Reef Water Quality Protection Plan Marine Monitoring Program:

2007/2008 Summary Report

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

JAMES COOK UNIVERSITY AUSTRALIA

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Department of Primary Industries and Fisheries

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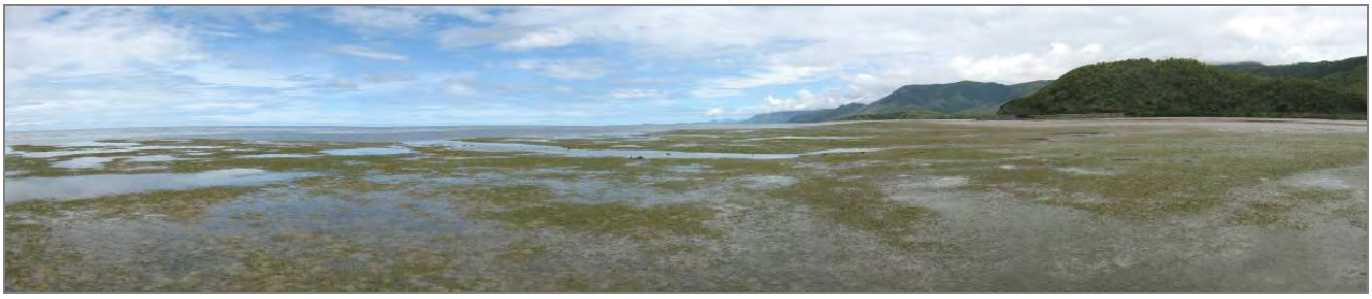

Seagrass meadow at Dunk Island.
Photograph courtesy of Queensland Primary Industries and Fisheries.

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This report along with relevant supporting documents is available for download from the Reef and Rainforest Research Centre Limited website:
http://www.rrrc.org.au/mmp/index.html

Reef & Rainforest
RESEARCH CENTRE

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Key Acronyms and Abbreviations

AIMS .... Australian Institute of Marine Science
CDOM .... Coloured dissolved organic matter
CSIRO .... Commonwealth Scientific and Industrial Research Organisation
DNRW .... Queensland Department of Natural Resources and Water
DPI&F................ Queensland Department of Primary Industries and Fisheries
ED .... Empore Disk sampler
EnTox .... National Research Centre for Environmental Toxicology, The University of Queensland
GBR .... Great Barrier Reef
GBRMP............. Great Barrier Reef Marine Park
GBRMPA .... Great Barrier Reef Marine Park Authority
HC .... Hard coral
JCU .... James Cook University
MA..................... Macroalgae
ML .... Mega-litres
MMP .... Marine Monitoring Program
MTSRF .... Marine and Tropical Sciences Research Facility
NRM .... Natural Resource Management
NTU .... Nephelometric Turbidity Units
PCA................... Principal Component Analysis
QLD................... Queensland
RRRC................ Reef and Rainforest Research Centre Limited
SC .... Soft coral
SE...................... Standard Error
SS...................... Suspended sediment

About this report

This report provides a summary of information collected as part of the Reef Water Quality Protection Plan Marine Monitoring Program during 2007/08, with a particular focus on the major flood events occurring in this period in the Burdekin and Fitzroy regions.

The information provided had been extracted from the following reports, also available for download from the RRRC website:

- **Bartkow**, M., Dunn, A., Komarova, T., Paxman, C. and Mueller, J. (2008) *Monitoring of organic chemicals in the Great Barrier Reef Marine Park and selected tributaries using time integrated monitoring tools*. Water Quality and Ecosystem Monitoring Programme Reef Water Quality Protection Plan. Final Report 2007/08. Report submitted to the Reef and Rainforest Research Centre.
- **Brando**, V. E., Schroeder, T., Dekker, A. G. and Blondeau-Patissier, D. (2008) *Reef Water Quality Protection Plan Marine Monitoring Program, Remote Sensing of GBR-wide water quality*. Final Report submitted to the Reef and Rainforest Research Centre.
- **Devlin**, M., Brodie, J., Bainbridge, Z. and Lewis, S. (2008) *Flood plumes in the GBR – The Burdekin and Fitzroy flood plumes, 2008*. *Case studies for Marine Monitoring Program.* Report submitted to the Reef and Rainforest Research Centre.
- **McKenzie**, L., Mellors, J. and Waycott, M. (2008) *Great Barrier Reef Water Quality Protection Plan Marine Monitoring Program, Intertidal Seagrass*. Final Report for the Sampling Period 1st September 2007 to 31st May 2008. Submitted to the Reef and Rainforest Research Centre.
- **Schaffelke**, B., Thompson, A., Carleton, J., Cripps, E., Davidson, J., Doyle, J., Furnas, M., Gunn, K., Neale, S., Skuza, M., Uthicke, S., Wright, M. and Zagorskis, I. (2008) *Water Quality and Ecosystem Monitoring Programme Reef Water Quality Protection Plan*. Final Report 2007/08. Report submitted to the Great Barrier Reef Marine Park Authority.
- **Schaffelke**, B., McAllister, F. and Furnas, M. (2008) *Water Quality and Ecosystem Monitoring Programme Reef Water Quality Protection Plan 3.7.2b: Marine flood plume monitoring. Final Report 2007/08.* Report submitted to the Reef and Rainforest Research Centre.
- **Marine Monitoring Program** (2009) *Methods and Quality Assurance/Quality Control Procedures June 2009.* Water Quality and Ecosystem Monitoring Program Report.

Executive Summary

In 2007/08 there were significant flood events in the Burdekin and Fitzroy regions and lower than average rainfall in the Wet Tropics and Mackay Whitsunday regions. This was an unusual year for rainfall with a reversal of the normal rainfall patterns in the Great Barrier Reef (GBR) catchment. It is well recognised that flood events are a driving factor in water quality on the GBR, introducing significant loads of terrestrial pollutants into inshore marine waters. This report provides monitoring results for key pollutants (herbicides, nutrients and sediments), assesses the acute ecological impacts of the Burdekin and Fitzroy River flood events, and summarises the status of coral and seagrass ecosystems in the inshore GBR during the 2007/08 period.

At a GBR-wide scale, ten of the fourteen inshore monitoring locations had chlorophyll values (a surrogate indicator of nutrient concentrations) above guideline trigger values specified for the GBR (GBRMPA 2009). Most of these sites were south of the Herbert River and reflected the third largest flood event in the Burdekin River and the fifth largest flood event in the Fitzroy River on record. During the Fitzroy River flood, most samples collected exceeded guideline trigger values for chlorophyll, suspended sediments and particulate nutrients. Inshore reefs closest to the Fitzroy River mouth experienced turbidity levels at light limiting levels (>5 NTU) for more than thirty days. Chlorophyll concentrations and turbidity levels in the Wet Tropics and Mackay Whitsunday regions reflect the lower river discharge experienced in these regions.

Under ambient conditions, the pesticide profile at inshore reef sites was dominated by the herbicides diuron, atrazine and hexazinone. Diuron was the most prevalent and the highest contributor to the overall herbicide toxicity load at all GBR inshore monitoring sites. The inshore waters of the Burdekin, Wet Tropics and Mackay Whitsunday regions had the highest concentrations of this herbicide. The lowest concentrations of herbicides detected were in the Cape York and Fitzroy regions. During flood conditions, concentrations of these pesticides were significantly higher. The pesticides tebuthiuron and atrazine were also detected in the Burdekin River and Fitzroy River plumes. Laboratory studies have shown the high toxicity of several commonly used pesticides in GBR catchments on marine organisms (e.g. Haynes *et al.* 2000a, Negri *et al.* 2005, Markey 2007). Residues of these pesticides (particularly the herbicides diuron and atrazine) are now ubiquitous in GBR lagoon waters adjacent to catchments with significant pesticide use (Haynes *et al.* 2000b, Shaw and Mueller 2005, Rohde *et al.* 2006).

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

A range of inshore biological indicators were also monitored, including coral cover trends, coral recruitment and seagrass reproductive capacity. Macroalgal cover is also monitored on reefs as macroalgae growth can be enhanced by elevated nutrients, competing with corals and potentially limiting coral settlement as they colonise available substrate. These indicators provide valuable insight into the current and future health and condition of the GBR.

The coral reefs in the Daintree, a northern sub-region of the Wet Tropics, are the only monitored sites in the GBR showing a marked increase in hard coral cover (32% to 47%). Coral cover on reefs in the Burdekin region has been consistently low since 2005 (around twenty percent). Reefs in the Fitzroy region have shown a substantial decline in hard coral cover in several locations (from 52% to 35-40%). Macroalgae cover was greatest during the

2007/08 monitoring period in reefs in the Burdekin and Fitzroy regions, with an average of 27% and 16% respectively. Reefs in the Daintree sub-region had the least macroalgae cover (<5%). In 2006, Severe Tropical Cyclone *Larry* caused localised physical damage to reefs offshore from Innisfail reducing coral cover at some Wet Tropics reefs. Although there has been high coral recruitment since Cyclone Larry, hard coral cover in the Wet Tropics region has remained the same or declined since 2006. Coral recruitment in the Burdekin and Fitzroy regions was low compared to other the regions.

The overall trend in seagrass cover across GBR monitoring locations is of increasing or recovering meadows since late in the 2005 dry season. Only two locations show a declining trend (Archer Point near Cooktown, and Townsville), however this appears to be a consequence of physical disturbance rather than water quality condition. These two locations also have increasing seed reserves, suggesting they have the ability to recover in the near future should physical disturbance abate. The average seagrass percent cover (over the past nine years of monitoring) at each of the intertidal seagrass habitats within the GBR are relatively similar: 21% for estuarine, 20% for coastal and 26% for reef habitats. However the patterns of abundance over the years are very different, depending on habitat.

Seagrass abundance at estuarine monitoring sites increased significantly in 2007, reversing the declining trend from early 2006. Seagrass abundance at coastal meadows has remained relatively stable over the years of monitoring with a significant increase late in the 2007 dry season. Seagrass abundance has fluctuated at reef-platform meadows in the last eight years, but has increased over the last couple of years. Within years, seagrass abundance fluctuates greatly between seasons.

Key to icons used in conceptual diagrams throughout this report.

1. Background

Water quality is a key issue for the health of the Great Barrier Reef, 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 Great Barrier Reef lagoon.

The water quality and ecosystem health monitoring program (Marine Monitoring Program) undertaken in the Great Barrier Reef lagoon assesses the long-term effectiveness of the Australian and Queensland Government's Reef Water Quality Protection Plan. The Reef Water Quality Protection Plan (the Reef Plan) was released by the Australian and Queensland Governments in October 2003. It focused 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". As part of the Reef Plan, the Reef Water Quality Protection Plan Marine Monitoring Program was established in 2005 to help assess the long-term status and health of GBR ecosystems. The monitoring program 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.

In 2007/08 the Reef Water Quality Marine Monitoring Program (MMP) was comprised of two core programs and seven sub-programs (Table 1.1). A consortium of monitoring providers in partnership with the North Queensland based Reef and Rainforest Research Centre (RRRC) undertook five of the sub-programs (highlighted in Table 1.2) contracted by the Great Barrier Reef Marine Park Authority.

The consortium included:

- The Queensland Department of Primary Industry and Fisheries (DPI&F);
- The University of Queensland, National Research Centre for Environmental Toxicology (EnTox);
- James Cook University (JCU);
- The Commonwealth Scientific and Industrial Research Organisation (CSIRO);
- The Australian Institute of Marine Science (AIMS); and
- The Reef and Rainforest Research Centre (RRRC).

Table 1.1: Marine Monitoring Program core and sub-programs.

	MMP core programs	MMP sub-programs
1	Inshore Biological Monitoring	Inshore coral reef monitoring
		Intertidal seagrass monitoring
		Assessing light as a driver of change in GBR seagrass
2	Water Quality Monitoring	Inshore marine water quality monitoring
		Flood plume water quality monitoring
		Inshore pesticide monitoring
		Remote sensing of GBR water quality

The RRRC was contracted by the Great Barrier Reef Marine Park Authority (GBRMPA) in May 2008 to coordinate and manage five of the seven sub-programs of the MMP. These tasks are sub-contracted to monitoring providers (under a co-investment model) with a long-term track record of monitoring and research in the relevant areas. The projects and sub-contractors managed by the RRRC are in Table 1.2.

Table 1.2: Monitoring providers and associated projects contracted by the RRRC to undertake MMP projects.

No.	Project title	Sub-contractors
1.1.3a	Condition, trend and risk in coastal habitats: Seagrass indicators, distribution and thresholds of potential concern (Intertidal seagrass monitoring)	DPI&F JCU
1.1.3b	Assessing light as a driver of change in seagrasses of the Great Barrier Reef	JCU
3.7.2b	Marine flood plume monitoring	JCU AIMS
3.7.8	Monitoring of organic chemicals in the Great Barrier Reef and selected tributaries using time integrated monitoring tools	UQ EnTox
3.7.9	Remote sensing of GBR-wide water quality	CSIRO

2. The Marine Monitoring Program

The Reef Water Quality Protection Plan Marine Monitoring Program assesses 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. The monitoring program has been designed (within funding constraints) using the best available science and is continuously improved with the advancement in scientific understanding. Through the RRRC, the MMP is strongly linked to research under the Marine and Tropical Science Research Facility (MTSRF), which provides important science for the continued improvement of water quality and ecosystem health indicators. Research into the conceptual understanding of the GBR ecosystem has been used to help determine key processes and relationships between marine water quality and ecosystem health. This information has been fundamental in identifying indicators to assess water impacts on GBR marine ecosystems.

The MMP has two core programs: (i) inshore GBR water quality monitoring, and (ii) inshore GBR biological monitoring of coral reefs and seagrass meadows, including biological indicators (Figure 2.1). The main water quality constituents and pollutants of concern (suspended sediments, nutrients and pesticides) are monitored during ambient and flood conditions through traditional grab sampling, passive sampling, data logger and remote sensing technologies. Inshore coral reef indicators that are monitored include benthic cover, coral demographics, genus diversity, coral recruitment and a foraminifera index. Intertidal seagrass indicators include: seagrass cover, reproductive potential (seed bank and flowering), epiphyte cover and tissue nutrient content. All monitoring undertaken as part of the MMP is subject to QA/QC assessment, for a detailed description of QA/QC procedures see *Methods and Quality Assurance/Quality Control Procedures* (CRC Reef Consortium 2005 and 2006, Marine Monitoring Program 2009).

2.1 Inshore GBR water quality monitoring

2.1.1 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 sediments, 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 carried out using traditional water sampling techniques, state of the art sensors with long-term data logging capacity and remote sensing.

<u>The main objectives of long term inshore water quality monitoring are to:</u>

- 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; and
- Provide environmental data to correlate with biological assessments of coral and seagrass status.

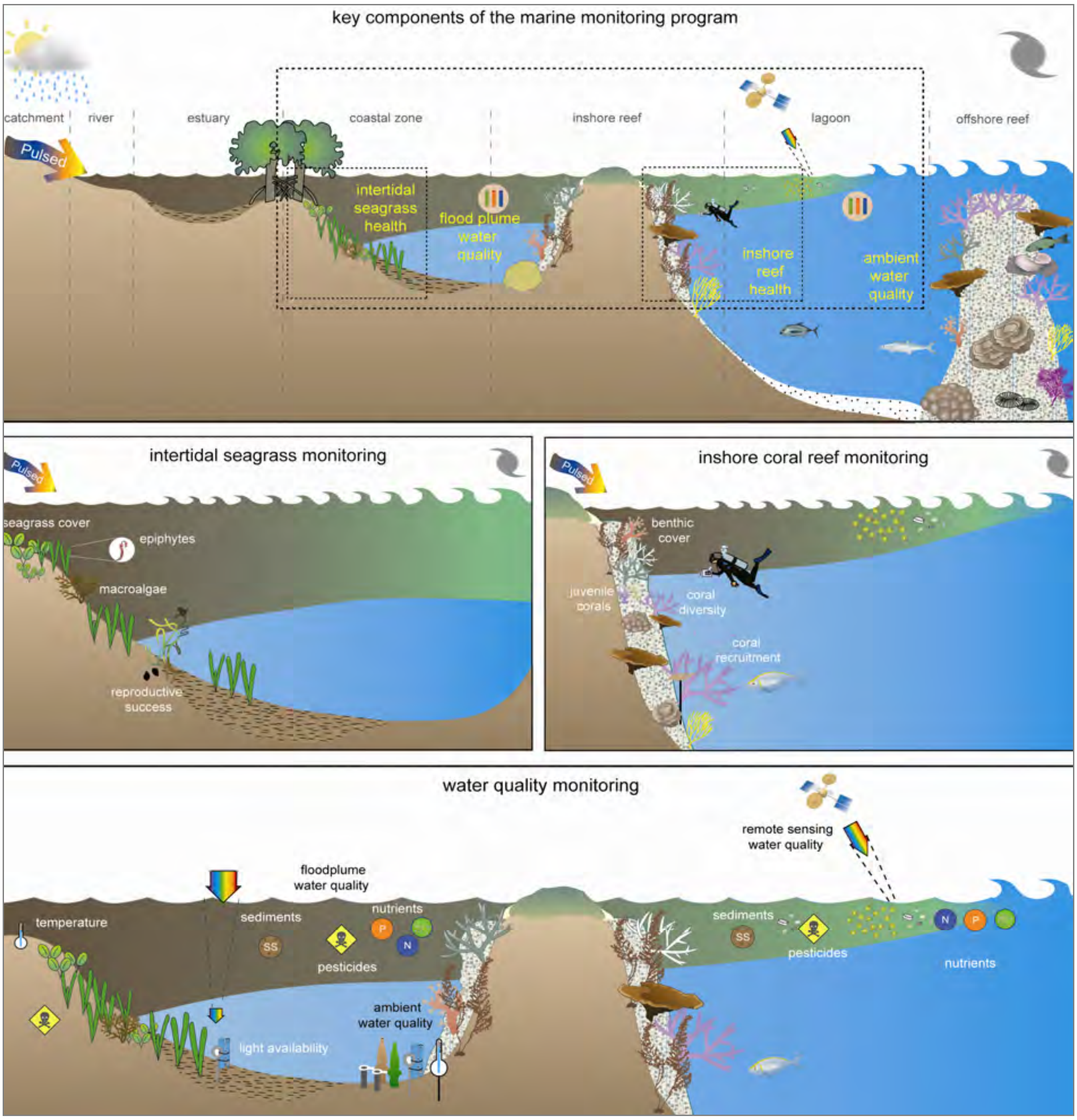


Figure 2.1: Conceptual representation of the MMP (Source: GBRMPA).

Water quality sampling is undertaken at fourteen core inshore coral reef monitoring sites during the wet season and dry season, for dissolved nutrients and carbon (NH_4, NO_2, NO_3, PO_4, $Si(OH)_4$), DON, DOP, DOC), particulate nutrients and carbon (PN, PP, POC), suspended solids (SS), turbidity (secchi depth), salinity and plant pigments (chlorophyll *a* and phaeophytin).

As part of the 2007/08 MMP, Eco FLNTUSB loggers were deployed at all fourteen water quality monitoring sites in October 2007 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.

Data time series were obtained for all fourteen deployment locations, with some data gaps. Time-series data are summarised as daily means, calculated from the readings obtained every ten minutes. The instrument readings were compared to relevant environmental data (daily discharge volume of the closest river (provided by DNRW) and averaged daily wind speed data from the nearest weather station of the Bureau of Meteorology (calculated from twice-daily readings available at http://www.bom.gov.au/climate/dwo). The recorded values were compared to the seasonally adjusted chlorophyll Guideline trigger values (GBRMPA 2009). For turbidity a suggested turbidity 'threshold' of 5 NTU was applied (beyond which corals may be severely light-limited based on experimental data; Cooper *et al.* 2007, Cooper *et al.* 2008). This threshold was deduced from turbidity and light measurements at two metres depth (LAT) and applied to the logger data from five metres depth, making it a conservative estimate of turbidity-related stress.

2.1.2 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 km^3 of freshwater is discharged each year by rivers and streams into the GBR lagoon, carrying between 10 and 15 x 10^6 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 summer wet season (November to May). This component of the MMP provides an assessment of the distribution of concentrations and distribution of major land-sourced pollutants in the GBR lagoon and quantifies the exposure of Reef ecosystems to these contaminants.

This project is linked to the MMP Inshore Marine Water Quality Monitoring and to MTSRF research Project 3.7.2 (Connectivity and risk: tracing materials from the upper catchment to the reef). This project will, over the course of the MMP, deliver information on the exposure of reef ecosystems to land-sourced pollutants in the inshore GBR.

<u>The main objectives of the flood monitoring are to:</u>

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

2.1.3 Pesticide concentrations

Pesticides are chemical contaminants sourced from agricultural, industrial and urban activities. Anthropogenic pollutants such as pesticides and antifoulants have been detected in the Great Barrier Reef environment since the 1970s (Olafson 1978). The effects from introducing land-based pollutants into the Great Barrier Reef are not well understood, however the potential for certain pollutants to impact on ecological processes and the health of reef ecosystems has been widely recognised (Haynes *et al.* 2000a, Brodie *et al.* 2001, Haynes *et al.* 2001).

Grazing and cropping (in particular sugarcane) account for significant land use in the GBR (Haynes *et al.* 2001). Pesticides commonly used in these industries include organophosphates (e.g. chlorpyrifos) and triazines (e.g. atrazine, simazine, ametryn, prometryn) as well as urea-based herbicides (e.g. diuron, tebuthiuron, flumeturon). 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 pollutants 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. Time integrated passive sampling techniques have been developed for the monitoring of trace organic pollutants in water. 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.

The pesticide monitoring program was designed to collect baseline data for pesticides in the GBR area. In 2007/08, routine monitoring was undertaken at thirteen inshore reef sites with samplers deployed for approximately thirty days during the wet season (November to March) and for two month periods during the dry season (April to October). Additional event sampling was undertaken at two river mouth sites. Samplers were also deployed for the collection and concentration of pesticides for toxicological testing at twelve inshore reef sites during the coral spawning season.

<u>The main objectives of pesticide monitoring are to:</u>

- Determine time-integrated concentrations of specific organic chemicals in inshore GBR waters to enable evaluation of long-term trends in pesticide concentrations.
- Assess the quantity and distribution of chemical pollutants that are transported to the GBR from rivers during flood events.
- Assess the environmental relevance of the presence of pesticides at inshore reefs and potential risks that may be associated with the exposure of coral zooxanthellae to these chemicals.

2.1.4 Remote sensing of GBR water quality

Information derived from remote sensing is cost-effective for determining spatial and temporal patterns of near-surface concentrations of suspended solids (as non-algal particulate matter), turbidity (as vertical attenuation of light), chlorophyll *a* (Chl) 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. This project includes the development of new analytical tools for understanding trends and anomalies of these waters (specifically wet season to dry season variability, river plume composition and extent and algal blooms) based on the optical characteristics of inshore GBR waters.

During 2007/08 significant investment was undertaken to further develop remote sensing as a monitoring tool for water quality (chlorophyll, CDOM, TSM and Kd) in the GBR. These improvements have markedly enhanced the confidence in remote sensing estimates and remote sensing will soon be the primary tool for detecting broad scale changes in GBR water quality.

<u>The main objectives of the remote sensing monitoring are to:</u>

- 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.
- Develop improved algorithms for water quality and atmospheric corrections for the waters of the GBR.

2.2 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.* 2000a, 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.

2.2.1 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.

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

The status of intertidal seagrass meadows is monitored four times a year at fifteen locations between Cooktown and Hervey Bay. Primary health indicators including seagrass cover, species composition, meadow area and reproductive status, as well as supporting water quality information including presence of herbicides, nutrients and temperature is collected. The ability for seagrass habitats to recover following disturbances is linked to their reproductive ability, and therefore reproductive effort is an indicator of the resilience of seagrass meadows. Two measures of seagrass reproduction are recorded: the presence of seeds, and reproductive effort (the number of reproductive structures – spathes, fruit, female flower or male flowers – per seagrass node).

<u>The main objectives of the seagrass monitoring are to:</u>

- 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.
- To detect long-term trends in ecologically significant pollutant concentrations from representative intertidal seagrass meadows in relation to large river inputs into the GBR.

