood influences during the 2008 and 2009 wet seasons.

Chlorophyll Guideline values for annual and dry season means were exceeded at all sites, and wet season means were exceeded at Geoffrey Bay and Pelorus Island (Table 3.4). The instrumental data also show clear flood signals for both the 2008 and 2009 wet seasons. High values for both chlorophyll and turbidity coincide with discharge from the Burdekin River (Table 3.4). Wet season exceedances were significant in Geoffrey Bay with 66% of all daily chlorophyll records above the Guideline value during the wet season. Wet season chlorophyll values at Pandora Reef and Pelorus Island were clearly associated with flood events, however, more than half of the dry season daily records were above the chlorophyll value.

Water quality Guideline exceedances

The exceedance of the Guidelines were assessed in the Burdekin Region for chlorophyll and suspended solids (retrieved from MODIS AQUA). The annual mean values of chlorophyll exceeded the Guideline value (0.45 ug/L) in 54% of the inshore area, 1% of the midshelf and none of the offshore areas (Figure 4.23). Exceedance of suspended solids Guideline values were recorded in 65% of the inshore, 5% of the midshelf and 3% of offshore areas.

Guideline exceedances for chlorophyll and suspended solids (using non-algal particulate matter as a proxy) were calculated for dry season (winter months) data, along with the Exceedance Probability for that period. The mean and the median values of chlorophyll exceeded the Guideline values for the inshore area, and the mean and median values of suspended solids differed for all areas (Table 4.6). The mean values were approximately two times higher than the medians (mean values would be driven by flood events).

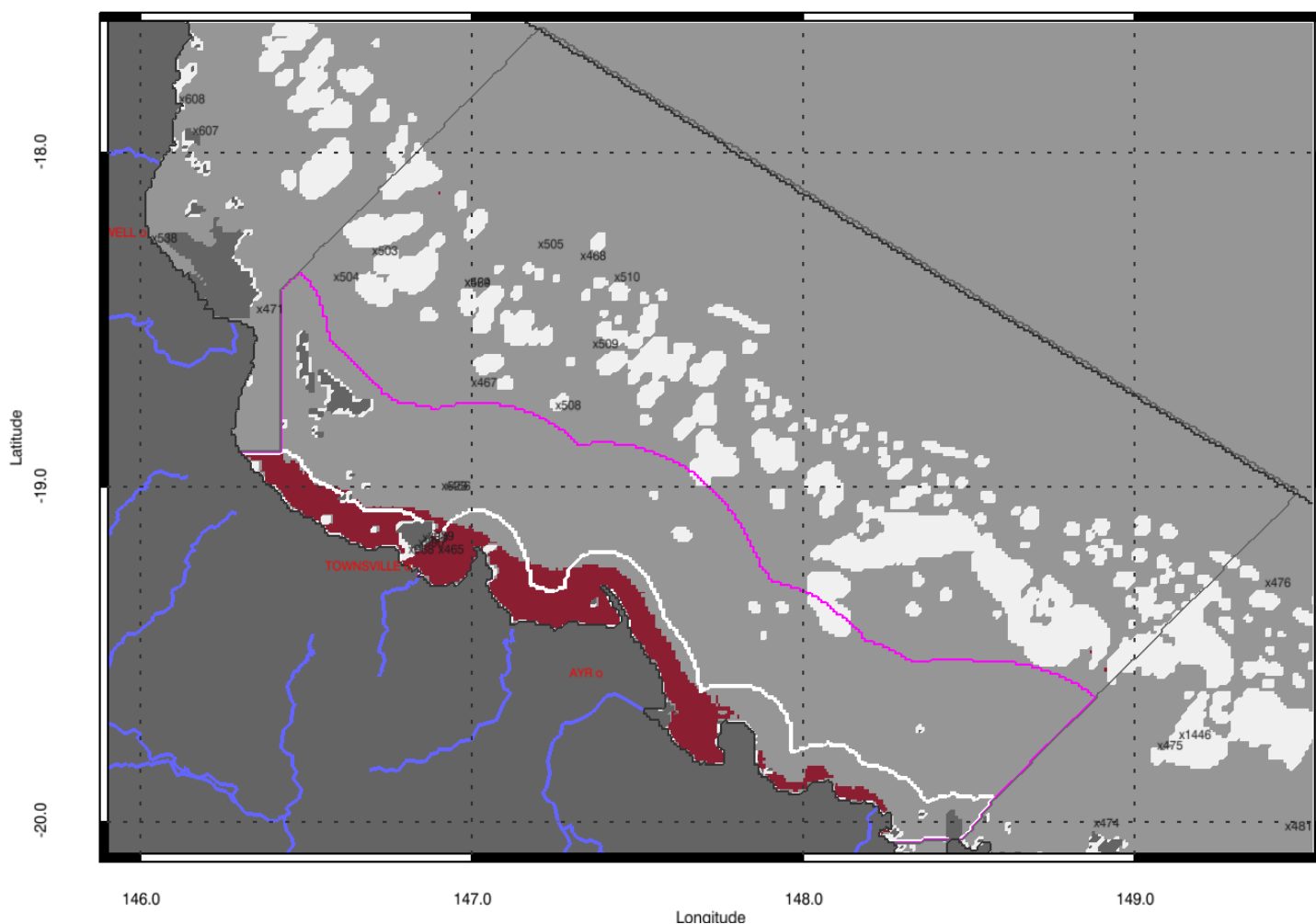


Figure 4.23: Annual mean chlorophyll exceedance map for the Burdekin Region, 1 May 2008 to 30 April 2009. Pixels are mapped in dark red when annual mean values exceed the thresholds. The white line represents Inshore boundary; pink line represents Midshelf boundary (Source: CSIRO).

Table 4.6. Summary of chlorophyll and suspended solid (using non-algal particulate matter as a proxy) exceedances for the dry season (winter months) for the Burdekin Region.

	Surface Area (km ²)	Chlorophyll (µg/L): 01-May-2008-31-Oct-2008			Suspended solids (mg/L): 01-May-2008-31-Oct-2008		
		Mean	Median	Exceedance Probability	Mean	Median	Exceedance Probability
Inshore	4463	0.648	0.480	57%	0.132	0.061	19%
Midshelf	11524	0.306	0.317	10%	0.025	0.021	0%
Offshore	32239	0.241	0.203	9%	0.025	0.021	0%

Note: Mean and Median report the mean and median concentrations calculated from all valid observations (i.e. number of cloud-free and error-free pixels – included in Brando *et al.* 2010). Exceedance Probability is the number of observations where the concentration exceeded the Guideline value divided by number of observation with (error-free) data for that period. Mean and median are presented in red and bold if they exceed the Guideline value.

Pesticide concentrations

The results for pesticide sampling in the Burdekin Region are summarised below.

Location:	Orpheus Island (7 deployments, wet and dry season)
Detections:	<ul style="list-style-type: none"> • Pesticides were detected in 5 of 7 sampling periods through the wet and dry seasons • Diuron was typically detected most commonly and at the highest concentrations – mean concentration 0.94 ng/L • Atrazine, hexazinone and tebuthiuron were also all detected in some samples • A number of other pesticides were detected in the non-polar passive samplers in one sample including phosphate tri-n-butyl, oxadiazon, propiconazole and bifenthrin but at low concentrations. The highest concentration was estimated for propiconazole at 5 ng/L.
Location:	Magnetic Island (9 deployments, wet and dry season)
Detections:	<ul style="list-style-type: none"> • Diuron was detected in all sampling periods – mean concentration 2.1 ng/L; range 1-4.4 ng/L • Atrazine (5/9 samples) and tebuthiuron (7/9 samples) were detected • The highest concentrations of both atrazine and diuron were detected early in the 2008 dry season (August/September 2008) • A number of other pesticides were detected in the non-polar passive samplers including phosphate tri-n-butyl, galaxolide, metolachlor, pendimethalin, TCP and DEET all at low concentrations. The highest concentration was estimated for DEET at 34 ng/L.
	Trends (4 years) <ul style="list-style-type: none"> • Pesticide concentrations varied between sampling periods and while the data indicated some seasonal trends these cannot be easily related to river flow, for example, the Burdekin River • No significant long term decrease in the concentration of pesticides in the water at Magnetic Island
Location:	Cape Cleveland (10 deployments, wet and dry season)
Detections:	<ul style="list-style-type: none"> • Pesticides were detected in eight of the samples • Diuron was detected most often but the concentrations of atrazine were typically higher than that of diuron, which differs from all other regions where diuron was the pesticide found at the highest mean concentrations. • The highest concentrations of both atrazine and diuron were detected in the wet season, January/February 2009. • A number of other pesticides were detected in the non-polar passive samplers including TCP, galaxolide, metolachlor, pendimethalin, phosphate tri-n-butyl and chlorpyrifos. The highest concentration was TCP at 19 ng/L during November 2008.

While the data shows differences between sites related to absolute concentrations and the specific pesticides detected, all three inshore reef sites sampled in the Burdekin Region had HEq less than 10 ng/L (Figure 4.24). There were no exceedances of the Guideline values.

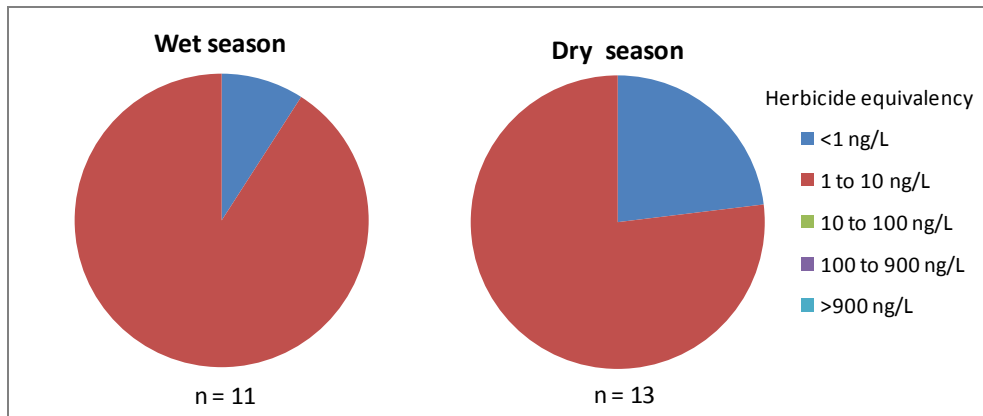


Figure 4.24: HEq index of all samples collected in Burdekin Region in wet and dry seasons 2008/2009.

4.3.2 Flood plume monitoring

Sampling

Sampling in the Burdekin River plume took place over a number of weeks at different locations within the plume (Figure 4.25). Initial sampling in February 2009 was taken at the mouth of the Burdekin River. Further sampling was undertaken around Magnetic Island and offshore sampling was undertaken along two transects out to the mid-shelf reefs in late March 2009.

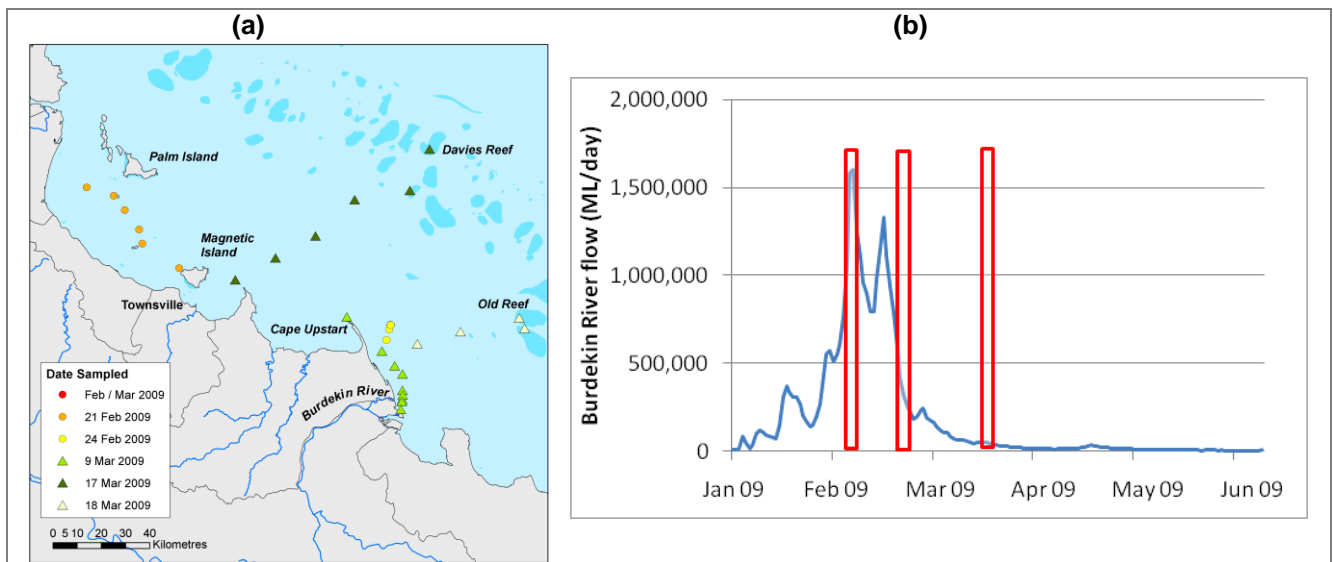


Figure 4.25: (a) Sampling sites offshore from the Burdekin River, January to March 2009; (b) Flow hydrograph for the Burdekin River in early 2009. The red boxes denote the periods of time in which sampling took place.

Water quality characteristics

Water samples collected over the wet season imply that there were long periods of time in which chlorophyll and suspended solid concentrations were elevated above wet season Guideline values. Given the sampling protocol it not possible to determine how persistent these elevated concentrations were.

During the initial stages of plume formation, there were almost 100% exceedance of all wet season Guideline values with the exception of chlorophyll. During the evolution of the plume in the 2009 event, concentrations remained high in samples measured around Magnetic Island. Later measurements in 2009 were taken further offshore and concentrations were generally below wet season Guidelines. Spatial representation of chlorophyll and suspended solid concentrations identified the areas which are most prone to high concentrations, including the zone between Magnetic Island and Palm Island (Figure 4.25a).

A total of sixteen samples (over three sampling campaigns) were collected for pesticide analysis offshore from the Burdekin River extending up to Hinchinbrook Island in the 2008/2009 wet season. There were no pesticides detected in flood plumes off the Burdekin in 2009. The very large flood event that occurred in the Burdekin River in 2009 had a total discharge of 29.5 million ML of water, most of which occurred in January-February 2009. However, residues of atrazine and tebuthiuron were detected in the Burdekin River earlier in the wet season at the 'Rocks' site (near the end-of-catchment; 13 January 2009) and at the Burdekin Falls dam (29 January 2009) and so residues of atrazine and tebuthiuron were in the plume waters during the January 2009 event flows before becoming diluted below detectable limits.

Remote sensing of flood plume extent

Burdekin River plume extent has been identified using remotely sensed images derived on 14 January 2009 (Figure 4.26). The top image illustrates the primary and secondary plume associated with the Burdekin River flood, and shows the turbid inshore plume moving north and offshore from the Burdekin mouth, almost reaching the inshore reefs (e.g. Old Reef). There is also a secondary plume visible in the left hand side of the picture, moving north. The image demonstrates clearly the large volume of high sediment water discharging from the Burdekin River. The extent of the secondary plume extended past the mid-shelf reefs and past the Palm Island group. The chlorophyll and CDOM images (lower images in Figure 4.26) were not able to identify the relevant concentrations of inshore parameters due to the high concentrations of suspended matter in the water.

Flood plume exposure

The plume exposure map for the Burdekin River (Figure 4.27) was calculated from the intersection of the plume image and type from both the aerial surveys (1996-1999) and remote sensing images (2002-2009) for the Burdekin Region. The number of reefs and seagrasses exposed to the plume waters varies from year to year, and is dependent on the type of plume. The primary extent of the Burdekin River plume is shown to regularly move past Cape Upstart. High exposure areas are identified between Cape Upstart and moving beyond Townsville, most likely to be influenced by the smaller rivers between the Burdekin River and Cleveland Bay. Medium to high exposure areas are identified offshore from the Burdekin River to past Magnetic Island. Medium to low exposure areas are identified past the Palms Island group and towards the offshore reefs.

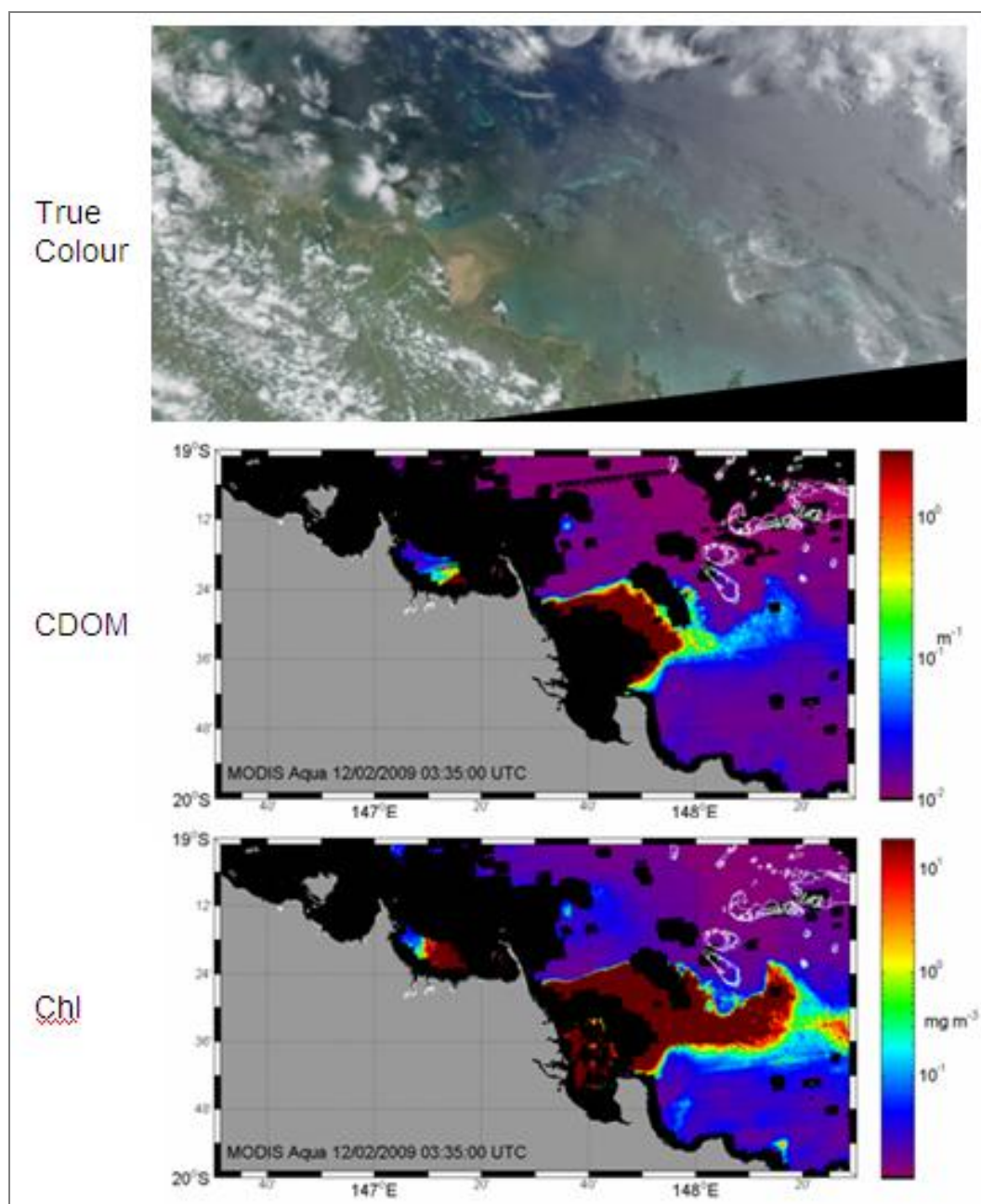


Figure 4.26: Remotely sensed images of the Burdekin River flood plume showing true colour, CDOM and chlorophyll on 14 January 2009. NASA images (Source: JCU).

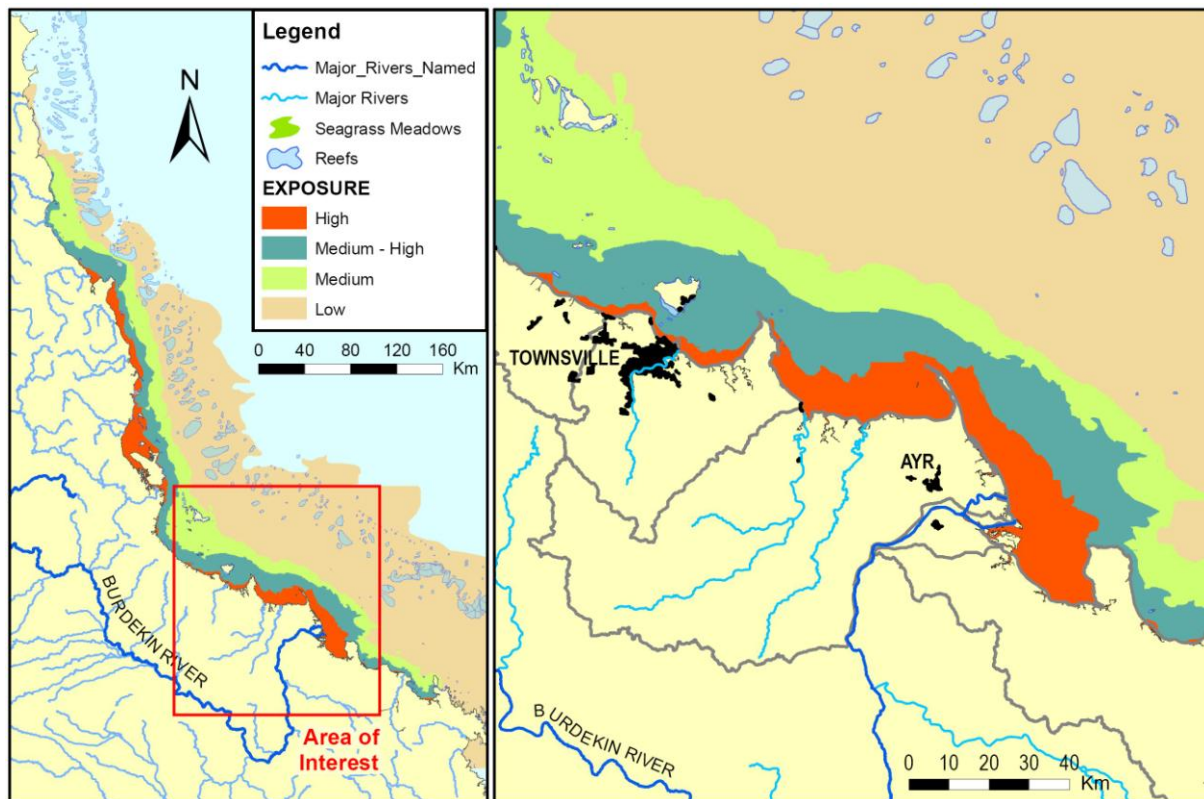


Figure 4.27: Exposure map for the Burdekin Region constructed from GIS imagery of plume extents from 1994 to 2009.

4.3.3 Inshore biological monitoring

Status of intertidal seagrass habitats

Within the Burdekin Region, coastal and reef seagrass sites are monitored at Bushland and Shelley Beaches, near Townsville, and Cackle and Picnic Bays on Magnetic Island. The monitoring area is a sediment deposition zone, so the seagrass meadow must cope with incursions of sediment carried by long shore drift. While episodic riverine delivery of freshwater nutrients and sediment is a medium time-scale factor in structuring these coastal seagrass meadows, it is the wind induced turbidity of the coastal zone that is likely to be a major short-term driver.

Key results from 2008/2009 and from comparisons of data to previous years include:

- Seagrass abundance declined at coastal habitats and was variable at reef habitats;
- Seagrass reproductive health status over the period 2006-2009 was assessed to be good at the Townsville coastal site, and variable at Magnetic Island.
- Seagrass tissues in both coastal and reef habitats had low C:N ratios, indicating a potentially low light environment. Decreasing C:N ratios at coastal sites since 2006 indicate decreasing light availability;
- Tissue C:P ratios indicate both coastal and reef habitats are nutrient rich (large P pool), with nutrient availability to the plant P limited at the coastal site and replete at the reef site, However, epiphytes declined at Townsville and was variable at Magnetic Island, following similar patterns as seagrass abundance.
- Epiphyte fouling of seagrass was highly variable at reef habitats and increased at coastal sites; and

- No pesticides were detected in sediments within seagrass meadows at locations within the Burdekin Region in 2009.

Seagrass community status

Coastal habitats: Coastal seagrass meadows at Bushland and Shelley Beaches are variable and have continued to decline in abundance since 2006, specifically, within and between years at both sites (Figure 4.28). Abundance at both sites showed strong seasonal patterns with cover high in the wet and low in the dry seasons. Both sites were dominated by *Halodule uninervis* with varying amounts of *H. ovalis*. By late in the 2009 wet season the Shelley Beach meadow was less than 35% of its baseline extent. Declines have also been observed over years at Bushland Beach, with extent in 2009 being 40% of the baseline.