2.2.2 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.

Inshore GBR coral reef surveys for the MMP estimate cover of various coral taxa as well as size-distribution of colonies as evidence of the extent of past and ongoing recruitment. In addition, settlement of corals is measured 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 (Section 2.1.1).
This project is linked to the MMP Inshore GBR Water Quality Monitoring and existing MTSRF projects; 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 project will deliver water quality specific assessment of inshore coral reef health.

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 for reef resilience.

3. GBR-wide overview

3.1 Inshore GBR marine water quality

River discharge in 2007/08

In the context of the entire GBR, more river water was discharged in 2007/08 than in the three previous years. The total discharge of the thirteen major rivers was approximately 55 million ML, thirty percent higher than the long-term average of 42 million ML (Figure 3.1). The majority of the discharge originated from the two dry tropic catchments, Burdekin and Fitzroy, which experienced the third and fifth largest flood events on record respectively. This is in contrast to the last three years of below average flow discharge, being 12 million ML, 20 million ML and 26 million ML for 2004/5, 2005/6 and 2006/7 respectively. In the 2007/08 wet season, the Barron, Pioneer, Burdekin and Fitzroy Rivers exceeded their long-term discharge averages, whereas the Normanby, Tully and Herbert Rivers were close to average. The Russell, Johnstone and O'Connell rivers were below average, and the Burnett River much below the long-term average, similar to the last three dry years in this catchment.

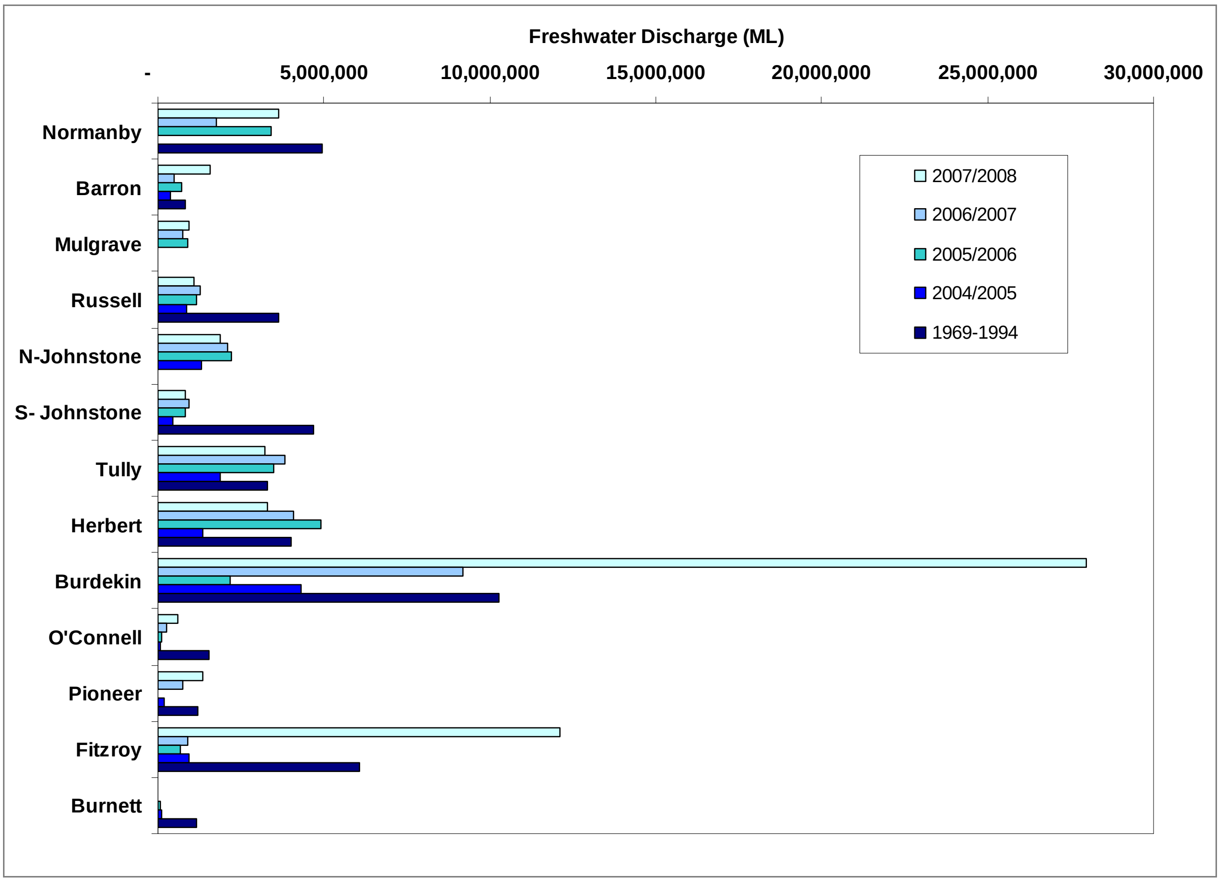


Figure 3.1: River discharge for thirteen major rivers in the GBR catchment in 2004/05, 2005/06, 2006/07 and 2007/08. Long-term averages are given for comparison (annual river discharge: 1969-94). Discharge data are the property and copyright of the State of Queensland (Department of Natural Resources and Water, 2008).

3.1.1 Great Barrier Reef water quality

Nutrient concentrations

In general, higher concentrations were found for a number of water quality parameters during the 2007/08 wet season compared with the 2007 dry season. For example, DIN, PN, PP, DOC, POC, suspended solids (Figure 3.2), chlorophyll and Si were all higher during the 2007/08 wet season. Salinity values were lower in the wet season due to freshwater river flows. Higher or similar values during the dry season were measured for DON, PO_4 (DIP), DOP and Secchi depths.

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

Similar to the two previous years monitoring, the carbon-nitrogen-phosphorus (C:N:P) ratios of the particulate fraction were slightly elevated compared to the Redfield ratio (106:16:1 – see Box 3.1). Averaged over all fourteen MMP locations, the C:N:P ratio in the dry season was 160:17:1, in the wet season: 133:11:1. This indicates higher carbon concentrations than expected and higher phosphorus availability during the wet season. C:N:P ratios of the dissolved species indicate high carbon and nitrogen concentrations compared to the Redfield ratio (averaged over all 14 stations in the dry season: 402:32:1, in the wet season: 457:22:1).

Box 3.1: The Redfield ratio (106:16:1) is a representation of the general average molecular ratio of carbon, nitrogen and phosphorus in phytoplankton (Atkinson and Smith 1983).

However, the composition of dissolved organic matter in GBR waters is unknown and it cannot be assumed that the high concentrations of organic carbon and nitrogen are bio-available for plankton production. Ratios of the readily bio-available inorganic N and P species indicate that GBR waters have a very high availability of phosphate (DIP); DIN to DIP ratios were ~1:1 in the dry season and 4:1 in the wet season, compared to the 16:1 Redfield ratio, which indicates that GBR waters are nitrogen limited.

A Principal Component Analysis (PCA) of the physical, biological and chemical variables measured at fixed water quality locations along the GBR over the three sampling years (2005/06, to 2007/08) separated sampling stations by wet and dry season (Figure 3.3). Samples collected at coastal sites during the wet season varied little, and the major flood event in the Fitzroy Region in 2008 changed the relationship between the regions only slightly to the one found in 2006/07. The results of the PCA for the dry season sampling showed some geographic separation between NRM Regions. Sampling locations in the Burdekin region continued to be characterised by elevated values of chlorophyll, total suspended solids, PP and PN. The relationship between total suspended solids and water column mixing (based on a ‘mixing index’ that considers wave period and station depth; Figure 3.3) suggests that elevated SS values were most likely due to re-suspension of lagoon floor sediments by the prevailing southeast trade winds which blow strongest during the dry season (April to August). River flow was most important during the wet season, and was responsible for a drop in salinity at coastal sites and was related to dissolved organic carbon concentrations (DOC). Distance to the nearest river mouth was not correlated with other PCA variables.

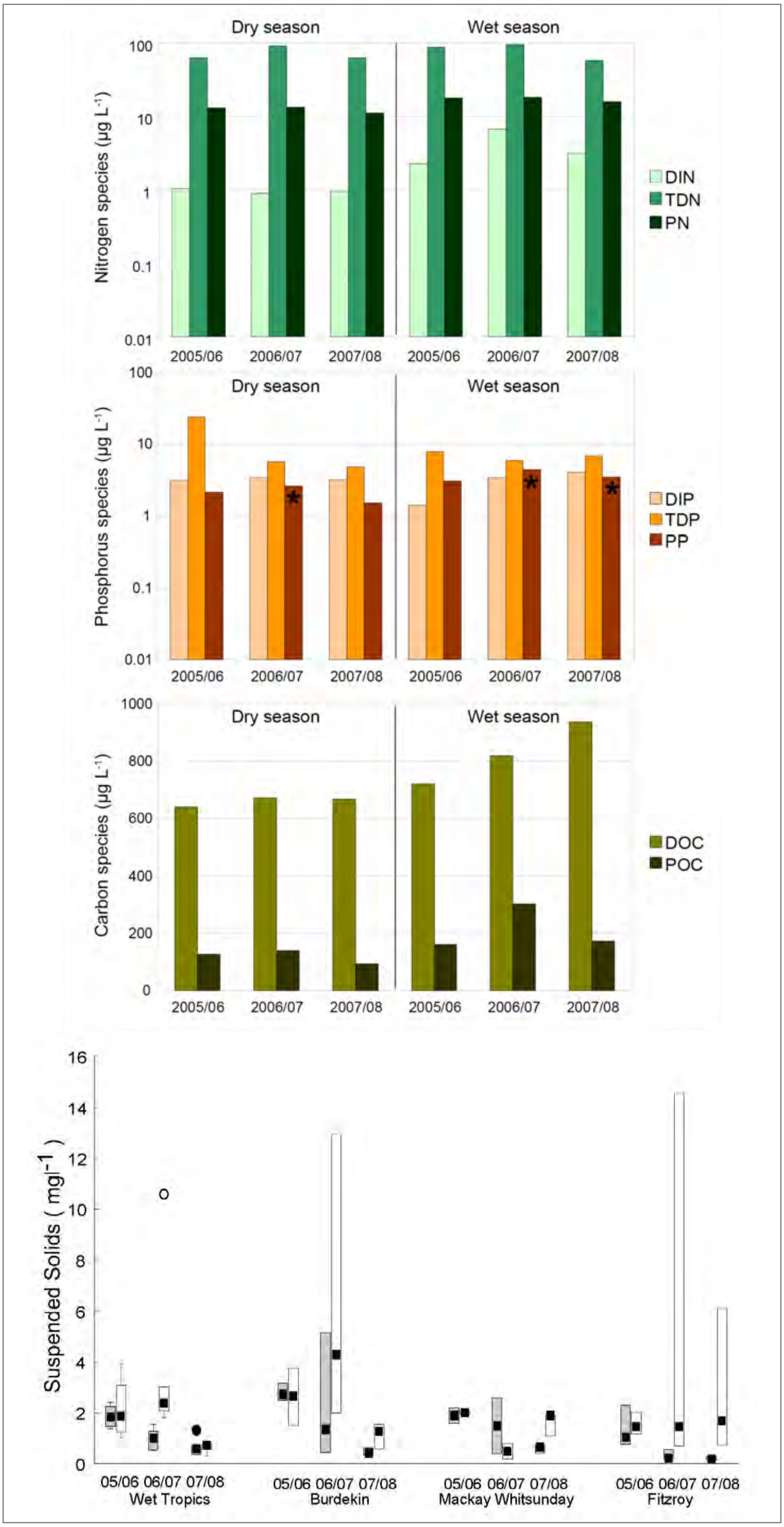


Figure 3.2: Average nitrogen, phosphorus, carbon species and suspended solids water concentrations measured at inshore reef sites in 2005/06, 2006/07 and 2007/08.

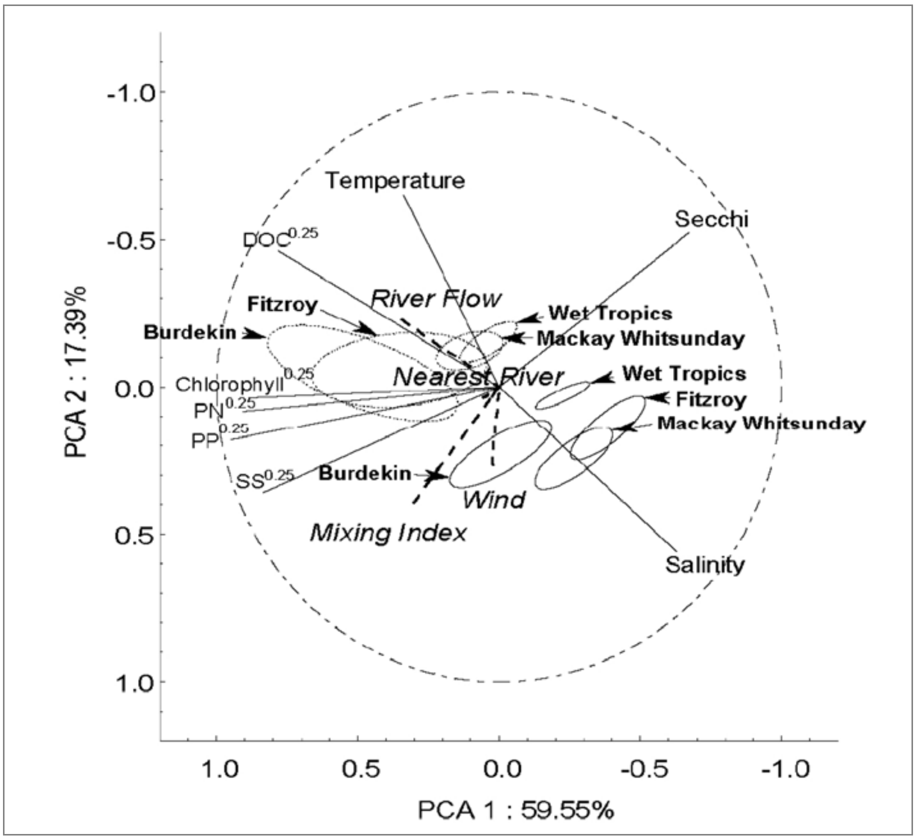


Figure 3.3: Bi plot of results from principal component analysis on water-quality parameters measured at various sites along the GBR coast between May 2005 and April 2007. Ellipses encompass 95% confident regions for the bivariate mean of coastal stations sampled in each region. Dashed ellipses represent wet season sampling (November to April) and solid ellipses dry season sampling (May to October). Unit circle denotes the range of the Pearson correlation coefficient.

Chlorophyll a and turbidity

Ten of the fourteen monitoring locations utilising continuous data loggers returned chlorophyll values above Water Quality Guidelines (GBRMPA 2009; Table 3.1), with eight of these being south of the Palm Island Group, which corresponds with the well defined (Brodie *et al.* 2007) southward increase of chlorophyll concentrations in inshore GBR waters (Table 3.2). Only one location (Pelican Island in the Fitzroy region) had generally very turbid water, and during the early 2008 floods the suggested photo-physiology threshold of 5 NTU was continuously exceeded for thirty days at this site. Three locations (Snapper and Dunk Islands in the Wet Tropics and Geoffrey Bay in the Burdekin region) were regularly turbid with values around 2 NTU and high values (>5 NTU) for more than ten percent of the record. All other locations had low mean turbidity around or below 1 NTU and only rare spikes of higher turbidity.

Table 3.1: Trigger values from Water Quality Guidelines for the Great Barrier Reef Marine Park (GBRMPA 2009) that are used for managers to take action if conditions exceed these levels.

	Water body			
Parameter	**Enclosed coastal**	**Coastal**	**Inshore**	**Offshore**
Chlorophyll (µg L^{-1})	2.0	0.32/0.63*	0.28/0.56*	0.28/0.56*
Secchi depth (m)	1.0/1.5**	10	11	17
Suspended solids (mg L^{-1})	5.0/15**	1.6/2.4*	1.4/2.0*	0.6/0.8*
Particulate nitrogen (µg L^{-1})	Not available	16/24*	16/24*	13.6/20.4*
Particulate phosphorus (µg L^{-1})	Not available	2.2/3.4*	20./3.0*	1.5/2.3*

* Seasonal adjustment: Summer/Winter

** Geographical adjustment: Wet Tropics/Central Coast

Table 3.2: Summary of chlorophyll (µg L^{-1}) and turbidity (NTU) data from deployments of WET Labs Eco FLNTU combination Fluorometer and Turbidity Sensors at fourteen inshore reef sites. "Above trigger value" refers to the percentage of days with mean values above the chlorophyll trigger values from the GBRMPA Water Quality Guideline (GBRMPA 2009) or the suggested turbidity threshold of 5 NTU (Cooper *et al.* in press).

NRM Region	Location	Chlorophyll (µg/L)		Turbidity (NTU)	
		Mean	**%>trigger**	**Mean**	**%>trigger**
Wet Tropics	Snapper Island	0.51	23	2.11	10
	Fitzroy Island	0.42	21	0.85	1
	Russell Island	0.28	3	0.45	0
	High Island	0.37	12	0.91	1
	Dunk Island	0.48	17	2.32	15
Burdekin	Pelorus Island	0.33	16	0.53	0
	Pandora Reef	0.53	48	1.11	2
	Geoffrey Bay	0.58	46	2.72	14
Mackay-Whitsunday	Double Cone Island	0.69	48	1.28	4
	Daydream Island	0.48	25	1.27	2
	Pine Island	0.73	69	1.67	4
Fitzroy	Barren Island	0.5	44	0.43	0
	Humpy Island	0.56	35	1.04	2
	Pelican Island	0.76	60	7.3	46

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

3.1.2 Flood plumes

Impact of floods in the GBR

The impact of flood plumes on inshore coral reefs and seagrass meadows can result from exposure to low salinities, the effects of sedimentation and exposure to elevated levels of pesticides and nutrients (Figure 3.4). 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.

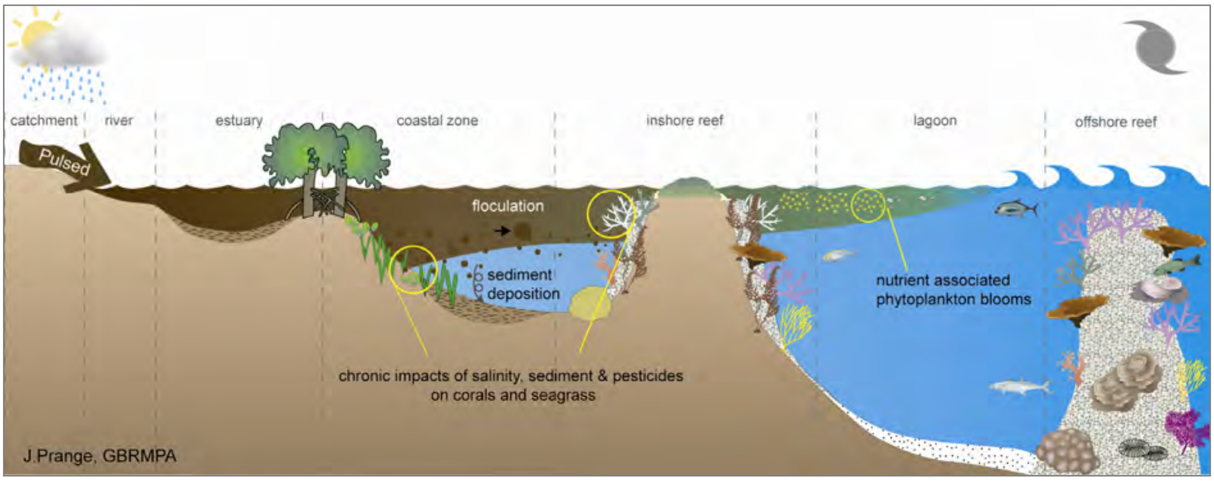


Figure 3.4: Representation of the impacts and processes of flood plumes in the inshore GBR.

Primary Plume

The primary flood plume (Figure 3.5) is defined by low salinity, high suspended sediment and particulate nutrient concentrations. The concentration of dissolved nutrient can also be very high in the primary plume but do not lead to increased primary production due to local light limiting conditions. High chlorophyll may be present in the primary plume and is derived from freshwater phytoplankton transported down the river.

Secondary Plume

As the particulate matter deposits out of the plume waters, the finer particulate matter is transported further away from the river mouth with the moving water body. Light availability increases as the waters move away from the river mouth and a combination of light and high concentrations of dissolved nutrients leads to higher concentrations of chlorophyll further out in the plume, with salinity ranges from about 5 to 25 ppt. The higher nutrient and chlorophyll concentrations and the higher salinity are indicative of what is termed secondary plumes. The secondary plume has a far greater extent, both spatially and temporally, than the primary plume, and the movement and transport of dissolved materials can range from tens to hundreds of kilometers away from the river mouth.

The extent and duration of secondary plumes and the impact on the biological communities is one of the key questions of this monitoring program. The extent of secondary plumes is best defined using remote sensing.

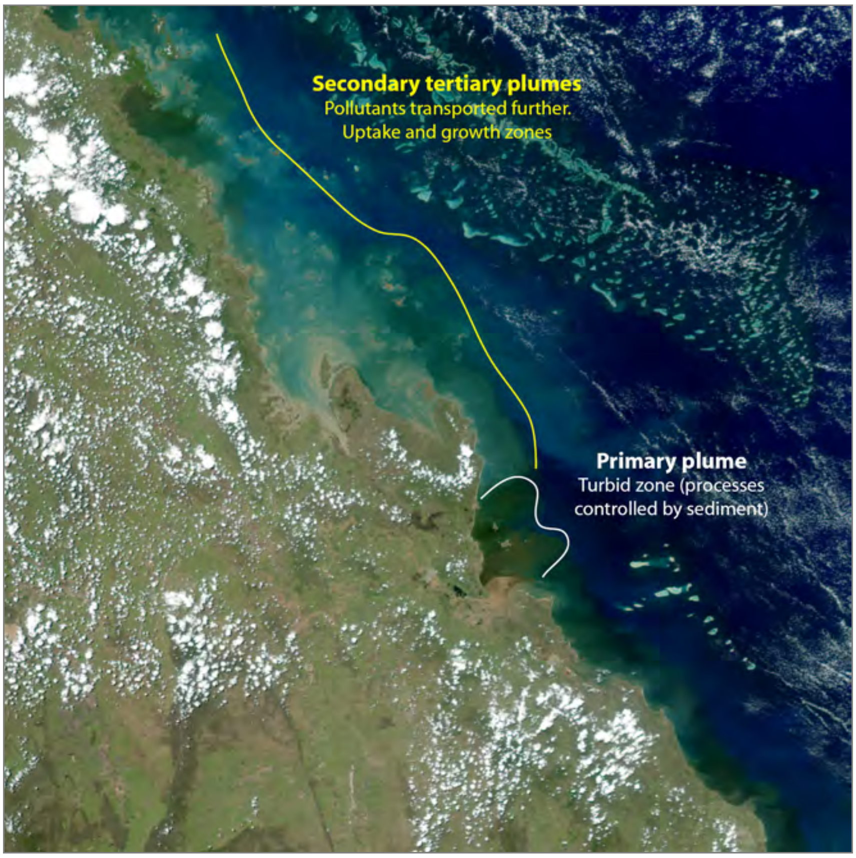


Figure 3.5: Satellite image of the Fitzroy River showing primary and secondary plumes.

3.1.3 Flood monitoring water quality

Flood plume extent

True colour images and CDOM maps were used to track the extent of the Fitzroy flood plume (Figure 3.6), the first image (28 January 2008), shows the primary plume constrained to the coast and within a small salinity zone. The image from 21 February 2008 shows the second flow event and a significant movement offshore of the higher CDOM signal, moving into the Swains and Capricorn Bunker reef systems. This high CDOM concentrations support the true colour images, also taken around that time, and show that the offshore influence of the Fitzroy flood was significant in the second flow event. By 7 March, the CDOM signal was once again constrained to the shore and measured only north of the river mouth.

To simulate flood plume dynamics, a verified three-dimensional hydrodynamic model (King *et al.* 2002, based on the MECCA model; Hess 1989), was applied to create computer simulations of the fate and mixing of discharges of freshwater from the Burdekin, Herbert, Tully, Johnstone, Russell, Barron, Daintree, Endeavour and Normanby Rivers. The model was used to simulate the distribution of river flood waters during the 2007/08 wet season (Figure 3.7). The modelling period was from 24 December 2007 until 17 April 2008, a total of 116 days. This model was applied to test its value to predict flood plume dispersal and actual salinity. The two major flood events in 2007/08 occurred in the Burdekin and Fitzroy Rivers and results of these events are provided in Sections 4.3 and 4.5 respectively.

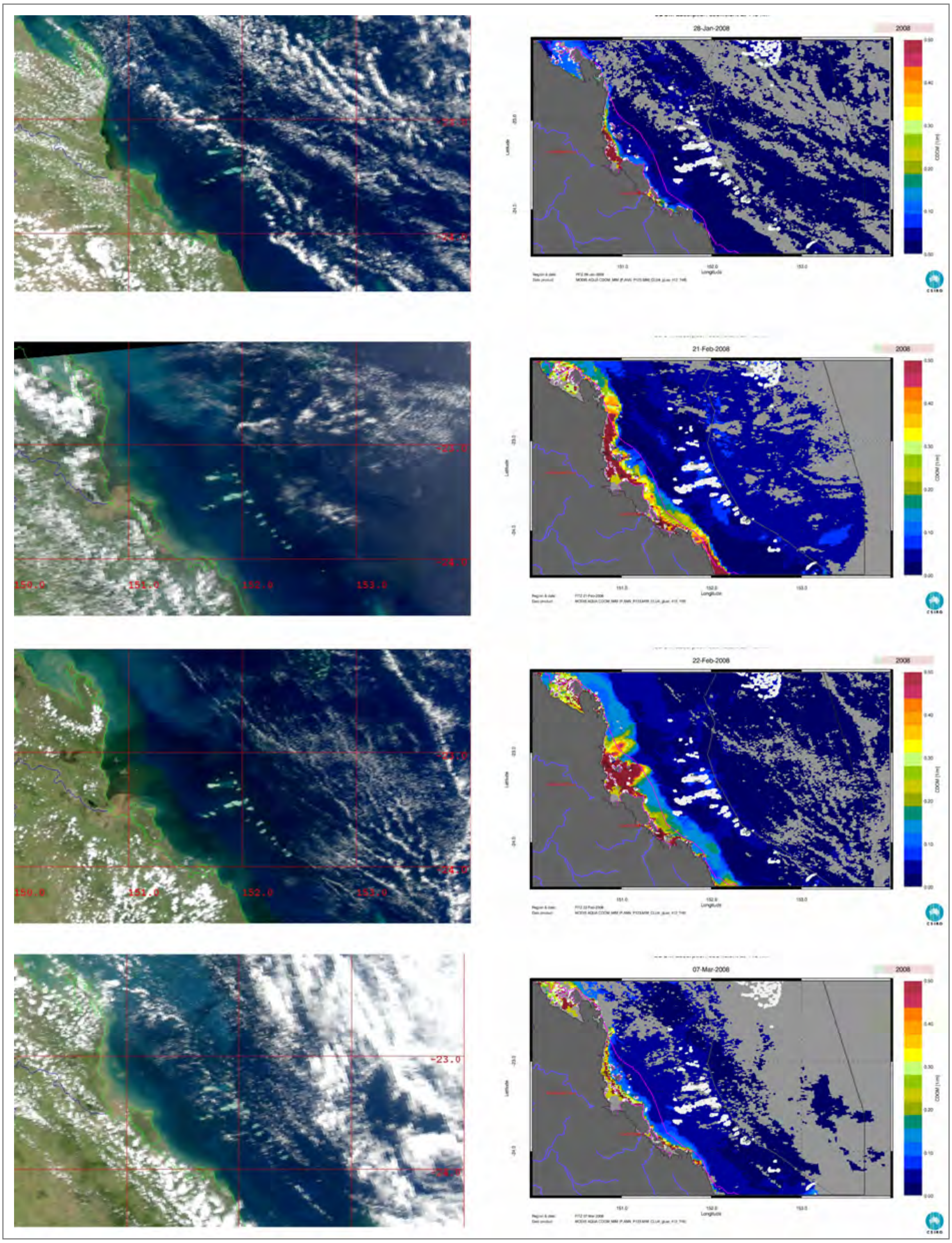


Figure 3.6: Daily true colour images and CDOM maps for key dates during the 2008 flood event for the Fitzroy Estuary – Keppel Bay sub-region. From top to bottom: 28 January 2008, 21 February 2008, 22 February 2008 and 7 March 2008.

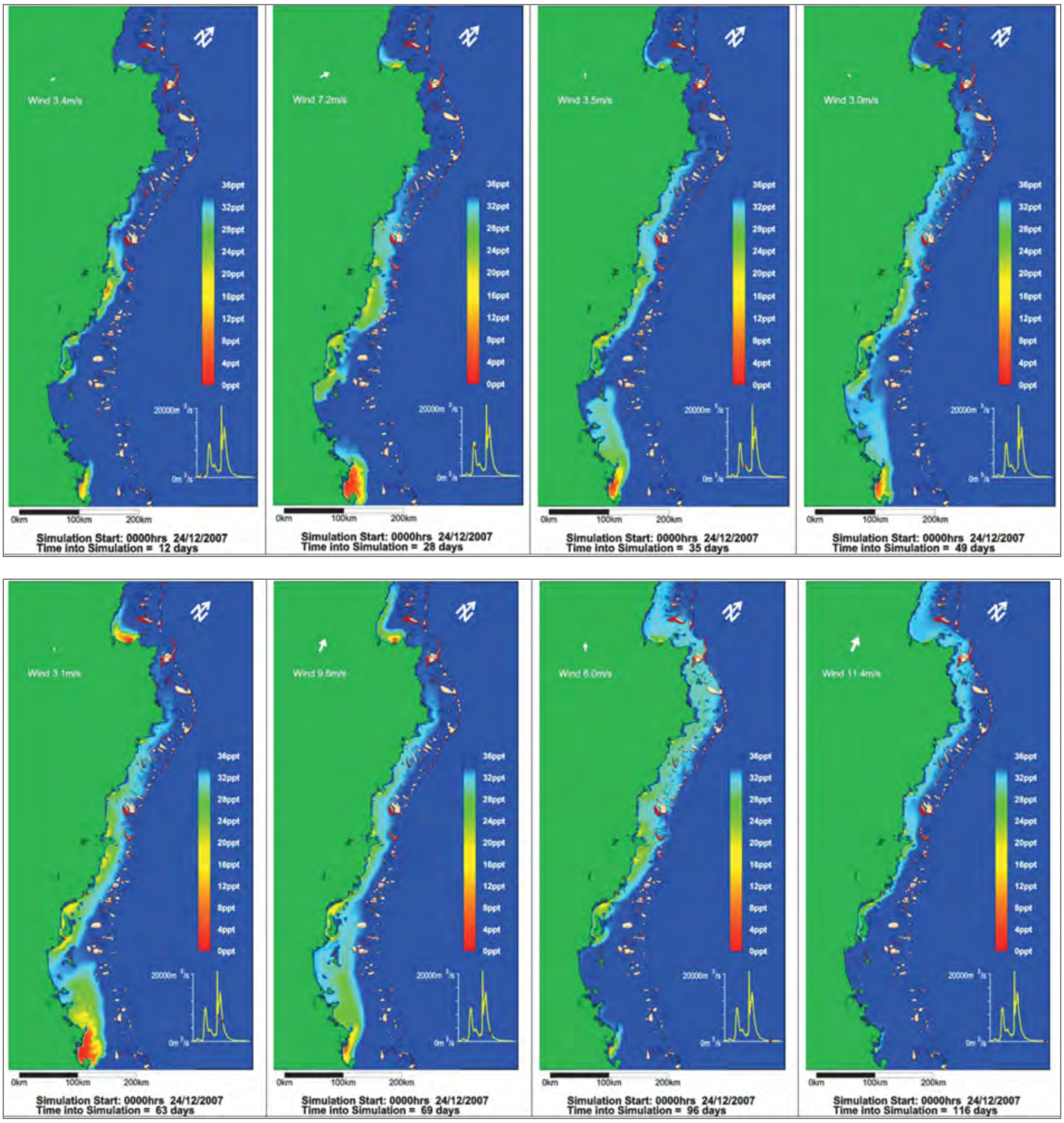


Figure 3.7: Simulated flood plume dynamics of the Burdekin, Herbert, Tully, Johnstone, Russell, Barron, Daintree, Endeavour and Normanby Rivers during the 2007/08 wet season, using a three-dimensional hydrodynamic model to map the movement of freshwater away from the river mouths (King *et al.* 2002).

3.1.4 Pesticide concentrations

This report details pesticide results from the April 2007 to April 2008 period of sampling and compares results to routine monitoring conducted in the previous two monitoring periods (2005/06 and 2006/07) for sites monitored during all sampling periods.

The pesticide profile at inshore reef sites was dominated by diuron, atrazine and hexazinone. For most sites diuron was detected at the highest concentrations, with the exception of Cape Cleveland and Magnetic Island where atrazine was also high. Sites in the Wet Tropics region had higher proportions of simazine compared to other regions.

Pesticide concentrations were generally higher in the 2007/08 wet season than the dry season at all sampling sites, often increasing by 1 to 2 orders of magnitude (Figure 3.8). This is probably a result of the application of pesticides during the wet season, with heavier rainfall then transporting them from the soil. Within sites, there was general consistency between the wet and dry seasons in the percentage contribution of the major herbicides detected, although some herbicides were only detectable in the wet season.

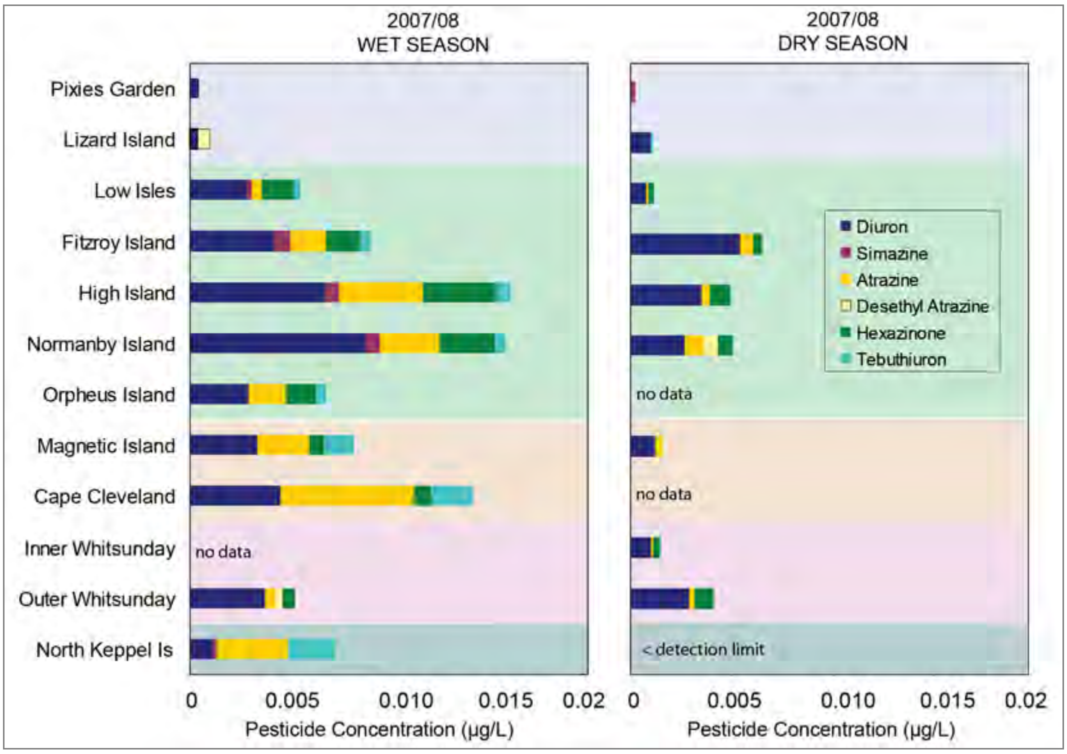


Figure 3.8: Average wet and dry season water concentrations of herbicides detected at inshore monitoring sites in 2007/08 using EDs.

During the initial three years of the monitoring program (2005/06 to 2007/08), herbicides have been detected at all inshore reef monitoring sites, although there were some clear differences between regions (Table 3.3). Overall, water concentrations of pesticides were lowest in both the Cape York and Fitzroy regions (typically below 2 ngL^{-1}). In the Wet Tropics the maximum water concentrations of individual pesticides were similar regardless of where samples were collected (e.g. maximum water concentration of diuron ranged from 12-15 ngL^{-1}). The maximum water concentrations of atrazine (4-7 ngL^{-1}) and hexazinone (3-6 ngL^{-1}) were also similar. There was wider variation in maximum and median water concentrations in the Burdekin region, however sampling at Cape Cleveland only occurred during the 2007/08 wet season and hence could bias results. Monitoring in the Mackay Whitsundays region showed that water concentrations of individual pesticides were generally higher at the monitoring site further offshore. Routine monitoring at the two river sites (Tully River and Pioneer River) detected both a wider range of pesticides and elevated water concentrations compared to inshore reef sites. Water concentrations for pesticides often exceeded 1,000 ngL^{-1}.

Pesticide residues were also detected in the flood plumes sampled from the Burdekin River and from the Fitzroy River. Tebuthiuron residues were detected in the Burdekin River plume up to 50 km from the river mouth. A sample collected near the mouth of the Burdekin River had the highest tebuthiuron concentration of 30 ngL^{-1}. This concentration exceeded the locally derived ecological trigger value for the Great Barrier Reef (20 ngL^{-1}: or 0.02 μgL^{-1} GBRMPA 2009). Higher tebuthiuron concentrations (range from 20-100 ngL^{-1}) were detected offshore from the Fitzroy River plume with a peak concentration of 100 ngL^{-1} detected near the mouth of the river. Tebuthiuron residues were detected up to 60 km from the mouth of the Fitzroy River.

Atrazine residues (and associated degradation products desethyl and desisopropyl atrazine) were also detected in the Fitzroy River plume (range from 40-280 ngL^{-1}) with a peak concentration of 280 ngL^{-1} near the mouth of the river. However, no samples exceeded the ecological trigger value for the Great Barrier Reef (700 ngL^{-1} or 0.7 μgL^{-1}: GBRMPA 2009). Both atrazine and tebuthiuron residues were detected in all pesticide samples collected in the Fitzroy River plume. The other herbicide detected in the Fitzroy River flood plume was metolachlor which was only detected in two samples collected near the mouth of the river in low concentrations (10 ngL^{-1}).

Phytotoxicity testing of samples collected at reef sites during coral spawning in 2007 and 2008 showed that extracts needed to be concentrated significantly to inhibit photosynthetic activity. In 2007, one sample from High Island exceeded detection limits. In 2008, only samples from three sites (Humpy and Halfway Islands, Barron Island, and Orpheus Island) produced a response above detection limits. Results were converted to diuron equivalencies and did not exceed 3 ng/L at any site.

Table 3.3: Maximum, wet season and dry season average herbicide concentrations (ng L^{-1}) detected using Empore Disks.

		Diuron	Simazine	Atrazine	Hexazinone	Tebuthiuron	Ametryn
Lizard Island	**Maximum**	**1.7**	**nd**	**nd**	**nd**	**0.24**	**nd**
(Jul 07 - Mar 08)	Wet (ave n=3)	0.38	nd	nd	nd	nd	nd
	Dry (ave n=2)	1.0	nd	nd	nd	0.12	nd
Pixies Garden	**Maximum**	**1.4**	**0.60**	**0.34**	**nd**	**nd**	**nd**
(Sep 06 - Mar 08)	Wet (ave n=4)	0.61	nd	0.09	nd	nd	nd
	Dry (ave n=4)	nd	0.15	nd	nd	nd	nd
Low Isles	**Maximum**	**12.3**	**1.1**	**4.0**	**3.8**	**1.5**	**nd**
(Jul 05 - Mar 08)	Wet (ave n=12)	3.1	0.18	0.89	1.2	0.16	nd
	Dry (ave n=9)	0.77	nd	0.037	0.075	nd	nd
Fitzroy Island	**Maximum**	**13.3**	**1.5**	**3.7**	**3.1**	**1.8**	**nd**
(Jun 05 - Feb 08)	Wet (ave n=13)	2.8	0.23	0.97	0.80	0.15	nd
	Dry (ave n=11)	3.1	0.034	0.18	0.097	nd	nd
High Island	**Maximum**	**14.0**	**1.1**	**6.8**	**6.0**	**1.3**	**0.28**
(May 06 - Feb 08)	Wet (ave n=6)	7.3	0.37	2.8	3.1	0.42	0.078
	Dry (ave n = 4)	2.3	nd	0.088	0.29	nd	nd
Normanby Island	**Maximum**	**15.0**	**1.8**	**3.9**	**3.1**	**1.9**	**nd**
(Jun 05 - Mar 08)	Wet (ave n=9)	5.7	0.34	2.1	1.7	0.26	nd
	Dry (ave n=8)	1.7	0.23	0.48	0.29	nd	nd
Dunk Island	**Maximum**	**4.1**	**0.41**	**1.7**	**0.72**	**0.33**	**nd**
(Apr 07)	Wet (ave n=1)	4.1	0.41	1.7	0.72	0.33	nd
	Dry (ave n=0)	no data	no data	no data	no data	no data	no data
Tully River	**Maximum**	**1 100**	**120**	**72**	**190**	**0.83**	**nd**
(Mar 07 - Mar 09)	Wet (ave n=5)	266	64	36	47	0.17	nd
	Dry (ave n=0)	no data	no data	no data	no data	no data	no data
Orpheus Island	**Maximum**	**4.5**	nd	**2.7**	**1.9**	**0.67**	nd
(Jul 05 - Mar 08)	Wet (ave n=8)	1.1	nd	0.47	0.39	0.12	nd
	Dry (ave n=7)	0.089	nd	nd	nd	nd	nd

		Diuron	Simazine	Atrazine	Hexazinone	Tebuthiuron	Ametryn
Magnetic Island	**Maximum**	**6.1**	nd	**8.0**	**1.5**	**2.8**	nd
(Jul 05 - Mar 08)	Wet (ave n=8)	2.7	nd	2.8	0.46	0.81	nd
	Dry (ave n=5)	0.65	nd	0.17	nd	0.0069	nd
Cleveland Bay	**Maximum**	**8.4**	nd	**19.6**	**1.4**	**6.3**	**nd**
(Nov 07 - Mar 08)	Wet (ave n=4)	4.6	nd	6.8	0.83	2.2	nd
	Dry (ave n=0)	no data	no data	no data	no data	no data	no data
Inner Whitsunday	**Maximum**	**9.4**	nd	**1.8**	**4.4**	**0.74**	**0.16**
(Nov 06 - Sept 07)	Wet (ave n=5)	4.7	nd	0.58	1.9	0.31	0.033
	Dry (ave n=2)	0.51	nd	nd	nd	nd	nd
Outer Whitsunday	**Maximum**	**16.2**	nd	**3.6**	**6.8**	**1.08**	**0.11**
(Nov 06 - Dec 07)	Wet (ave n=7)	5.6	nd	0.92	1.9	0.19	0.015
	Dry (ave n=2)	3.3	nd	nd	1.0	nd	nd
Pioneer River	**Maximum**	**1 700**	**7**	**1 500**	**730**	**11**	**72**
(Oct 05 - Mar 08)	Wet (ave n=16)	**448**	**2**	**433**	**174**	**1**	**18**
	Dry (ave n=7)	**42**	**nd**	**39**	**30**	**1.6**	**1.8**
North Keppel	**Maximum**	**1.9**	**0.48**	**7.2**	**nd**	**4.8**	**nd**
(Jul 05 - Jan 08)	Wet (ave n=8)	0.97	0.06	0.90	nd	0.60	nd
	Dry (ave n=6)	0.23	nd	nd	nd	nd	nd

Herbicide equivalency

Herbicide (PSII) equivalency concentrations were calculated 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. This can be used as a relative measure of risk to inshore reef habitats.

Herbicide equivalencies (Herbicide$_{EQ}$) were calculated for the inshore GBR and river sampling sites. The maximum, average wet and average dry season Herbicide$_{EQ}$ was calculated for each site based on the available site data (Table 3.4). The maximum Herbicide$_{EQ}$ at the inshore GBR sites ranged from 1.4 ngL^{-1} at Pixie Garden to 18.7 ngL^{-1} at the Outer Whitsunday Island sampling site. The maximum Herbicide$_{EQ}$ at the two river sites monitored were 1,167 ngL^{-1} in the Tully River and 2,269 ngL^{-1} in the Pioneer River (during ambient sampling only). At all marine sites monitored in the GBR, diuron contributed highest to the Herbicide$_{EQ}$. This is partially due to the fact that diuron is detected at highest concentrations at the majority of marine sites (compare Figure 3.9 to Figure 3.10) and of the herbicides detected, diuron has the greatest relative potency (see Figure 3.10). As a consequence, sites in the Wet Tropics (adjacent to the Barron, Russell, Mulgrave, and Johnstone Rivers), Burdekin (adjacent to the Barratta Creek, Haughton and Burdekin Rivers) and the Mackay Whitsunday (adjacent to Pioneer and O'Connell Rivers) regions may be considered most at risk to herbicide impacts. The results also confirm that the herbicide diuron is the herbicide of greatest concern for the inshore GBR.

Table 3.4: Relative potency used for the calculation of $Herbicide_{EQ}$.

Herbicide	Relative potency (based on IC10*)
Diuron	1.0
Hexazinone	0.27
Atrazine	0.17
Simazine	0.03
Tebuthiuron	0.15
Ametryn	3.1
Flumeturon	0.06
Prometryn	2.0
Atrazine desethyl	0.02
Des-isopropyl atrazine	0.005

* 10% inhibitory concentrations.

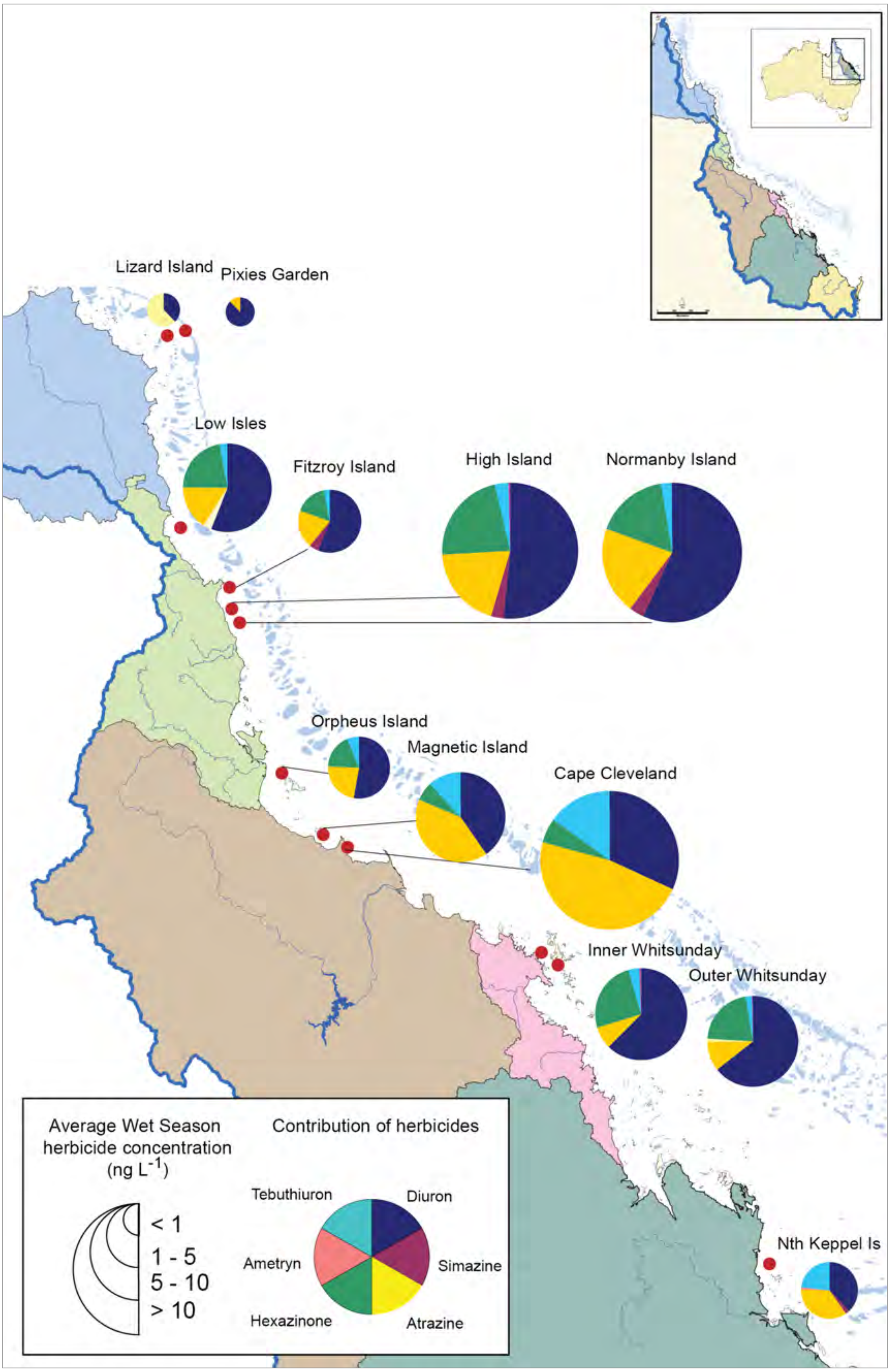


Figure 3.9: Average wet season concentrations of herbicides detected at inshore monitoring sites (from 2005-2008) and the relative contribution of the individual herbicides to the total concentration.