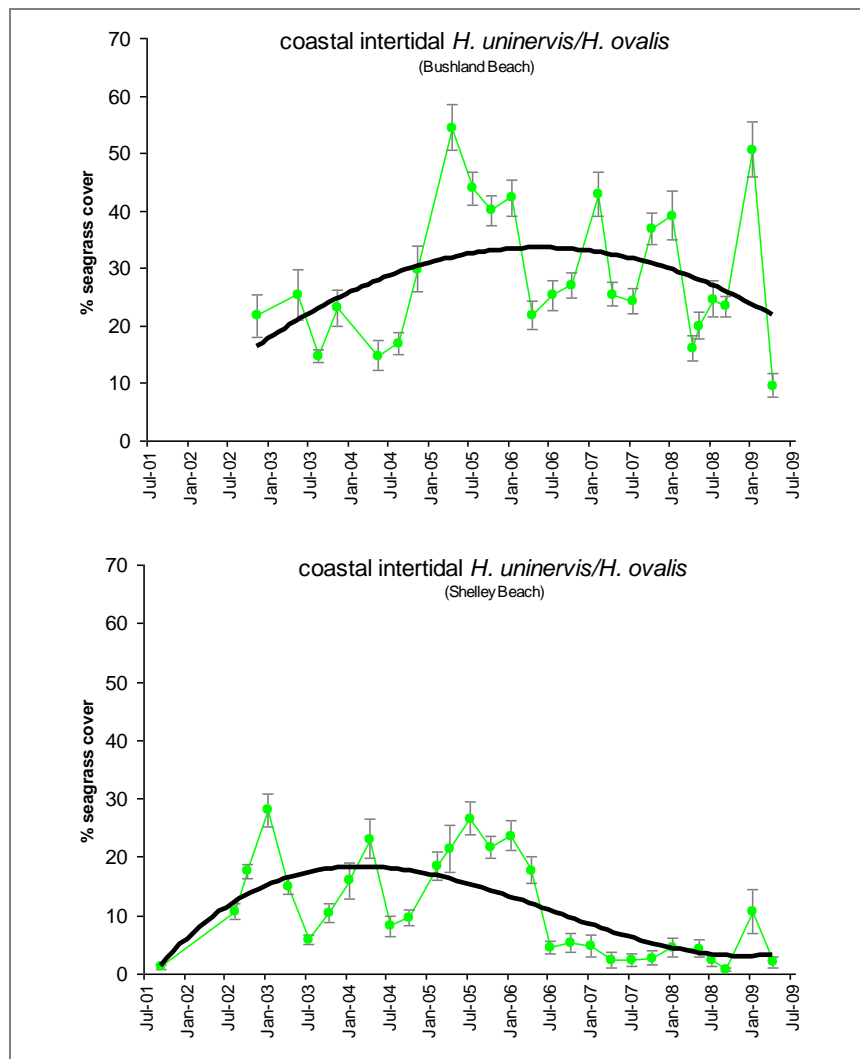


Figure 4.28: Change in seagrass abundance (percentage cover) at coastal intertidal sites in the Burdekin Region.

Reef habitats: Offshore habitats monitored in the Burdekin Region are monitored on the fringing reef flats of Magnetic Island. Over the 2008/2009 monitoring period, seagrass cover at both sites declined (Figure 4.29). Although seagrass abundance late in the 2008 dry season were similar to 2009, abundances following the 2009 wet season were significantly lower than previously reported in 2008 (Figure 4.29). Picnic Bay was dominated during this

last monitoring period by *H. uninervis* while the adjacent Cockle Bay site was dominated by *C. serrulata* / *T. hemprichii*.

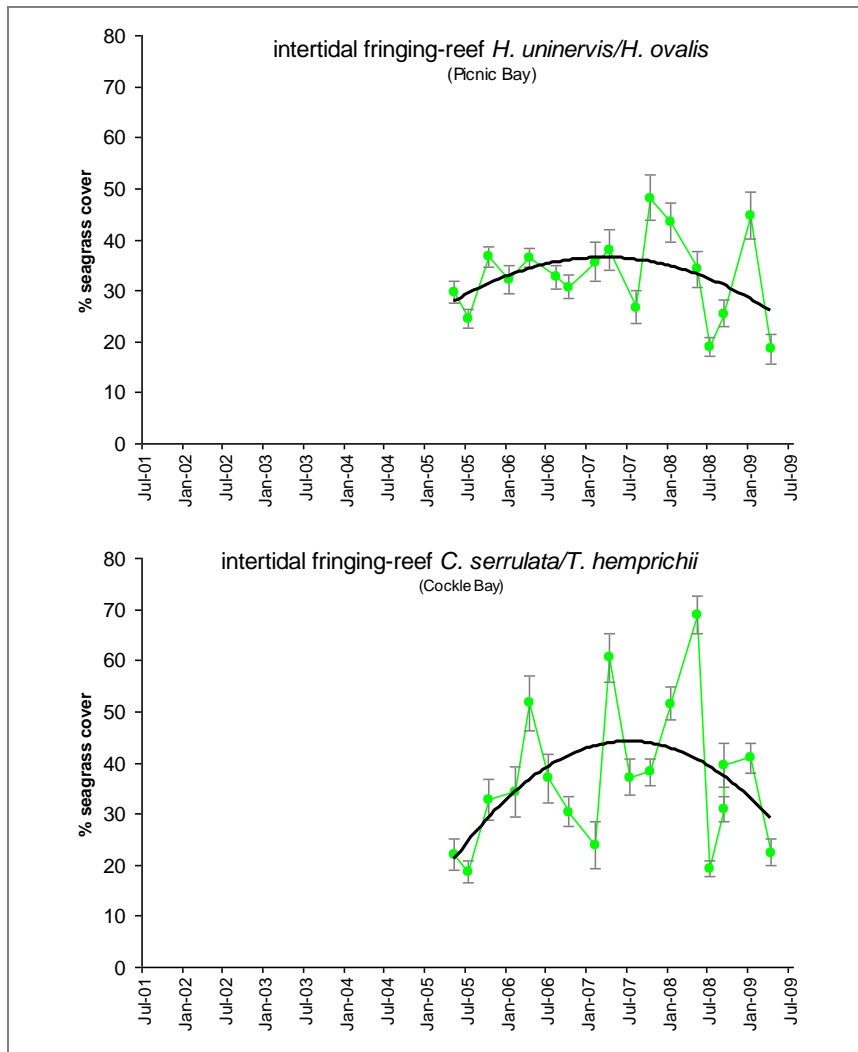


Figure 4.29: Change in seagrass abundance (percentage cover) at reef sites in the Burdekin Region.

Seagrass environment status

Light environment (indicators of light availability): Seagrass leaf tissue C:N ratios for both the coastal intertidal and offshore reef habitats were below 20 (Figure 4.30) indicating reduced light environments. At the coastal intertidal sites patterns of declining C:N since 2006 in *H. uninervis* may indicate declining light availability.

Nutrient environment: The nutrient status of the habitats at both the coastal intertidal and reef sites indicates that these locations are all nutrient rich (nutrient saturated), containing a large phosphorous pool. Also, the N:P ratio indicates that all species at Magnetic Island in 2008 are nitrogen limited (Figure 4.30).

Epiphyte cover on seagrass leaf blades at coastal sites was highly variable and is correlated with seagrass abundance. Epiphyte cover, although higher than the previous monitoring period, has continued to decline from the peaks reported in 2005. Epiphyte cover at reef sites differs greatly between sites. At Picnic Bay, epiphyte cover is generally <40%, compared to Cockle Bay where it is >50% on average. Epiphyte abundance appears to be increasing at Picnic Bay, whereas at Cockle Bay it appears to be decreasing. Macro-algae cover at coastal sites was variable and has remained low over the two sampling years. Macro-algae at Cockle Bay was predominately composed of *Halimeda* spp., however in 2008, the composition of *Hydroclathrus* spp. was increasing. There does not appear to be any clear long-term trend in macro-algae abundance.

Coral habitats

The extended period of monitoring of the reefs in this Region highlights the intense and frequent nature of disturbance to some reefs (Ayling and Ayling 2005). The largest disturbance since monitoring began in 1989 was coral bleaching in 1998, which affected all target reefs in this Region, and again in 2002, where bleaching was less severe but still affected the majority of coral communities. Cyclonic disturbances in 1990 (Tropical Cyclone *Joy*), 1996 (*Justin*) and 2000 (*Tessi*) impacted some reefs, and a large decrease in coral cover attributed to Cyclone *Tessi* may also include the effects of elevated numbers of COTS in the same year. During the period 1991-1999 flood plumes extended to most reefs in 1994, 1997 and 1998 (Devlin *et al.* 2001). Monitoring studies (Ayling and Ayling 2005; Sweatman *et al.* 2005) found no discernable direct effects of these flood plumes on the coral communities. Even though disturbance has been severe and frequent on the majority of reefs monitored in this Region, there has been some evidence of increasing coral cover between disturbances, though recovery has been slow.

Given the frequency and severity of disturbance events in this Region it is not surprising that the Regional average hard coral cover was lower and cover of macroalgae higher than all other Regions in 2005 (Figure 4.31). There were no substantial disturbances between surveys in 2005 and 2008, or substantial indications of recovery with the cover of the major benthic groups relatively stable on most reefs (Figure 4.31). The only exception was at Lady Elliot Reef where hard coral cover increased markedly between 2005 and 2008 due mostly to an increase in the cover of *Acroporidae* spp.

The density of juvenile hard coral colonies was higher at Lady Elliot Reef at two metres than at any other reef in the Region (Figure 4.32). It is proposed that the lack of recovery of the hard coral community at other reef sites is due to the extremely low densities of juvenile colonies observed (Figure 4.32).

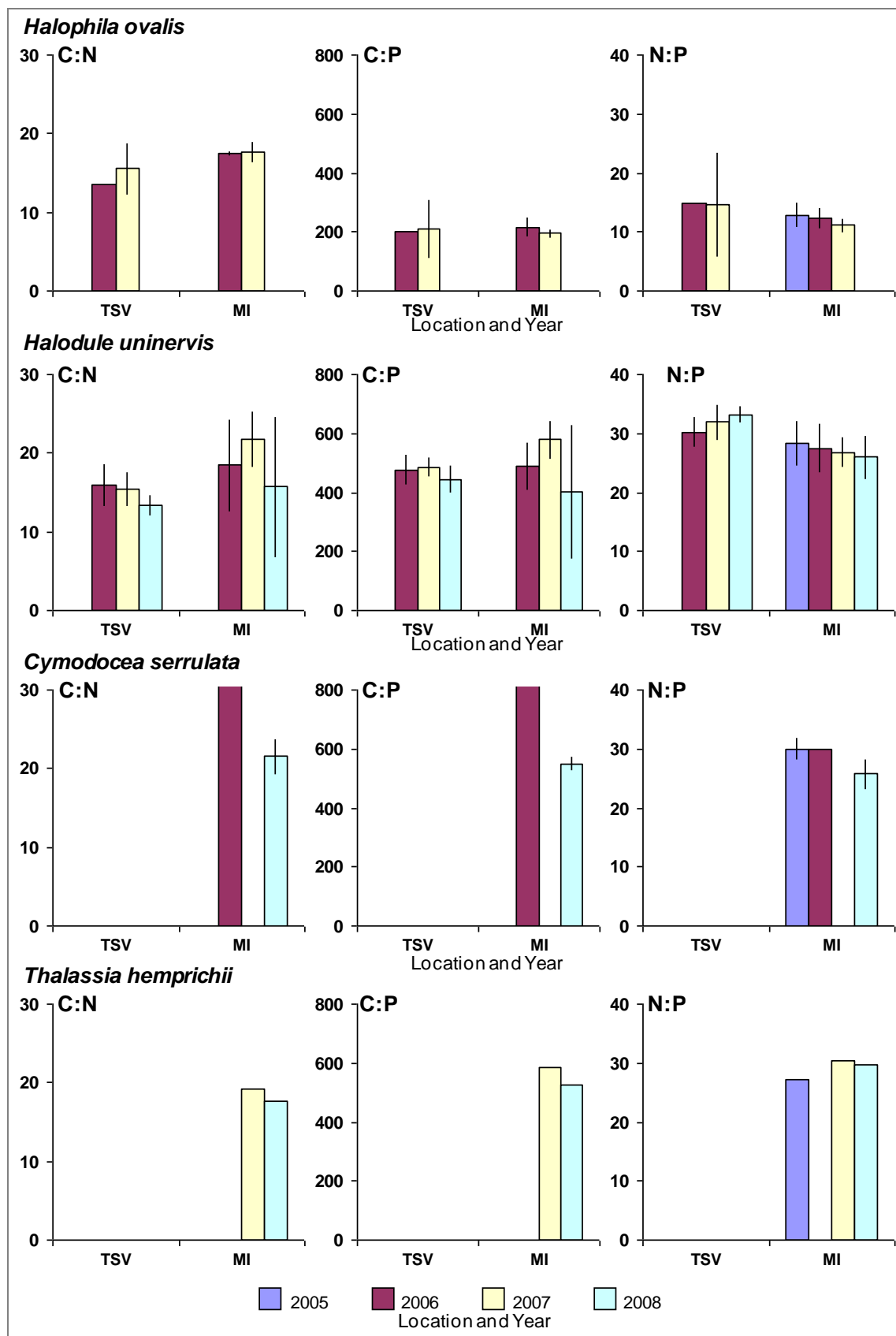


Figure 4.30: Plant tissue ratios C:N, C:P and N:P for seagrass species in the Burdekin Region. TSV=Townsville, MI=Magnetic Island (mean and SD displayed).

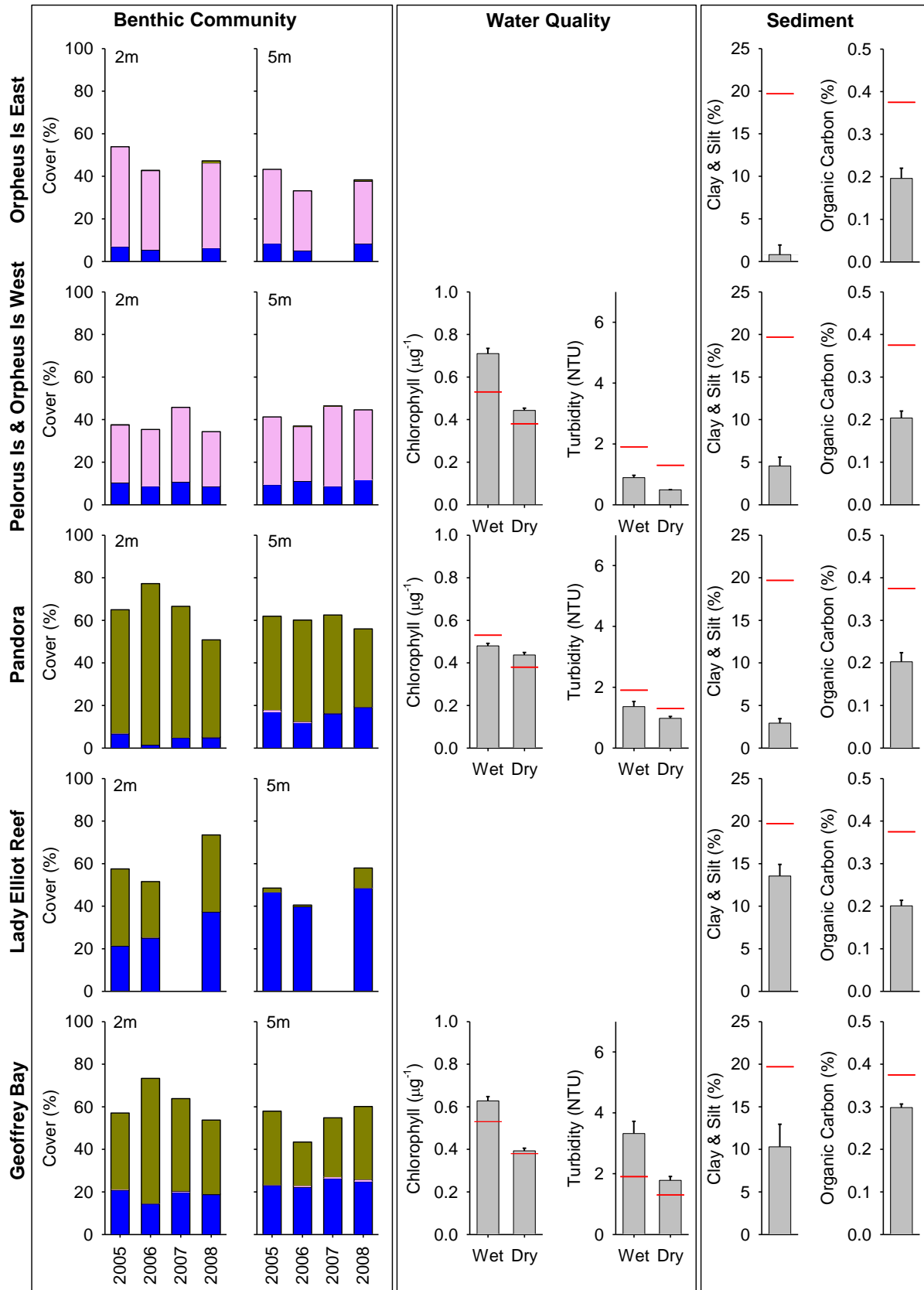


Figure 4.31: Percent cover estimates of major benthic groups: hard coral (blue), soft coral (pink) and macroalgae (green) for each sampling year and water quality and sediment quality parameters on reefs in the Burdekin Region. Red reference lines indicate the average density at each depth over all years from all reefs and Regions.

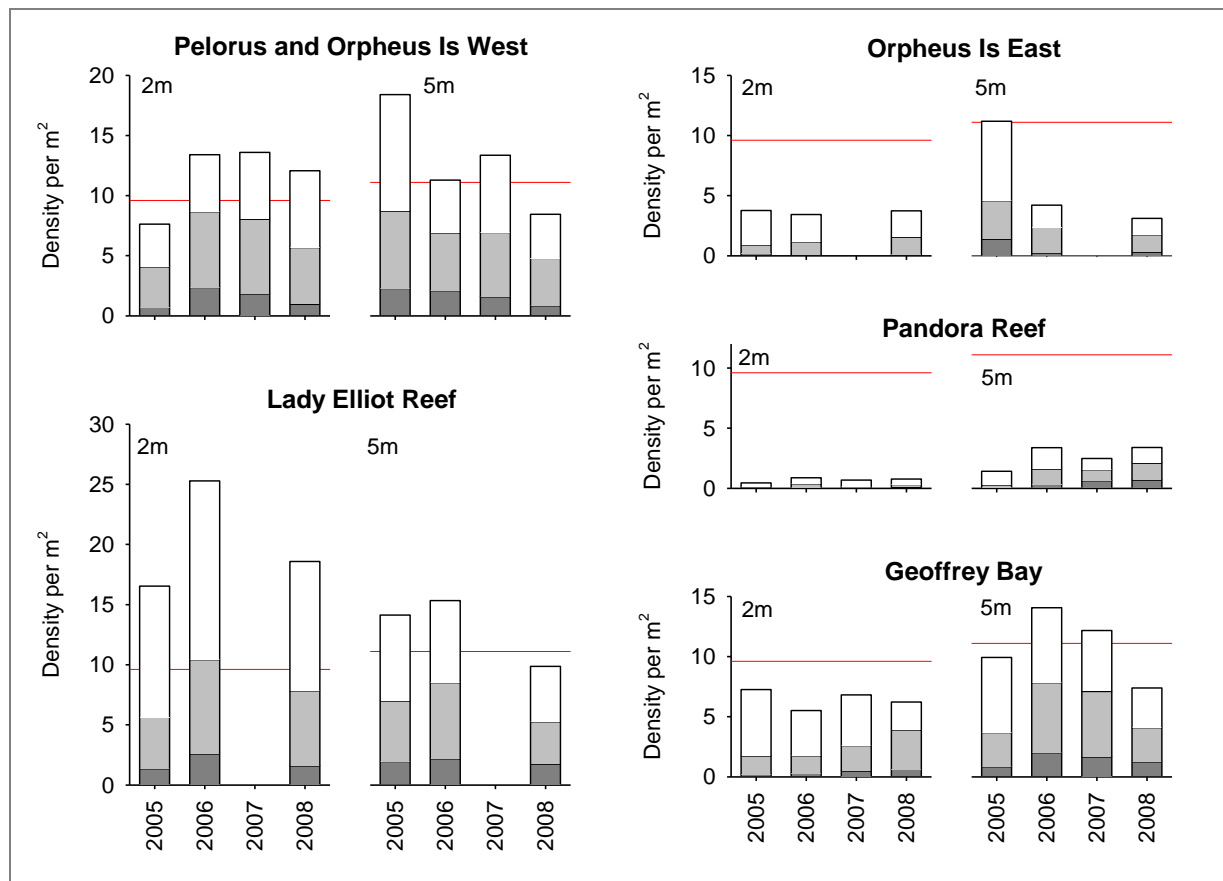


Figure 4.32: Density of juvenile hard coral colonies standardised to the area of available substrate for settlement on reefs in the Burdekin Region. Bars are cumulative densities over the three size classes: <2 cm (dark grey), 2-5 cm (pale grey) and >5 cm to 10 cm (white). The average density over all years at each depth is indicated by the red reference line.

The overall assessment of coral community status for reefs in this Region was lower than for the Wet Tropics Region to the north and the Whitsunday sub-Region to the south (Table 4.7). The communities at Geoffrey Bay and Pandora Reef scored very poorly with high cover of macroalgae, low coral recruitment and evidence of increases in cover despite a lack of disturbance; all indicating poor community status. Status at Orpheus Island east is ambiguous and while the overall combined cover of hard and soft corals is moderately high, there has been no evidence of growth over the period 2005-2008. Macroalgal cover is very low, but there were also extremely low densities of coral recruits. Pelorus Island and Orpheus Island west had higher densities of hard coral juveniles especially at two metres. For Lady Elliot Reef, status was positive at two metres where increasing coral cover and high density of juvenile colonies outweighed the negative influence of high macroalgal cover. At five metres the moderately high and stable coral cover, above average density of juvenile colonies and more moderate cover of macroalgae also led to a positive community status.

Table 4.7: Reef by depth estimates of coral community status of reefs in the Burdekin Region.

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

Note: The status assessments are aggregates over three indicators: coral cover, macroalgae cover, and juvenile hard coral density (see Table 3.9 for more detail). Coral cover trend indication: u = 'up', s = 'stable', d = 'decreasing'.

4.4. Mackay Whitsunday Region

Regional context and drivers

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.

The annual river flow of all of the Mackay Whitsunday rivers in 2008/2009 (October 2008 to October 2009) slightly exceeded the long term median annual flow (Table 3.2). In particular the Proserpine River flows were 1.77 times the long term median annual flow, and the Plane Creek flows were 1.67 times the long term median annual flow.

In the Mackay Whitsunday Region water quality, flood plumes, seagrass habitats, and coral reefs are monitored as part of the MMP. Overviews of these results are below.

4.4.1 Inshore water quality

The main sources of sediments to the Mackay Whitsunday Region are the Proserpine and O'Connell Rivers. These catchments have heavy rainfall and altered land use and, importantly, reefs in this area are considered to be at high risk from agricultural runoff (Brodie and Furnas 2001). The group of reefs studied here have the highest levels of clay/silt, nitrogen and organic carbon in sediments across all Regions (Figure 4.37). Further, levels of inorganic carbon, associated with reefal deposits, are the lowest among catchments and years. This suggests that a high proportion of fine terrigenous material is present and that the residence time for these clay/silt deposits is much longer than in other catchments.

Nutrients, chlorophyll and turbidity

Guideline values were exceeded at all three sampling locations for dry season means of chlorophyll and wet and dry season secchi depth (see Table 3.4) except for Daydream Island in the wet season. Chlorophyll values for wet season means were also exceeded at Pine Island. Between 65 and 100% of dry season chlorophyll values were above the Guideline value, which is higher than in any other Region monitored. Suspended solid means exceeded dry season Guideline values at both Daydream and Pine Islands.

Of the locations in this Region, Pine Island generally had the highest seasonal means for all variables, followed by Daydream Island. Double Cone Island generally had lower values, which is not surprising as this monitoring location is furthest away from the mainland coast and the influence of rivers. The instrumental readings confirm the clear gradient of locations away from riverine influence. Concentrations of chlorophyll and turbidity values were highest at Pine Island and lowest at Double Cone Island.

During the 2008/2009 wet season, most recorded turbidity maxima were associated with flood influences. However, the turbidity records show a regularity that implies a strong tidal influence and high turbidity values are associated with the summer king tides, especially at Pine and Daydream islands (Schaffelke *et al.* 2009b).

Water Quality Guideline exceedances

The exceedance of Guideline values were assessed in the Mackay Whitsunday Region for chlorophyll and suspended solids (retrieved from MODIS AQUA). The annual mean values of chlorophyll exceeded the Guideline value (0.45 µg/L) for 24% of the inshore area, 3% of the midshelf and none of the offshore areas (Figure 4.33). Exceedance of suspended solids Guideline values were recorded in 35% of the inshore, 2% of the midshelf and 0% of offshore areas.