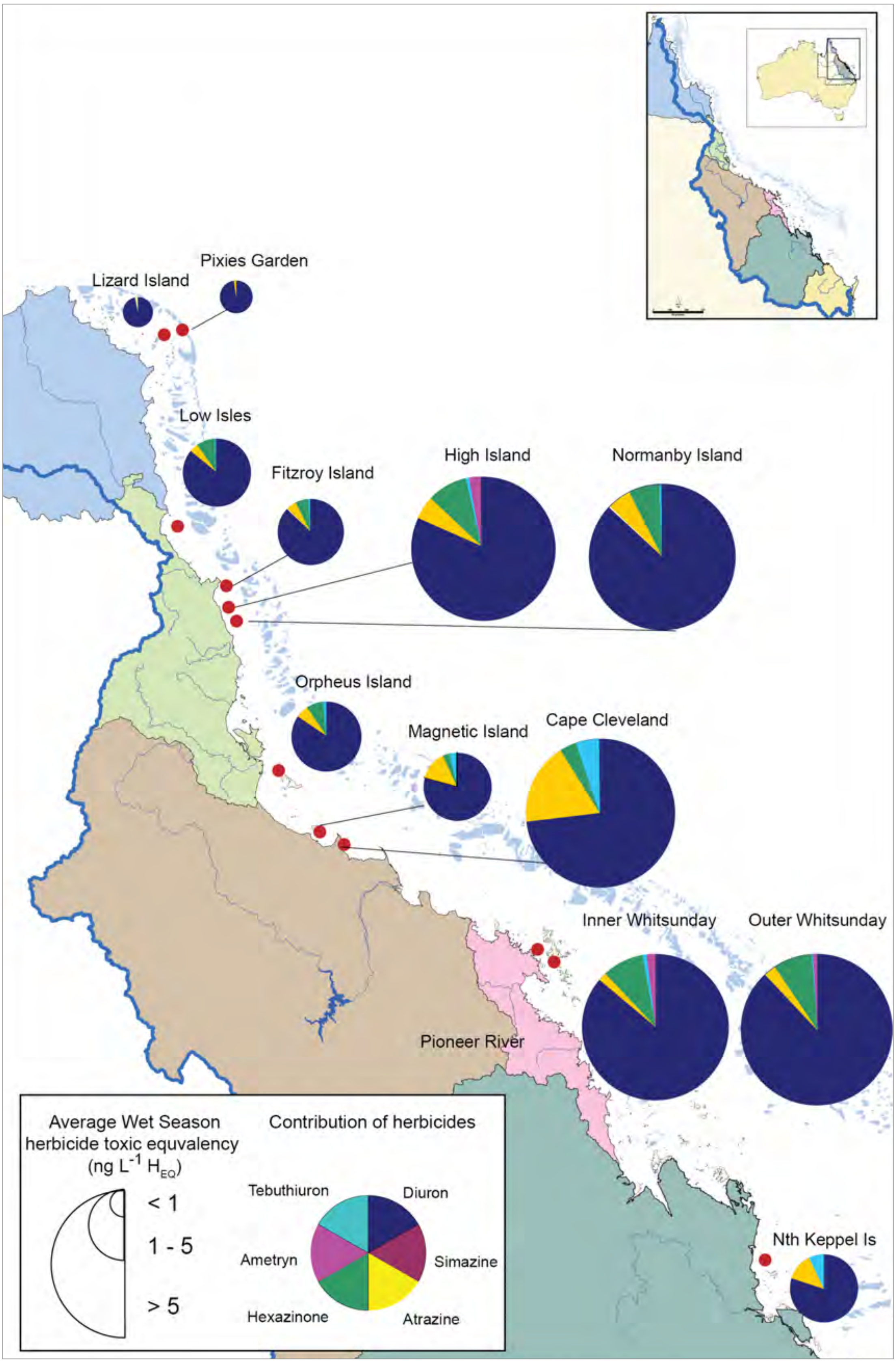


Figure 3.10: Average wet season Herbicides toxic equivalency at inshore monitoring sites (from 2005-2008) and the relative contribution of the individual herbicides to the total $Herbicide_{EQ}$.

3.1.5 Remote sensing of GBR water quality

The statistical distributions of the chlorophyll *a* data retrieved with the algorithm from MODIS-AQUA images were compared with the *in situ* data from previous GBR long-term monitoring for each region for the wet and dry seasons of 2005/06 (Figure 3.11). The comparison showed that the ranges of the measured *in situ* samples typically fell within the ranges of the remotely sensed values, and that higher chlorophyll values were present in waters in the coastal region compared with inshore regions and offshore waters.

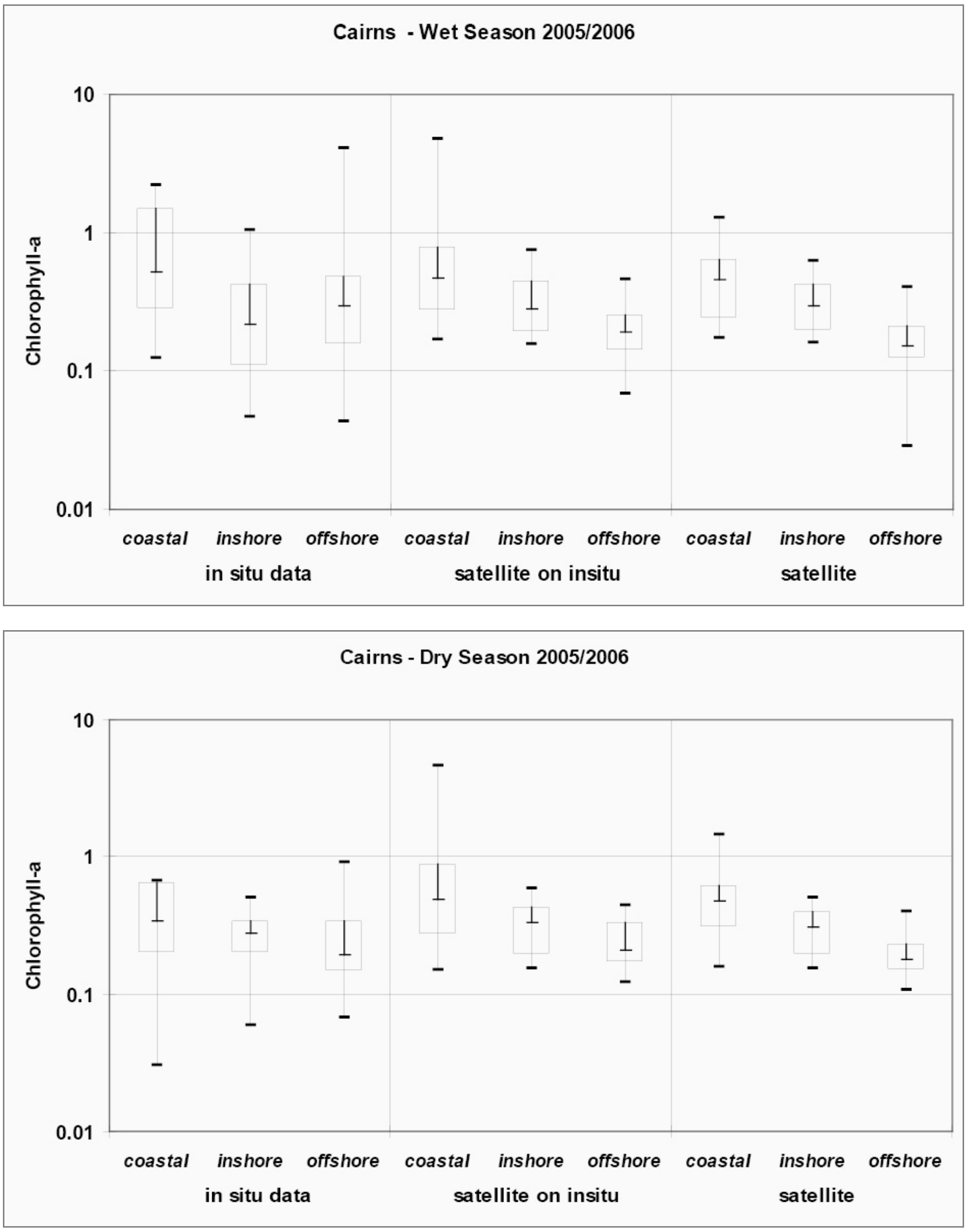


Figure 3.11: Comparison of chlorophyll concentrations retrieved from MODIS-AQUA data with *in situ* data for the Cairns region. Graphs represent the 2005/06 dry and wet seasons. The box-whiskers plots are organised in three panels: *in situ* data from the GBR LTMP; satellite-derived, time-series data of the pixel encompassing the *in situ* sites; and all satellite-derived, time-series data. Coastal, inshore and offshore regions are presented in each panel.

The CSIRO Environmental Earth Observation Group developed a software suite to produce from daily remote sensed data a number of derived products suited to the specific needs of end-users, in a number of outputs, including maps, animations, statistical compliance assessments and alert or anomaly systems.

The software suite enables the production of maps of:

- Minimum, maximum, median, logmean, mean, STD of chlorophyll, TSM, CDOM and Kd for the GBRWHA.
- Maps of 5th, 25th, 75th and 95th of chlorophyll, TSM, CDOM and Kd for the GBRWHA.
- Weekly, monthly, seasonal, and yearly and long term statistics.
- Assessment of the exceedance of Water Quality Guidelines for water quality variables.

As an example, the wet and dry season median maps of chlorophyll (Figures 3.12a and 3.12b) for the Fitzroy Estuary-Keppel Bay region show high chlorophyll concentrations near the coast and in the estuary to lower concentrations towards the east. Median values of Chlorophyll *a* to 0.5 μgL^{-1} extended as far as the Capricorn Bunker Group for both seasons.

The wet and dry season median maps of coloured dissolved organic matter (CDOM; Figures 3.12a and 3.12b) for the Fitzroy Estuary–Keppel Bay region show values higher than 0.20 m^{-1} in for a coastal band approximately ten kilometres wide, up to fifty kilometres north of the river mouth for the wet season, while during the dry season values were higher than 0.20 m^{-1} only for the area close to the river mouth.

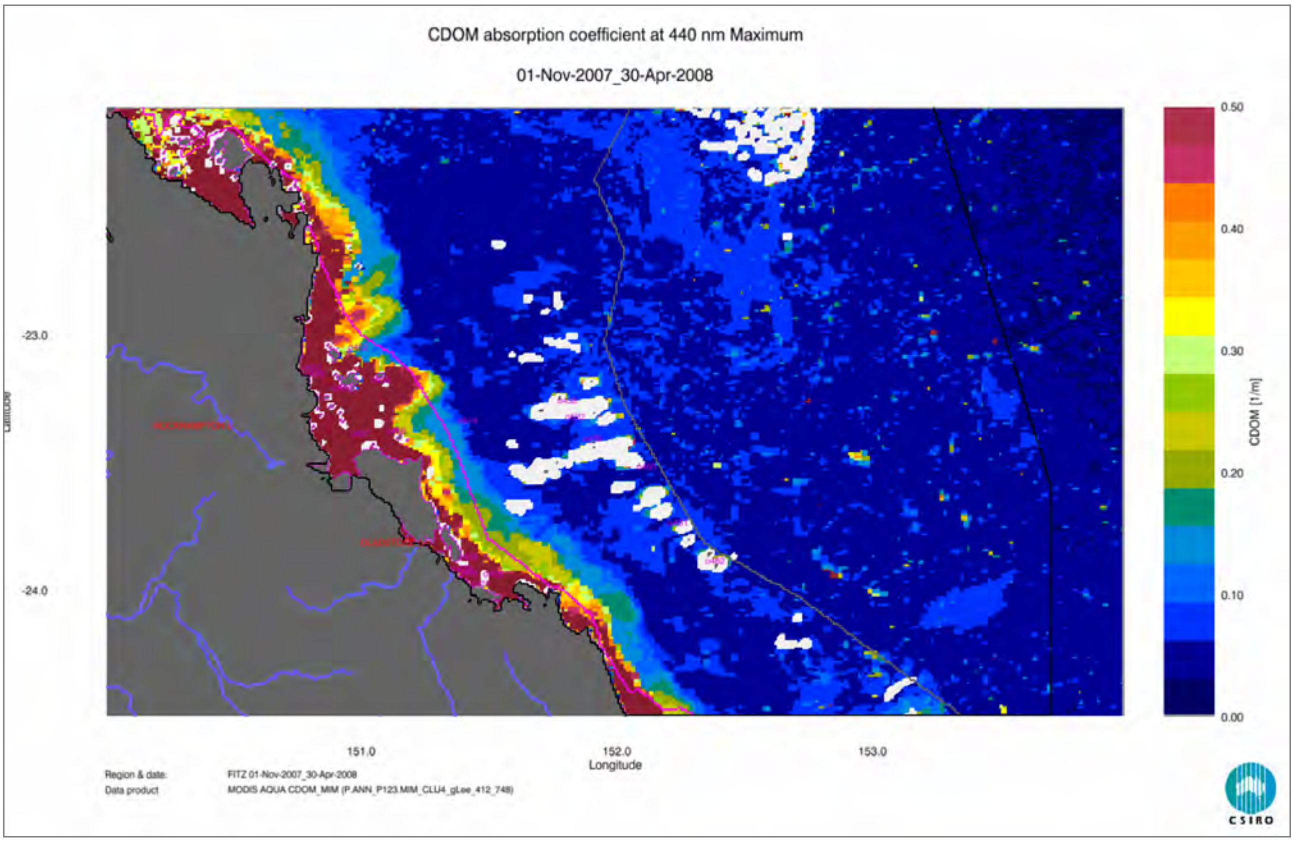


Figure 3.12a: Map of maximum retrieved value of CDOM for the wet season 2007/08 for the Fitzroy Estuary-Keppel Bay sub-region.

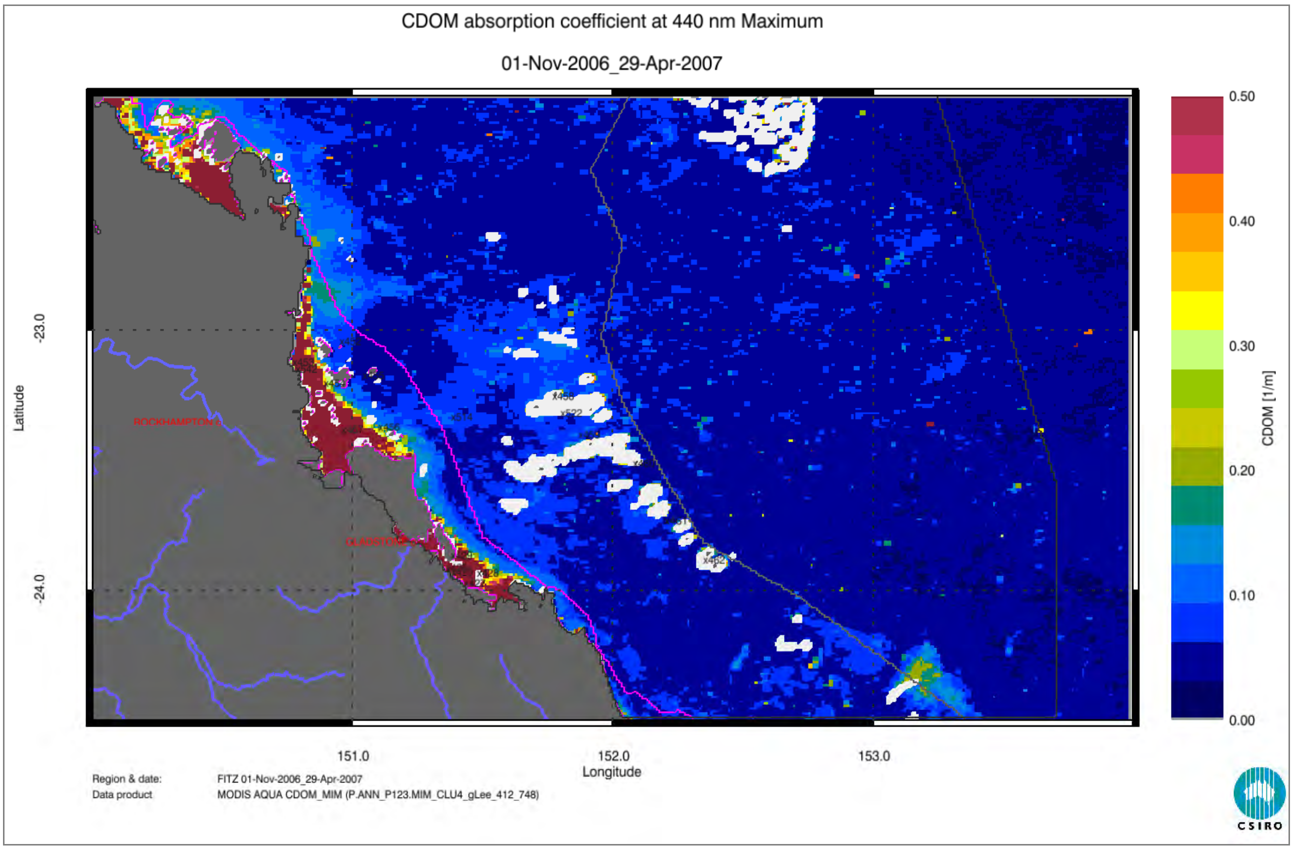


Figure 3.12b: Map of maximum retrieved value of CDOM for the dry season 2007/08 for the Fitzroy Estuary-Keppel Bay sub-region.

The wet and dry season median maps of non-algal particulate matter (as a measure of total suspended matter) for the Fitzroy Estuary–Keppel Bay region show similar gross patterns as for the CDOM distribution, although locally there are differences (for example, increased levels of non-algal particulate matter extend out further into the lagoon in the northeast area of Shoalwater Bay.

The wet and dry season median maps of vertical attenuation of light for the Fitzroy Estuary–Keppel Bay region show similar gross patterns as for the chlorophyll, dissolved organic matter and non-algal particulate matter distribution, indicating that all parameters show a similar seasonal pattern (Brando *et al.* 2008).

3.2 Inshore GBR biological monitoring

3.2.1 Inshore seagrass meadows

There are a range of environmental pressures on seagrass meadows along the GBR coast including those resulting from river discharges, and from urban and industrial development. The types of influences/pressures on seagrass differ for each region of the GBR. Monitoring results indicate that intertidal seagrass meadows are influenced by factors that affect primary production, mainly light availability and nutrients. Seagrass in the GBR can be split into four major habitat types: estuary/inlet, coastal, reef and deepwater (Carruthers *et al.* 2002) (Figure 3.13). All but the outer reef habitats are significantly influenced by seasonal and episodic pulses of sediment- and nutrient-rich river flows, resulting from high volume summer rainfall. Cyclones, severe storms, wind and waves as well as macro grazers (fish, dugongs and turtles) influence inshore seagrass habitats to varying degrees. The result is a series of dynamic, spatially and temporally variable seagrass meadows.

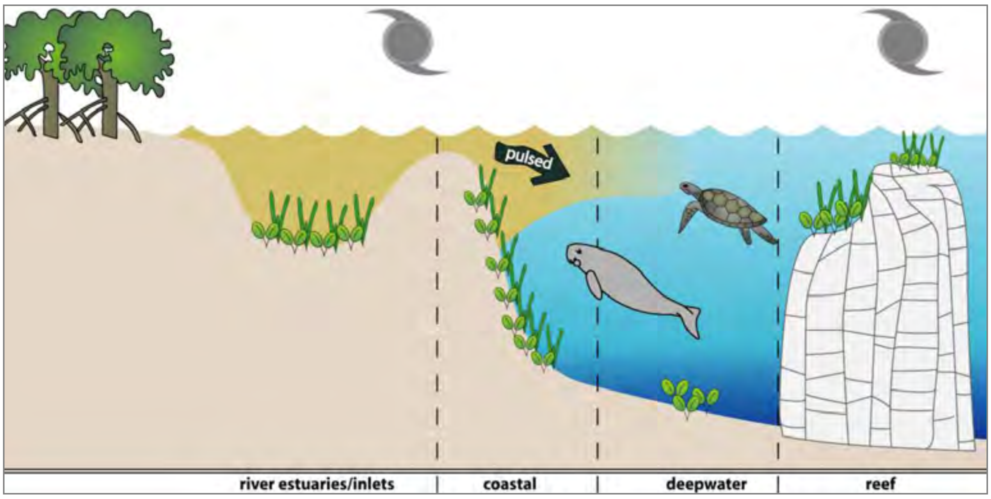


Figure 3.13: Conceptual model of seagrass habitats in northeast Australia (from Carruthers *et al.* 2002).

3.2.2 Status of GBR seagrass meadows

Seagrass meadows monitored by the MMP over the 2007/08 period indicate that seagrass meadows range from good to fair condition on a GBR-wide scale. Localised declines were observed at two, geographically separated locations (Archer Point, near Cooktown, and Townsville). However as these locations have relatively large seed banks and low epiphyte/macroalgae abundance, they have a degree of resilience for recovery.

Estuarine seagrass meadows

Estuarine seagrass meadows are characterised by high nutrient availability and low light regimes due to highly turbid waters and overgrowth by epiphytes and macroalgae. Nine-year seagrass cover in GBR intertidal meadows averages 21%. Seagrass abundance at estuarine monitoring sites increased significantly in 2007 (Figure 3.14), reversing a declining trend from early 2006.