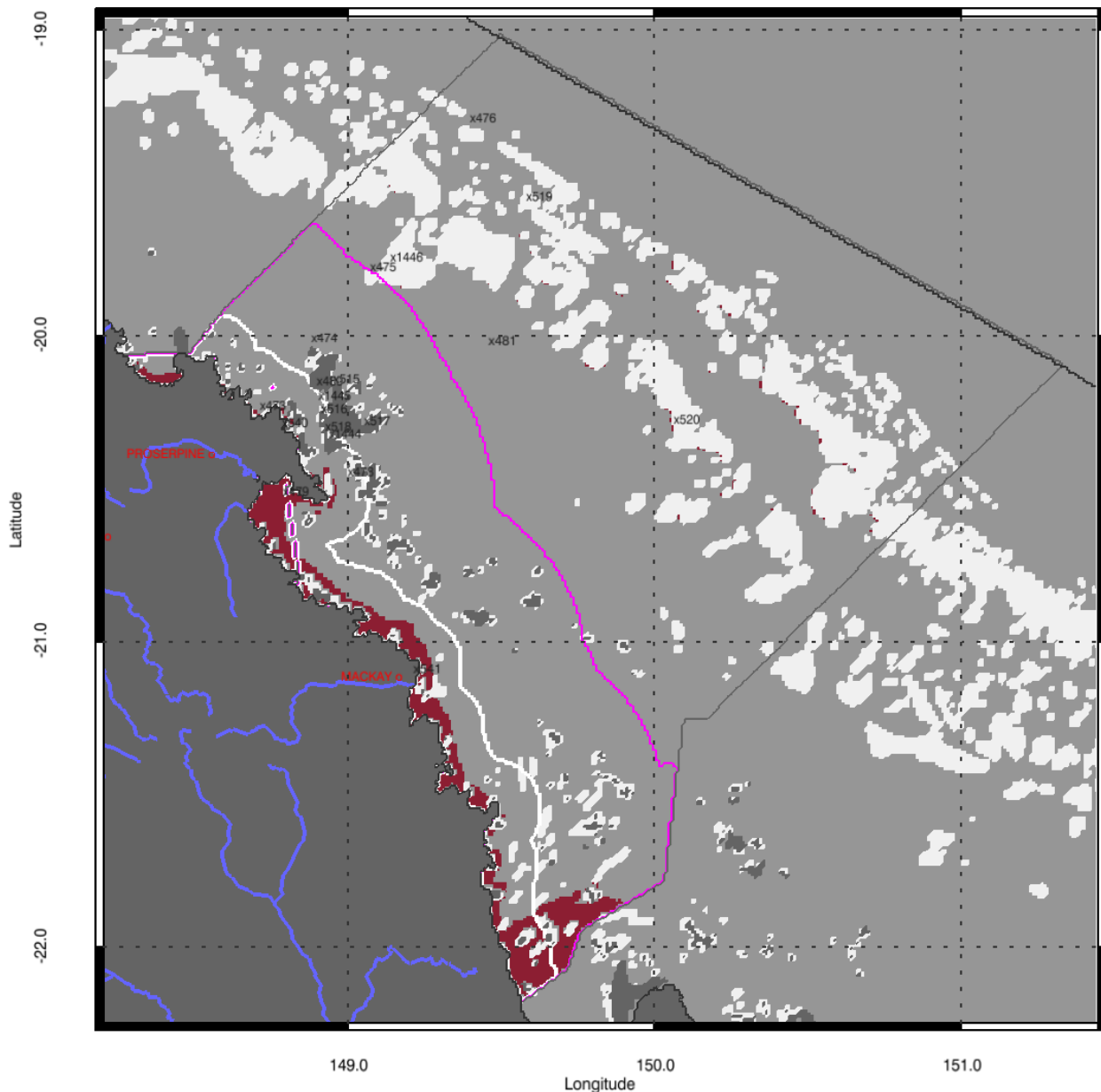


Figure 4.33: Annual mean chlorophyll exceedance map for the Mackay Whitsunday Region, 1 May 2008 to 30 April 2009. Pixels are mapped in dark red when annual mean values exceed the threshold. The white line represents Inshore boundary; pink line represents Midshelf boundary (Source: CSIRO).

Guideline exceedances for chlorophyll and suspended solids (using non-algal particulate matter as a proxy) were calculated for dry season (winter months) data, along with the Exceedance Probability for that period. The mean and the median values of chlorophyll did not exceed the Guideline values, and the mean values of suspended solids exceeded the Guideline values for the inshore, midshelf and offshore areas (Table 4.8). The mean and median values for the suspended solids concentration differed substantially for all areas. The mean values were two to three times higher than the medians.

Table 4.8: Summary of chlorophyll and suspended solid (using non-algal particulate matter as a proxy) Guideline exceedances for the dry season (winter months) in the Mackay Whitsunday Region.

	Surface Area (km ²)	Chlorophyll (µg/L): 01-May-2008-31-Oct-2008			Suspended solids (mg/L): 01-May-2008-31-Oct-2008		
		Mean	Median	Exceedance Probability	Mean	Median	Exceedance Probability
Inshore	5761	0.45	0.40	35%	3.73	1.73	42%
Midshelf	12869	0.30	0.30	10%	2.68	1.03	33%
Offshore	32396	0.30	0.25	21%	1.17	0.34	33%

Note: Mean and Median report the mean and median concentrations calculated from all valid observations (i.e. number of cloud-free and error-free pixels – included in Brando *et al.* 2010). Exceedance Probability is the number of observations where the concentration exceeded the Guideline value divided by number of observation with (error-free) data for that period. Mean and median are presented in red and bold if they exceed the Guideline value.

Pesticide concentrations

Routine pesticide monitoring of the Pioneer River (end of catchment site) detected a broad range of pesticides using passive samplers for polar chemicals detected a broad range of pesticides. Highest concentrations were atrazine and diuron, followed by hexazinone, ametryn, flumeturon, tebuthiuron, simazine and prometryn. The concentrations of atrazine, diuron and hexazinone varied over a large range and were on several occasions close to, or in excess, of 1,000 ng/L. The maximum monthly concentrations were similar to the 'event mean concentrations' calculated by Lewis *et al.* (2009) for the Pioneer River for diuron and hexazinone in the 2004/2005 and 2005/2006 wet seasons.

A range of other pesticides were detected in non-polar passive samplers including chlorpyrifos, chlorfenvinphos, diazinon, dieldrin, galaxolide, metolachlor, pendimethalin, phosphate tri-n-butyl, propazine, propiconazole, TCP, terbutryn and trifluralin (concentrations are presented in Paxman *et al.* 2009). It should be noted that the concentration of diazinon exceeded the Guideline value for this pesticide by two orders of magnitude.

The HEq concentration of the Pioneer River end of catchment samples collected in 2008/2009 range from 10-100 ng/L in 2008 through to >900 ng/L in January 2009 and 100-900 ng/L in February and March 2009. The suggested overall index is 100-900 ng/L.

Event sampling for the Pioneer River estimated monthly maximum diuron and atrazine concentrations up to 1,600 ng/L and 1,400 ng/L respectively from samplers deployed prior to the first main wet season event. Interestingly the concentrations during the event obtained using both event passive samplers, baseline passive samplers and limited grab samples were substantially lower at 136 ng/L and 101 ng/L for diuron and atrazine respectively,

although this monitoring was undertaken later in the wet season and potentially at an extended period of time after pesticide application which typically occurs earlier in the season.

The results for pesticide sampling in the Mackay Whitsunday Region are summarised below.

Location:	Inner Whitsundays (3 deployments, wet and dry season)
Detections:	<ul style="list-style-type: none"> • Diuron was detected in all samples – mean concentration 44.7 ng/L. • Atrazine, desethyl atrazine and hexazinone were also detected in low concentrations in 2 samples and tebuthiuron was detected once. • Atrazine, hexazinone and tebuthiuron were also all detected in some samples • There was a notable outlier in the data with a mean predicted diuron concentration of 120 ng/L during the August/September 2009 period. As the blank for this period showed no contamination and no other pesticides except atrazine were detected in this sample, it is suggested that some form of contamination of the sample or the site through a point source (potentially antifoulant) has occurred.
Location:	Outer Whitsundays (3 deployments, wet and dry season)
Detections:	<ul style="list-style-type: none"> • Diuron, atrazine and tebuthiuron were detected in two samples. • The concentrations of atrazine were typically higher than those of diuron, which is not usual at other sites. • A maximum concentration of 4.1 ng/L was estimated for tebuthiuron. • Galaxolide and TCPD were detected in the non-polar passive samplers in the wet season.
	Trends (4 years)
	<ul style="list-style-type: none"> • Data show relatively variable results with a potential indication of a decrease in the concentration over the three year monitoring period.

Most of the reef sites sampled in the Mackay Whitsunday Region had HEq in the range 1-10 ng/L (Figure 4.34), and despite there being an uncharacteristically high diuron concentration at the Inner Whitsunday site there were no exceedances of the Guideline values.

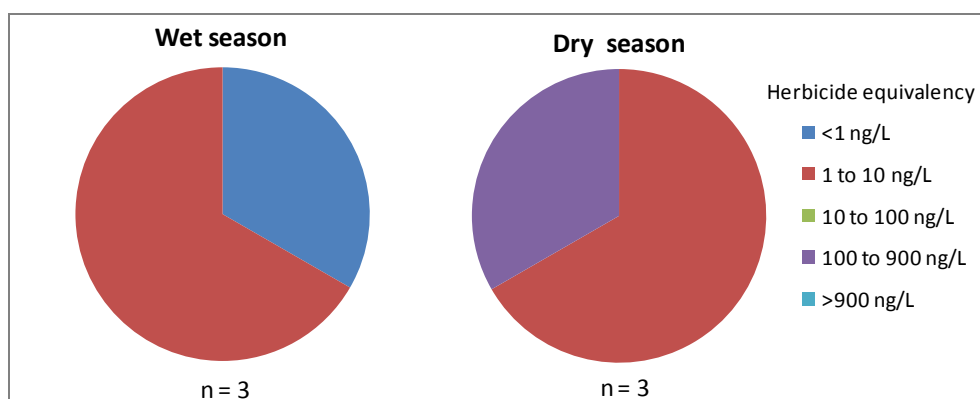


Figure 4.34: HEq index of all samples collected in Mackay Whitsunday Region in wet and dry seasons 2008/2009.

4.4.2 Flood plume monitoring

Water sampling was undertaken in plume waters from the O'Connell River prior to wet season flow but no detailed information is available on water quality characteristics in flood plumes in the Mackay Whitsunday Region throughout the season as efforts to monitor plumes in the 2008/2009 sampling period focused on the Burdekin and Tully Rivers.

A limited campaign of pesticide sampling was conducted in the Region over the 2008/2009 wet season. A small 'first flush' flow event was sampled offshore from the O'Connell River (six samples) through to the Whitsunday Islands on 17 January 2009. Pesticides were detected in the plume waters with the highest concentrations found near the mouth of the O'Connell River: diuron 0.15 µg/L, atrazine (0.06 µg/L) and hexazinone (0.4 µg/L). Detectable levels of pesticides (0.01 µg/L diuron) reached Cape Conway during this event. The pesticides displayed a conservative mixing trend as the river waters became mixed with seawater. Concentrations of these pesticides off the O'Connell River mouth were consistent with previous years. Further detail of this sampling is provided in Devlin *et al.* 2009.

An additional five samples were collected in the Whitsunday Islands (19-20 February 2009) and pesticides were detected at offshore sites, with diuron (0.01 µg/L) detected at Edward Island and bromacil (0.02 µg/L) detected at Deloraine Island. No pesticide residues were detected at the inshore sites which included Daydream, Pine and Double Cone Islands. The pesticides detected at the sites further offshore are probably sourced to local runoff or potentially sourced to anti-fouling paints on boats.

The Pioneer River had a minor flow event that was sampled for flow and pesticide concentrations and one set of passive samplers were deployed in the Pioneer River (7-13 March 2009). A range of polar pesticides were quantified with diuron and atrazine dominating the pesticide profile, followed by hexazinone, and ametryn. Overall the water concentration of pesticides tended to decrease during the monitoring period, although the concentration of diuron in the water fluctuated significantly. Decreasing levels of phosphate tri-n-butyl were detected in co-deployed non-polar passive samplers throughout the flow event. As expected, pesticide levels were markedly higher in the Pioneer River mouth than at inshore reef sites, which is consistent with previous data.

4.4.3 Inshore biological monitoring

Status of intertidal seagrass habitats

Estuarine seagrass monitoring is in Sarina Inlet, and meadows are typically intertidal on the large sand/mud banks of sheltered estuaries. Every year, seagrass in this habitat must cope with extremes of flow and associated sediment and freshwater loads from December to April when eighty percent of the annual discharge occurs. Monitoring of intertidal coastal seagrass habitats is undertaken on the sand/mud flats adjacent to Cannonvale in southern Pioneer Bay. Potential impacts to these habitats are declines in water quality associated with urban activity, marina development and agricultural land use. Reef habitat seagrass meadows are monitored at Hamilton Island. Habitat drivers for reef seagrass meadows in the Region are exposure to air, and desiccation. Major threats include physical damage or removal due to increased tourism activities and coastal developments, such as marinas.

Key results from 2008/2009 and from comparisons with data from previous years include:

- Coastal and estuarine intertidal seagrass abundance has been variable over time and has continued to decline at the reef location in this Region;
- Seagrass reproductive health status was variable over the period 2006-2009. In 2008/2009, seed counts declined from previous years at the Pioneer Bay (coastal) and Sarina Inlet (estuarine) site;

- Seagrass tissue ratios of C:N indicate that all sites were low light environments, and levels were at their lowest since measurement commenced in 2006;
- All habitats were nutrient rich (large P pool). Nutrient availability to the plant was N limited at the Pioneer Bay site and replete at the estuarine and reef sites. Although sediment nutrient data was generally highly variable, levels found at reef and coastal sites were high, particularly for sediment P which was the highest of any GBR site indicating a potential issue of nutrient enrichment in the Region;
- Epiphyte cover on seagrass leaf blades was highly variable at inshore coastal and estuarine sites and appears seasonal, with higher abundance in the dry season. Epiphyte cover declined at the reef habitat sites over the monitoring period; and
- No pesticides were detected in the seagrass meadow sediments in 2009.

Seagrass community status

Coastal habitats: The meadows were dominated by *Halodule uninervis* and *Zostera capricorni* mixed with *Halophila ovalis*. Seagrass abundance has fluctuated at the coastal sites between and within years (Figure 4.35) though there is no consistent trend.

Estuarine habitats

This habitat is dominated by *Zostera capricorni* with some *Halophila ovalis*. Seagrass cover late in the 2009 wet season was similar to cover recorded in previous monitoring periods for the same time of year (Figure 4.35). There is insufficient data across months within years to determine whether seasonal patterns exist but seagrass abundance appears to be greater at the estuarine sites late in the dry season than late in the wet season.

Reef habitats

These sites are dominated by *Halodule uninervis* with some *Halophila ovalis*. Seagrass cover has continued to decline at the Hamilton Island site since monitoring began (Figure 4.35). The declines in seagrass abundance appear predominantly the result of declining meadow extent through 2008 and 2009.

Seagrass environment status

Light environment (indicators of light availability): Seagrass tissue C:N ratios in the Mackay Whitsunday Region have mostly declined since 2007 (Figure 4.36) indicating a reduction in light availability. Levels of C:N were at their lowest since measurement commenced in 2006.

Nutrient environment: The C:P ratios of seagrass at all sites were mostly lower in 2008 than in previous years indicating a larger phosphorous pool and nutrient enrichment (Figure 4.36). N:P ratios showed no consistent trend between sites and no significant differences were observed. However, in 2008, nutrient availability to the plant was N limited at the Pioneer Bay site and replete at the estuarine and reef sites (Figure 4.36). Although sediment nutrient data was generally highly variable, levels found at reef and coastal sites were high, particularly for sediment phosphorus which was the highest of any GBR site indicating a potential issue of nutrient enrichment in the Region.

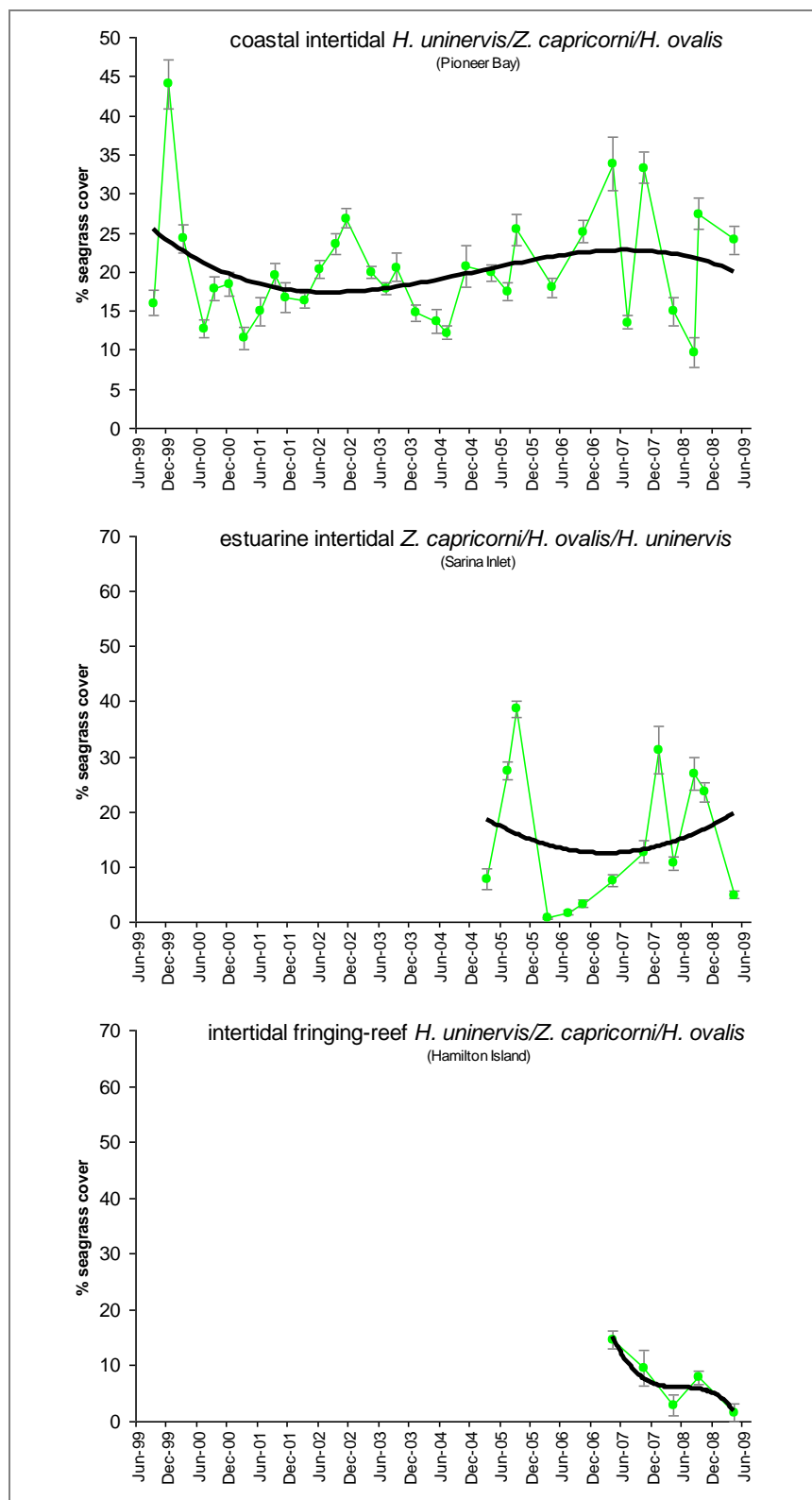


Figure 4.35: Change in seagrass abundance (percent cover) within the Mackay Whitsunday Region.

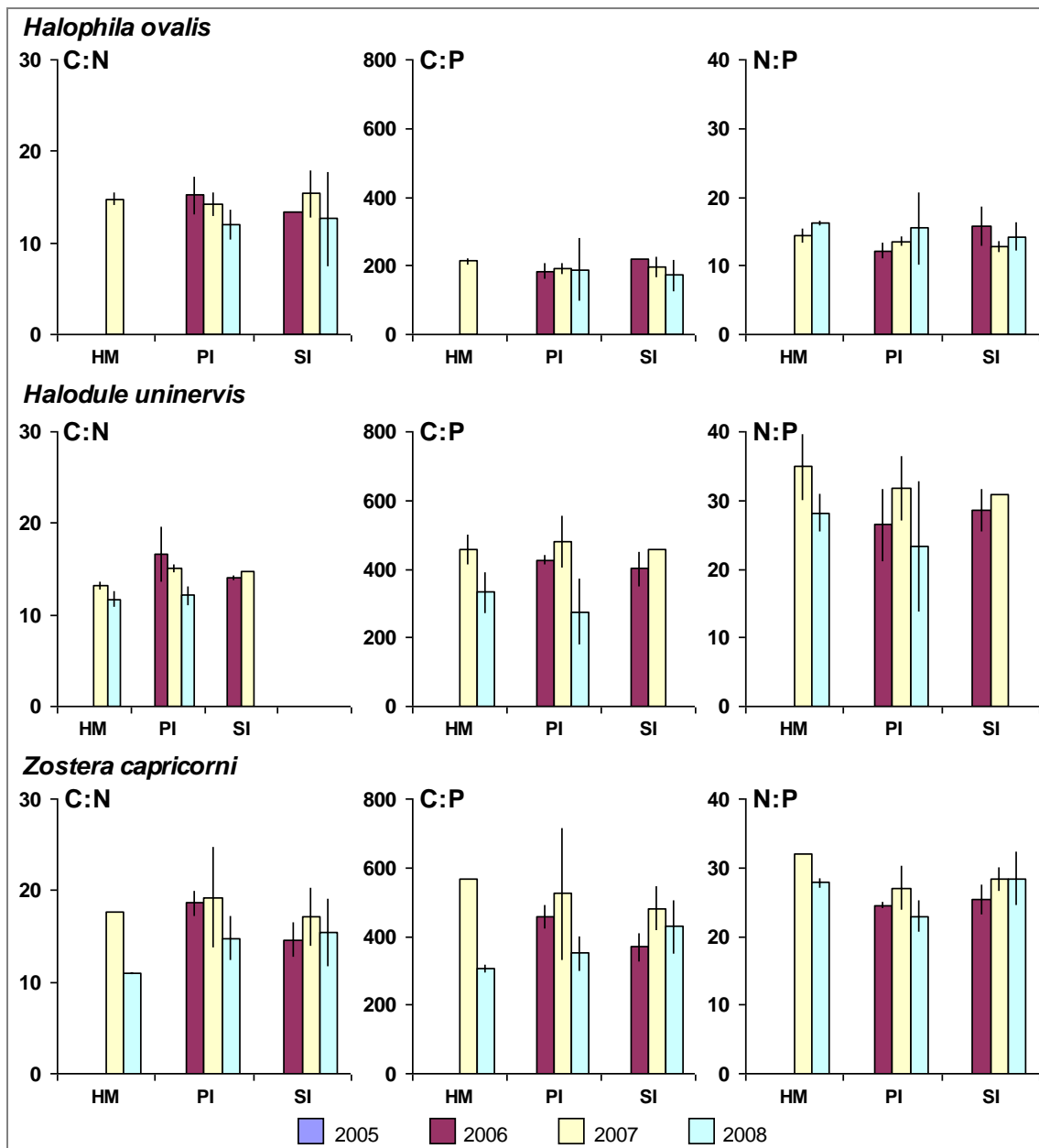


Figure 4.36: Plant tissue ratios for seagrass species in the Mackay Whitsunday Region. HM=Hamilton Island marina, PI=Pioneer Bay Inlet, SI=Sarina Inlet (mean and SD displayed).

Epiphyte cover on seagrass leaf blades was highly variable at inshore coastal and estuarine sites and appears seasonal, with higher abundance in the dry season. Cover in 2008/2009 was similar to the previous monitoring period at the coastal sites, but significantly higher at the estuarine sites. Epiphyte cover declined at the reef habitat sites over the monitoring period. Percentage cover of macro-algae at coastal sites is variable and significantly higher than estuarine or reef habitat sites. Over the monitoring period, macro-algae abundance has declined at coastal sites.

Coral habitats

The Whitsunday inshore reef sites are steep-sloped and relatively sheltered by the surrounding continental islands. The influence of the sediment environment is significant in this catchment, and, as it changes with increasing exposure and/or light levels northward to Double Cone Island, so the dominance of functional coral groups changes. Pine Island, the

reef site closest to the rivers, has a diverse coral community of sediment-tolerant corals (e.g. *Turbinaria* sp.), reflecting lower light levels and higher turbidity, particularly at five metres. This is in contrast to the other reef sites in the catchment, where coral communities are dominated by either Acroporidae (Daydream Island) or Poritidae families (Double Cone Island).

Between 2005 and 2008 there were no major acute disturbances to the reefs in this Region. The coral community has remained relatively stable over the sampling period with slight increases at Double Cone, Shute and Tancred Islands (two metres), and at both depths at Pine Island (Figure 4.37). Conversely cover of hard corals at Daydream Island decreased in 2008 (Figure 4.37). Observed changes in hard coral cover are mostly accounted for by changes in the family Acroporidae (Figure 4.37).

There were no substantial changes to the cover of either soft corals or macroalgae over the period 2005-2008 (Figure 4.37). The cover of macroalgae has remained consistently low on all reefs with the exception of Pine Island (two metres). As with other Regions, the presence of persistent macroalgal communities occurs on reefs with annual mean chlorophyll levels at or above the Guideline value, with the exception of Double Cone Island where chlorophyll levels are above this threshold but macroalgae are largely absent.

The density of juvenile colonies over the period 2005 to 2008 has declined from moderate levels in 2005-2006 to low levels in 2008 (Figure 4.38). The obvious exception to this was Shute and Tancred Islands where the density of hard coral juveniles has been consistently high. Despite this regionally high density of juvenile colonies cover at Shute and Tancred Islands overall hard coral cover has not increased, potentially indicating high mortality rates or a lack of growth of these small colonies.

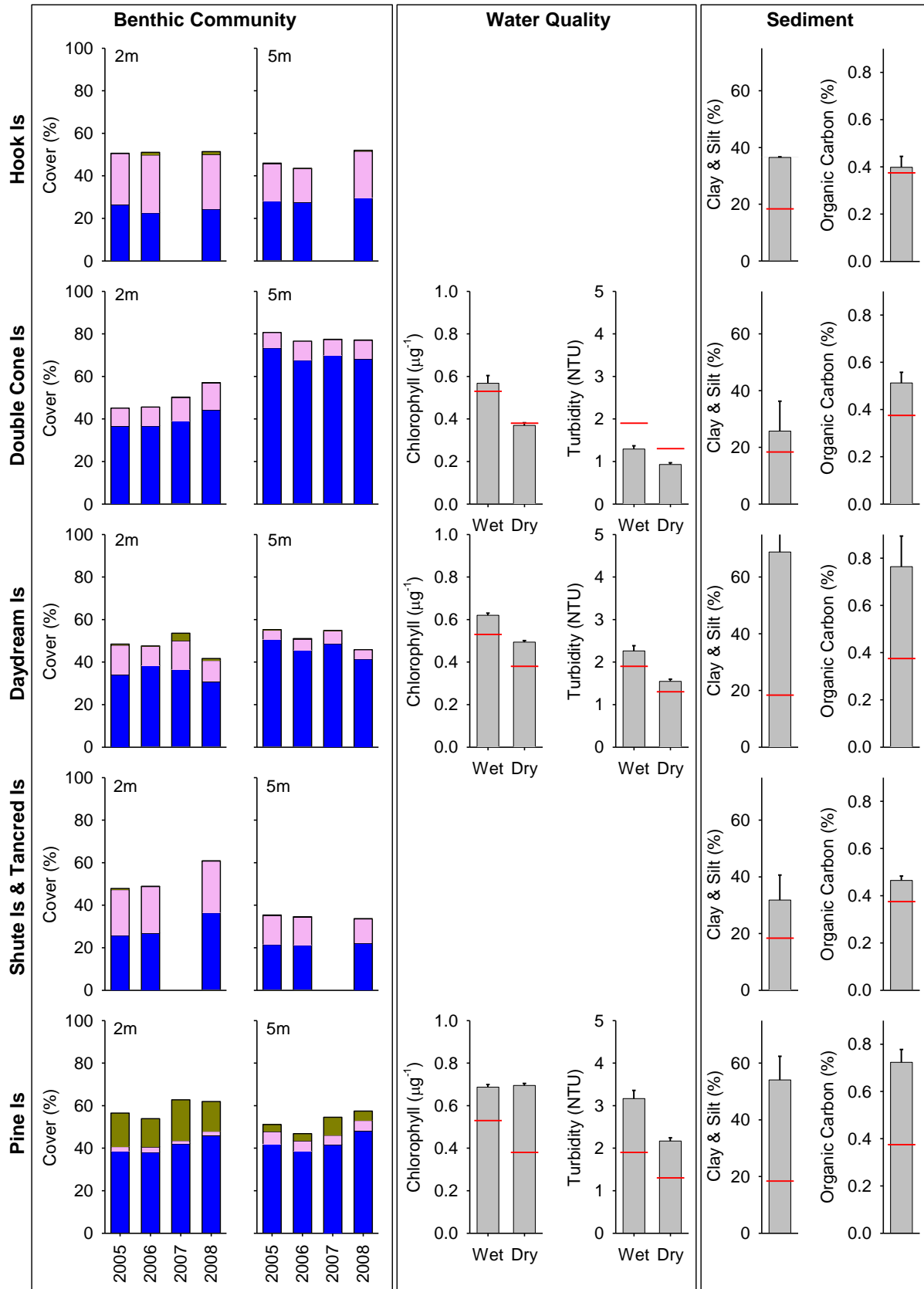


Figure 4.37. Percent cover estimates of major benthic groups: hard coral (blue), soft coral (pink) and macroalgae (green) for each sampling year and water quality and sediment quality parameters on reefs in the Mackay Whitsunday Region. Red reference lines indicate the average values of environmental data from reef sites.

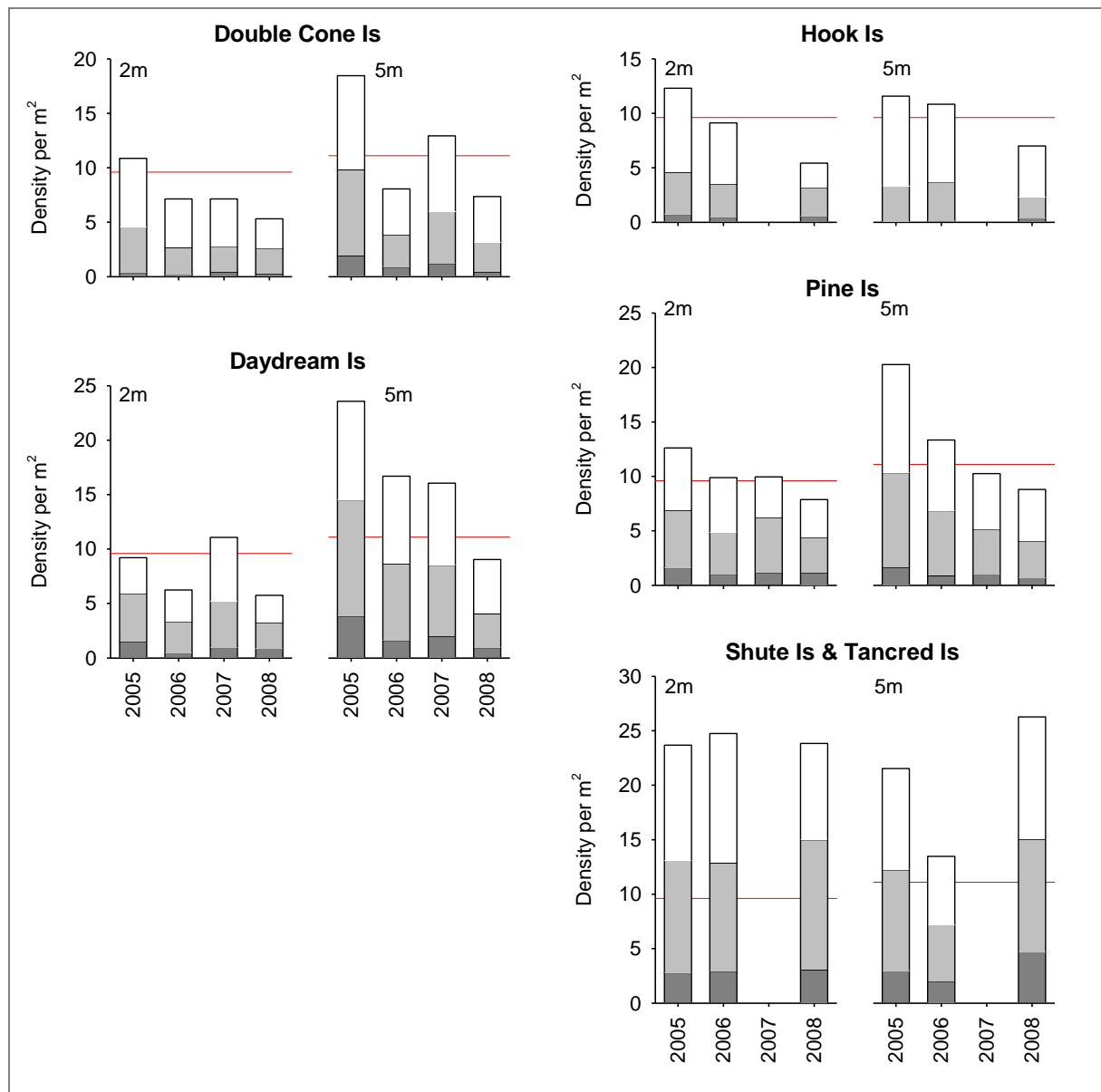


Figure 4.38: Density of juvenile hard coral colonies standardised to the area of available substrate for settlement on reefs in the Mackay Whitsunday Region. Bars are cumulative densities over the three size classes: <2 cm (dark grey), 2-5 cm (pale grey) and >5 cm to 10 cm (white). The average density over all years at each depth is indicated by the red reference line.

In the assessment of status coral communities, this Region scored highly with generally high cover of corals and low cover of macroalgae (Table 4.9). The only community to not return a positive assessment of status was Pine Island which was the only location to have had a persistently high cover of macroalgae.

Table 4.9: Reef by depth estimates of coral community status of reefs in the Mackay Whitsunday Region.

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

Note: The status assessments are aggregates over three indicators: coral cover, macroalgae cover, and juvenile hard coral density (see Table 3.9 for more detail). Coral cover trend indication: u = 'up', s = 'stable', d = 'decreasing'.

4.5. Fitzroy Region

Regional context and drivers

The Fitzroy Region is a large dry tropical catchment with cattle grazing as the primary land use (Brodie *et al.* 2003). Fluctuations in climate and cattle numbers greatly affect the state and nature of vegetation cover, and therefore, the susceptibility of soils to erosion, which leads to runoff of sediments and associated nutrients.

The main river system influencing the Region is the Fitzroy River. The reef waters sampled in this group have the lowest clay and silt levels of all catchments. Levels of organic carbon are low, while nitrogen levels remain average with a modest increase in 2008, perhaps as a result of flooding in February 2008. A strong gradient in water quality exists between the reefs in this Region with increasing distance from both the coast and Fitzroy River mouth. This is clearly evident in the differences in turbidity and chlorophyll. As an example, clear distinction between coral communities at Peak and Pelican Islands and reefs further from shore (Middle, Humpy, Halfway and Barren Islands) reflect the sharp difference in environmental setting between these otherwise nearby reefs.

The annual river flow of the Fitzroy River in 2008/2009 (October 2008 to October 2009) was less than the long term median flow, with a relative difference of 0.81 (refer to Table 3.2). The Fitzroy River had only one major flood event during the monitoring period, in late 2008. Information on flow of the Fitzroy River from January to May 2009 shows a peak in flow between mid-February and mid-March 2009 (Figure 4.39).

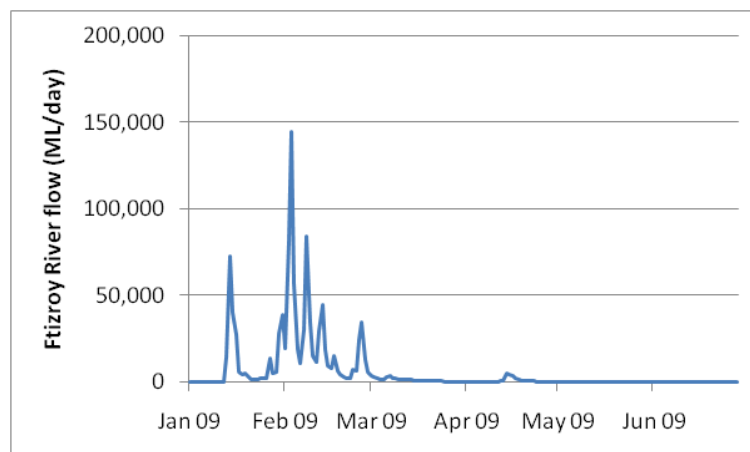


Figure 4.39: Flow rates of the Fitzroy River from January to June 2009.

Water quality, flood plumes, seagrass habitats, and coral reefs are monitored as part of the MMP in the Fitzroy Region. Overviews of these results are provided below.

4.5.1 Inshore water quality

Nutrients, chlorophyll and turbidity

The three sampling locations in Keppel Bay are located on a gradient away from the Fitzroy River (Figure 2.5). Guideline values were exceeded at Pine Island for all parameters, except for particulate nitrogen in the dry season. Water quality at Barren Island, the sampling location furthest offshore, was within the Guideline values, while Humpy Island exceeded the chlorophyll, particulate phosphorus and secchi depth wet season values (Table 3.4). Chlorophyll values for annual and seasonal means were exceeded at Pelican Island, and dry season means at Humpy Island (Table 3.4). Seasonal exceedances of Guideline values were significant at this location with 42% and 52% of all daily chlorophyll records for wet and dry seasons, respectively, above the Guideline value. Humpy and Barren Islands also had high chlorophyll for a substantial part of the dry season.

Turbidity was highest at Pelican Bay, which is closest to the Fitzroy River and lowest at Barren Island, the location furthest away (Table 3.4). Annual and seasonal turbidity means for Pelican Island were above the Guideline value for suspended solids and 31% of daily records over the whole period (October 2007 to February 2009) were above the suggested 5 NTU limit for severe coral photo-physiological stress (Cooper *et al.* 2007; 2008). Pelican Island had the highest turbidity of all fourteen inshore GBR monitoring locations (Table 3.4). Most of the turbidity maxima were associated with the major 2008 flood event however, Pelican Island regularly experienced wind-driven resuspension, which led to frequent spikes in turbidity.

Water Quality Guideline exceedances

The exceedance of Guidelines were assessed in the Fitzroy Region for chlorophyll and suspended solids (retrieved from MODIS AQUA). The annual mean values of chlorophyll exceeded the Guideline value (0.45 µg/L) for 35% of the inshore area, 2% of the midshelf and none of the offshore areas (Figure 4.40). Exceedance of suspended solids Guideline values were recorded in 35% of the inshore, 2% of the midshelf and none of offshore areas.

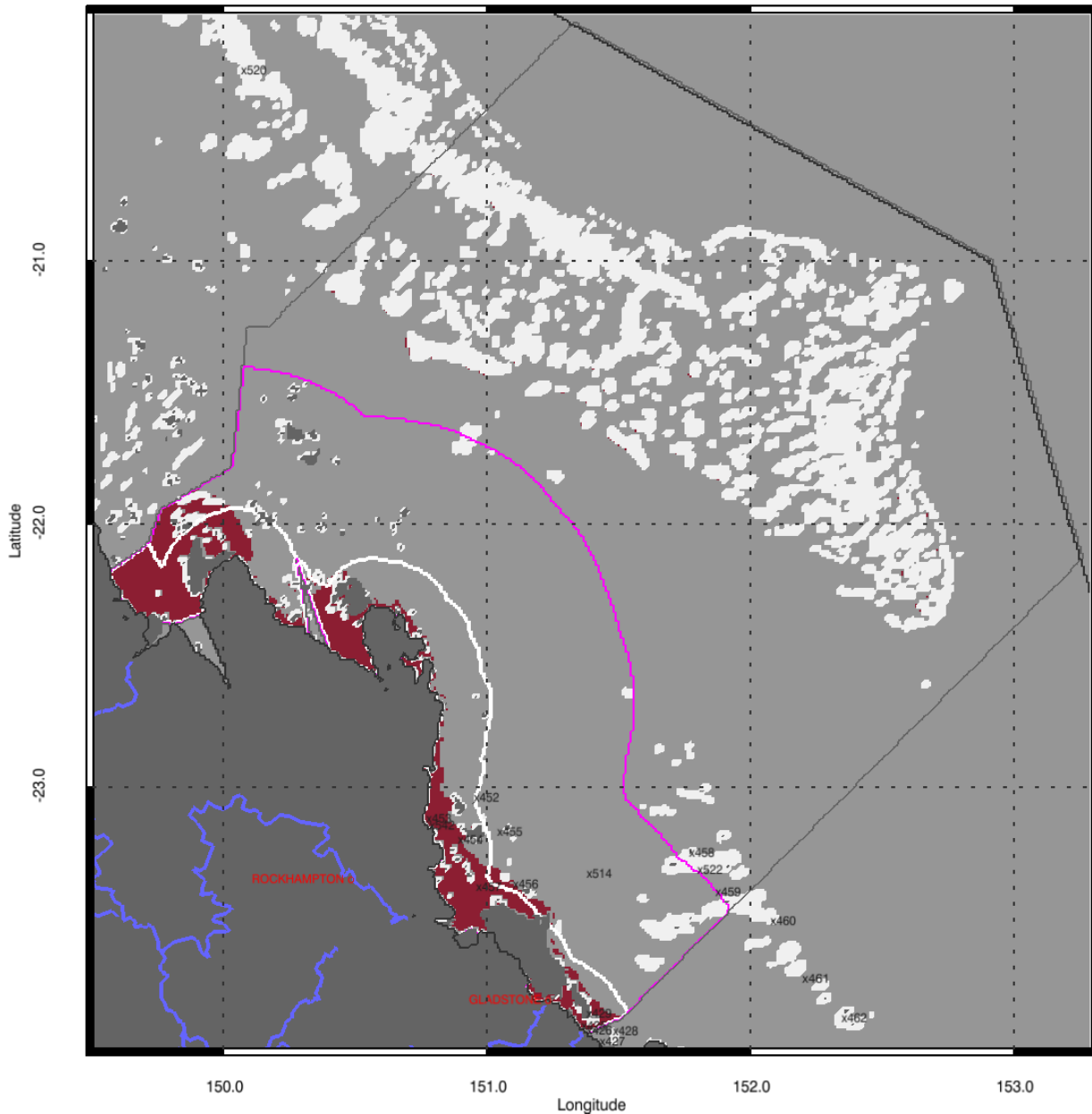


Figure 4.40: Annual mean chlorophyll Guideline exceedance map for the Fitzroy Region, 1 May 2008 to 30 April 2009. Pixels are mapped in dark red when annual mean values exceed the threshold. The white line represents the Inshore boundary; pink line represents the Midshelf boundary (Source: CSIRO).

Guideline exceedances for chlorophyll and suspended solids (using non-algal particulate matter as a proxy) were calculated for dry season (winter months) data, along with the Exceedance Probability for that period. The mean value of chlorophyll exceeded the Guideline value for the inshore area, and the mean values of suspended solids exceeded the Guideline values for the inshore and offshore areas (Table 4.10). The mean and median values for the suspended solids concentration differed substantially for all areas. The mean values were 2.5 times higher than the medians.

Table 4.10: Summary of chlorophyll and suspended solid (using non-algal particulate matter as a proxy) Guideline exceedances for the dry season (winter months) in the Fitzroy Region.

	Surface Area (km ²)	Chlorophyll (µg/L): 01-May-2008-31-Oct-2008			Suspended solids (mg/L): 01-May-2008-31-Oct-2008		
		Mean	Median	Exceedance probability	Mean	Median	Exceedance Probability
Inshore	7942	0.76	0.44	48%	3.80	1.47	41%
Midshelf	19477	0.34	0.34	14%	1.30	0.31	17%
Offshore	61048	0.29	0.25	19%	0.94	0.27	27%

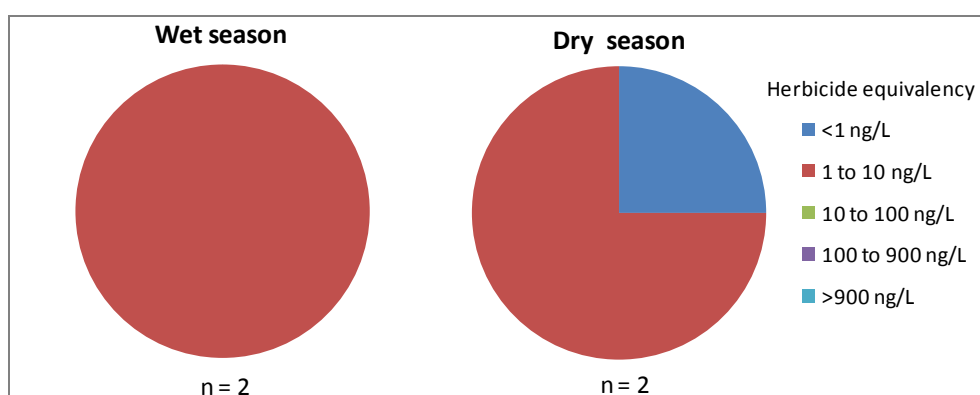
Note: Mean and Median report the mean and median concentrations calculated from all valid observations (i.e. number of cloud-free and error-free pixels – included in Brando *et al.* 2010). Exceedance Probability is the number of observations where the concentration exceeded the Guideline value divided by number of observation with (error-free) data for that period. Mean and median are presented in red and bold if they exceed the Guideline value.

Pesticide concentrations

The results for pesticide sampling in the Fitzroy Region are summarised below.

Location:	North Keppel Island (6 deployments, wet and dry season)
Detections:	<ul style="list-style-type: none"> • Diuron was detected in all samples but at consistently low concentrations - mean concentration 0.82 ng/L. • Tebuthiuron was also detected on one occasion at low concentrations (0.18 ng/L). • TCP was the only pesticide detected using non-polar passive samplers in July-August 2008, and the estimated time- averaged concentration of TCP is about 11 ng/L for that period.
Trends (4 years)	<ul style="list-style-type: none"> • There were consistently low pesticide concentrations at the North Keppel Island site.

All samples from all sites in this Region received a HEq less than 10 ng/L (Figure 4.41) and there were no exceedances of the Guideline values.

**Figure 4.41:** HEq index of all samples collected in Fitzroy Region in the wet and dry seasons 2008/2009.

4.5.2 Flood plume monitoring

The Fitzroy River peak in mid-February was sampled for pesticide concentrations, and six sets of passive samplers were deployed during and after the main flow event. Results showed that atrazine dominated the polar pesticides with a maximum water concentration of 254 ng/L. Tebuthiuron was the second highest polar pesticide, with a maximum of 64 ng/L. These results are in contrast to event monitoring in the previous year which showed that tebuthiuron dominated followed by atrazine (refer to Devlin *et al.* 2009).

Land use has a substantial effect on the type of pesticides in flood waters from the Fitzroy River basin. Tebuthiuron was the dominant pesticide detected during the 2007 floods which originated from grazing land. The 2008 flood waters were dominated by atrazine which originated from cropping and grazing. The data are consistent with findings by Packett *et al.* (2009) who also found similar event mean concentrations during 2007 and 2008 events in the Fitzroy Region, including tebuthiuron being the dominant pesticide in the 2007 event and atrazine in the 2008 event. Other polar pesticides that were detected included desethyl atrazine, simazine, desisopropyl atrazine, diuron, and hexazinone. Prometryn, flumeturon and ametryn were also present, mostly below 1-2 ng/L.

4.5.3 Inshore biological monitoring

Status of intertidal seagrass habitats

Coastal sites are monitored in Shoalwater Bay, and are located on the large intertidal flats of the north western shores of Shoalwater Bay. The remoteness of this area (due to its zoning as a military exclusion zone) ensures a near pristine environment, removed from anthropogenic influence. The estuarine sites are located within Gladstone Harbour, a heavily industrialised port. Estuarine seagrass habitats in the southern Fitzroy Region tend to be intertidal, on the large sand/mud banks in sheltered areas of the estuaries. These southern estuarine seagrasses (Gladstone Harbour) are potentially vulnerable to impacts from local industry and inputs from the Calliope River. Inshore reef sites are located in Monkey Beach at Great Keppel Island.

Key results from 2008/2009 and from comparisons of data to previous years include:

- Coastal and estuarine seagrass meadows remain highly variable, and reef seagrasses at Great Keppel Island have declined in abundance since 2007;
- Over the period 2006-2009, reef and estuarine sites had variable seagrass reproductive health status and the coastal site had stable reproductive health status. However, no seeds were measured in all locations in 2008/2009;
- Estuarine and reef seagrass habitats had potentially low light environments, whilst the coastal site had moderate light availability. The estuarine and reef habitats were rich in nutrients (larger P pool) except for the coastal site that was nutrient poor. Nutrient availability to the plant was replete at all locations;
- Seagrass epiphytes were variable at all sites; and
- No pesticides were detected in the sediments of any seagrass habitats in 2009.

Seagrass community status

Seagrass species composition differed greatly between the inshore coastal and estuarine and reef habitats.

Coastal habitats: Inshore coastal sites were dominated by *Zostera capricorni* with some *Halodule uninervis*. Seagrass cover decreased slightly in 2008/2009 from the peak values observed late in the 2007 dry season but remains higher than when monitoring commenced in early 2007 (Figure 4.42).

Estuarine habitats: Estuarine sites were dominated by *Zostera capricorni*. Species composition has remained stable, however abundance has differed greatly between years (Figure 4.42). Abundance observed in the late 2008 dry season was the highest recorded since 2005. Abundance late in the 2008 wet season was significantly lower than the same time in 2008.

Reef habitats: The inshore reef monitoring sites at Great Keppel Island differ greatly from the coastal and estuarine sites, and are composed predominately of *Halodule uninervis*. Seagrass abundance has continued to decline since monitoring was established in 2007 (Figure 4.42). Due to the paucity of data no seasonal patterns are apparent. The declines in seagrass abundance appear predominantly the result of declining seagrass meadow extent since 2007.

Seagrass environment status

Light environment (indicators of light availability): Tissue nutrient ratios in seagrass meadows at Gladstone Harbour and Great Keppel Island sites indicate these sites are low light environments ($C:N < 20$).

Nutrient environment: With the exception of *Zostera capricorni* in Shoalwater Bay, C:P ratios of all species at all sites in the Fitzroy Region were below 500, indicating the presence of a relatively large phosphorous pool. The N:P ratios of all seagrass species at all sites in the Fitzroy Region were below 30 late in the dry season of 2008 indicating that meadows were either replete or nitrogen limited (Figure 4.43).

Epiphyte cover on seagrass leaf blades at Shoalwater Bay was relatively low but higher and more variable at Gladstone Harbour and Great Keppel Island. Epiphyte cover at coastal sites in 2008/2009 was similar to the previous monitoring period and appears seasonal with higher abundance in the dry season of each year. Epiphyte cover at Great Keppel Island was higher during the late wet season compared to the late dry, however due to the paucity of data it is not possible to compare between years. Macro-algae cover is generally low at Shoalwater Bay and Great Keppel Island, however it has fluctuated greatly at the estuarine sites in Gladstone Harbour.