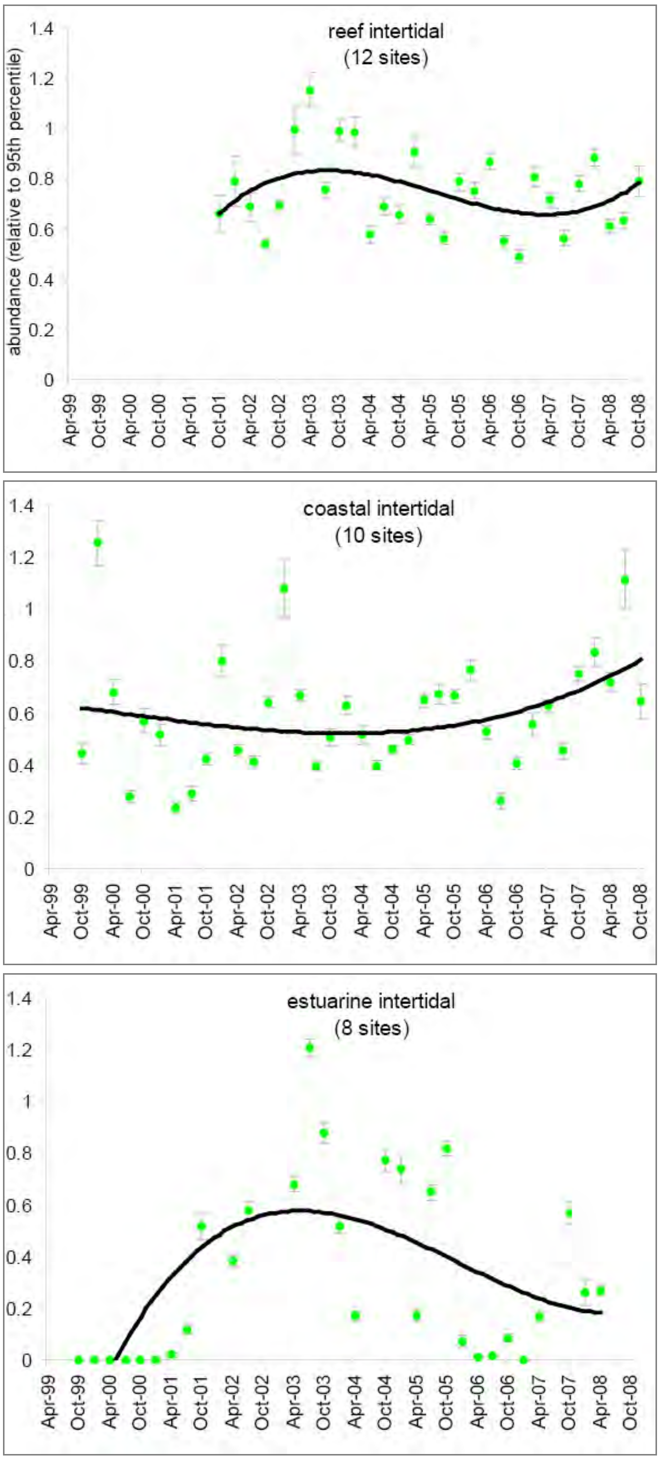


Figure 3.14: Generalised trends in seagrass abundance (percent cover, ± Standard Error) for each habitat type (sites pooled) relative to the 95th percentile (equally scaled). The 95th percentile is calculated for each site across all data. NB: Polynomial trendline for all years pooled.

Coastal seagrass meadows

Coastal seagrass meadows are characterised by generally adequate light and nutrient availability for growth, but are subject to periods of elevated temperatures and disturbance from wind-generated turbidity, waves and floods. Nine-year seagrass cover averages twenty percent and seagrass abundance has remained relatively stable over the years of monitoring. However a significant increase late in the 2007 dry season is typical of short-term fluctuations that sometimes occur.

Reef top seagrass meadows

The meadows are characterised by high light availability and low nutrient environments. Nine-year seagrass cover averages 26% and seagrass abundance has fluctuated at intertidal reef-platform seagrass meadows in the last eight year, but has increased over the last couple of years (Figure 3.15). Within years, seagrass abundance fluctuates greatly between seasons. The more successful seagrass species in reef habitats of the GBR include *Cymodocea rotundata*, *Thalassia hemprichii*, and the colonising species *Halophila ovalis* and *Halodule uninervis*.

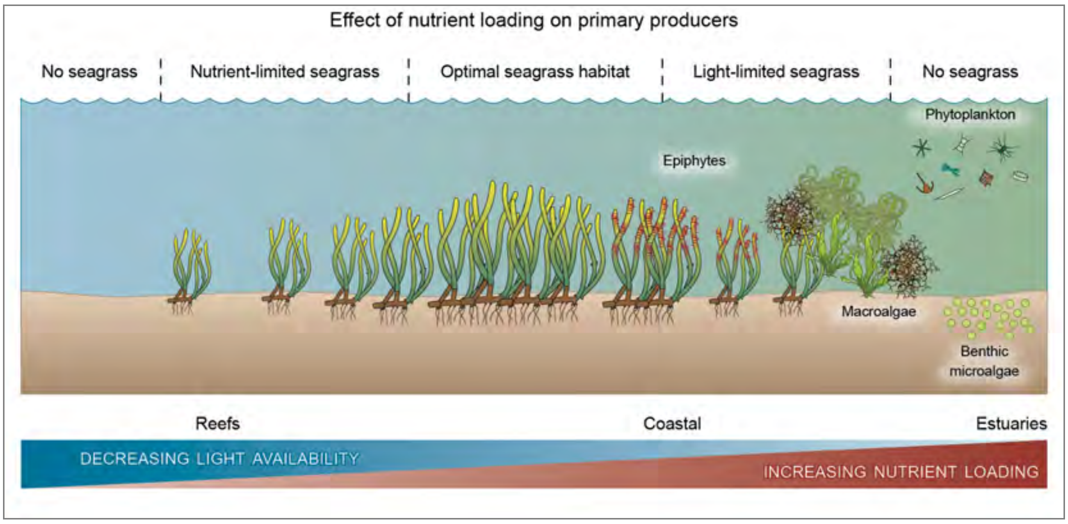


Figure 3.15: General model of nutrient loading in a seagrass meadow.

Generally, seagrass cover and abundance was higher over the last monitoring period compared to previous years. At the scale of locations and sites, there is considerable variability in meadow cover but at a GBR-wide scale monitoring does not show any long term trends. Most observed changes are likely to be linked to short term environmental events. The only notable change in species composition occurred at Pioneer Bay in the Mackay Whitsunday region. This meadow is becoming more *Zostera sp.* dominated, and the sediments more mud dominated. This is likely to be a normal succession event.

Intertidal seagrass meadow distribution (meadow area) has changed little since monitoring was established. Seagrass meadow distribution over the 2007/08 sampling period declined in some locations due to natural physical disturbance (sediment movement), but on a GBR-wide scale has shown little change in the long-term.

In addition, several sites are seen to be recovering following disturbance based on changes in seagrass cover. The region with the greatest seed banks and reproductive effort was the Burdekin region, followed by the Wet Tropics and Mackay Whitsundays regions (Table 3.5).

Evidence of significant amounts of reproductive effort across the majority of sites monitored by the MMP suggests the seagrass meadows are typically resilient to loss.

Although epiphyte cover was lower late in the 2008 monsoon compared to late in the 2007 dry season, the difference was not significant. Generally trends in epiphyte cover are similar to seagrass abundance, but amplitude differs between habitats. Macro-algae abundance was generally low but variable in coastal/reef meadows, with a slight increase observed in estuarine meadows. Low but detectable concentrations of diuron were recorded in sediments across a number of intertidal seagrass monitoring locations over the last sampling period, suggesting wide spread contamination possibly from diffuse sources.

Table 3.5: Summary of condition and overall trend of seagrass at GBR monitoring locations. Values are October 2007 – April 2008 with the long-term average in parentheses. Red = poor; green = good; yellow = fair; white = ambiguous or insufficient data. Amber = sites of concern with respect to water quality. || = no change.

NRM	Location	Seagrass Cover (%)	Seagrass Seeds (no. m^{-2})	Reproductive effort (no. $core^{-1}$)	Meadow (area)	Epiphytes (%)	Macro-Algae (%)	$C:N_{plant}$ status	$C:P_{plant}$ status	$N:P_{plant}$ status	$N:P_{sediment}$ trend (status)
Cape York	Archer Point *(reef)*	15-13 (19) decline	323-255 (162) increase	increase	increase	29-11 (23) decline	7-2 (9) decline	moderate	poor	P limited	N↑P || (N>P)
Wet Tropics	Yule Point *(coast)*	15-29 (15) increase	526-382 (429) stable	increase	increase	15-51 (17) increase	<1 (2) variable	low	rich	replete	N || P↓ (N<P)
	Green Is *(reef)*	38-34 (42) increase	nil	stable (low)	stable	7-25 (24) increase	5-5 (4) stable	moderate	poor	replete	N↓P↓ (N<P)
	Lugger Bay *(coasl)*	4-6 (4) recovering	0-17 (14) decline	decrease (low)	recovery	5-1 (3) variable	0 (<1) variable	low	rich	replete	N || P↓ (N=P)
	Dunk Is *(reef)*	12-15 (12) NA	4-42 (9) NA	NA	NA	7-10 (10) NA	6-8 (7) NA	moderate	poor	replete	NA (N<P)
Burdekin	Townsville *(coast)*	24-14 (19) decline	4793-7388 (3227) increase	increase (high)	decline	7-23 (17) decline	6-1 (4) decline	low	rich	P limited	N↑P↓ (N>P)
	Magnetic Is *(reef)*	43-56 (35) increase	14-8 (34) decline	stable	stable	51-54 (42) stable	21-6 (8) stable	moderate	poor	N limited	N↓P↓ (N<P)
Mackay Whitsunday	Pioneer Bay *(coast)*	33-15 (20) increase	166-225 (279) increase	increase	increase	22-13 (15) decline	10-2 (13) stable	low	rich	P limited	N↑P↓ (N<P)
	Hamilton Is* *(reef)*	10-3 (9) NA	nil	NA	NA	31-25 (23) NA	1-3 (2) NA	low	poor	NA	NA (N<P)
	Sarina Inlet *(estuary)*	13-11 (14) recovery	0 (66) variable	increase	variable	31-2 (16) variable	2-<1 (1) variable	low	rich	replete	N↑P↓ (N<P)

NRM	Location	Seagrass Cover (%)	Seagrass Seeds (no. m^{-2})	Reproductive effort (no. $core^{-1}$)	Meadow (area)	Epiphytes (%)	Macro-Algae (%)	$C:N_{plant}$ status	$C:P_{plant}$ status	$N:P_{plant}$ status	$N:P_{sediment}$ trend (status)
Fitzroy	Shoalwater *(coast)*	36-32 (27) increase	nil	NA	stable	15-10 (12) decline	5-<1 (6) decline	moderate	poor	N limited	N↓P↓ (N<P)
	Great Keppel *(reef)*	6-2 (3) NA	nil	NA	NA	32-53 (34) NA	14-5 (8) NA	low	rich	P limited	NA (N<P)
	Gladstone *(estuary)*	25-18 (16) recovery	nil	increasing	recovery	33-30 (27) variable	9-28 (22) stable	low	rich	N limited	N↑P↓ (N<P)
Burnett Mary	Rodds Bay *(estuary)*	41-7 (24) NA	0-8 (4) NA	decreasing	NA	9-1 (5) NA	1-3 (2) NA	moderate	poor	N limited	NA (N<P)
	Urangan *(estuary)*	0.2-0.8 (16) recovery	nil	increasing	recovery	2-1 (19) decline	<1 (1) variable	low	rich	N limited	N↓P↓ (N=P)

3.2.3 Inshore coral reefs

Inshore coral reefs in the GBR are exposed to a range of acute disturbances, such as cyclonic winds, bleaching and crown-of-thorns starfish, as well more chronic disturbances such as those related to runoff (e.g. increased sedimentation and nutrient loads), which disrupt processes of recovery such as recruitment and growth. The reef monitoring sites are close to the sampling locations for lagoon water quality to assess the relationship between reef communities and water quality as well as other, more acute impacts, such as cyclones.

One salient attribute of a healthy ecological community is that it should be self-perpetuating and 'resilient', that is: able to recover from disturbance. One of the ways in which water quality is most likely to shape reef communities is through effects on coral reproduction and recruitment. Laboratory and field studies show that elevated concentrations of nutrients and other agrichemicals and levels of suspended sediment and turbidity can affect one or more of gametogenesis, fertilisation, planulation, egg size, and embryonic development in some coral species (reviewed by Fabricius 2005). High levels of sedimentation can affect larval settlement or net recruitment of corals. Similar levels of these factors may have sub-lethal effects on established adult colonies. Because adult corals can tolerate poorer water quality than recruits, and colonies are potentially long-lived, reefs may retain high coral cover even under conditions of declining water quality, but have low resilience.

3.2.4 Status of inshore GBR coral reefs

Overall, analyses of hard and soft coral community composition for the GBR showed relatively little change between 2006 and 2007 compared to that observed between 2005 and 2006. This may be due in part to an absence of disturbances after the 2006 survey period and reinforces the influence that disturbance events, coupled with chronic water quality have in shaping coral communities.

Acute disturbances to coral reefs in localised areas of the Wet Tropics (Cyclone Larry) and Fitzroy (coral bleaching) regions in 2006 influenced the benthic condition documented during the 2007/08 surveys. The continued effects from these physical disturbances that impacted some reefs may have long-term consequences for reefs already affected by poor water quality. Coral cover declined at sites on Dent Island in the Mackay Whitsunday region, and High Island and the Frankland Islands Group in the Wet Tropics region. On reefs of the Frankland Islands Group, the red algae of the genera *Laurencia* and *Hypnea* were growing thickly among branches of *Porites*.

Hard coral cover

There was an overall increase in hard coral cover from 31% in 2006 to 33% in 2007. This result reflects small increases in cover in all regions and sub-regions with the exception of the Tully Herbert sub-region (Figure 3.16). Cover in 2007 was, however, still significantly lower overall than that observed in 2005. Increased cover to 2007 did not account for the reductions from 2005 to 2006 resulting from the localised disturbances of Cyclone *Larry* in the Wet Tropics region and coral bleaching in the Fitzroy region. While the reefs that were not disturbed in 2006 had increased cover between 2006 and 2007 this was not the case for the majority of reefs impacted by either Cyclone *Larry* or coral bleaching. On these impacted reefs hard coral cover typically declined further, indicating lowered resilience to recover from cyclone damage.

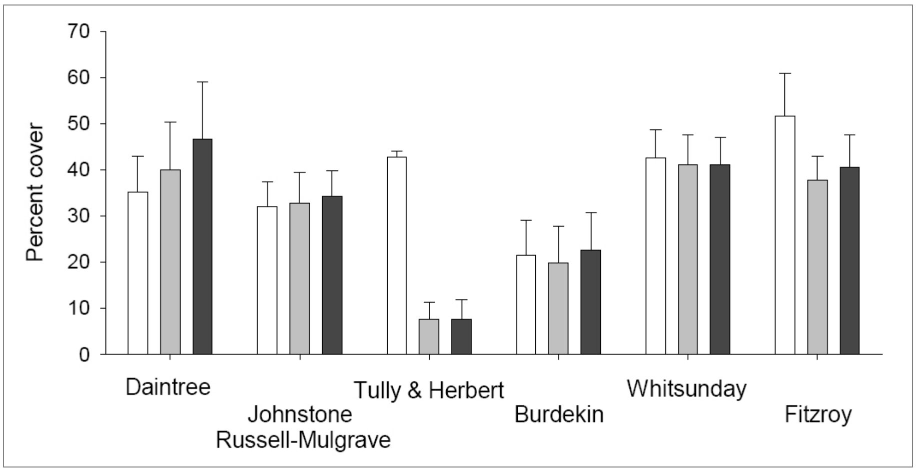


Figure 3.16: Average cover of hard coral on reefs for each region/sub-region (+/- standard error). For each region the first (clear) bar represents data from 2005, the second (pale grey) bar represents data from 2006 and the third (dark grey) bar 2007 data.

Soft coral cover

There was no overall difference in the cover of soft corals between surveys in 2006 and 2007 or between surveys in 2005 and 2007 (Figure 3.17). This lack of trend in soft coral cover however, masks the differing trajectories among regions, with most regions increasing slightly in soft coral cover and others decreasing (e.g. Tully Herbert sub-region decreased from 6.5% in 2005 to 0.5% in 2007).

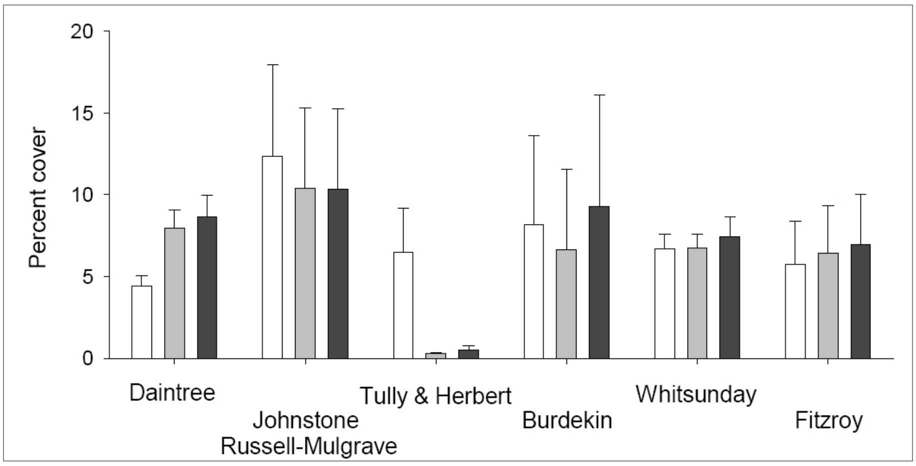


Figure 3.17: Average cover of soft coral on reefs for each region/sub-region (+/- standard error). For each region the first (clear) bar represents data from 2005, the second (pale grey) bar represents data from 2006 and the third (dark grey) bar 2007 data.

Macroalgae cover

Competion between corals and macroalgae is key in determining the abundance of corals on reefs. Macroalgae can overgrow corals, reduce the amount of light available to corals for photosynthesis, or limit the amount of substrate available for coral larvae to settle. The cover of macroalgae in the GBR is generally variable through time compared to that of corals, primarily due to the short life spans of individual thalli or life history stages, seasonality and the potential for high growth rates. The overall average cover of macroalgae has increased in each consecutive survey from 9% in 2005 through 11% in 2006 to 13% in 2007. Much of these increases were attributable to rapid colonisation of space at relatively few sites following disturbance events.

In 2007, the cover of macroalgae varied among regions (Figure 3.18). Algal cover on reefs in the Burdekin and Fitzroy regions was higher than that observed in the Daintree and Johnstone sub-regions or Mackay Whitsunday region. Macroalgae cover was also significantly higher on reefs in the Tully Herbert sub-region than those in the Daintree sub-region (Figure 3.18). The relatively high algal cover on reefs in the Burdekin region has been consistent from 2005 to 2007.

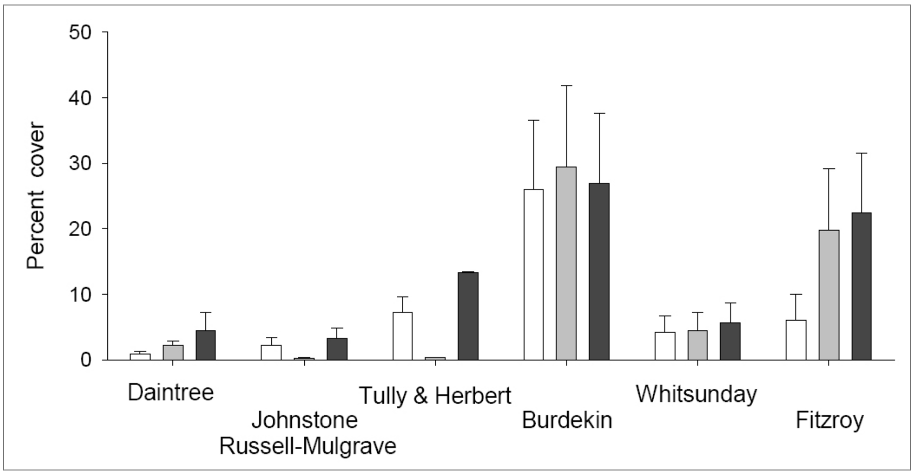


Figure 3.18: Average cover of macroalgae on reefs for each region/sub-region (+/- standard error). For each region the first (clear) bar represents data from 2005, the second (pale grey) bar represents data from 2006 and the third (dark grey) bar 2007 data.

Density and count of juvenile coral colonies

The overall average number of juvenile colonies per square metre of available substrate did not differ between 2006 and 2007 (Figure 3.19a). Comparing the density of coral recruits between 2006 and 2007 within each region and sub-region separately indicated that while most conformed to the overall trend of ‘no change’, an increase from six to eleven juvenile colonies per square metre of available substrate was noted in the Daintree sub-region (Figure 3.19a).

Analysis of the number of juveniles per square metre of transect provides similar results to the analysis that accounts for the area of available substratum with no overall differences in abundance between 2006 and 2007 but significantly lower abundance in 2007 than in 2005, which was driven by reductions on cyclone-impacted reefs. The average numbers of juvenile colonies have remained reasonably stable over the three years of sampling in the Fitzroy, Mackay Whitsunday and Burdekin regions (Figure 3.19b).

A comparison among regions in 2007 showed that the average number of juvenile colonies, corrected for available substratum area was significantly lower on reefs in the Fitzroy region than those in the Daintree, Johnstone, Russell Mulgrave sub-regions or Mackay Whitsunday regions. Similarly, the number of juvenile sized colonies per square metre of transect (uncorrected for available space) was significantly lower in the Fitzroy region than either the Tully Herbert, Johnstone and Russell Mulgrave sub-regions or the Mackay Whitsunday region (Figure 3.19b).

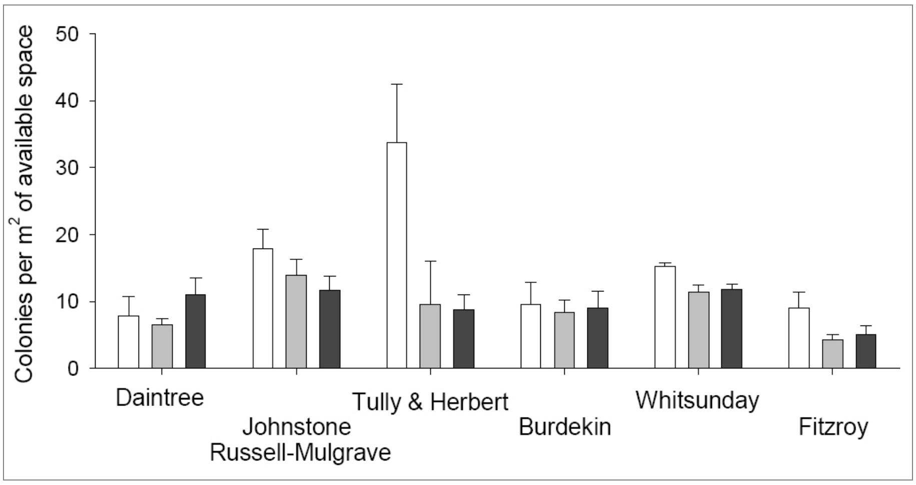


Figure 3.19a: Average density of hard coral colonies <10 cm in diameter per square metre of available substratum on reefs for each region/sub-region (+/- standard error). For each region the first (clear) bar represents data from 2005, the second (pale grey) bar represents data from 2006 and the third (dark grey) bar 2007 data. Note that data from 2005 are not directly comparable to later years due to a change in methodology.

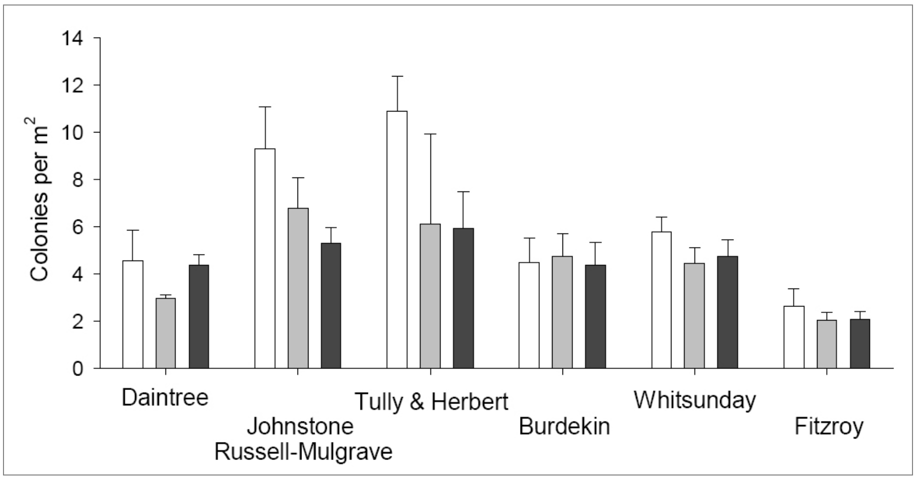


Figure 3.19b: Average number of hard coral colonies <10 cm in diameter on reefs for each region/subregion (+/- standard error). For each region the first clear) bar represents data from 2005, the second (pale grey) bar represents data from 2006 and the third (dark grey) bar 2007 data. Note that data from 2005 are not directly comparable to later years due to a change in methodology.