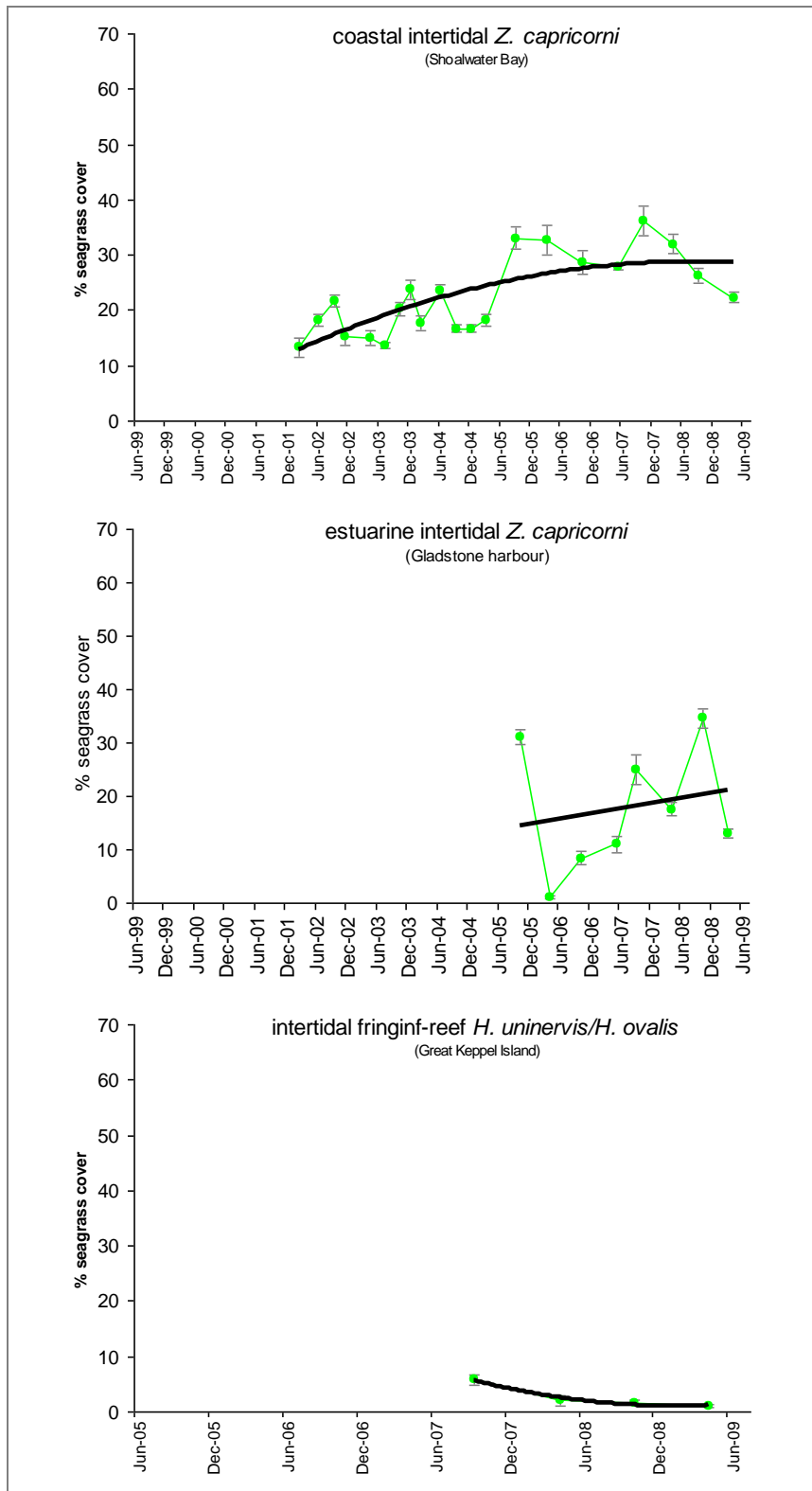


Figure 4.42: Change in seagrass abundance (percent cover) at intertidal (coastal and estuarine) meadows in the Fitzroy Region.

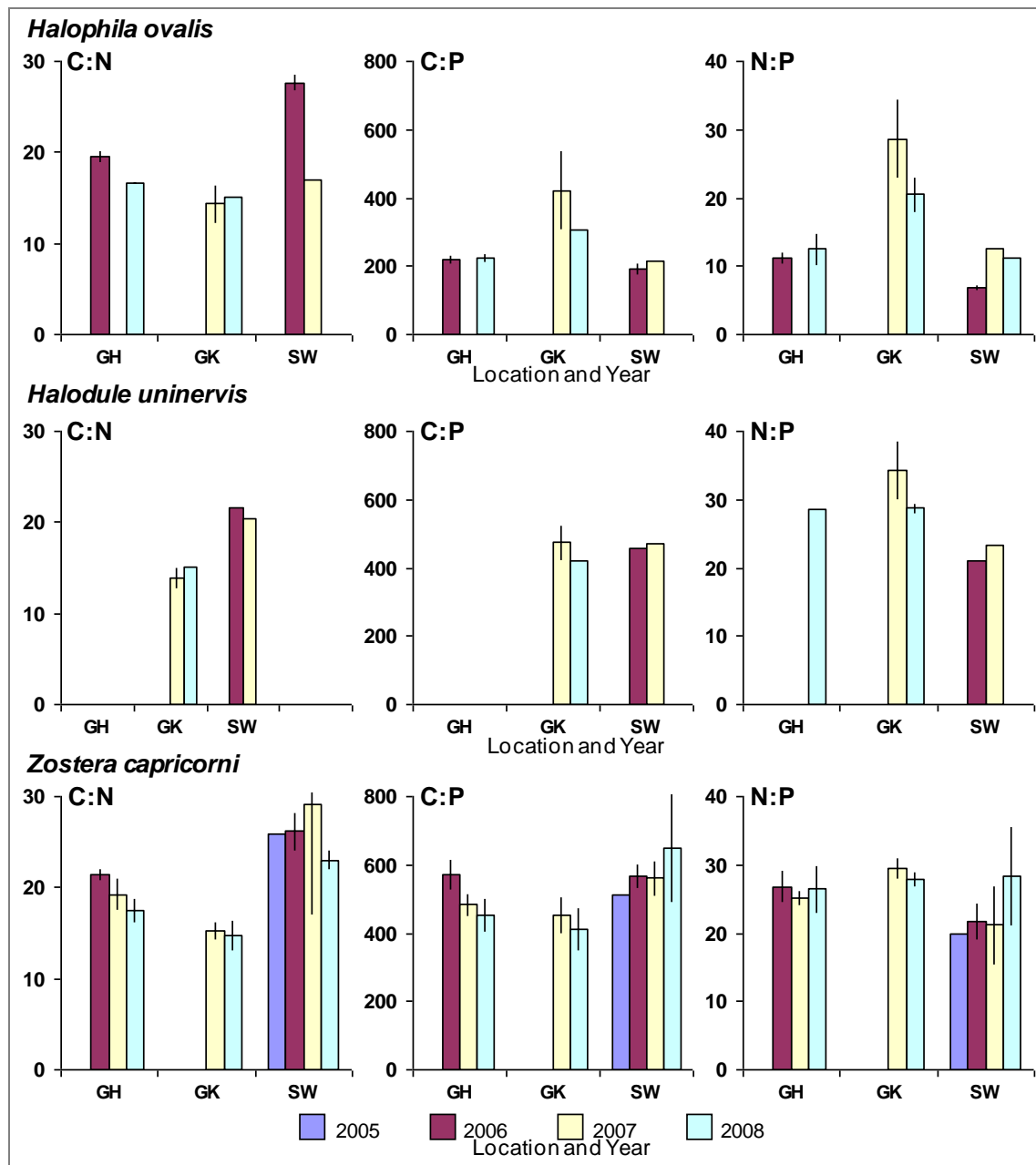


Figure 4.43: Plant tissue ratios C:N, C:P and N:P for seagrass species in the Fitzroy Region. GH=Gladstone Harbour, GK=Great Keppel Island, SW=Shoalwater Bay (mean and SD displayed).

Coral habitats

Historical data on benthic communities are available for three of the six reefs selected in this Region – Humpy, Halfway and Middle Island Reefs. These sites were first monitored in 1989 and 1991 (Van Woesik 1991). Between 1991 and 2006, several disturbance events have caused reductions in coral cover at reefs in this Region. The most severe disturbance was the Fitzroy River flood in 1991 (Van Woesik 1991). Subsequent declines in hard coral cover were associated with coral bleaching in 1998, 2002 and 2006. Coral cover showed rapid recovery following bleaching in 1998 and 2002 (Sweatman *et al.* 2007).

Hard coral communities in this Region are dominated by *Acropora*, which are fast to recover from disturbance, as was evident in 2007 with coral cover increasing at Barren, Humpy and Halfway Islands following declines in 2006 due to bleaching (Figure 4.44). Hard coral cover declined again by 2008 due to the combined impacts of an unusually strong northerly wind and severe flooding of the Fitzroy River which affected reefs at Barren, Humpy and Halfway Islands and presumably Middle Island, though this reef was not surveyed in 2007.

Differences in coral community response to disturbance, and as a result composition, is due to a strong turbidity gradient between Pelican Island and the more offshore islands, such as Pelican Island (Figure 4.44). On more turbid reefs coral cover was not impacted by the 2006 bleaching event with slight increases in cover observed at two metres and cover remaining unchanged at five metres between 2005 and 2006 (Figure 4.44). Cover continued to increase at Pelican Island at two metres to 2007. In 2008, cover at two metres at both inshore islands had dropped, almost certainly as a result of inundation by the Fitzroy River flood plume while the five-metre coral communities remained stable.

Associated with the mortality of corals at Middle, Humpy and Halfway Islands and to a lesser extent Barren Island, following bleaching in 2006 was an increase in the cover of macroalgae of the genus *Lobophora*. While still present in 2008 the cover of *Lobophora* had decreased on all these reefs (Figure 4.44). The macroalgae communities at Pelican and Peak Islands were more diverse and better established when these reefs were first visited in 2004.

Regionally, the density of hard coral recruits was low (Figure 4.45). This along with the rapid increase in cover following disturbances to the branching *Acropora* communities indicates recovery was largely due to the growth of colonies surviving disturbance rather than through recruitment and subsequent growth of new colonies. A possible exception is at two metres at Pelican Island, where surveys in 2004 (Sweatman *et al.* 2007) recorded high numbers of small *Acropora* colonies and subsequent observations indicated it was the growth of this cohort that resulted in the increase in cover to 2007.

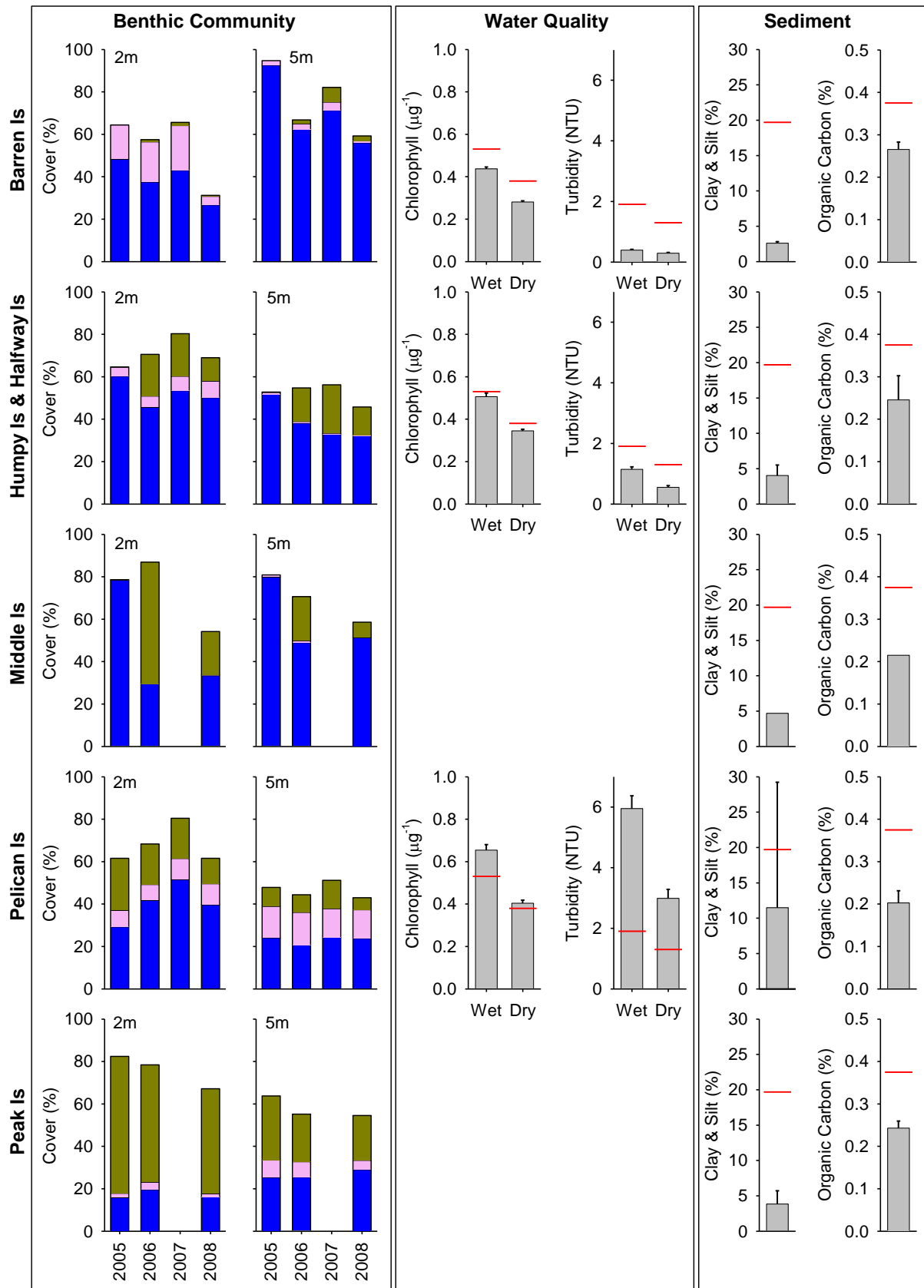


Figure 4.44: Percent cover estimates of major benthic groups: hard coral (blue), soft coral (pink) and macroalgae (green) for each sampling year and water quality and sediment quality parameters on reefs in the Fitzroy Region. Red reference lines indicate the average values of environmental data from reef sites.

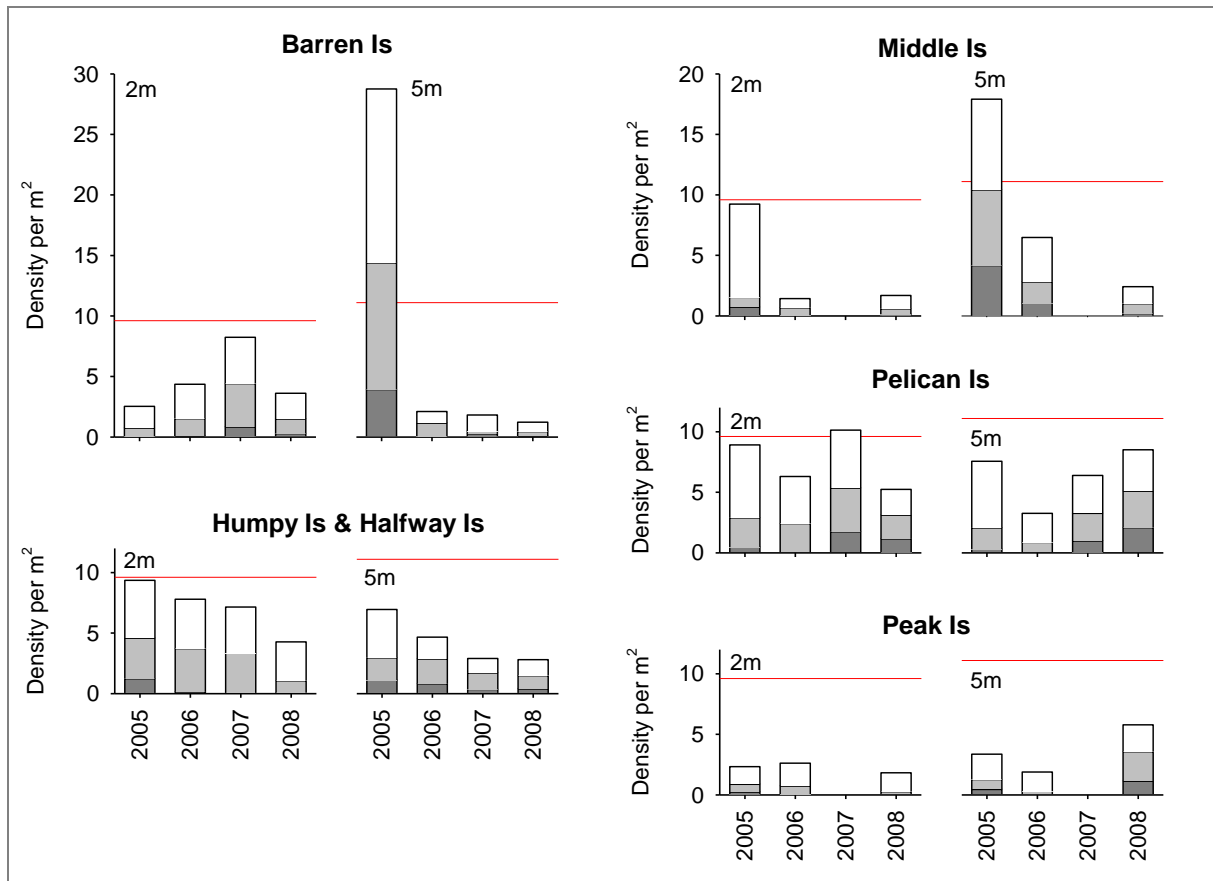


Figure 4.45: Density of juvenile hard coral colonies standardized to the area of available substrate for settlement on reefs in the Fitzroy Region. Bars are cumulative densities over the three size classes: <2 cm (dark grey), 2-5 cm (pale grey) and >5 cm to 10 cm (white). The average density over all years at each depth is indicated by the red reference line.

Assessment of coral community status indicated lower than expected values for reefs in this Region (Table 4.11) particularly considering the rapid recovery from disturbances recorded in the past (Sweatman *et al.* 2007; Diaz-Pulido *et al.* 2009). The low scores generally resulted from high cover of macroalgae and low densities of juvenile colonies from 2006-2008. The high cover of a taxonomically diverse macroalgae community at Pelican and Peak Islands most likely represents a typical benthic community of rocky reefs in turbid water in the tropical-temperate transition zone. Similarly, the low-diversity coral communities at the more offshore reefs have proven resilient to disturbance despite low numbers of juveniles with coral recovery the result of growth of surviving fragments rather than settlement and growth of new colonies. Whether these communities would therefore recover from more severe or frequent disturbances that caused total mortality (reducing scope for recovery by re-growth from fragments) is unknown.

Table 4.11: Reef by depth estimates of coral community status of reefs in the Fitzroy Region.

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

Note: The status assessments are aggregates over three indicators: coral cover, macroalgae cover, and juvenile hard coral density (see Table 3.9 for more detail). Coral cover trend indication: u = 'up', s = 'stable', d = 'decreasing'.

4.6. Burnett Mary Region

Regional context and drivers

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 annual river flow of the Burnett River in 2008/2009 (October 2008 to October 2009) was equivalent to the long term median flow (refer to Table 3.2) and no major flood events were recorded.

Inshore water quality, flood plumes, and coral reefs are not monitored in the Burnett Mary Region. The results of remote sensing applications for water quality and seagrass habitat monitoring are presented in this Regional report.

4.6.1 Inshore water quality

Nutrients, chlorophyll and turbidity

Water Quality Guideline exceedances

The exceedance of the Guidelines were assessed in the Burnett Mary Region for chlorophyll and suspended solids (retrieved from MODIS AQUA). The annual mean values of chlorophyll exceeded the Guideline values (0.45 µg/L) for 27% percent of the inshore area, 2% of the midshelf and none of the offshore areas (Figure 4.46). Exceedance of suspended solids Guideline values were recorded in 13% of the inshore, 2% of the midshelf and 3% of offshore areas.

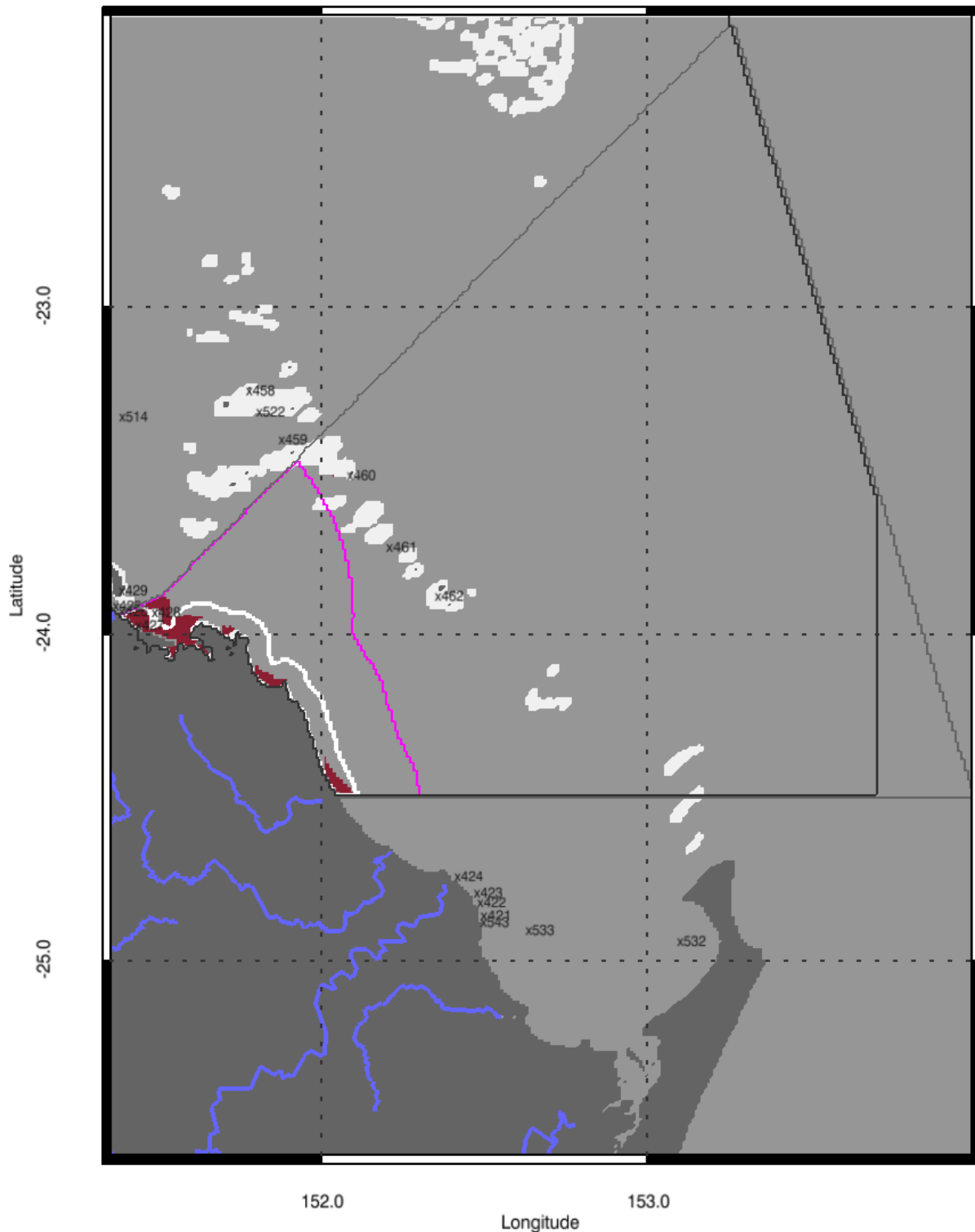


Figure 4.46: Annual mean chlorophyll Guideline exceedance map for the Burnett Mary Region, 1 May 2008 to 30 April 2009. Pixels are mapped in dark red when annual mean values exceed the threshold. The white line represents the Inshore boundary; pink line represents Midshelf boundary (Source: CSIRO).

Guideline exceedances for chlorophyll and suspended solids (using non-algal particulate matter as a proxy) were calculated for dry season (winter months) data, along with the Exceedance Probability for that period. The mean values of chlorophyll exceeded the Guideline values for the inshore area, and the mean values of suspended solids did not exceed the Guideline values (Table 4.12).

Table 4.12: Summary of chlorophyll and non-algal particulate matter (as a measure of suspended solids) Guideline exceedance for the dry season for the Burnett Mary Region.

	Surface Area (km ²)	Chlorophyll (µg/L): 01-May-2008-31-Oct-2008			Suspended solids (mg/L): 01-May-2008-31-Oct-2008		
		Mean	Median	Exceedance Probability	Mean	Median	Exceedance Probability
Inshore	950	0.49	0.45	49%	1.03	0.40	13%
Midshelf	3426	0.34	0.35	17%	0.61	0.18	10%
Offshore	34557	0.24	0.22	5%	0.31	0.11	11%

Note: Mean and Median report the mean and median concentrations calculated from all valid observations (i.e. number of cloud-free and error-free pixels; Brando *et al.* 2010). Exceedance Probability is the number of observations where the concentration exceeded the Guideline value (in red) divided by number of observation with (error-free) data for that period.

4.6.2 Inshore biological monitoring

Status of intertidal seagrass habitats

The majority of seagrass meadows in the Burnett Mary Region are within coastal and estuarine habitats, however only estuarine seagrass habitats are monitored. Seagrass meadows in this Region are exposed to a range of anthropogenic impacts including agricultural land use and coastal development. Urangan (Hervey Bay) sites in the south are on a large intertidal mud/sand bank adjacent to the Urangan marina and close to the Mary River. Rodds Bay is in the north and the monitoring sites are located on large intertidal mud banks. The seagrass meadows in this area must survive pulsed events of terrestrial run-off, sediment turbidity, salinity drops, temperature-related threats and desiccation due to the majority being intertidal.

Key results from 2008/2009 and from comparisons with data from previous years include:

- Seagrass abundance has varied greatly across the Region, and significant declines occurred in 2009;
- Over the period 2006-2009, seagrass reproductive health status at Rodds Bay was good, but poor at Urangan. No seeds were measured in these locations in 2008/2009;
- Seagrasses at Urangan appear to still be recovering from flood-related loss in 2006;
- Seagrass leaf tissue C:N ratios indicate seagrass to be growing in a low light environment within Urangan, and a moderate light environment within Rodds Bay. Seagrass habitats were nutrient rich (larger P pool) and nutrient availability to the plant was N limited at Rodds Bay and replete at Urangan.
- Seagrass epiphyte cover was low. ; and
- No pesticides were detected in sediments within seagrass habitats during 2009.

Seagrass community status

The estuarine seagrass habitats in the Region were dominated by *Zostera capricorni* with minor components of *Halophila ovalis* and some *Halodule uninervis*. The meadow at Urangan has been in a state of recovery since 2006, but has shown little improvement over the last year (Figure 4.47). The *Z. capricorni* scattered across the intertidal banks in 2008 increased in cover late in the 2008 dry season but became more isolated following the 2009 wet season with mean cover below one percent (Figure 4.47). The biggest change during the last year was at one site in Rodds Bay, where seagrass that was abundant in 2008 was completely absent following the 2009 wet season.

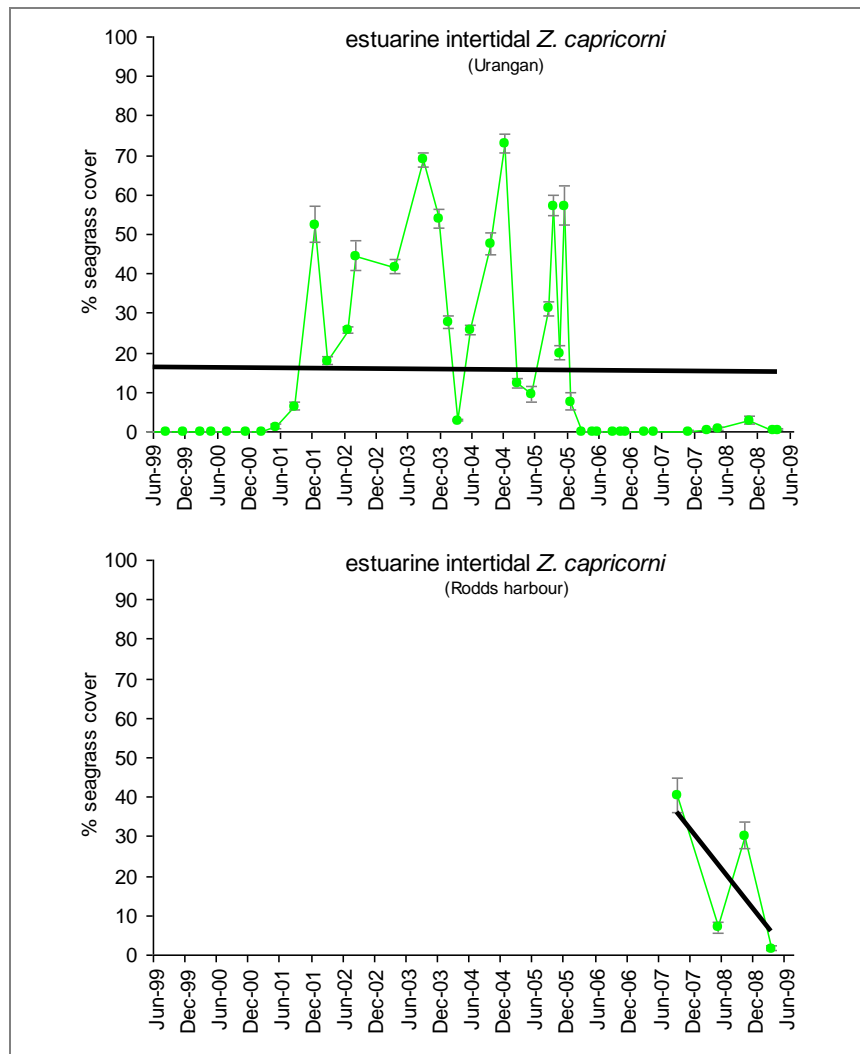


Figure 4.47: Change in seagrass abundance in estuarine intertidal seagrass habitats within the Burnett Mary Region over the last decade.

Seagrass environment status

Light environment (indicators of light availability): Seagrass meadows in Rodds Bay were one of the few sites in 2008 to be defined as a moderate light environment with C:N values mostly above 20 (Figure 4.48). Levels of C:N in Rodds Bay showed no significant difference in 2008 relative to 2007. In Urangan, levels were lower and indicative of a low light environment.

Nutrient environment: C:P ratios in the late 2008 dry season were unchanged relative to 2007 (Figure 4.48); these were tested as having no significant difference ($p > 0.05$) at Rodds Bay, but the numbers of repeats were insufficient to test at Urangan. These levels were all below 500, indicating seagrasses with a relatively large phosphorus pool (nutrient rich). Levels of the N:P ratio were also unchanged and indicative of a replete or potentially nitrogen limited environment (Figure 4.48).

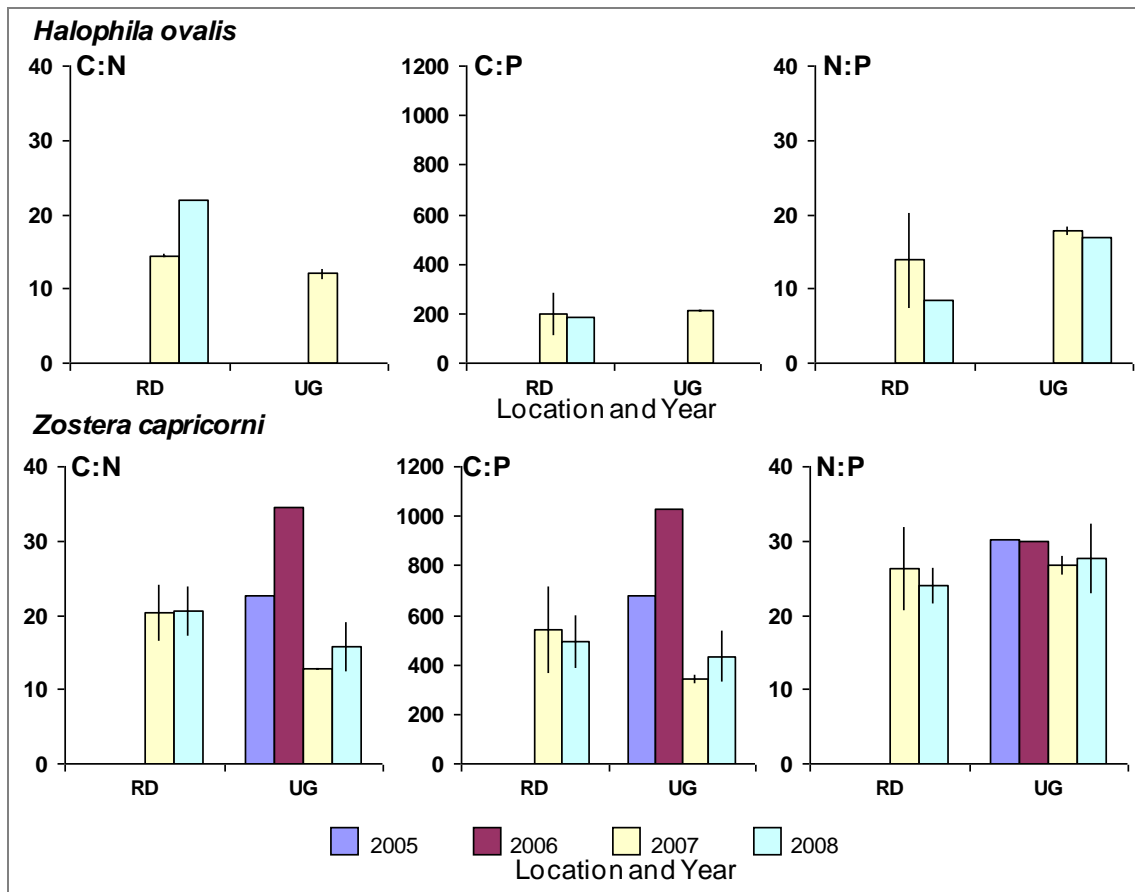


Figure 4.48: Plant tissue ratios for sampling years in the Burnett Mary Region (sites have been pooled). RD=Rodds Bay, UG=Urungan (mean and SD displayed).

Epiphyte cover on the seagrass leaf blades at Urangan were highly variable over the years of monitoring and were higher in 2008 than the previous few years. Percentage cover of macro-algae has continued to remain low. Epiphyte cover and macro-algae were similarly low in Rodds Bay.

5. Discussion

Scientists and managers now acknowledge that the continued management of regional and local disturbances such as nutrient runoff and overfishing is vital to provide corals and reef-associated organisms with the maximum resilience to cope with global stressors, such as climate change (Bellwood *et al.* 2004; Marshall and Johnson 2007; Carpenter *et al.* 2008; Mora 2008). The management of water quality remains an essential response to ensure the long-term protection of the GBR and its resilience to future disturbances. The MMP is an integral component of the Reef Plan Paddock to Reef Program, documenting the status of inshore water quality and GBR habitats since 2005. The MMP also draws on complementary research, such as the MTSRF program, and earlier monitoring data to interpret results and assess spatial and temporal trends.

In 2008/2009, the MMP was in the fourth year of monitoring. This has enabled the analysis of temporal trends in water quality and biological indicators to be considered within many of the subprograms for the first time. In addition, the Guidelines have been finalised and provide a point of reference to trigger a management response in the protection and maintenance of GBR ecosystem health. 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 season and dry seasons. For example, chlorophyll is estimated to be twenty percent higher than the annual mean in the wet season, and twenty percent lower than the annual mean in the dry season. Presently, the wet season is defined as January to March, and 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 compliance with the Guidelines when considering seasonal means. Therefore, it is recommended that further work is undertaken to consider defining the wet season and dry season 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 including the remote sensing.

The MMP data has been used to document exceedances of the Guidelines for all water quality parameters, to develop a pesticide index that assesses the pesticide concentrations at monitoring sites, describe the spatial and temporal trends of GBR seagrass meadows, and to develop a coral health metric that assesses the condition of reef monitoring sites over time. The key findings and their implications are presented and discussed below.

5.1 Inshore water quality status and trends

Water quality in the inshore GBR showed clear reducing gradients away from river mouths for all parameters. This was driven by depth and seasonal factors, such as flood events and resuspension due to wave and wind action. Chlorophyll and suspended solids concentrations exceeded Guideline values throughout the year, and in each region.

Comprehensive water quality sampling has been undertaken in the Wet Tropics, Burdekin, Mackay Whitsunday and Fitzroy Regions over the four years of the MMP. In 2008/2009, remote sensing applications were tested 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.

Nutrients, chlorophyll and suspended solids

The water quality data for the GBR lagoon were compared with the Guideline values. Direct water sampling in 2008/2009 indicated that most water quality variables at Dunk Island (Wet Tropics Region), Magnetic Island (Burdekin Region) and Pelican Island (Fitzroy Region) did not comply with the Guideline values. Instrumental monitoring indicated that Daydream and Pine Islands in the Mackay Whitsunday Region also had chlorophyll and suspended solid levels that exceeded Guideline values. For the 2008/2009 period, the Fitzroy River had below median flow and the high chlorophyll and turbidity values during the wet season are more likely to be associated with wind-driven resuspension.

Further analyses of the four years of water quality data to investigate drivers of water quality conditions in the GBR indicated that forty percent of the variation in the water quality data set was explained by the variables of month (20%), resuspension index (7%), river flow (6.2%) latitude (3.8%) and year (3.5%). Most interestingly, longitude and 'distance to nearest river' did not make a significant contribution ($p > 0.05$). Most variation was explained by the factor of 'month' highlighting that the time of sampling (related to season) is the most discernible driver of observed patterns in water quality in the inshore GBR (Schaffelke *et al.* 2009a).

Results to date for the longest water quality dataset in the GBR since 1989, the *Cairns Coastal Transect*, indicate that flood events and resuspension events around the time of sampling are the most prominent drivers of water quality variables (Schaffelke *et al.* 2009b). The highest concentrations of all water quality parameters were measured in periods with above median flood events over several years (e.g. 1989-1991 and 1999-2001).

Remote sensing applications used to evaluate compliance with the Guidelines showed regular exceedances of chlorophyll and suspended solid values across all regions in inshore areas during the dry season and annually. These results are based on a high number of observations during the dry season for the offshore area (in the order of millions of observations). While wet season values have been assessed, they were not reported due to (as yet) unresolved uncertainties related to cloud cover and model validation. These uncertainties relate to the high frequency of cloud cover during the wet season, and whether remote sensing effectively captures the extreme concentrations of chlorophyll and suspended solids during these periods. This has implications for the estimates of mean values for the wet season (and to a lesser extent annually) but is unlikely to bias the annual median. Therefore this report provides assessments of compliance using both the mean and median, however, further evaluation of the statistical robustness of this approach is required. These same challenges affect the estimates of model accuracy, which are currently based primarily on dry season observations, and further model validation is required for the wet season.

The flood monitoring results also support the understanding that concentrations of all water quality parameters are intrinsically linked in both time and space to riverine flow during high flow events. Flow volumes and water quality concentrations are also linked to location of the flooding of sub-catchments. Flood plume sampling in the 2008/2009 wet season associated with the Tully and Burdekin Rivers, and a sampling event in the Mackay Whitsunday Region, showed elevated concentrations of chlorophyll and suspended solid concentrations in inshore locations. Additionally, pesticides were detectable at several locations throughout the wet season. Furthermore, the concentrations recorded across the wet season imply that there were long periods of time in which chlorophyll and suspended solid concentrations were elevated above wet season Guideline values for inshore marine waters adjacent to the Tully and Burdekin Rivers. Observation of the coral reef communities in the inshore reef areas off the Tully River during 2008/2009 wet season showed the occurrence of coral bleaching in many locations (Fabricius, AIMS, pers. comm. 2009). However, the relationship between the flood monitoring results and coral reef condition has not been fully investigated

at this stage and longer term, more chronic impacts, such as reduced recruitment success, may take more time to detect.

The persistence of these elevated concentrations of chlorophyll and suspended solids has yet to be shown. However, single exceedances of the Guideline values have been identified from the flood plume water quality data and used to extrapolate plume behaviour in correlation with river flow and remote sensing images. Further work to obtain integrated time series data throughout high flow events, including more extensive sampling of depth profiles and continuous *in situ* logger data in combination with *in situ* surveys of coral reefs, will assist in improving the correlation of flood monitoring data with the long-term changes in pollutant concentrations and ecological impacts.

New work in designing the reporting metrics for inshore water quality data from the three primary data sources (autonomous loggers, passive samplers and remote sensing), and investigation of how to combine the assessment over more variables is needed to provide a higher degree of integration and interpretation of results.

Pesticide concentrations

During the initial four years of the monitoring program (2005/2006 to 2008/2009), pesticides have been detected at all inshore reef monitoring sites with some clear differences between Regions. Routine monitoring showed the pesticide profile at inshore reef sites is dominated by diuron, atrazine and hexazinone. Other chemicals that can be detected regularly included tebuthiuron and simazine. For most sites diuron was detected at the highest concentrations.

Pesticide concentrations were generally higher in the wet season than the dry season at all sampling sites, often increasing by one to two orders of magnitude. The seasonal difference is most likely due to the fact that pesticide application generally occurs during the wet season, with heavier rainfall mobilising these chemicals and transporting them from catchments to the inshore reef sites. Overall, water concentrations of pesticides were lowest in both the Cape York and Fitzroy Regions (typically below 2 ng/L). The Fitzroy Region had below average river flow for the 2008/2009 period, which would have limited the delivery of pesticides and other water quality contaminants to the inshore marine environment.

In the Wet Tropics Region, the maximum water concentrations of individual pesticides ranged from 2-15 ng/L. Maximum concentrations in the Burdekin Region ranged from 0.2-10 ng/L, and monitoring in the Mackay Whitsunday Region showed that water concentrations for pesticides were all less than 4.7 ng/L (with the exception of one result of 120 ng/L considered to be an outlier but still below the Guideline value for diuron). These results are consistent with data from previous monitoring years.

All data were assessed using a preliminary Pesticide Index based on the Herbicide Equivalency (HEq) to rate results from different sites. All Regions that were monitored for pesticides were assessed to have pesticide ratings in the lower ranges (generally <10 ng/L) and only the Cape York Region had an average pesticide rating in the range <1 ng/L. There were no exceedances of the Guidelines values for pesticides. Further effort is required to progress from proxy based ratings of HEq to categories of ecotoxicology for future reporting.

Pesticide concentrations measured in the Burdekin and Tully River flood plumes were variable, with the highest concentrations detected in low salinity waters sampled close to the peak of the flow events. The type of pesticides detected in the flood plumes varied spatially and temporally, and appeared to correlate to adjacent land use and land management practices. In the Burdekin Region, residues of atrazine and tebuthiuron were detected in the Burdekin River earlier in the wet season (January 2009) near the end of catchment site and at the Burdekin Falls dam. In this Region, sugar cane farming is the primary source of

pesticides other than tebuthiuron (mainly diuron but also atrazine, ametryn, hexazinone), and grazing lands are the primary source of tebuthiuron (Brodie *et al.* 2009). In the Mackay Whitsunday Region, diuron, atrazine and hexazinone were detected; these pesticides are generally associated with sugar cane cultivation in the Region (Brodie *et al.* 2009; Lewis *et al.* 2009). Pesticides detected at offshore locations (but not inshore locations) in the Whitsunday sub-Region in February 2009 are likely to be sourced from local runoff of diuron. In the Tully River plumes, diuron, atrazine, hexazinone and simazine residues were all detected in the January 2009 samples and diuron and hexazinone residues were detected in the samples collected in February 2009. These pesticides (except for simazine) are known to be derived from sugar cane cultivation; the sources of simazine are not widely known but it is mostly used in plantation forestry (Brodie *et al.* 2009). While the concentrations detected in February 2009 were considerably lower, the fact that residues were still detected following high river flows in both January and February 2009 suggests longer term persistence in marine waters, or chronic delivery of pesticides to the GBR.

Overall, the data suggest that high chlorophyll and suspended solid levels are the main water quality issues in the GBR lagoon throughout the year and that elevated pesticide concentrations are largely correlated with wet season delivery and low salinity (plume) waters. The continued monitoring of these parameters will provide important information to determine the specific delivery pathway(s) of nutrients and suspended solids, and whether targeted management options may be required for some locations or Regions that continue to show high concentrations of these pollutants. While nutrients and suspended solids are likely to take extended periods of time to respond to land management improvements, reductions in pesticide runoff to the GBR could be detectable in much shorter timeframes. Accordingly, it is probable that more intensive pesticide sampling in this program and at end of catchment locations is likely to assist in providing shorter term indicators of water quality improvement in response to land management change in the GBR catchments.

5.2 Inshore biological monitoring status and trends

5.2.1 Intertidal seagrass status

Findings from the 2008/2009 monitoring period indicated that intertidal seagrass meadows in the GBR appear to be in a relatively stable condition in terms of abundance and composition, and appear to have recovered from previous declines in several locations. Seagrass species composition has varied over time (since 2003).

Abundance of inter-tidal seagrasses at sampling locations in the Cape York and the Wet Tropics Regions did not change during the 2008/2009 monitoring period, however locations from the Burdekin Region to the southern GBR are either variable or declined during the late 2009 wet season.

Seagrass abundance at estuarine monitoring sites continues to vary greatly seasonally, with significant 'boom and bust' cycles. Abundances appear to be affected by flood events (Preen *et al.* 1995), with the declines in the late 2009 wet season at many of the southern GBR coastal and estuarine sites attributed to flooding.

Over the entire period of the currently available data (2006-2009) all seagrass monitoring sites showed some evidence of reproductive effort (measured as the number of seeds per square metre). However, the sites at Green Island (Cairns), Lugga Bay (Tully River/Mission Beach) and Urangan (Mary River/Hervey Bay) showed virtually no production of reproductive structures across the entire sampling period. A continued absence of flowering and fruiting in these sites will result in poor capacity to recover from disturbance. Inter-annual differences in sexual reproduction are evident and these differences principally relate to the decline of meadows.

Seagrass epiphyte cover appears to be increasing in coastal areas. Combined with evidence from tissue nutrient ratios, data indicates that some sites, particularly coastal sites within the Wet Tropics and Burdekin Regions are becoming nutrient saturated environments. Seagrass ecosystems can survive under nutrient saturated conditions until they reach a point of extreme stress, when the ecological balance changes and decline happens quickly. Macroalgal abundance in seagrass meadows is generally low but variable in coastal and reef habitats.

At the spatial scales of locations and sites, there is considerable variability in seagrass meadow cover. Most changes are likely linked to short-term environmental events and local scale impacts. Seagrasses as bioindicators of the environmental conditions of the GBR indicate a general trend of reducing light availability and nutrient enrichment. Tissue nitrogen levels within the Wet Tropics and Burdekin Regions coastal and mid-shelf reef habitats have increased over the last fifteen years and further increased from 2005 to 2008. The implications of this are that in these Regions many of the sites are becoming nutrient saturated. This finding correlates with data from the water quality monitoring program where chlorophyll and turbidity levels routinely exceeded the Guideline values.

Within canopy temperatures of seagrass meadows were warmer at northern locations and cooler at southern locations compared to previous monitoring years. Temperatures above 40°C were recorded at Picnic Bay, Magnetic Island; these temperatures are known to be detrimental to seagrass health.

In conclusion, the health of inter-tidal seagrasses in the GBR are variable across locations and sites, and there is concern about declining abundance and light availability, lower reproductive potential, higher nutrient enrichment, and the development of nutrient saturated conditions at a number GBR monitoring sites. Ongoing monitoring is important to determine if these preliminary findings can be confirmed.

5.2.2 Coral reef status

Of the reefs surveyed in both 2007 and 2008 there was no overall change in the cover of hard corals (mean hard coral cover over all Regions was 36% in both years). Increases in cover on reefs in the Wet Tropics Region were essentially cancelled out by decreases on reefs in other Regions. Reefs in the Wet Tropics Region mostly showed increases in coral cover, with those reefs impacted by Tropical Cyclone *Larry* in 2006 showing signs of recovery and other reefs in the Region continuing a longer-term increasing trend.

On reef sites, the average density of juvenile colonies per square metre has reduced from a high of 5.8 in 2005 to a low of 3.9 in 2008. This decline has been observed in all Regions. It is possible that such variation occurs naturally. However, as there are no previous studies of this nature only future data from this program can provide estimates of the scales and magnitudes of variation in juvenile abundances. The fact that coral cover has remained relatively stable over the same period excludes space (or lack of) as an explanation for the observed declines. Possible explanations for these declines include a combination of variation in river flows and response to disturbance events.

Over the period 2005-2008 the average number of hard coral genera recorded in this monitoring program on the fourteen reef sites has remained relatively stable or increased slightly in 2008. At the level of genus there is no evidence of a loss of diversity.

Estimates of coral community status presented as a *coral reef health index* were calculated as an aggregate score for four indicators: coral cover, macroalgal cover, juvenile hard coral density, and settlement of coral spat. Table 3.9 provides a more detailed explanation of the

threshold values for positive, neutral, and negative assessments for each of the four indicators.

A positive score of coral community status was found for the Daintree and Johnstone-Russell/Mulgrave sub-Regions with coral communities on average showing generally high coral cover that increased during periods without acute disturbance, and the reefs had low cover of macroalgae and relatively high densities of juvenile colonies. Negative status scores were returned for reefs in the Herbert Tully sub-Region of the Wet Tropics and also reefs in the Burdekin Region. On average, reefs in these Regions had relatively high cover of macroalgae and moderate to low coral cover that did not show clear evidence of increase. There has been no recovery observed in the Herbert Tully sub-Region post Cyclone *Larry* in 2006, which may be an indication of local environmental conditions hindering recruitment and recovery. However, more surveys over time are required to detect any conclusive trends.

Coral communities in the Mackay Whitsunday Region had a positive score of coral community status. Average coral cover was high but did not increase despite a lack of acute disturbance. The cover of macroalgae was low and the relative density of juvenile colonies and settlement of spat to tiles was moderate relative to other Regions.

The assessment of coral community status in the Fitzroy Region was marginally positive with high average coral cover and high settlement of spat but also high macroalgal cover and low densities of juvenile colonies. In this Region corals have been repeatedly affected by flood events and coral bleaching with substantial declines in coral cover observed in 1998, 2002 and 2006. However, rapid recovery has been well documented (Sweatman *et al.* 2007; Diaz-Pulido *et al.* 2009).

5.3 Emerging relationships (forcing factors) that influence ecosystem response

Since the commencement of the MMP, one of the primary challenges for the program has been the integration of water quality data with GBR ecosystem responses at both Regional and GBR-wide scales. The theory of these relationships is well established, and there is abundant evidence from Australia and overseas, that the overall health of seagrass and coral reef habitats are affected by the quality of the water in which they live. The risk to marine organisms in the GBR from reduced water quality and the apparent biodiversity loss of inshore reefs and seagrass meadows adjacent to catchments with intensive agriculture has been described in recent years (see Brodie *et al.* 2008; DeVantier *et al.* 2006; Fabricius 2005; Schaffelke *et al.* 2005; Pandolfi *et al.* 2003; Haynes *et al.* 2000a). For example, a correlation between water quality parameters and coral reef condition is evident throughout water quality gradients in the Whitsunday Island sub-Region (Fabricius and De'ath 2004; Fabricius *et al.* 2005). Observed changes include variations in the cover, composition and relative abundance of hard corals, soft corals and macroalgae, recruitment effects on juvenile hard corals and changes to the abundance of coral bioeroders. Catchment runoff, physical disturbance, low light levels and low nutrient concentrations, respectively, are the main drivers of each of the three seagrass habitat types found in the GBR, and changes to any or all of these factors may cause seagrass decline (Waycott *et al.* 2005). In addition, several studies have demonstrated the risks due to increased nutrient concentrations, including increased frequency of crown of thorns starfish outbreaks (Brodie *et al.* 2005). Laboratory studies have shown the high toxicity of several commonly used pesticides in GBR catchments on marine organisms (eg. Haynes *et al.* 2000a; Negri *et al.* 2005). Residues of these pesticides (particularly the herbicides diuron and atrazine) are now ubiquitous in GBR lagoon waters adjacent to catchments with significant pesticide use (Brodie *et al.* 2008; Prange *et al.* 2009; Rohde *et al.* 2006; Shaw and Mueller 2005; Haynes *et al.* 2000b) and the chronic effects of these pesticides are unknown.

The application of this knowledge to the MMP has allowed the program design to be optimised over the four years of implementation, and has also assisted with data interpretation. An overview of the relationships between the MMP seagrass status, coral status and water quality data as they are currently understood is provided below.