Community composition: hard coral genera

The taxonomic diversity of hard corals is considered a measure of reef health, with diverse reefs able to recover from disturbances faster. There was no overall difference in the average richness of hard coral genera between 2005 and 2007 or 2006 and 2007. However, there was some variability between years in some regions. Changes in richness between 2006 and 2007 were marginal with slight increases in the Burdekin region and Daintree sub-region and slight declines in the Fitzroy region and Tully Herbert sub-region (Figure 3.20).

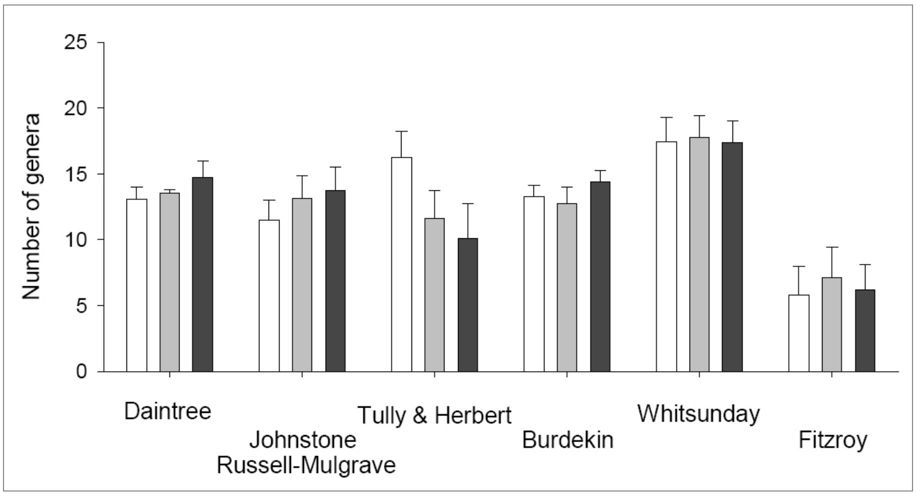


Figure 3.20: Average number of hard coral genera per site per depth on reefs for each region/sub-region (+/- standard error). For each region the first (clear) bar represents 2005 data, the second (pale grey) bar represents 2006 data and the third (dark grey) bar 2007 data.

Community composition: juvenile hard coral colonies

In the 2007/08 sampling period, estimates of juvenile hard coral species richness showed the highest richness on reefs in the Mackay Whitsunday region, the Johnstone Russel Mulgrave sub-region of the Wet Tropics, and the Burdekin region. Reef in the Fitzroy region had the lowest juvenile hard coral richness (Figure 3.21). Estimates of the richness of juvenile corals from 2007 are not directly comparable to those from previous years due to an increase in the survey area introduced in 2007. Increasing the area of transects will likely result in increased richness as individuals of rare genera are more likely to be recorded.

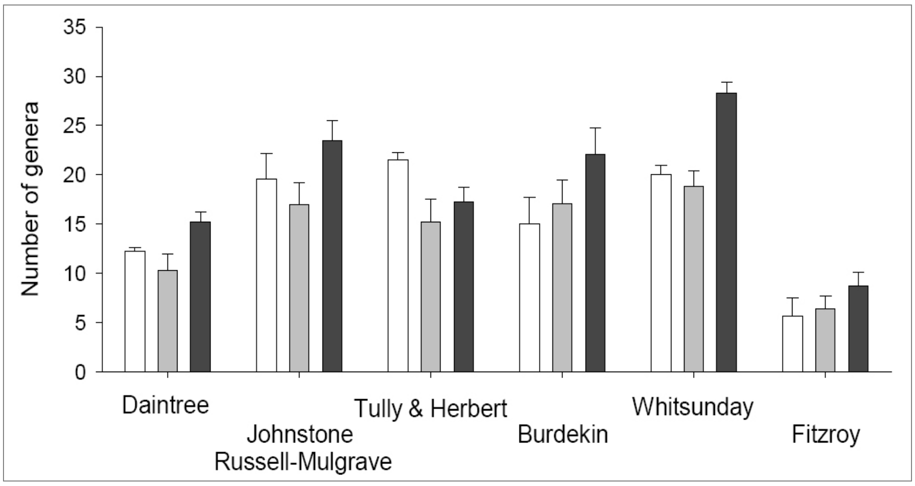


Figure 3.21: Average number of hard coral genera represented by colonies <10 cm in diameter per site per depth on reefs in each region/sub-region (+/- standard error). For each region the first (clear) bar represents 2005 data, the second (pale grey) bar represents 2006 data and the third (dark grey) bar 2007 data.

Coral settlement (recruitment)

Comparison of coral settlement among regions in 2007 shows, on average, that settlement in the Wet Tropics was more than three times higher than in the Mackay Whitsunday region, and four to five times higher than in the Burdekin and Fitzroy regions (Figure 3.22). However, there was significant variation in settlement rates recorded among the reefs within most regions. The exception to this was the Burdekin region where recruitment was very similar on all reefs.

Temporal comparisons between regions sampled in 2006 and 2007 showed that settlement was significantly higher in 2007. This overall increase was driven by a significant increase in the Wet Tropics region and a lesser increase in the Mackay Whitsunday region. These increases contrasted the observed decline in the Fitzroy region (Figure 3.22). Differences in settlement between 2006 and 2007 varied among the reefs within regions, however, all six reefs sampled in the Wet Tropics region showed higher settlement in 2007 than observed in 2006.

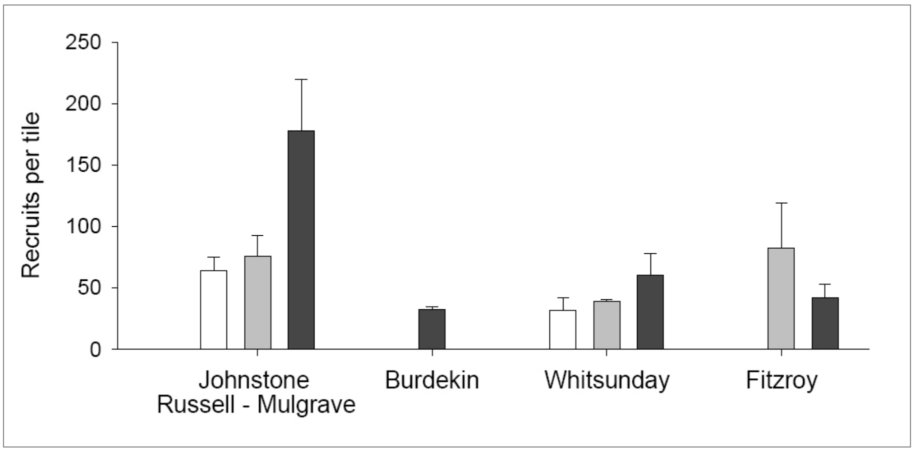


Figure 3.22: Average number of hard coral recruits per tile on reefs in each region/sub-region (+/- standard error). Estimates are for five metres depth tile deployments only. Colour of bars represent sampling years within each region data from the 2005/06 summer are represented by clear, the 2006/07 summer pale grey and the 2007/08 summer dark grey.

Reef sediment composition

Sediment variables of interest for understanding of benthic community dynamics are highly correlated. The content of nitrogen in the sediment is positively correlated to the proportion of fine grain sizes (<0.031 mm) in the sample (Figure 3.23) and both these variables were negatively correlated to the inorganic carbon content. Sediment composition in the Mackay Whitsunday region was substantially different to the other regions with very high concentrations of sediment nitrogen, a high proportion of fine grain sizes and relatively low content of inorganic carbon.

Variation in benthic community attributes was assessed against estimates of sediment quality by separately modelling each combination of benthic community attribute and sediment quality variable.

Hard coral cover showed a relationship to all three sediment variables with the variance in cover explained by the sediments ranging from twenty percent for the proportion of sediment with grain-size classified as clay through to medium silt (<0.031 mm) through to 26% for the nitrogen content of the sediments. Hard coral cover was generally higher on reefs with high sediment nitrogen content and higher proportions of finer grained sediments. Conversely, hard coral cover was lower on reefs with higher inorganic carbon content typical of reef derived sediments. The number of hard coral genera recorded per site (richness) was also higher at reefs with higher proportions of finer grained sediments.

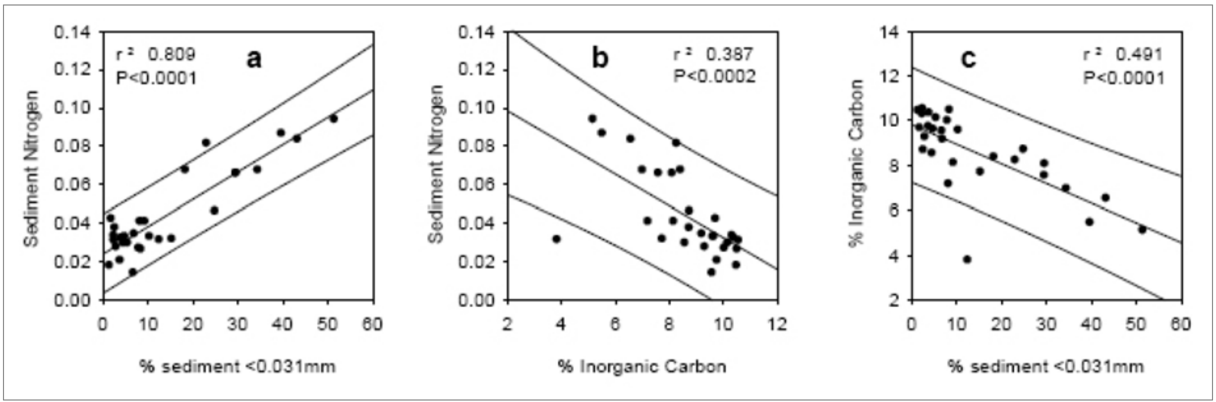


Figure 3.23: Relationships between ecologically relevant measures of sediment quality: (a) nitrogen content and proportion of fine grain sizes (<0.031mm); (b) nitrogen and inorganic carbon content; and (c) inorganic carbon content and proportion of fine grain sizes (<0.031mm).

Foraminifera assemblages

Foraminiferan assemblages in all regions were highly diverse, with highest diversity observed in the Burdekin and Whitsunday regions. The FORAM index varied widely between reefs with values between about 2 and 10. Higher indices express a larger proportion of symbiont-bearing taxa, interpreted as indicative of lower nutrient/lower turbidity conditions.

Heterotrophic foraminifera were associated with high values of particulate matter in the water and fine sediments (<63 and 63-250 µm grain size) with high sediment carbon and nitrogen content. In contrast, symbiont-bearing species were associated with low turbidity and high inorganic carbon content in the sediment. Thus, light availability for symbiont-bearing foraminifera and food availability for heterotrophic taxa appear to be the main drivers for foram community composition.

Several reefs with foraminifera assemblages dominated by autotrophic taxa were located in waters with above average (for inshore reefs) light conditions and with little organic content in the sediments. Most distinct among these are the front reefs of High Island, Frankland Group Pandora Reef and Havannah Island. In contrast, the landward reef locations at the same sites were dominated by heterotrophic foraminifera species (leading also to lower FORAM indices), have less light available and sediments with higher organic content.

The assemblage composition showed distinct regional patterns and these patterns reflected environmental conditions, which are, at least to some extent, related to water quality. The pooled 'light and particulate' water quality variable (PN, PP, POC, DOC, SS, chlorophyll, Secchi depth) was clearly correlated with foraminiferan assemblage composition, most likely by influencing light availability (i.e. more autotrophic taxa are detected in 'clearer' waters). The concentrations of inorganic carbon and nitrogen in the sediments, which were also significantly correlated with foraminifera assemblage composition (i.e. more heterotrophic taxa are detected in sediment rich in organic matter), are determined by both, nutrient inputs and hydrodynamic conditions, indicated by the strong correlation of sediment organic composition with small sediment size.

3.2.5 Inshore reef resilience

The complex relationship between coral reef communities, their environment and disturbance (Figure 3.24) make it challenging to identify the causes of any apparent lack of resilience of inshore reefs. There are significant differences between the reef communities monitored in the MMP and initial data analyses indicate that these differences are related to their environmental setting (CRC Reef Consortium 2006, Sweatman *et al.* 2007, Schaffelke *et al.* 2007). Part of this environmental setting is defined by the geographical (latitudinal) location. Hard corals on the southernmost survey reefs (Fitzroy region), had low taxonomic richness, supporting the documented latitudinal gradient of declining coral biodiversity on GBR reefs (DeVantier *et al.* 2006). Finer scales of variation (such as neighbouring reefs having quite different coral communities) are likely to be caused by intermittent local disturbances and subsequent recovery. Land runoff influenced water quality is likely to play a regional and local role in shaping coral reef communities, with a nutrient gradient apparent along dilution gradients away from river mouths and the mainland coast due to the coastal and inshore water body being generally well-mixed (Cooper *et al.* 2007). Sedimentation and associated turbidity can vary on a local reef scale, being controlled by local hydrodynamics (wind, tides, and exposure) and the river-based influx of new suspended sediment and organic matter (proximity to river mouths; Wolanski *et al.* 2008).

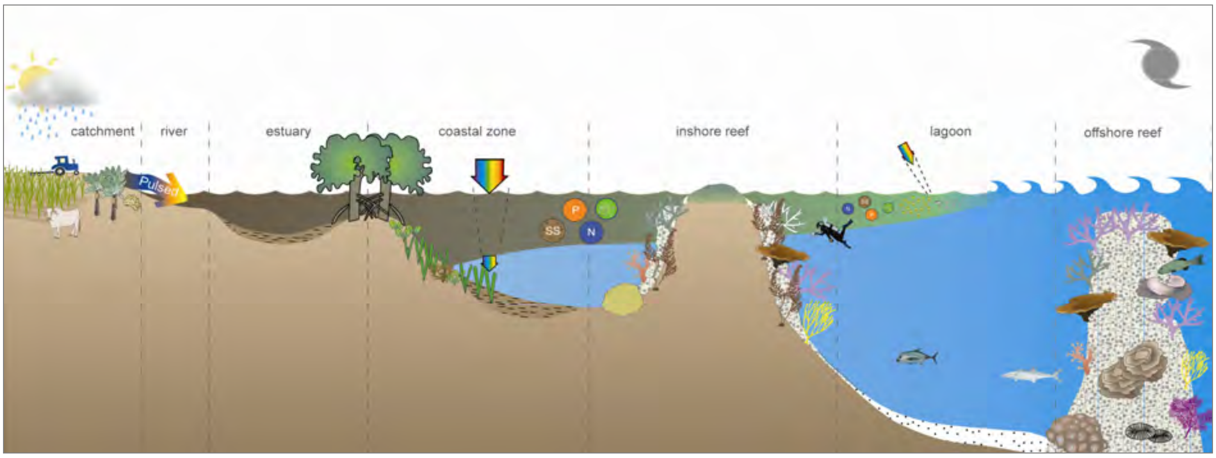


Figure 3.24: Conceptual representation of the links between catchment to reef and how terrestrial influences vary depending on location, hydrodynamics and local conditions.

4. Regional Reports

The Reef Rescue Water Quality Marine Monitoring Program assesses water quality and ecosystem condition for each of the six Natural Resource Management regions of the GBR (Figure 4.1). The information collected complements regional monitoring of land management practices and catchment water quality.

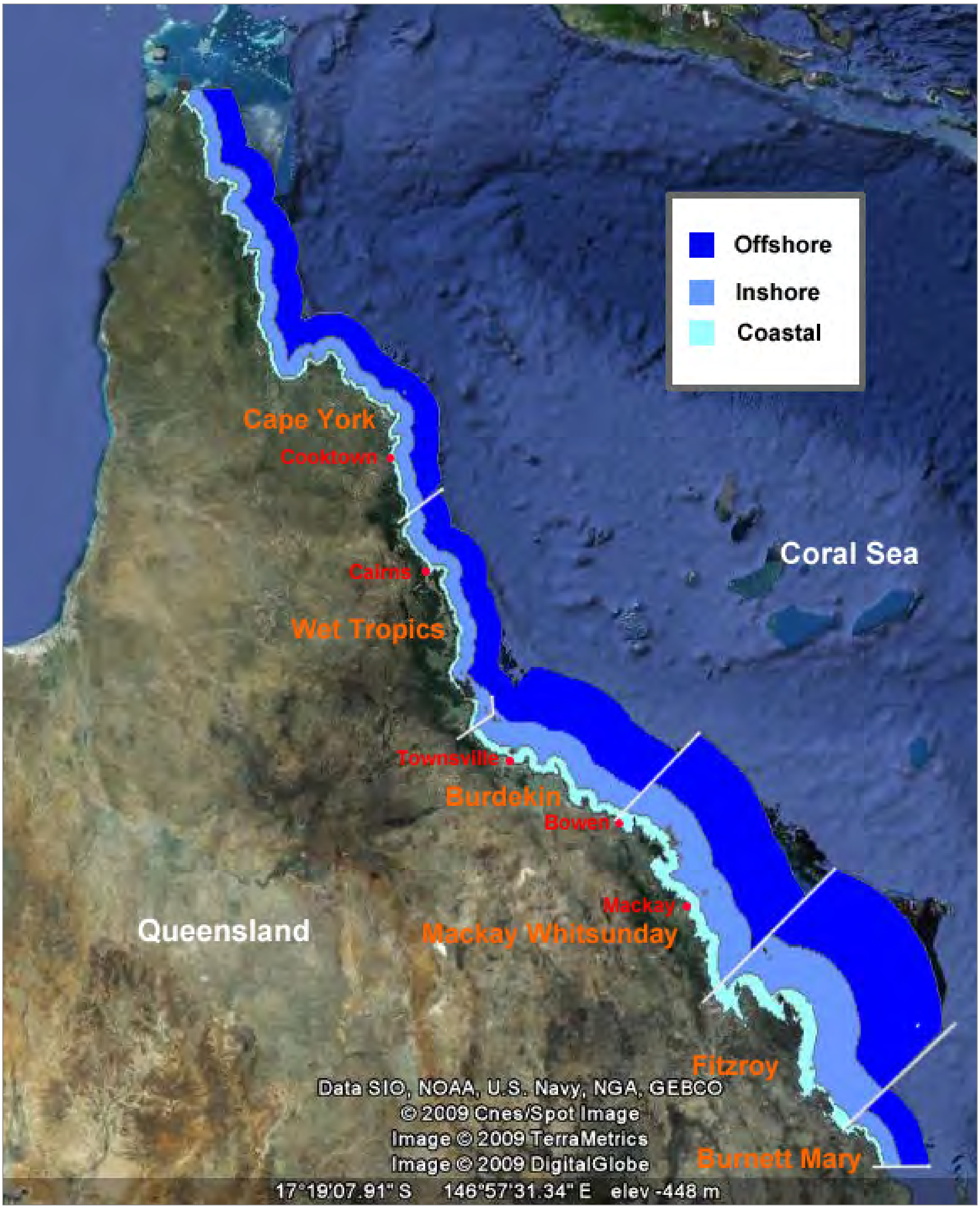


Figure 4.1: Overview of the six Queensland Natural Resource Management regional boundaries where they extend into the MMP study area.

4.1 Cape York region

Cape York Peninsula is the northernmost extremity of Australia. From its tip at Cape York it extends southward in Queensland for about 800 km, widening to its base, which spans 650 km 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 there are several large catchments that empty into the GBR; the Normanby, Endeavour and Lockhart Rivers. The region has a monsoon climate with distinct wet and dry seasons with mean annual rainfall ranging from 1715 mm in the Starke region to 2159 mm near the Lockhart River airport. Most rain falls between December and April. Cape York is an area of exceptional conservation value and has cultural value of great significance to both Indigenous and non-Indigenous communities. The majority of the land is relatively undeveloped, therefore water entering the GBR lagoon is perceived to be of a high quality.

The only inshore water quality monitoring conducted in the Cape York region is chlorophyll and pesticide sampling. Other water quality parameters, flood plumes and coral reefs are not monitored in the Cape York region so only the results of the chlorophyll and pesticide sampling, and seagrass habitat monitoring are presented within this regional report.

Water Quality

There is no significant cross-shelf gradient (from inshore to offshore) in chlorophyll concentrations in the Cape York region. The lowest regional annual median chlorophyll values for offshore sites over the three monitoring years were recorded adjacent to the Cape York region, and were below the Guideline trigger value of 0.40 μgL^{-1}.

Pesticide monitoring at two sites in the Cape York region – Lizard Island and Pixies Garden – recorded water concentrations of pesticides typically below 2 ngL^{-1} with median values at the detection limit. Pesticide monitoring at Lizard Island commenced in August 2007 and a total of five sets of samples were analysed. Diuron, tebuthiuron and two breakdown products of atrazine were detected at low concentrations. Only diuron was detected more than once, with a maximum water concentration of 1.8 ngL^{-1}. (Diuron is a consitituent of antfoulant paint, and may be sourced from visiting vessels that frequent the sampling embayment over the winter months). Desisopropyl atrazine and tebuthiuron were present in the dry season, while desethyl atrazine was detected in the wet season.

Pesticide monitoring at Pixies Garden was continuous from September 2006 and a total of eight sets of samples were analysed. Diuron, atrazine, simazine and desethyl atrazine were detected at low concentrations. Diuron was detected three times with a maximum water concentration of 1.4 ngL^{-1}. Atrazine, simazine and desethyl atrazine were only detected once each. Median values for all chemicals were at the detection limit. Atrazine and simazine were detected in the wet season and dry season respectively whereas diuron was only detected in the two wet seasons. Monitoring at both sites only occasionally detected tributyl phosphate at concentrations between 2 and 4 ngL^{-1}.

The pesticide concentrations detected in the Cape York region are low relative to other regions, and may be explained by the limited agricultural land use and the dilution of chemicals transported north from southern catchments by northern long shore currents.

Seagrass and coral habitats

Approximately three percent of all mapped seagrass meadows in the Cape York region are located on fringing-reefs (Coles *et al.* 2007) where physical disturbance from waves, swell and associated sediment movement primarily control seagrass growth in these habitats (Figure 4.2). Monitoring of intertidal seagrass meadows within the Cape York region is carried out at two sites on a fringing reef platform at Archer Point.

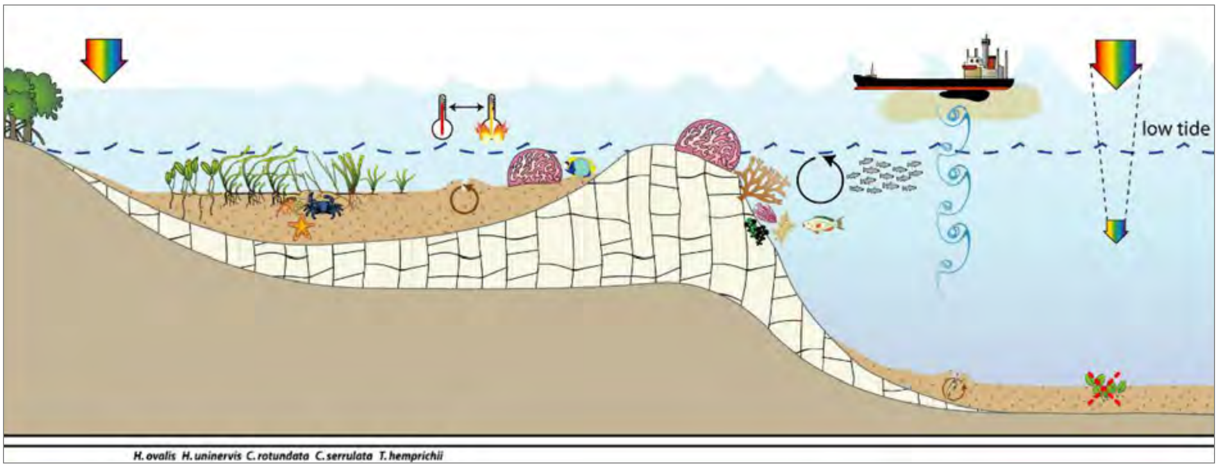


Figure 4.2: Conceptual diagram of reef-platform habitats in the Cape York region – major control is pulsed physical disturbance, salinity and temperature extremes.