5.3.1 Seagrass status and water quality

The distribution and growth of seagrasses is dependent on a variety of factors such as temperature, salinity, nutrient availability, substratum characteristics, and underwater light availability (related to turbidity) as well as hydrodynamic factors, e.g. waves and currents. The greatest potential loss of seagrasses is associated with downstream effects of land use and from global influences such as climate change and the related possible increase in storm intensity (Schaffelke *et al.* 2005). In relation to water quality, the most common cause of seagrass loss is the reduction of light availability due to chronic increase in dissolved nutrient concentrations which leads to proliferation of macroalgae thereby reducing the amount of light reaching seagrass (e.g. phytoplankton, macroalgae or algal epiphytes on seagrass leaves and stems), or chronic and pulsed increases in suspended solids and particles leading to increased turbidity (Schaffelke *et al.* 2005). In addition, seagrass species have specific environmental requirements and changes in sediment characteristics can affect their survival (for example, when a sediment becomes sandy, a species adapted to mud may be lost).

Several additional indicators are measured in the MMP in an attempt to identify the relationship between seagrass health and water quality characteristics. Specifically, seagrass tissue nutrients and epiphyte cover are measured to assess the consequences of nutrient availability and light on seagrass health. In 2008/2009, temperature loggers were deployed to measure thermal stress on seagrass meadows. Additionally, sediment pesticide concentrations were measured at sampling locations. Reproductive health of seagrasses was also included as an indication of the resilience of seagrasses to recover from the loss of an area of seagrass through the recruitment of new plants.

Seagrass tissue C:N ratios <20 are indicative of low light environments (Johnson *et al.* 2006). In 2008, seagrass from all three habitat types (coast, reef and estuary) had C:N ratios <20; these levels have mostly declined since 2005, with levels of C:N within *Halophila ovalis* significantly and consistently declining from 2006 to 2008. These low C:N levels in 2008 potentially indicate a reduction in light availability.

Seagrass tissue C:P values <500 most likely indicate phosphorus enriched habitats (Burkholder *et al.* 2007). Such ratios were present in reef, estuary and coastal habitats for all species (except coastal *Zostera capricorni* in 2008). These values have mostly decreased since 2005 indicating increasing nutrient enrichment of seagrass sediments.

Tissue N:P levels of 25-30 indicate seagrass to be nutrient replete, and their environment to be nutrient saturated (Johnson *et al.* 2006). Within all species and habitats (except *Halodule uninervis* in coastal habitats) levels of N:P were below 30 in 2008, indicating potential limitation of N, and enrichment of P. Specifically within reef and estuary environments *H. uninervis* and *Zostera capricorni* had sufficient nutrients. Within coastal habitats these levels have consistently increased since 2005, indicating increasing levels of nitrogen enrichment. This was a significant trend of increase within *H. uninervis* (the dominant coastal species). Within estuary and reef habitats, N:P has remained mostly unchanged between years over the four years of the MMP.

Locations where seagrasses are growing in generally low light environments (C:N ratio is low), with a relatively large phosphorus pool (C:P ratio <500) and an even larger N pool (N:P is high) would indicate relatively poor water quality. Three coastal locations met these criteria

in the 2008/2009 monitoring period: Luggar Bay and Yule Point (both Wet Tropics Region) and Townsville (Burdekin Region). Flood plume modelling estimates indicate that Yule Point is within a zone impacted annually (Devlin *et al.* 2001) by the Barron River. During major flood events, plumes from the Mulgrave-Russell and Johnstone Rivers could also impact Yule Point. In the southern section of the Wet Tropics, the coastal seagrass meadows of Luggar Bay would be influenced primarily by the Tully and Murray Rivers (approximately 8km and 15km south of Luggar Bay respectively) which experience regular flood events (Devlin and Schaffelke 2009a). The Townsville (coastal) monitoring sites are located in the zone of influence of the Burdekin River, which experienced significant flow events in the last two years. It is estimated that the inshore areas north of the Burdekin River (including Magnetic Island) receive riverine waters on a less frequent basis, perhaps every two to three years (Wolanski *et al.* 1981; Maughan *et al.* 2008).

Devlin and Schaffelke (2009) reported that approximately 93% of seagrass meadows within the Tully sub-Region of the Wet Tropics were inundated every year by primary flood plumes, exposing the seagrass to intermittently high sediment and high nutrient concentrations and potentially high loads of total suspended sediment. Luggar Bay and Dunk Island are also located within the modelled diuron (0.1-0.9 ng/L) first flush plume zone for the Tully-Murray Rivers (Lewis *et al.* 2009). Although no pesticides were present in seagrass sediments in the 2008/2009 monitoring period, they have been reported previously from Luggar Bay in April 2006 (McKenzie *et al.* 2006). Pesticides have never been reported from seagrass sediments on Dunk Island, however monitoring was not established at this location until late in the 2006 dry season.

The long-term consequences of degraded water quality (low light, elevated nutrients) reported at some seagrass locations in this study are unclear. Although little is known about the physiological mechanisms that control seagrass responses to nutrient enrichment, increased growth is generally expected until light interactions result in seagrass decline (Touchette and Burkholder 2000; Burkholder *et al.* 2007). Seagrasses also respond at the meadow scale to nitrogen enrichment. Shifts in seagrass dominance as a consequence of nitrogen enrichment have been reported in tropical seagrasses, where species with higher elemental requirements have a competitive advantage (Fourqurean *et al.* 1997; Burkholder *et al.* 2007). Elevated nutrient content of plants can also increase rates of herbivory. For example, Boyer and others (2004) reported nutrient enrichment increased consumption of seagrass by thirty percent. Grazing by macro-herbivores (dugong, green sea turtle), has a significant impact on the structure of seagrass communities in northern Australia (Carruthers *et al.* 2002).

Seagrasses respond to changes in light at a range of time-scales from seconds to months. Many of the physical expressions of seagrass health (e.g. percent cover) take weeks to months to occur, therefore, it is useful to consider the light environment of the seagrass meadows on these scales. The deployment of four light loggers at intertidal and subtidal seagrass meadows in the Burdekin (Magnetic Island) and Wet Tropics Regions (Dunk Island, Green Island, Low Isles) in 2008/2009 indicated that seagrass responses to light may not follow annual changes in solar radiation, and may be related to poor water quality. However, light measurements at canopy height are not a true indication of water quality as the seagrasses are growing at different depths. To assist in clarifying the results, water quality loggers (chlorophyll and turbidity loggers) will be deployed at subtidal seagrass sites (Magnetic Island, Dunk Island and Green Island) in 2009/10. Data from these loggers will help to elucidate the source of changes in light at the seagrass meadows in an effort to elucidate thresholds and the role of light as a driver in seagrass distribution.

Seagrasses also respond to light limitation at the plant scale (e.g. pigment content, leaf morphology) and meadow scales (e.g. distribution and species composition; Ralph *et al.* 2007). As minimum light requirements for seagrasses are generally species-specific, species

better adapted to low light would be competitively advantaged by lower light environments (Ralph *et al.* 2007). However, seagrasses will only persist until light conditions are insufficient to maintain a positive carbon balance, leading to a decline in seagrass growth and distribution (Ralph *et al.* 2007). The threshold at which this occurs is currently being investigated as part of a collaborative research project through the MTSRF and will assist to interpret the MMP data in future reporting.

Pollutants such as pesticides (in particular herbicides), metals and petrochemicals clearly affect seagrass health, although there are few examples of a definite causal link between seagrass loss and herbicide concentrations, and none in Queensland (McKenzie *et al.* 2009). However, based on laboratory aquarium studies, it is known that diuron suppresses photosynthesis in several seagrass species at concentrations previously detected in coastal and intertidal seagrasses adjacent to catchments with high agricultural use (Lewis *et al.* 2009; McMahon *et al.* 2005; Haynes 2000b). The key risk factor for the run-off of herbicides is likely to be significant rainfall occurring shortly after application. While herbicides were not detected in sediments in 2008/2009, they were detected in the water column in the passive samplers and in the flood plume. However, these locations do not coincide sufficiently with the seagrass meadows to allow any robust conclusions to be drawn regarding herbicide detections and seagrass health for the 2008/2009 sampling year.

The initial results of within canopy temperatures of seagrass meadows revealed that further investigation is warranted, as temperatures exceeded those that are thought to be detrimental to seagrass health.

The reproductive health of seagrasses was assessed as an indicator of the ability of seagrass meadows to recover after disturbance or loss through the recruitment of new plants. This assessment showed that seagrasses from Green Island, Lugga Bay and Urangan were in poor reproductive health. Without the production of seeds, the capacity of these seagrass meadows to recover will be impacted. Given that coastal seagrasses are prone to small scale disturbances that cause local losses and then recover in relatively short periods of time, the need for a local seed source is considerable. These sites require further assessment to determine the cause of their ongoing inability to produce seeds and evaluate if this indicates system decline.

Further knowledge is required of the synergistic effects between higher nutrient concentrations and exposure to other pollutants, and between water quality parameters and other disturbances or factors that influence health and production of seagrasses. These influences are interlinked in complex ways and the findings of the MMP and supporting MTSRF research is increasing the understanding of these links.

5.3.2 Coral status and water quality

Environmental conditions clearly influence the benthic communities found on coastal and inshore coral reefs of the GBR. These reefs differ markedly from those found in clearer, offshore waters (e.g. Done 1982; Wismer *et al.* 2009). Within the inshore zone there appears to be a threshold beyond which environmental conditions are not suitable for coral reef development, indicated for example by the historical lack of corals on hard substrates in some areas. Where coral reefs can develop, the environmental conditions, such as water quality, explain some of the considerable variation in coral community composition (Thompson *et al.* 2009; Fabricius *et al.* 2004; van Woesik *et al.* 1999; van Woesik and Done 1997) and most likely reflects species-specific environmental tolerances (e.g. Anthony 2006; Anthony and Connolly 2004; Anthony and Fabricius 2000; Stafford-Smith and Ormond 1992). The processes shaping biological communities, however, are complex and variable depending on spatial and temporal scales and are likely to include local interactions of various factors such as water quality, climate change and physical disturbance. This

complexity may obscure the relationships between coral communities and specific environmental conditions and has hampered the quantification of anthropogenic impacts on inshore coral communities.

Specific indicators of environmental stress on coral reef communities have been used to document stress-related changes in benthic community composition. For example, reef sediments in the Mackay Whitsunday Region have consistently high levels of fine grained particles, compared to other regions, and these values have increased since 2005. Densities of juvenile corals in the Mackay Whitsunday Region have declined at the same time as these observed changes in sediment composition. The increase in fine grain sediment particles are related to changes in river flows of the nearest rivers (Proserpine, O'Connell and Pioneer Rivers); flows were below long-term medians for several years prior to 2005 and since 2006 have been substantially higher than median flow levels. Fluctuating sediment loads from the catchment lead to local changes in marine sediment composition. As turbidity is largely a function of wave and tidal resuspension (Larcombe *et al.* 1995), changes in sediment composition toward finer grained particles would logically lead to increased levels of turbidity. Both turbidity and sedimentation have the potential to stress corals by reducing light availability for photosynthesis, with sedimentation also incurring an energy cost to corals when active removal is required. Juvenile corals are most susceptible to turbidity and sedimentation (Fabricius 2005).

Clear changes in sediment composition have not been observed in other Regions, however, similar correlations between higher river flows in recent years and lower juvenile coral densities are consistent across Regions. Detailed time series of turbidity are now becoming available for the fourteen core MMP reefs from the water quality monitoring instruments deployed since October 2007. This will allow the tracking of turbidity levels after flood events of different magnitude. A current MTRSF research project also focuses on the question of how water quality in the inshore zone of the GBR is linked to sediment discharges from rivers and aims to answer the questions of how long catchment-sourced fine particles remain in the system and undergo resuspension, and how water clarity changes throughout the year, especially after flood events (Wolanski *et al.* 2008; Humphrey *et al.* 2008).

Inshore coral community composition also showed a relationship to water column chlorophyll *a* levels at ten of the fourteen cores reef sites. Where the annual mean Guideline value for chlorophyll *a* (0.45 µg/L) was exceeded (see Table 3.4), reefs generally had a high cover of macroalgae (eg. Pandora Reef and Geoffrey Bay in the Burdekin Region). Where annual means were below the Guideline value, macroalgal cover was low (eg. Snapper Island in the Wet Tropics Region). The exceptions to this pattern were Barren and Humpy Islands in the Fitzroy Region, which had high cover of the brown macroalgae *Lobophora variegata* despite low chlorophyll concentrations, and Pelorus Island (Burdekin Region) and Double Cone Island (Mackay Whitsunday Region) which exceeded the chlorophyll Guideline value but currently have only low macroalgal cover. It would be of interest to observe how these communities change after an acute disturbance increases available substratum for algal colonisation (see Done *et al.* 2007; Diaz-Pulido *et al.* 2009).

Coral communities vary along the steep environmental gradients within the inshore zone (Anthony and Connolly 2004; Fabricius *et al.* 2005) and are generally located on a gradient away from major river mouths (De'ath and Fabricius 2008). This pattern was documented by the MMP. Coral reef communities will be susceptible to any deterioration in environmental conditions, such as rates of sedimentation, levels of turbidity, nutrient concentrations or other pressures associated with anthropogenic activities in the connected catchments or coastal zones. Conversely, if improvements under Reef Plan lead to better water quality in the inshore GBR, it is expected that coral communities would change over time to reflect the improved conditions (De'ath and Fabricius 2008), including increased resilience to future disturbances such as thermal bleaching (Woolridge 2009).

While responses of coral reef communities to turbidity and nutrients are relatively well understood (e.g. Fabricius 2005; De'ath and Fabricius 2008; Thompson *et al.* 2009; Uthicke *et al.* in press), responses to pesticide exposure have only been documented in controlled laboratory experiments (e.g. Negri *et al.* 2005). As demonstrated in this report, inshore reefs are regularly exposed to detectable concentrations of pesticides during flood plumes (see also Lewis *et al.* 2009) and concentrations at inshore reefs are measurable during both the wet and dry seasons (see also Prange *et al.* 2009). The consequences of this chronic exposure are currently unknown and further investigation is required. However, chronic stress due to poor water quality is likely to manifest as either an increase in the susceptibility of corals to disturbance events such as thermal bleaching (Wooldridge 2009) or inhibition of their recovery following a disturbance. Either or both of these outcomes would result in a change in community composition. Such shifts are likely to occur after disturbance events as species suited to the changed environmental conditions will predominantly re-colonise available substratum. This differs from non-disturbed communities where gradual shifts in environmental conditions may be masked by physiological (Anthony and Fabricius 2000) and morphological (Anthony *et al.* 2005) plasticity of corals that allow existing colonies to persist in conditions they would not be able to recruit into, forming relic communities.

Perhaps of most concern is the proposed synergy between nutrient loads and susceptibility of corals to thermal bleaching (Wooldridge 2009). Increased sea temperatures have globally increased the frequency of broad scale and severe mortality events of coral reefs (Hoegh-Guldberg 1999; Wilkinson 2004). The poor status of coral reef communities in the Burdekin Region is likely to be the result of coral mortality during the mass bleaching event in the summer of 1998 (Berkelmans 2004; Sweatman *et al.* 2007) and subsequent limited recovery. Susceptibility to thermal stress can be heightened by poor water quality and recovery hindered (Hoegh-Guldberg *et al.* 2007). The negligible increase in coral cover in the Burdekin Region may be due to a lack of larval supply and low survival, indicated by regionally low settlement of spat and low density of hard coral juveniles (Thompson and Dolman 2009). With the frequency and severity of disturbance events projected to increase in response to continuing rises in greenhouse gases (Steffen 2009) any increase in coral susceptibility to thermal stress as a result of local anthropogenic nutrient loads will have significant consequences for GBR inshore reef communities. Interactions between water quality and climate change are poorly understood and require further practical investigation.

The monitoring of settlement of spat to tiles, juvenile coral abundance and adult community cover provided insights into coral community dynamics and effects of environmental conditions on these key life stages. Based on the information available to date, increases in adult cover during non-disturbance periods are generally due to increases in the cover of the family Acroporidae, both through the growth of existing colonies and settlement and growth of juvenile colonies. The family Acroporidae is well known for its rapid growth, which gives it a short-term competitive advantage over slower growing taxa (e.g. Baird and Hughes 2000). It is, however, more susceptible to disturbance than many other taxa (Woodley *et al.* 1981; Baird and Marshall 2002; Sweatman *et al.* 2007). Adult coral cover has not increased on reefs with few juvenile and adult Acroporidae, despite a lack of disturbance. Exceptions are reefs in the Johnstone-Russell/Mulgrave sub-region of the Wet Tropics where the cover of *Porites* sp. has increased. In communities with high coral cover a lack of increase may simply reflect the lack of space into which corals can grow or recruit. When cover is moderate or low and space is available, a lack of increase during periods with no disturbance suggests a lack of resilience, likely to be related to the environmental conditions at the locations. On reefs that have shown recovery after disturbance, juvenile colonies of a wide range of taxa were found but this species diversity was not present on settlement tiles, implying insufficient broodstock may be available at local and regional scales. In contrast, larvae of *Acroporidae* are the predominant species recorded on settlement tiles, but are only common in the juvenile and adult communities of a few reefs, predominantly those with

generally low turbidity (Thompson *et al.* 2009). It appears that spat availability alone does not translate into recruitment to the juvenile coral community. Either an inability of *Acroporidae* sp. to settle on the natural reef substratum (e.g. due to high sedimentation) or post settlement mortality of spat, could explain this observation and further work is required to determine this low settlement.

The recognised differences in the species composition of coral reef communities provide a useful starting point for the detection of long-term trends in coral reef benthos. The results to date indicate that the particulate components of marine water quality (suspended solids, particulate nutrients and carbon) may be emerging drivers of coral reef communities.

5.4 Links with other Programs and future directions

The information collected in the MMP is intended to be compared with measurements of the source and delivery of land-based pollutants to the GBR to support Reef Plan monitoring and evaluation initiatives. In 2008/2009, considerable effort went into designing the Reef Plan Paddock to Reef Integrated Monitoring, Modelling and Reporting Program supported through Reef Plan and Reef Rescue initiatives. The program will use a combination of monitoring and modelling techniques to inform progress on achieving sediment and nutrient load reduction targets by 2013. In the next four years, monitoring and modelling results will be used to report end-of-catchment loads of key pollutants for every major catchment in the GBR for current condition (2008/2009 wet season) and changes in these loads every year thereafter (2010-2013). In the longer term, the Reef Plan will also need to demonstrate progress against the long-term goal added in the 2009 revision of the Reef Plan, which is to ensure that by 2020 the quality of water entering the GBR from adjacent catchments has no detrimental impact on the health and resilience of the Reef. The program involves monitoring and modelling a range of attributes including management practices and water quality at the paddock, sub catchment, catchment and marine scales. This approach requires the ability to link the monitoring and modelling outputs at each scale and then across scales, and is described in detail in the Program design document (Department of the Premier and Cabinet 2009). Integration and alignment of several programs, including the MMP will be essential to ensure reporting against the Reef Plan targets.

There is increasing confidence in the MMP to demonstrate improvements that may be attributed to Reef Plan investment, particularly as spatial and temporal comparisons of future monitoring data can be made with the four years of existing data. However, a major limitation for detection of improvements in water quality and GBR ecosystem health is the ability to detect change in the system within the policy timeframes of management of the GBR (Bainbridge *et al.* 2009). System variability, due to factors including natural delivery of sediments and nutrients, natural disturbances and limitations in our capacity to monitor and model material transport and fate (Waterhouse *et al.* 2009; Bainbridge *et al.* 2009) all combine to make detection of trends in the short to medium term difficult (an exception may be the detection of response to improved pesticide management).

Notwithstanding substantial advances in remote sensing capability for GBR water quality monitoring in recent years, there are still limitations which require further development before the techniques can be applied as a compliance tool. In particular, the number of available observations is significantly lower in the wet season than the dry season for all Regions, thereby reducing the available dataset for validation and assessment. This is due to the higher cloud cover and aerosol concentration in the monsoon season. It is possible that the cloud cover introduces a sampling bias, which in turn will affect the estimate of the median and mean concentration or any other statistical analysis of the imagery. The effect of cloud cover and of a biased sampling for cloud free data needs further investigation using time series data from a moored sensor or the output from biogeochemical models. In addition, the presence of *Trichodesmium* leads to a gross underestimation and overestimation of

chlorophyll in the water column because of (sub) surface expression and spatial heterogeneity. To overcome this issue, it is recommended that an operational algorithm to identify *Trichodesmium* affected pixels for MODIS imagery be implemented followed by development of an inversion algorithm to estimate chlorophyll for pixels with a *Trichodesmium* expression.

Further validation is also a priority for future effort for remote sensing applications. Recently, the statistical distributions of the chlorophyll concentrations retrieved with the algorithm from MODIS-AQUA data were compared with the *in-situ* data from the GBR Long Term Monitoring Program (AIMS) for each Region for the wet and dry seasons 2005/2006. In general the results show a higher chlorophyll value (expressed as medians and 25% to 75% percentiles) for the *in situ* samples and the remote sensing estimates of inshore waters than for midshelf and offshore waters. In general, the measured *in situ* sample ranges were within the remotely sensed values, however, further validation and comparison would enhance confidence in the application of these techniques as a monitoring tool for Paddock to Reef reporting.

This highlights the importance of the need for innovative monitoring and modelling techniques, and an improved understanding of the system dynamics to inform management decisions relating to altered water quality in the GBR.

In particular, linkages between marine ecosystem response and external drivers including freshwater flow, end of catchment pollutant loads, the occurrence and intensity of cyclonic events and climate change need to be more fully understood to enable full performance evaluation of Reef Plan. While the MMP provides an extremely important component of the evaluation, models (catchment, end of catchment and marine) are required to simulate the generation, transport, fate and impacts of contaminants as they pass from catchments through estuaries and into the GBR lagoon and beyond. A new project commenced in October 2009 to progress the development of a GBR-wide hydrodynamic model. The models still need to be supported by robust monitoring activities for calibration and validation, and future research that supports development of ecosystem health indicators, understanding of the relationships between external drivers and ecosystem response and integration of various monitoring techniques will play an important role in further optimisation of the program.

6. Conclusions

In conclusion, the four years of monitoring under the MMP up to 2008/2009 have provided valuable insights into the spatial and temporal patterns of water quality in the inshore GBR, and the status of GBR ecosystems – seagrass meadows and coral reefs. The data suggest that high chlorophyll (as an indicator of bio-available nutrients) and turbidity levels are the main water quality issues in the GBR throughout the year and that elevated pesticide concentrations are largely correlated with low salinity (flood plume) waters and wet season delivery. The continued monitoring of these parameters will provide important information to determine the specific delivery pathway of these variables and whether revised management interventions may be required for some locations or Regions that continue to show high concentrations of these pollutants.

While water quality indicators such as nutrients and suspended solids are likely to take extended periods of time to respond to the influence of land management improvements (for example, years to decades), reductions in pesticide runoff to the GBR lagoon should be detectable in much shorter timeframes. Accordingly, more intensive pesticide sampling at end of catchment locations will assist in providing shorter term indicators of water quality improvement in response to land management practice change in GBR catchments. In addition, further work in designing the metrics that will be used to report compliance with the Guidelines for inshore water quality data, and investigation of how to combine the assessment over more variables is needed to provide a higher degree of integration and confidence in these results.

It is now possible to identify emerging trends between inshore GBR water quality and the status of key GBR ecosystems – seagrasses and coral reefs. For example, there is information regarding seasonal patterns of water quality, inshore ecosystems that are at risk of regular exposure to flood plumes and further data that supports current knowledge regarding pollutants of concern in relation to ecological impacts that can inform future management. Future monitoring under the MMP, coupled with new information from complementary MTSRF research, will provide further insight into where management effort should be focused both in the GBR catchment and in the marine environment. As changes in land management practices in the GBR catchments under Reef Plan lead to decreased loads of sediments, nutrients and pesticides to GBR coastal and inshore waters, associated changes in coral reef communities can be expected to be detected after an initial lag period. Although it must be acknowledged that other external drivers will always present uncertainties in attributing land-based improvements to ecosystem response. High frequency water quality monitoring and improved system understanding will improve this assessment. In particular, linkages between marine ecosystem response and external drivers including freshwater flow, end of catchment pollutant loads, the occurrence and intensity of cyclonic events and climate change need to be more fully understood to enable full performance evaluation of Reef Plan. In addition, while the development of remote sensing techniques through this program is showing positive advances as a high frequency water quality monitoring technique over a large spatial extent, better integration of remote sensing and in situ sampling will help to reveal how and with what degree of confidence remote sensing can start to replace in situ sampling.

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Appendix 1: Marine Monitoring Program methods

Inshore GBR water quality monitoring

Ambient water quality

Marine water quality monitoring is carried out in the inshore waters of the GBR (within twenty kilometres of the coast) to assess trends over time in concentrations of key water quality indicators: suspended solids, nutrients and pesticides. Monitoring is required to establish the extent of improvements in GBR lagoon water quality resulting from reductions in pollutants discharged from GBR catchments. Monitoring is conducted at fourteen inshore sites associated with marine biological monitoring that allows for comparisons of these water quality and biological data sets. Sampling is undertaken using traditional water sampling techniques, state of the art sensors with long-term data logging capacity and remote sensing.

The main objectives of long-term inshore water quality monitoring are to:

- Determine persistent spatial patterns and, where long-term data are already available, long-term (decadal) trends in inshore water quality within the GBR lagoon, particularly in inshore habitats most directly affected by river runoff;
- Determine local water quality using autonomous instruments for high-frequency measurements at inshore reef sites;
- Develop improved algorithms for water quality and atmospheric corrections for the application of remote sensing techniques in the waters of the GBR;
- Assess spatial and temporal trends in near-surface concentrations of suspended solids, turbidity, CDOM and chlorophyll *a* for the coastal and lagoon waters of the GBR;
- Determine time integrated baseline concentrations of specific organic chemicals in water with the aim to evaluate long-term trends in pesticide concentrations along inshore waters of the GBR; and
- Provide environmental data to correlate with biological assessments of coral and seagrass status.