Results of seagrass monitoring indicate that seagrass cover has declined from 15% to 13% (Figure 4.3), seagrass seeds, reproductive effort and meadow area have all increased, and epiphytes and macroalgae have declined in the 2007/08 monitoring period.

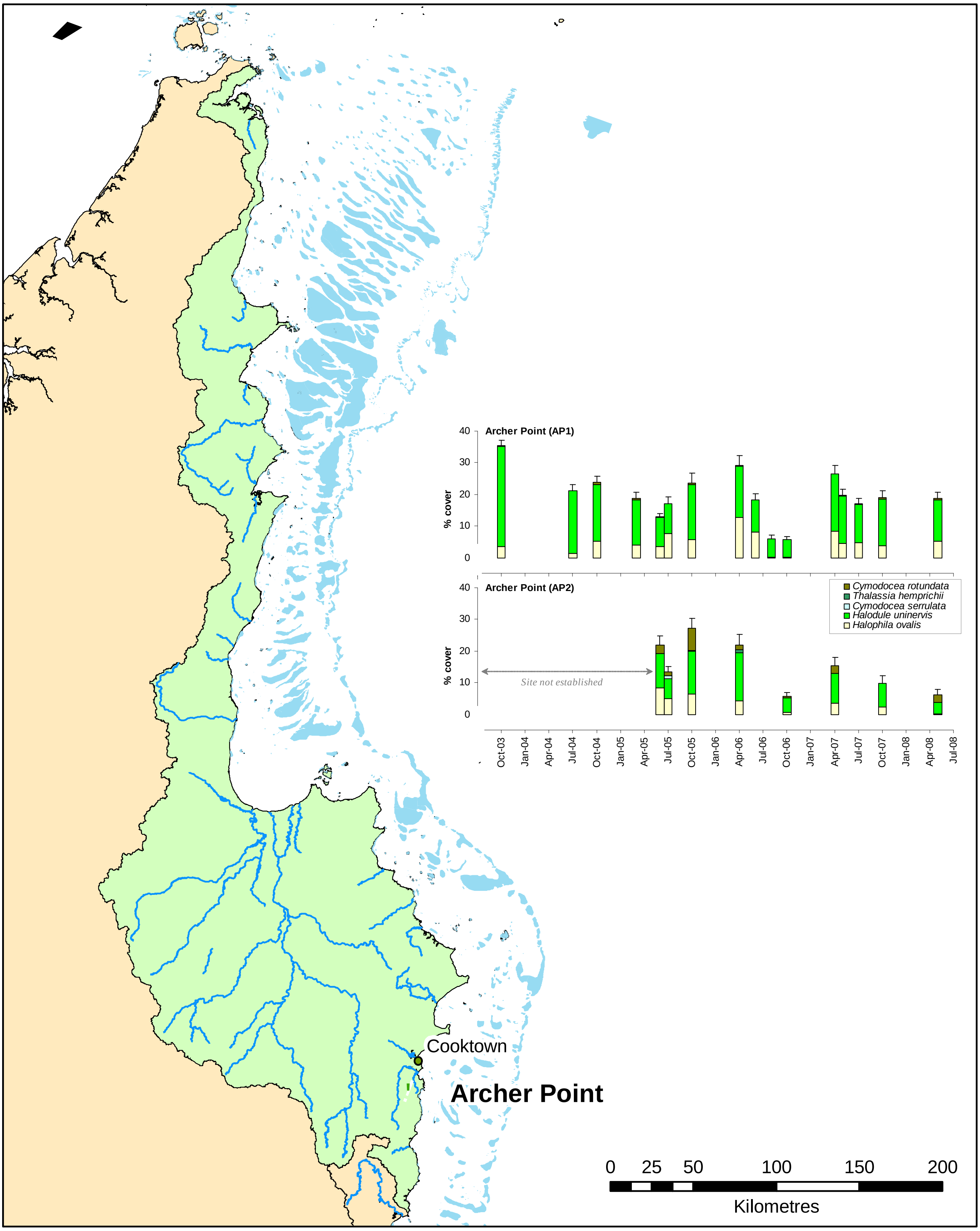


Figure 4.3: Mean percentage cover for each seagrass species at Archer Point monitoring sites (+Standard Error). Note: if no sampling was conducted then x-axis is clear.

4.2 Wet Tropics region

Water quality

Field deployments of WET Labs Eco FLNTUSB combination fluorometer and turbidity sensors at five sites in the Wet Tropics region measured daily temperature, chlorophyll and turbidity for the 2007/08 sampling period (Figures 4.4, 4.5 and 4.6).

The ‘Cairns Coastal Transect’, has been regularly sampled by AIMS since 1989 and is the only available long-term data set for a comprehensive range of water quality parameters in the GBR lagoon with which to conduct temporal trend analyses. 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 *a* (Chl; μgL^{-1}), particulate nitrogen (PN; μgL^{-1}), particulate phosphorus (PP; μgL^{-1}), suspended solids (SS; mgL^{-1}), total dissolved nitrogen (TDN; μgL^{-1}) and total dissolved phosphorus (TDP; μgL^{-1}).

These six parameters have shown temporal trends over sampling years in previous analysis (De’ath 2005, CRC Reef Consortium 2006, Schaffelke *et al.* 2007) or are most likely to show temporal trends because they are less variable over small spatial and temporal scales and are considered to integrate water column processes.

All parameters, except chlorophyll *a*, showed significant long-term patterns (Figure 4.7) with all parameters (except chlorophyll *a*) measured at reduced concentrations since 2001. Long-term trends were non-linear with the exception of particulate phosphorus (PP), which showed a linear trend of declining values over time. Dissolved organic nitrogen (DON) and dissolved organic phosphorus (DOP) increased in the mid to late 1990s, peaked around 2003 and then declined. Suspended solids (SS) increased in the early to late 1990s, peaked around 1999 and then declined. Particulate nitrogen (PN) and chlorophyll levels fluctuated over the years (which may be an indication of a multi-year cycling), peaked around 1999 but showed a generally decreasing trend over time.

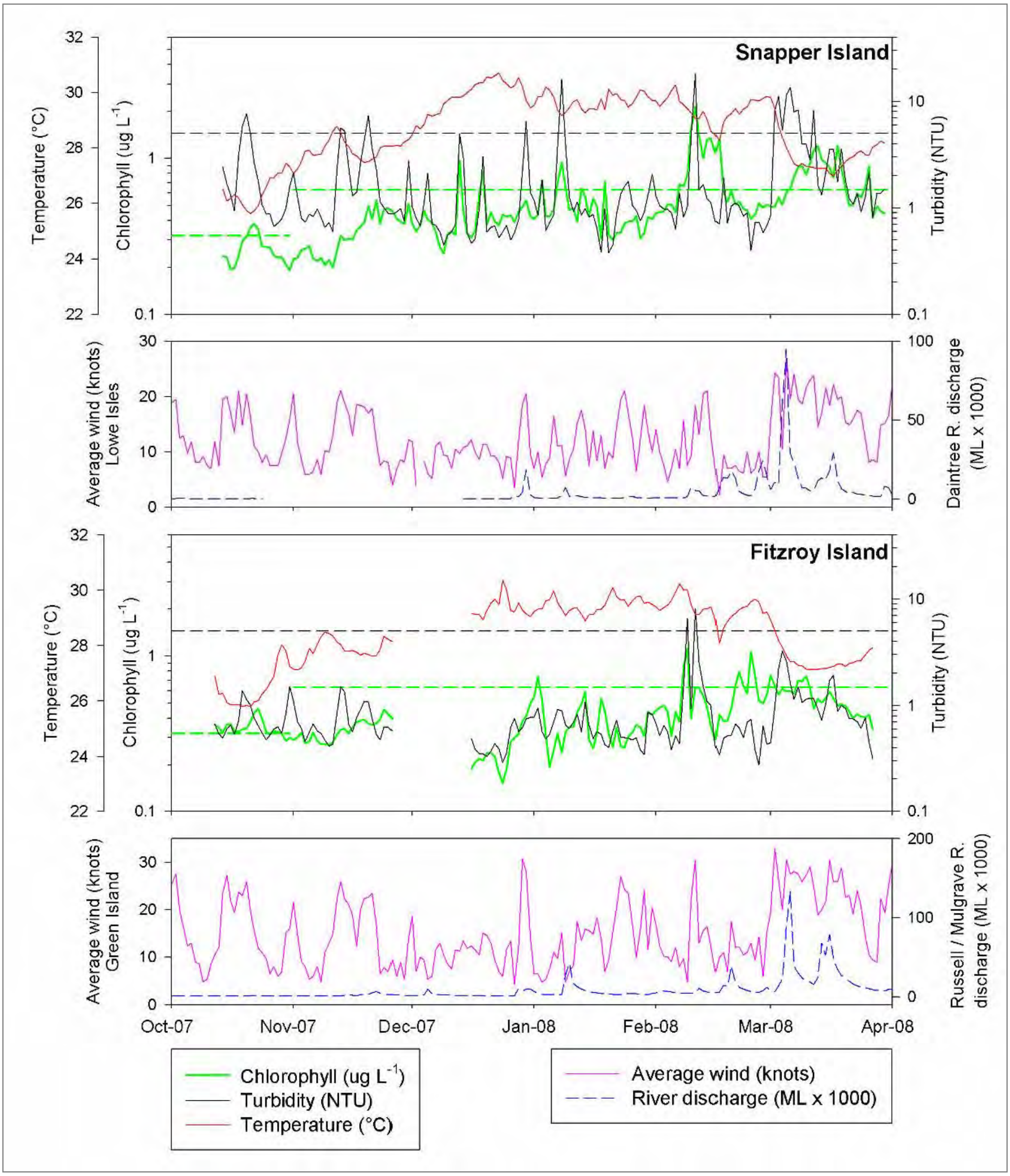


Figure 4.4: Time series of chlorophyll (μg L^{-1}, green line) turbidity (NTU, black line) and temperature (°C, red line) from field deployments of WET Labs Eco FLNTUSB combination fluorometer and turbidity sensors at Snapper and Fitzroy Islands in the Wet Tropics region. Additional panels represent daily mean wind speeds from weather stations closest to the deployment locations (knots, pink solid line) and discharge volumes from the closest river (ML x 1000, blue dashed line). Green horizontal dashed lines represent the chlorophyll trigger values in the Water Quality Guidelines (GBRMPA 2009), black dashed lines represent the suggested turbidity threshold of 5 NTU, beyond which corals may be severely light-limited (Cooper *et al.* 2008).

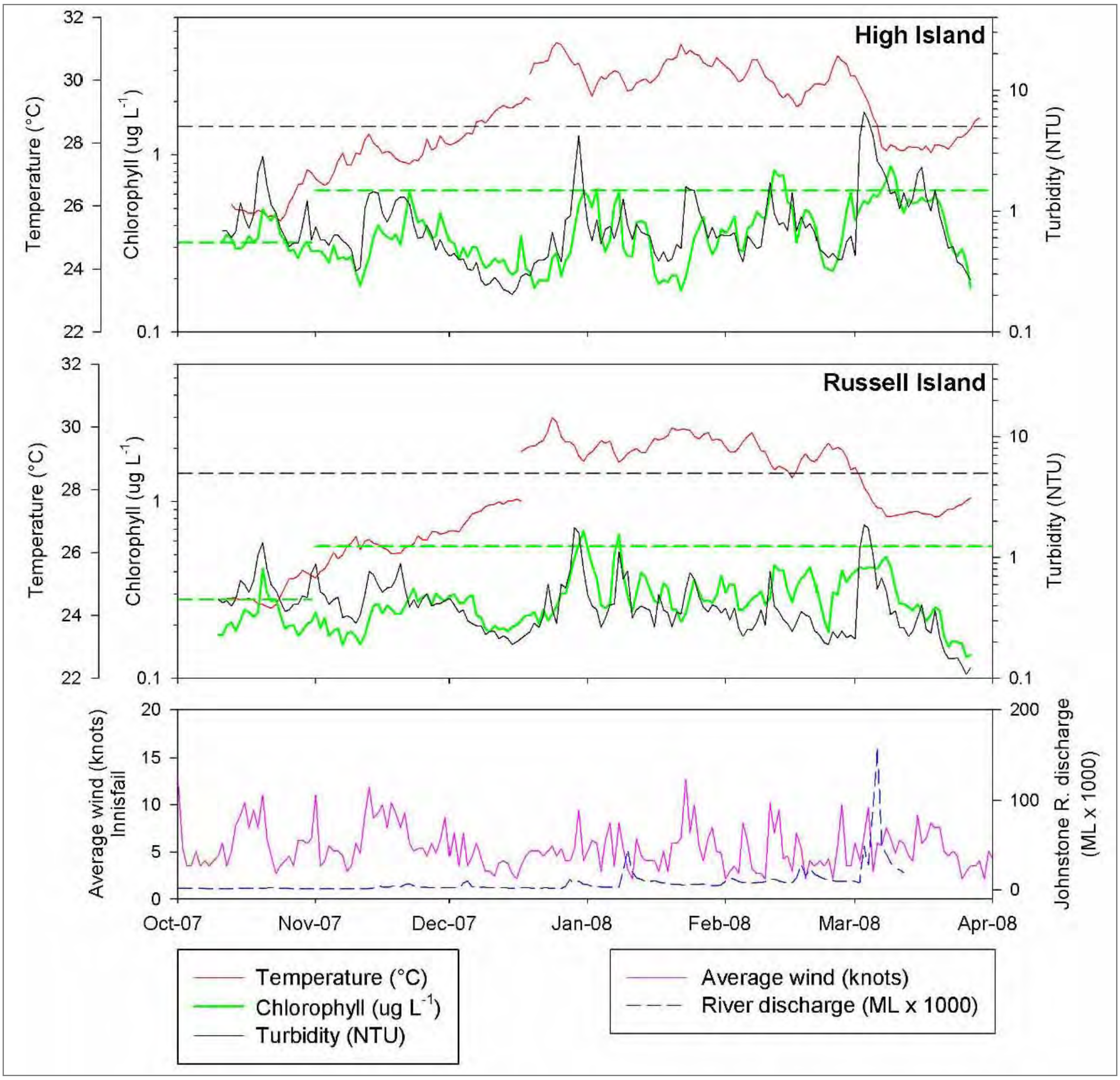


Figure 4.5: Time series of chlorophyll (µg L^{-1}, green line) turbidity (NTU, black line) and temperature (°C, red line) from field deployments of WET Labs Eco FLNTUSB combination fluorometer and turbidity sensors at High and Russell Islands in the Wet Tropics region. All other details as per Figure 4.4.

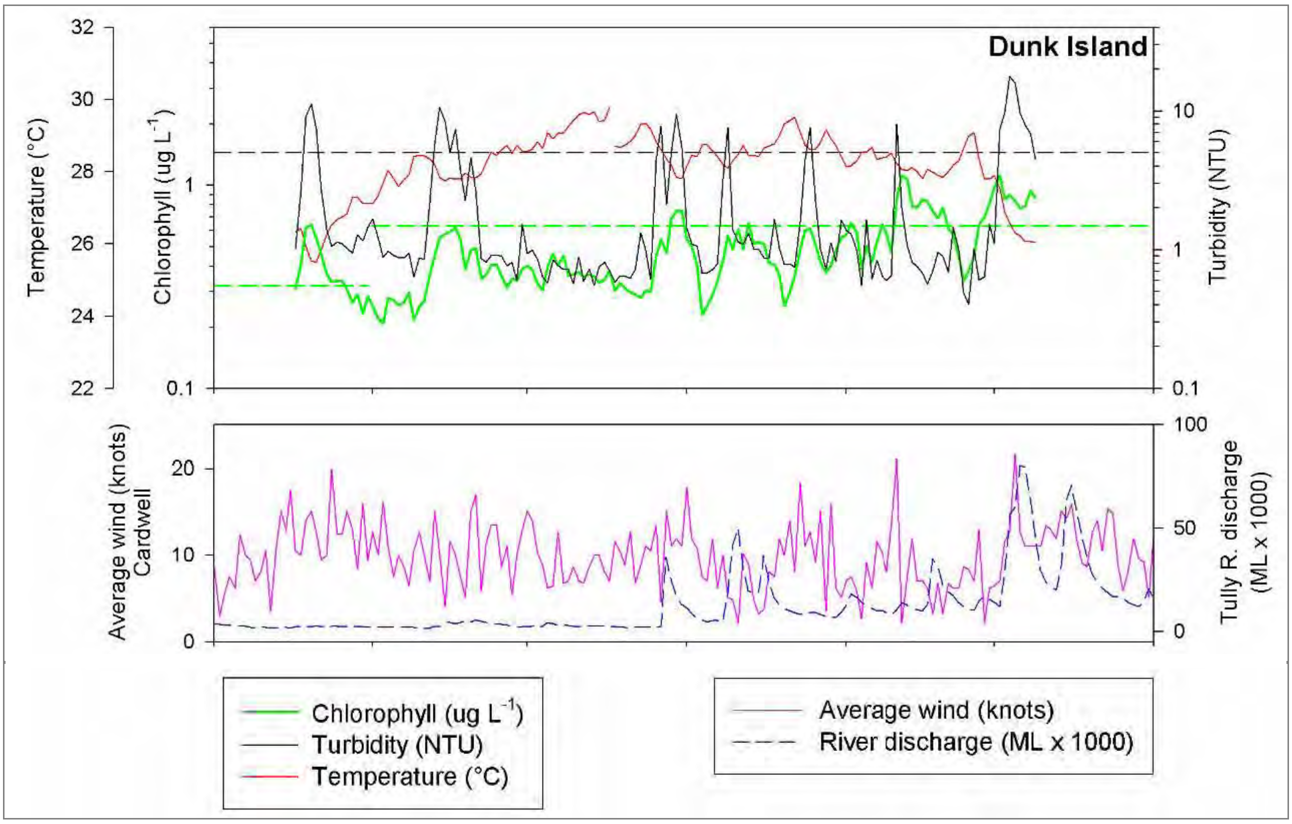


Figure 4.6: Time series of chlorophyll (µg L^{-1}, green line) turbidity (NTU, black line) and temperature (°C, red line) from field deployments of WET Labs Eco FLNTUSB combination fluorometer and turbidity sensors at Dunk Island in the Wet Tropics region. All other details as per Figure 4.4.

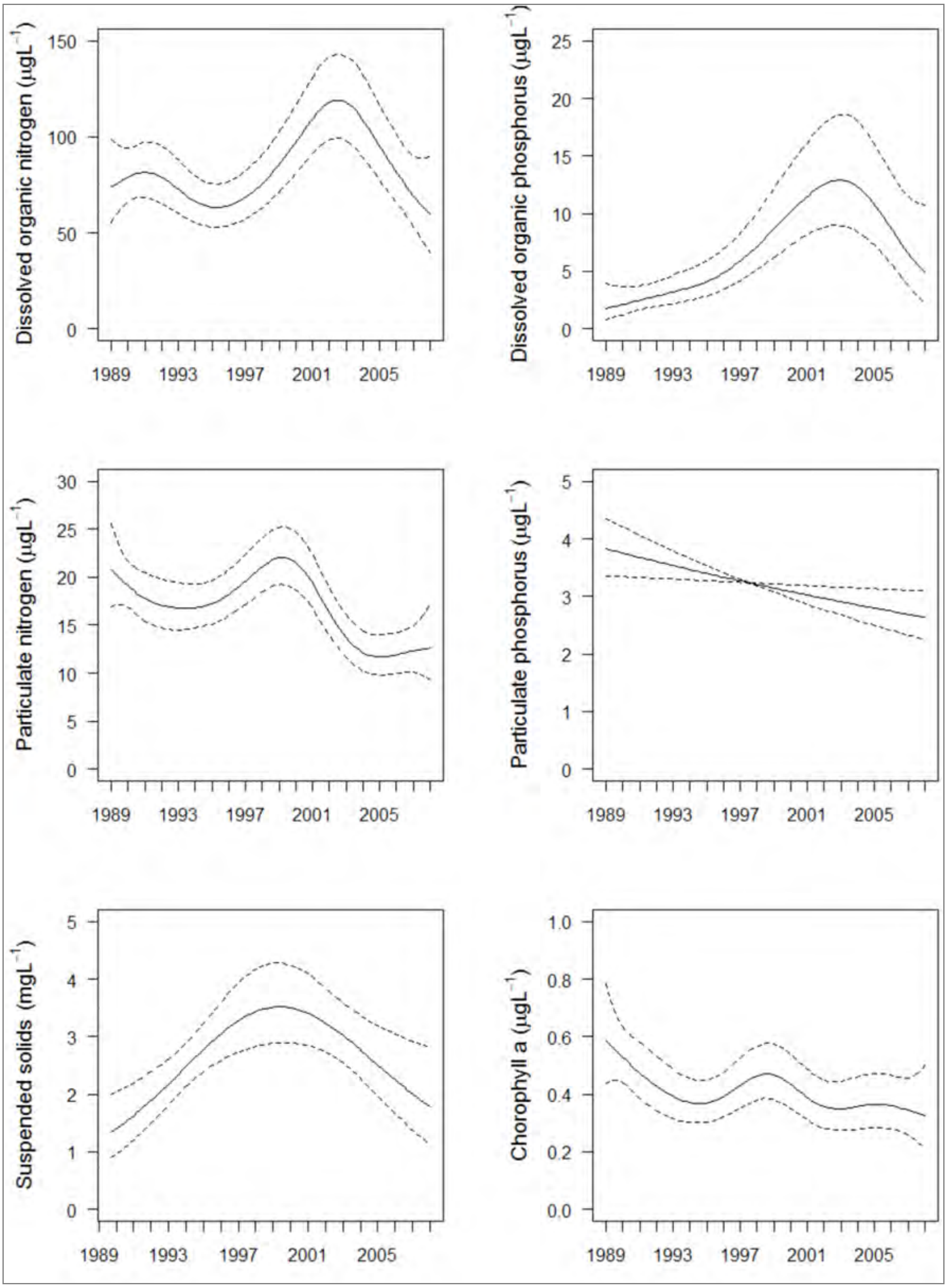


Figure 4.7: Water quality trends from 1989 to 2008 (partial effects) for dissolved organic nitrogen (µgL^{-1}), dissolved organic phosphorus (µgL^{-1}), particulate nitrogen (µgL^{-1}), particulate phosphorus (µgL^{-1}), suspended solids (mgL^{-1}) and chlorophyll *a* (µgL^{-1}).

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 seagrass meadows at Yule Point and Lugger Bay are located on naturally dynamic intertidal sand banks, protected by fringing reefs. These meadows are dominated by *Halodule uninervis* with some *Halophila ovalis* and are often exposed to regular periods of disturbance from wave action and sediment movement. The sediments in these locations are relatively unstable, restricting seagrass growth and distribution. The Barron, Tully and Hull Rivers are a major source of pulsed sediment and nutrient input to these monitored meadows (Figure 4.8).

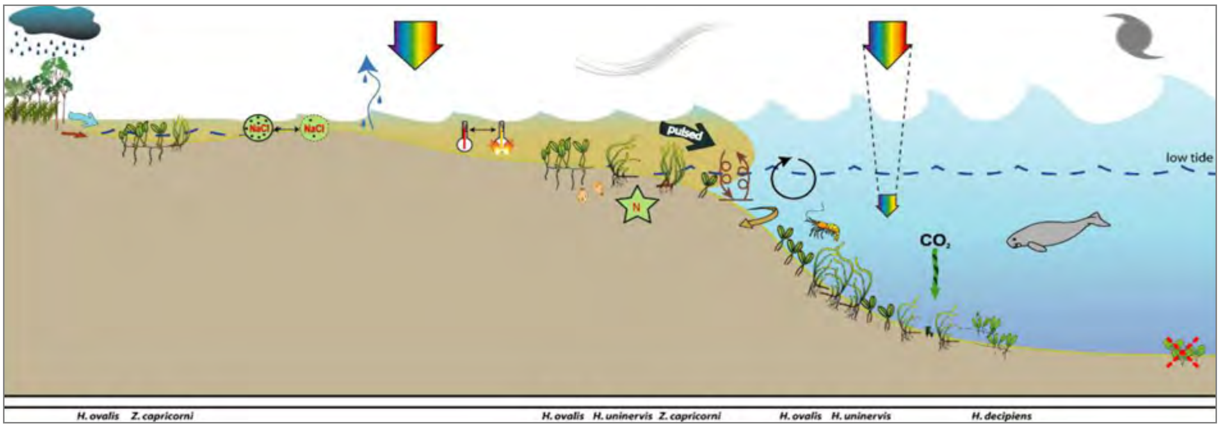


Figure 4.8: Conceptual diagram of coastal habitat (<15 m) in the Wet Tropics region – major control is catchment runoff, salinity and temperature extremes.