The location of the water quality monitoring sites are shown in Figure A1.1.

Manual water quality sampling is undertaken at fourteen core inshore coral reef monitoring sites during the wet and dry seasons (refer to Figure A1.2) for dissolved nutrients and carbon (NH_4 , NO_2 , NO_3 , PO_4 , $\text{Si}(\text{OH})_4$), DON, DOP, DOC), particulate nutrients and carbon (PN, PP, POC), suspended solids (SS), turbidity (secchi depth), salinity and plant pigments (chlorophyll *a* and phaeophytin). Sampling of the six open water stations of the 'Cairns Coastal Transect', which has been undertaken by the Australian Institute of Marine Science (AIMS) since 1989, was also continued in 2008.

Autonomous water quality loggers (Eco FLNTUSB loggers) were also deployed at all fourteen water quality monitoring sites (Figure A-1.1) at five metres' depth (LAT), near the inshore reef surveys sites. The Eco FLNTUSB combination instruments perform simultaneous *in situ* measurements of chlorophyll fluorescence, turbidity and temperature at ten-minute intervals. Time-series data are summarised as daily means, calculated from the readings obtained every ten minutes. Instrumental data are validated by comparison with chlorophyll and suspended solid concentrations obtained by analyses of water samples collected close to the instruments, carried out at each change-over.

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

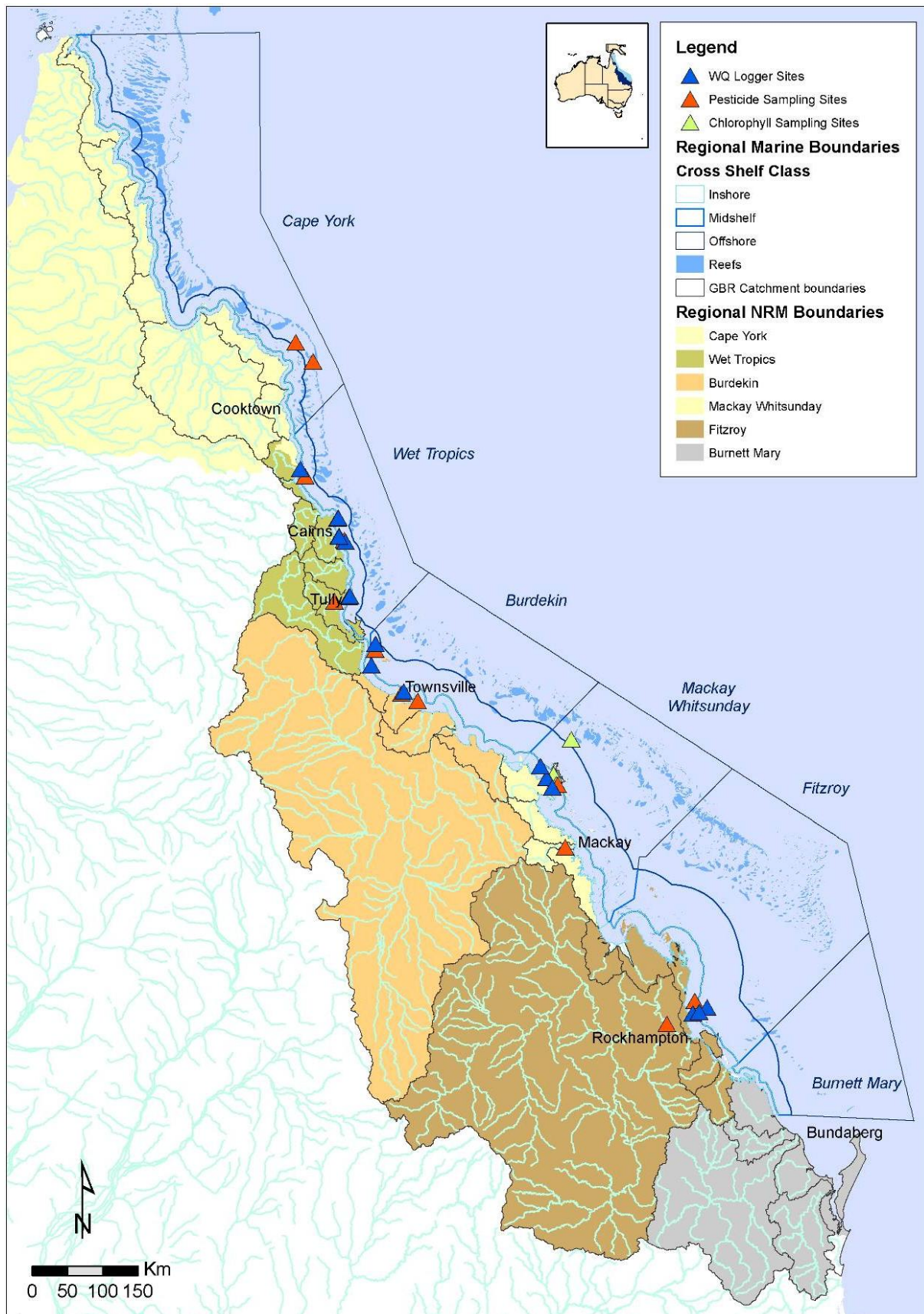


Figure A1.1: Inshore water quality sampling locations in the Marine Monitoring Program.

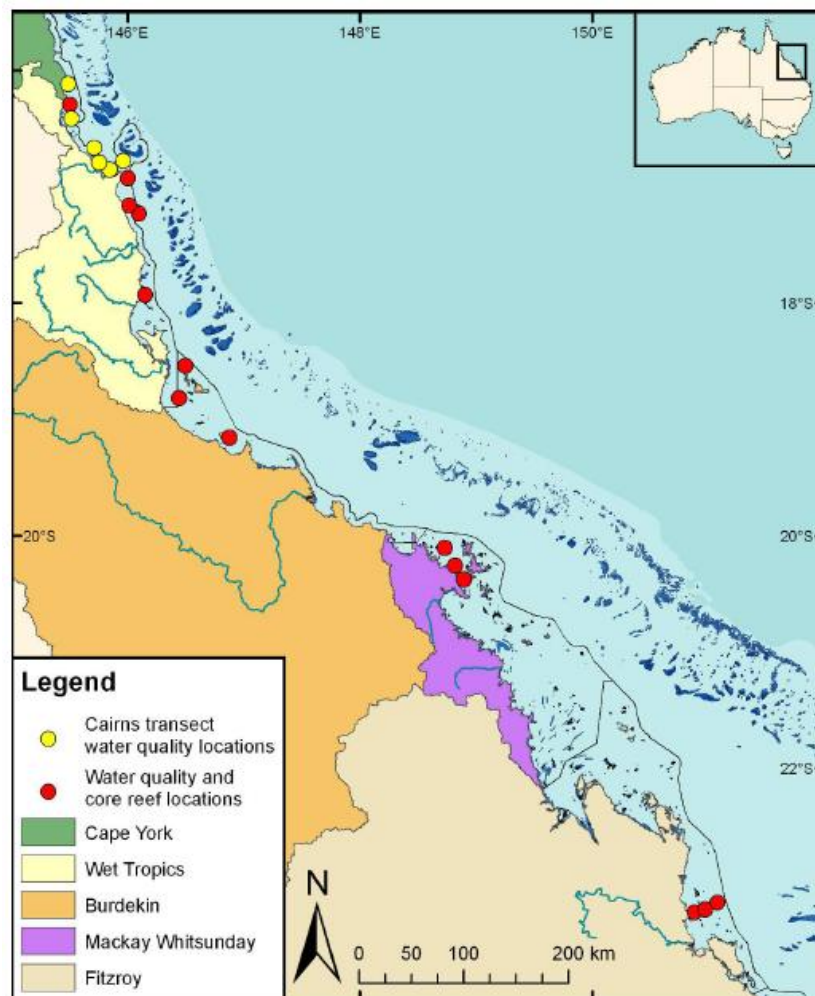


Figure A1.2: Sampling locations under the MMP inshore marine water quality task, Cairns Coastal Transect. Red symbols indicate the fourteen locations where autonomous water quality instruments (temperature, chlorophyll and turbidity) were deployed and regular water quality was undertaken; these locations are also coral reef sites under the inshore coral reef monitoring (see Figure A1.3). Yellow symbols are the locations of the Cairns Coastal Transect, sampled by the AIMS from 1989-2008 (Source: AIMS).

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 K_d), chlorophyll *a* and coloured dissolved organic matter (CDOM) for the 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.

The application of the NASA standard atmospheric correction algorithm as implemented in SeaDAS v5.1.1 systematically retrieves negative water-leaving radiances for the GBR coastal waters. A new atmospheric correction algorithm has been developed for GBR coastal waters by inverse modelling of radiative transfer (RT) calculations within a coupled ocean-atmosphere system by utilizing an artificial neural network (ANN) technique (Schroeder *et al.* 2008). The proposed atmospheric correction scheme provides a significant improvement in accuracy for the retrieval of reflectance data from MODIS Terra/Aqua measurements. From match-up analysis within coastal waters an overall mean absolute percentage error of 17.5%

within the spectral range of 412-748 nm is derived. The algorithm simultaneously estimates the concentration of chlorophyll, total suspended solid, CDOM and the vertical attenuation coefficient, K_d and has been improved in the last twelve months through further adjustment of optical properties of phytoplankton, incorporation of new Artificial Neural Network atmospheric correction and further validation.

Since the commencement of the MMP, significant investment from the program has supported development of remote sensing as a monitoring tool for water quality (chlorophyll, CDOM, TSM and K_d) in the GBR. These improvements have enhanced the confidence in remote sensing estimates and it is intended that remote sensing will soon be a primary tool for detecting broad scale changes in GBR water quality. In 2008/2009 new analytical tools were investigated for understanding trends and anomalies of GBR waters (specifically wet season to dry season variability, river plume composition and extent of algal blooms) based on the optical characteristics of inshore GBR waters and validation with *in situ* water quality data where possible.

Notwithstanding substantial advances in remote sensing capability for water quality monitoring in the GBR in recent years, there are still some limitations which require further development before the techniques can be applied as a compliance tool. In particular, the number of available observations is significantly lower in the wet season than the dry season for all the regions, thereby reducing the available dataset for validation and assessment. This is due to the higher cloud cover and aerosol concentration in the monsoon or wet season. It is possible that the cloud cover introduces a bias in the sampling, which in turn will affect the estimate of the median and mean concentration or any other statistical analysis of the imagery. The effect of cloud cover and of a biased sampling for cloud free data needs further investigation using time series data from a moored sensor or the output from biogeochemical models. In addition, the presence of *Trichodesmium* leads to a gross underestimation and overestimation of chlorophyll in the water column because of (sub-) surface expression and spatial heterogeneity. To overcome this issue, it is recommended that an operational algorithm to identify *Trichodesmium* affected pixels for MODIS imagery be implemented followed by development of an inversion algorithm to estimate chlorophyll for pixels with a *Trichodesmium* expression.

Further validation is also a priority for future effort. The statistical distributions of the chlorophyll retrieved with the algorithm from MODIS-AQUA data were compared with the *in situ* data from the Great Barrier Reef Long Term Monitoring Program (AIMS) for each region for the wet and dry season 2005/2006. In general the box-whiskers plots show a higher chlorophyll value (expressed as medians and 25-75th percentiles) for the *in situ* samples and the remote sensing estimates of the waters in the coastal region than for the waters in the Inshore region and the Offshore region. Most of the times the ranges of the measured *in situ* samples fall within the ranges of the remotely sensed values.

Pesticide concentrations were measured at thirteen inshore reef sites (Figure A1.1) using passive samplers. Samplers were deployed for approximately thirty days during the wet season (November to March) and for two month periods during the dry season (April to October).

The pesticide monitoring component of the MMP was originally designed to collect baseline data on pesticides in the GBR in terms of presence and extent, and is gradually progressing to improve our understanding of the spatial and temporal distribution of pesticides in the GBR. This improved understanding is required as the effects of introducing pesticides into the GBR are not well understood, despite the fact that the potential for pesticides to impact on ecological processes and the health of reef ecosystems has been widely recognised (Brodie *et al.* 2001; Haynes *et al.* 2001; Bengtson-Nash *et al.* 2005; Brodie *et al.* 2008). The

MMP data therefore contributes to an improved understanding of the ecological effects of pesticides on GBR ecosystems.

Pesticides commonly used in cropping and grazing (dominant industries in the GBR catchment) include organophosphates (e.g. chlorpyrifos) and triazines (e.g. atrazine, simazine, ametryn, prometryn) as well as urea-based herbicides (e.g. diuron, tebuthiuron, flumeturon) (Lewis *et al.* 2009). Depending on the physical properties of these pesticides, their mobility and half lives vary, but those that are persistent and mobile have the potential to be transported from the sites of application in the catchment via rivers into the marine environment. Many of these pesticides occur at trace levels that are very difficult to detect and quantify, yet these low concentrations may ultimately pose a chronic risk to the environments they contaminate. The MMP therefore employs time integrated passive sampling techniques to monitor trace organic pollutants in marine waters. When deployed for an extended period of time (30-60 days) these samplers can accurately predict average water column concentrations of a range of pesticides. This is the primary approach adopted for pesticide monitoring in the MMP.

Flood plume water quality

Riverine flood plumes are of significant ecological importance to the GBR as river runoff is the principal carrier of eroded soil (sediment), nutrients and contaminants from the land into the coastal and inshore lagoon waters (Furnas 2003). On average, approximately 70 km³ of freshwater is discharged each year by rivers and streams into the GBR lagoon, carrying between 10 and 15 x 10⁶ tonnes of fine sediment (Furnas 2003). On a year-to-year basis, runoff volumes typically range within three-fold of the long-term mean.

Most of the runoff to the GBR lagoon is delivered in discrete, short-lived flood events during the five-month wet season (November to May). The marine flood plume monitoring component of the MMP provides an assessment of the distribution of concentrations and major land-sourced pollutants in the GBR lagoon during flow events and quantifies the exposure of GBR ecosystems to these contaminants. However, due to the large size of the GBR, the short-term nature and variability (hours to weeks) of runoff events and the often difficult weather conditions associated with floods, it is very difficult and expensive to launch and coordinate comprehensive runoff plume water quality sampling campaigns across large sections of the GBR. To counter this variability, the MMP has adopted a multi-pronged approach in the assessment of the exposure of the GBR inshore coral reefs to materials transported into the lagoon from GBR catchment rivers. This component of the program is directly linked to the MMP Inshore GBR Water Quality Monitoring described above and to MTSRF Project 3.7.2 *Connectivity and risk: Tracing materials from the upper catchment to the reef* and Project 2.5i.1 *Hydrodynamics at the whole-of-GBR scale*.

The main objectives of the marine flood plume monitoring are to:

- Describe water quality gradients in flood plumes from selected rivers at particular points in time by campaign-style grab and instrumented sampling (nutrients, suspended solids, chlorophyll *a*, and pesticides); and
- Quantify the exposure of reef ecosystems to these land-based contaminants.

Plume manual water quality sampling was undertaken in the flood plume waters of the Wet Tropics and Burdekin Regions in the 2008/2009 wet season, with one pre-event sampling effort in the Mackay Whitsunday Region. Depth profiles using a Hydrolab were collected at most locations for pH, salinity, dissolved oxygen and turbidity, and a new chlorophyll probe was trialled, although equipment failures resulted in data gaps on some sampling campaigns. Surface water samples were collected at all sites for dissolved nutrients (NH₄, NO₂, NO₃, PO₄, DON, DOP), particulate nutrients (PN, PP), suspended solids (SS), plant pigments (chlorophyll *a* and phaeophytin) and CDOM. Samples were also

collected at selected sites for pesticides, phytoplankton counts, trace metals and sediment characteristics (the latter two are reported in detail under MTSRF Project 3.7.2).

Plume remote sensing techniques were applied (by JCU and the CSIRO) to assist in understanding the movement, extent and duration of flood plumes. In 2008/2009, true colour images were extracted to identify the extent of the riverine plume, available algorithms were applied to satellite images to extrapolate chlorophyll and colour dissolved organic matter (CDOM) data for the appropriate images, and imagery was used as a near-real time tool to guide field sampling with imagery processed on a daily basis to provide information of plume movement to scientists taking *in situ* samples.

Plume extent and exposure in the Tully and Burdekin Rivers was estimated using aerial images from 1994-1999 combined with remote sensing images from 2002-2009 to describe the full extent of riverine plumes from the Tully River during eleven events and the Burdekin River during seven events. The derived CDOM absorption at 412 nm combined with careful examination of quasi-true colour and chlorophyll *a* images provided the information used to define river plume 'type' (primary, secondary and tertiary) and extent. Plume exposure mapping was then produced using a combination of plume classification and ArcMap geoprocessing.

Inshore GBR biological monitoring

Extensive research has shown that land-based water quality pollutants can have potentially deleteriously impact on sensitive marine ecosystems that are found in the inshore areas of the GBR, such as coral reefs and seagrass meadows (Haynes *et al.* 2000; Negri *et al.* 2005; Fabricius 2005). Monitoring of these marine ecosystem that are recognised as being most at risk from land-based pollutants is undertaken to assess their current condition and to identify any trends in their status over time. The location of inshore biological monitoring sites are shown in Figure A1.3.

Inshore seagrass meadows

Inshore seagrass meadows form critical ecosystems of the GBR. The inshore seagrass monitoring program quantifies temporal and spatial variation in the distribution of intertidal seagrass meadows and correlates, where possible, seagrass status with change in delivery of land-sourced contaminants. A large part of the seagrass monitoring program is conducted by community volunteers through *Seagrass Watch*.

Seagrass status and resilience is measured across all Regions in estuary, coastal and reef locations. Seagrass monitoring sites have been located as close as practicably possible to river mouth and inshore marine water quality programs (dependent on historical monitoring and location of seagrass meadows) to enable correlation with concurrently collected water quality information.

The main objectives of the seagrass monitoring are to:

- Detect long-term trends in seagrass abundance, community structure, distribution, reproductive health and nutrient status from representative intertidal seagrass meadows in relation to large river inputs into the GBR; and
- Detect long-term trends in ecologically significant pollutant concentrations from representative intertidal seagrass meadows in relation to large river inputs into the GBR.

Components of the seagrass monitoring in the MMP are linked to existing MTSRF Project 1.1.3 *Condition, trend and risk in coastal habitats: Seagrass Indicators, distribution and thresholds of potential concern*, and will deliver a water quality specific assessment of seagrass health for the MMP.

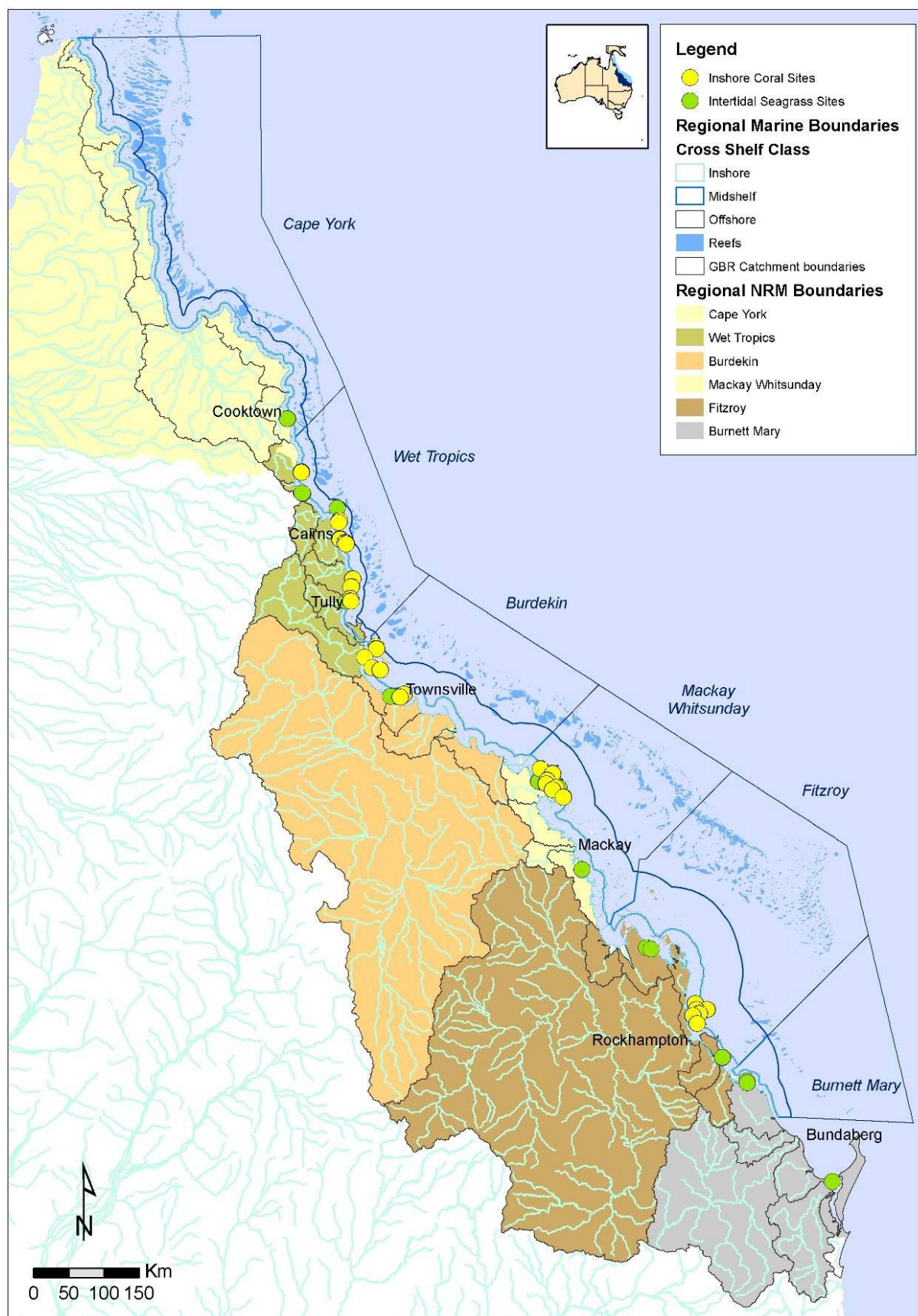


Figure A1.3: Location of inshore biological monitoring locations in the Marine Monitoring Program.

The status of intertidal seagrass meadows was monitored bi-annually at thirty sites in fifteen locations between Cooktown and Hervey Bay (Figure A1.3). Sites were monitored for seagrass cover, species composition and meadow area (edge mapping). Additional information was collected at each site for canopy height, within-canopy temperature, algae cover, epiphyte cover and macrofaunal abundance.

Supporting water quality information including seagrass tissue nutrients, sediment nutrients and sediment herbicides was collected at all locations. Seagrass canopy light was also measured at inshore and offshore locations in the Cairns and Townsville locations.

Seagrass resilience is the ability for seagrass habitats to recover following disturbances and is linked to their reproductive ability, and therefore reproductive effort is an indicator of the resilience of seagrass meadows. Two measures of seagrass reproduction were recorded at each site: the presence of seeds, and reproductive effort (the number of reproductive structures – spathes, fruit, female flower or male flowers – per seagrass node).

Inshore coral reefs

Inshore coral reef communities are at risk from impacts caused by acute disturbances such as cyclones, coral bleaching and crown of thorns starfish as well disturbances such as those related to runoff (e.g. increased sedimentation, and nutrient and pesticide loads), which may disrupt processes of recovery including recruitment and growth. The inshore coral reef monitoring program is designed to document spatial and temporal trends in the benthic reef communities on selected inshore reefs.

The main objectives of the coral monitoring program are to:

- Provide annual time series of community status of inshore reefs as a basis for detecting changes related to water quality and other disturbances; and
- Provide information about ongoing coral recruitment on GBR inshore reefs as a measure of reef resilience.

The reef monitoring sites are close to the sampling locations for lagoon water quality to assess the relationship between reef communities and water quality as well as other, more acute impacts. Within each Region, reefs are selected that represent a gradient in exposure to runoff, largely determined as increasing distance from river mouth in a northerly direction. To account for spatial heterogeneity of benthic communities within reefs, two sites were selected and stratified by depth. Within each site and depth fine scale spatial variability is accounted for by the use of five replicates. Reefs within each Region are designated as either core or cycle reefs. Core reef locations have annual coral reef benthos surveys, coral settlement assessments, autonomous water quality instruments (temperature, chlorophyll and turbidity) and regular water quality sampling. Non-core (cycle) reef locations have benthos surveys every two years, and no water quality assessments. Exceptions are Snapper Island (water quality instruments, regular water sampling, coral annual surveys, but no coral settlement) and Dunk Island (water quality instruments, regular water sampling, but coral surveys every other year).

This project is linked to the MMP Inshore GBR Water Quality monitoring and existing MTSRF Project 3.7.1 *Marine and estuarine indicators and thresholds of concern* and Project 1.1.1 *Status and trends of species and ecosystems of the Great Barrier Reef*. This component of the MMP will deliver water quality specific assessment of inshore coral reef health.

The status of inshore coral reefs was assessed at 24 inshore reef locations in four NRM Regions: the Wet Tropics, Burdekin, Mackay Whitsunday and Fitzroy Regions (Figure A1.3).

The coral monitoring continued to survey the cover of benthic organisms, the numbers of genera, the number of juvenile-sized coral colonies and sediment quality at each location.

Coral reef resilience is measured using coral recruitment as an indicator combined with the above information collected on current and past status. Coral recruitment monitoring continued at three core sites in each of the four NRM Regions using settlement plates.

Assessments of sediment quality and assemblage composition of benthic foraminifera (a water quality bioindicator in the testing phase; Uthicke and Nobes 2008) were new components of the coral reef monitoring which provided additional information about the environmental conditions at individual reefs. Water quality sampling is routinely carried out at all reef monitoring sites to allow correlation with reef condition.