Monitoring at Green Island occurs on the large intertidal southwest reef-platform and the meadow is dominated by *Cymodocea rotundata* and *Thalassia hemprichii* with some *Halodule uninervis* and *Halophila ovalis*. Shallow, unstable sediment, fluctuating temperature, and variable salinity in intertidal regions characterise these habitats. Physical disturbance from waves and swell and associated sediment movement primarily control seagrass growth in these habitats (Figure 4.9).

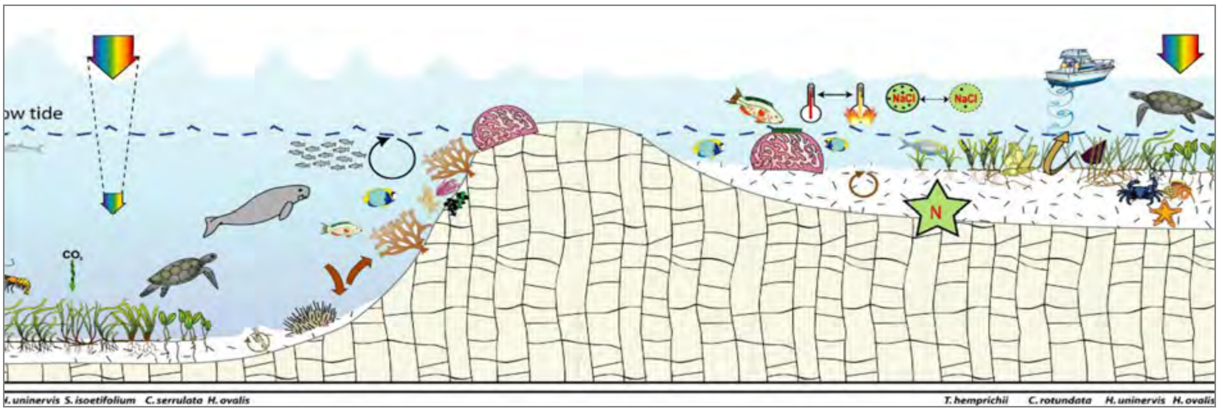


Figure 4.9: Seagrass reef habitats (<15 m) in the Wet Tropics region – major control is nutrient limitation, temperature extremes, light and grazing.

Seagrass cover in the Wet Tropics region increased significantly at both Yule Point sites (from about 10% to 30%), and remained relatively stable at Green Island during the 2007/08 sampling period (Figure 4.10). The Lugger Bay and Dunk Island sites were only monitored once during the 2007/08 period with approximately 6%, and 12-18% seagrass cover respectively (Figure 4.10).

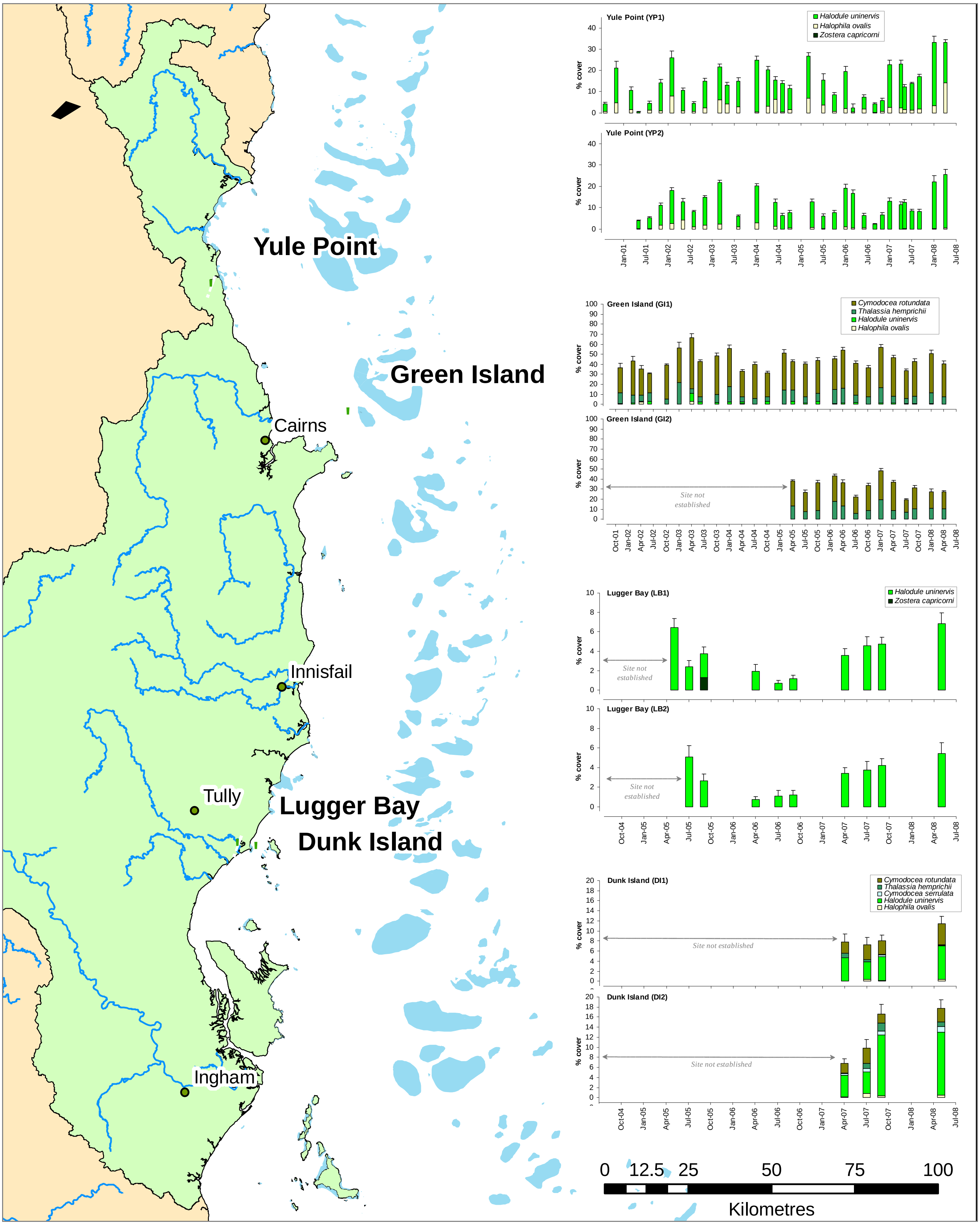


Figure 4.10: Mean percentage cover for each seagrass species at Townsville MMP long-term monitoring sites (+ Standard Error). Note: If no sampling conducted then x-axis is clear.

Coral reef habitats

Coral reef surveys in 2006 in the Wet Tropics region documented localised reductions to hard coral, soft coral and macroalgae cover on several reefs due most likely to the passage of Cyclone *Larry*. In 2007, the re-surveyed impacted reefs showed little recovery of the coral communities and an increase in macroalgae cover, which colonised space made available by the reductions in coral cover.

The Daintree sub-region was the only region to show a marked increase in hard coral cover between the 2005 and 2007 surveys, with average cover rising from 32% to 47% (see section 3.2.4; Figure 3.16).

Reefs in the Johnstone and Russell-Mulgrave sub-regions, where the Burdekin River flood plume and Cyclone Larry had relatively little influence, showed slight increases in hard coral cover from 2005 to 2007; 32% to ~35% (Figure 4.11).

Reefs in the Tully Herbert sub-region had significantly lower hard coral cover than other regions in 2007 (Figure 4.12). Coral cover in 2005 in this sub-region was high (~45%) and not substantially different to other sub-regions, which was not the case in 2006 and 2007 when coral cover declined to <10%. Reduced hard coral cover on reefs on the Tully Herbert sub-region may be associated with physical disturbance caused by Cyclone Larry. These reefs were also exposed to secondary plume waters from the Burdekin River flood in early 2008.

There was a substantial decline in soft coral cover in the Tully Herbert sub-region which had significantly lower cover than elsewhere (Figure 4.12) having reduced from 6.5% in 2005 to 0.3% in 2006. This decline occurred after Cyclone Larry and there has been negligible recovery detected since, with the mean cover in 2007 being 0.5%. In comparison, soft coral cover on reefs in the Johnstone and Russell Mulgrave sub-regions remained stable at around 12% from 2005 to 2007 (Figure 4.11). In the Tully Herbert and to a lesser extent the Johnstone and Russell Mulgrave sub-regions, macroalgae increased between 2006 and 2007 (Figures 4.11 and 4.12).

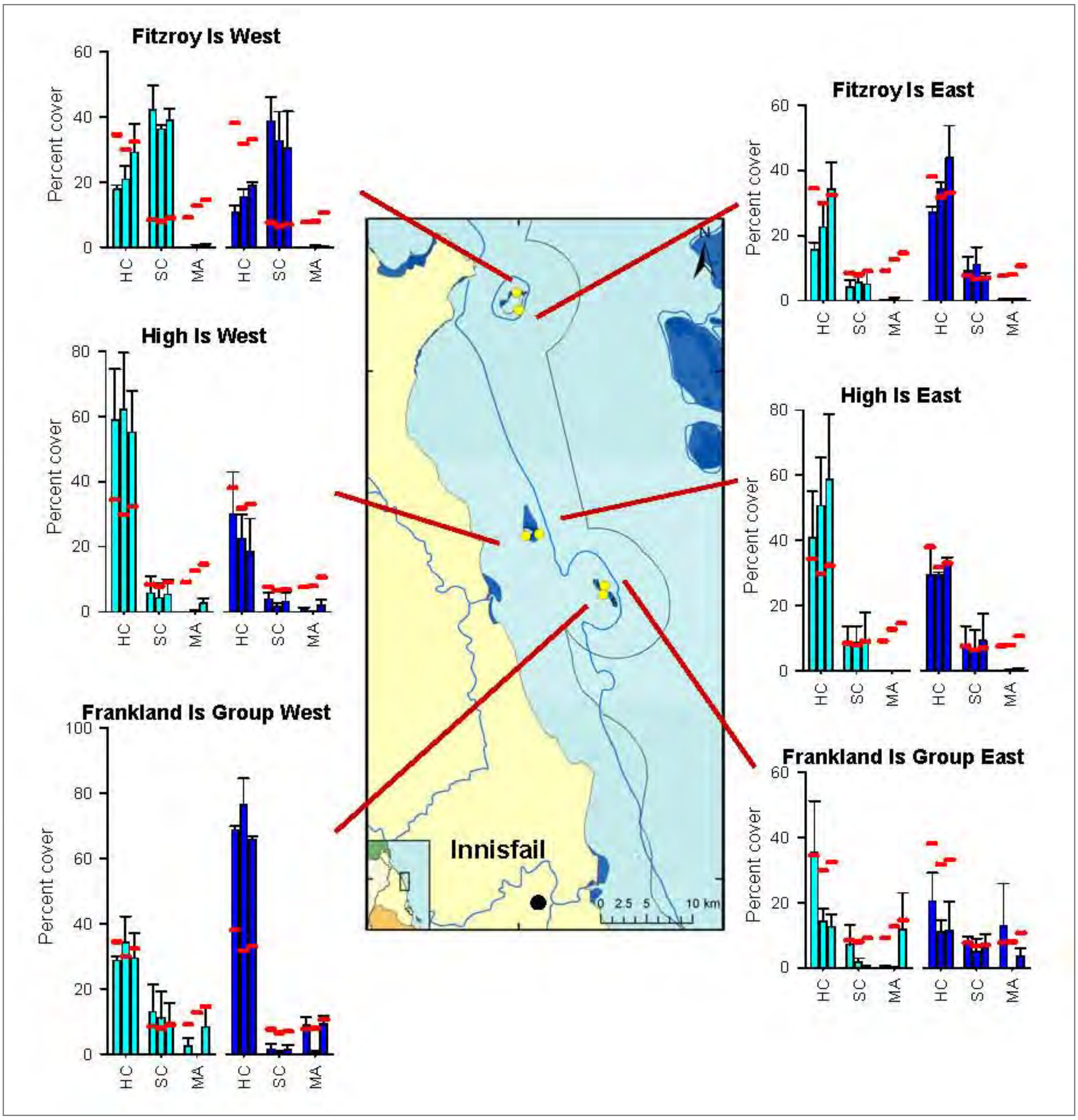


Figure 4.11: Percent cover estimates of major benthic groups, hard coral (HC), soft coral (SC) and macroalgae (MA) on reefs in the Johnstone Russell-Mulgrave sub-region of the Wet Tropics region. Pale blue bars represent values for two metres' depth and dark blue bars for five metres' depth. Average values for each group and depth from all reefs and regions combined are indicated by red lines. For each benthic group the three bars represent, from left to right, data from 2005, 2006 and 2007.

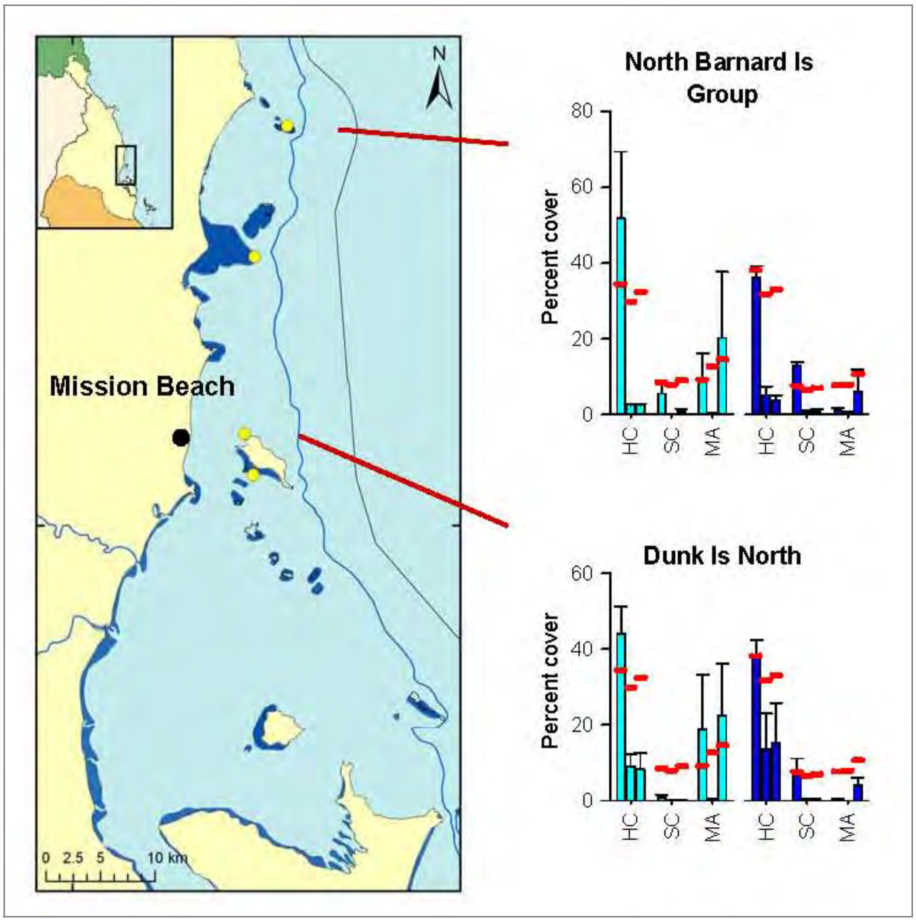


Figure 4.12: Percent cover estimates of major benthic groups, hard coral (HC), soft coral (SC) and macroalgae (MA) on reefs in the Herbert Tully sub-region of Wet Tropics region. Pale blue bars represent values for two metres' depth and dark blue bars for five metres' depth. Average values for each group and depth from all reefs and regions combined are indicated by red lines. For each benthic group the three bars represent, from left to right, data from 2005, 2006 and 2007.

A comparison of the densities of juvenile corals observed in 2007 to those recorded in 2005 showed reductions at some reefs in the Johnstone, Russell Mulgrave and Tully Herbert sub-regions still evident with substantially lower densities of juvenile colonies in 2007 (Figures 4.13 and 4.14). Considering the numbers of juvenile colonies irrespective of the available substrate indicates that lower density of juvenile colonies in the cyclone impacted sub-regions predominantly reflects fewer juveniles rather than an increase in the area available for substrate recruitment. Numbers of recruit-sized colonies are still lower on impacted reefs than observed prior to disturbance as there has been insufficient time for new recruits to have settled and grown to a size visible in the surveys (Figure 4.15).

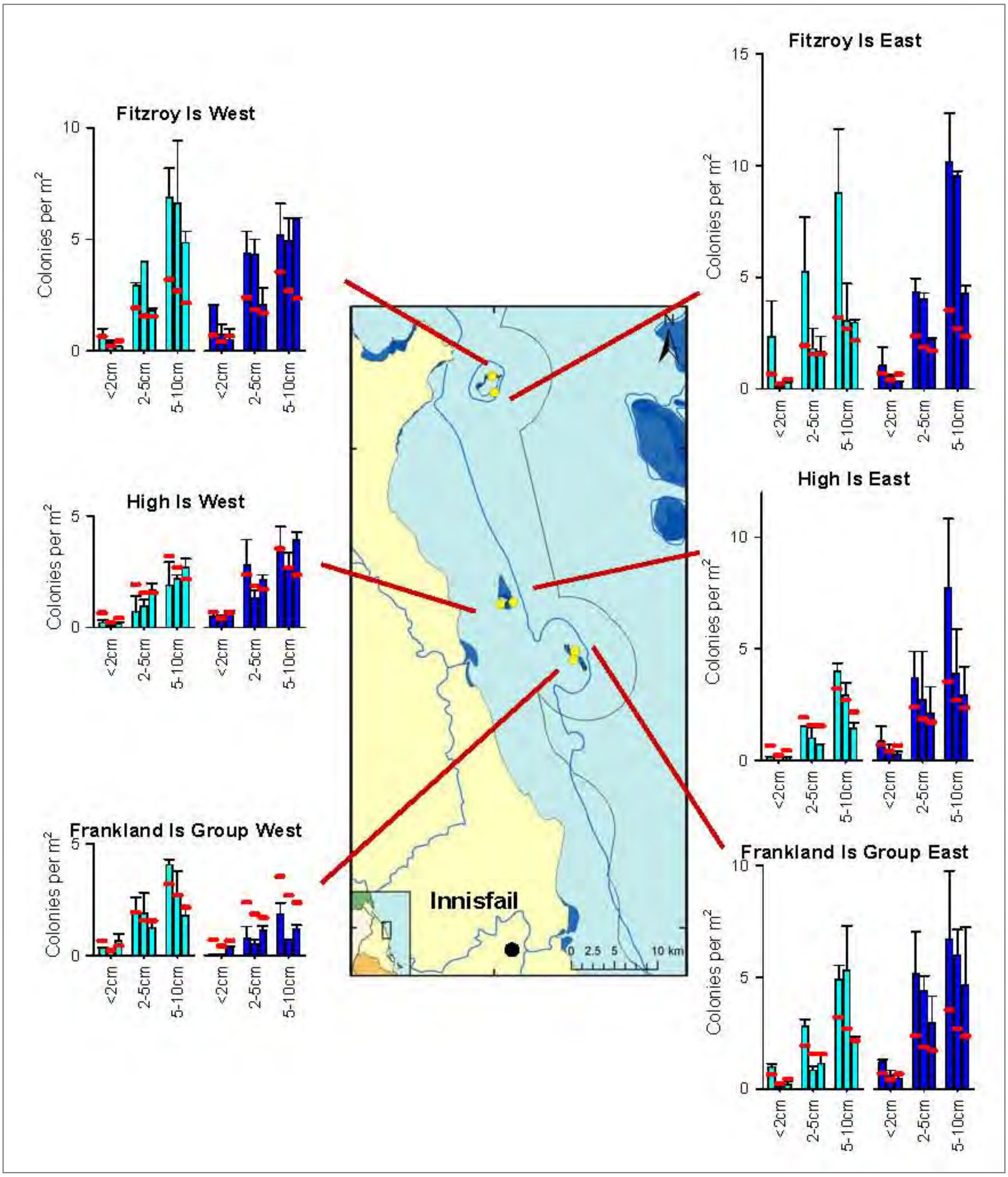


Figure 4.13: Abundance of juvenile hard coral colonies by size class for reefs in the Johnstone Russell-Mulgrave sub-region of the Wet Tropics region. Pale blue bars represent values for two metres' depth and dark blue bars for five metres' depth. Average values for each size class and depth from all reefs and regions combined are indicated by red lines. For each size class the three bars represent, from left to right, data from 2005, 2006 and 2007.

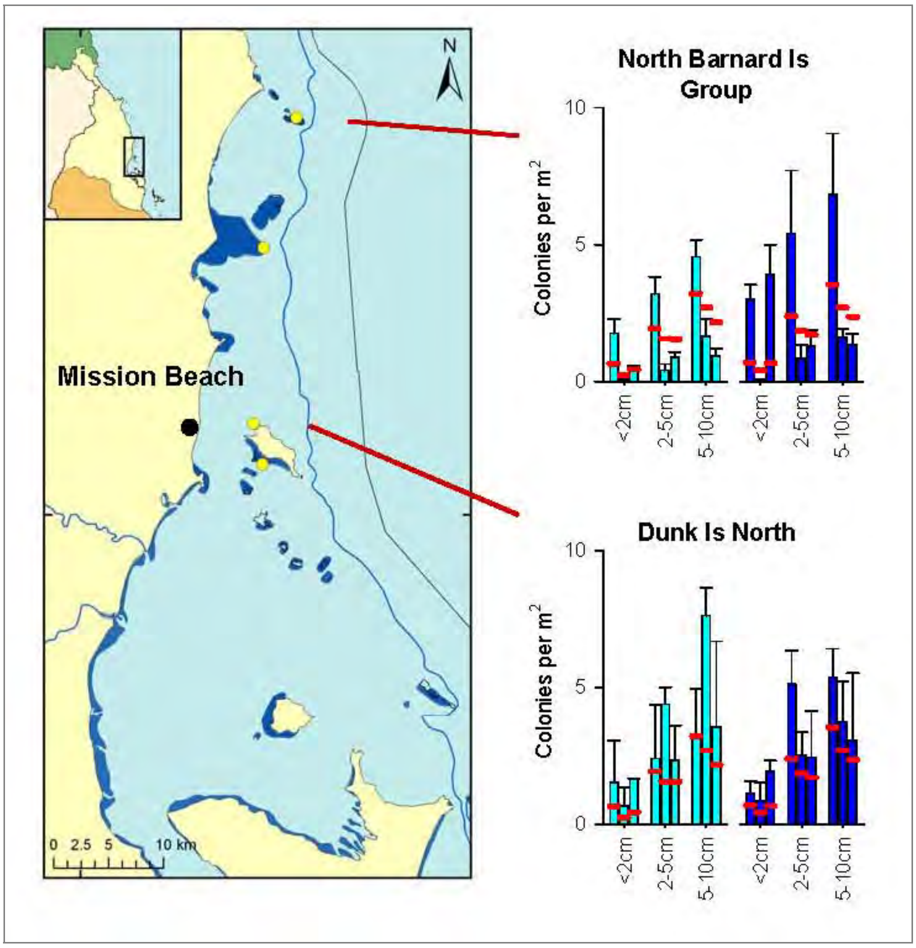


Figure 4.14: Abundance of juvenile hard coral colonies by size class for reefs in the Herbert Tully sub-region of Wet Tropics region. Pale blue bars represent values for two metres' depth and dark blue bars for five metres' depth. Average values for each size class and depth from all reefs and regions combined are indicated by red lines. For each size class the three bars represent, from left to right, data from 2005, 2006 and 2007.

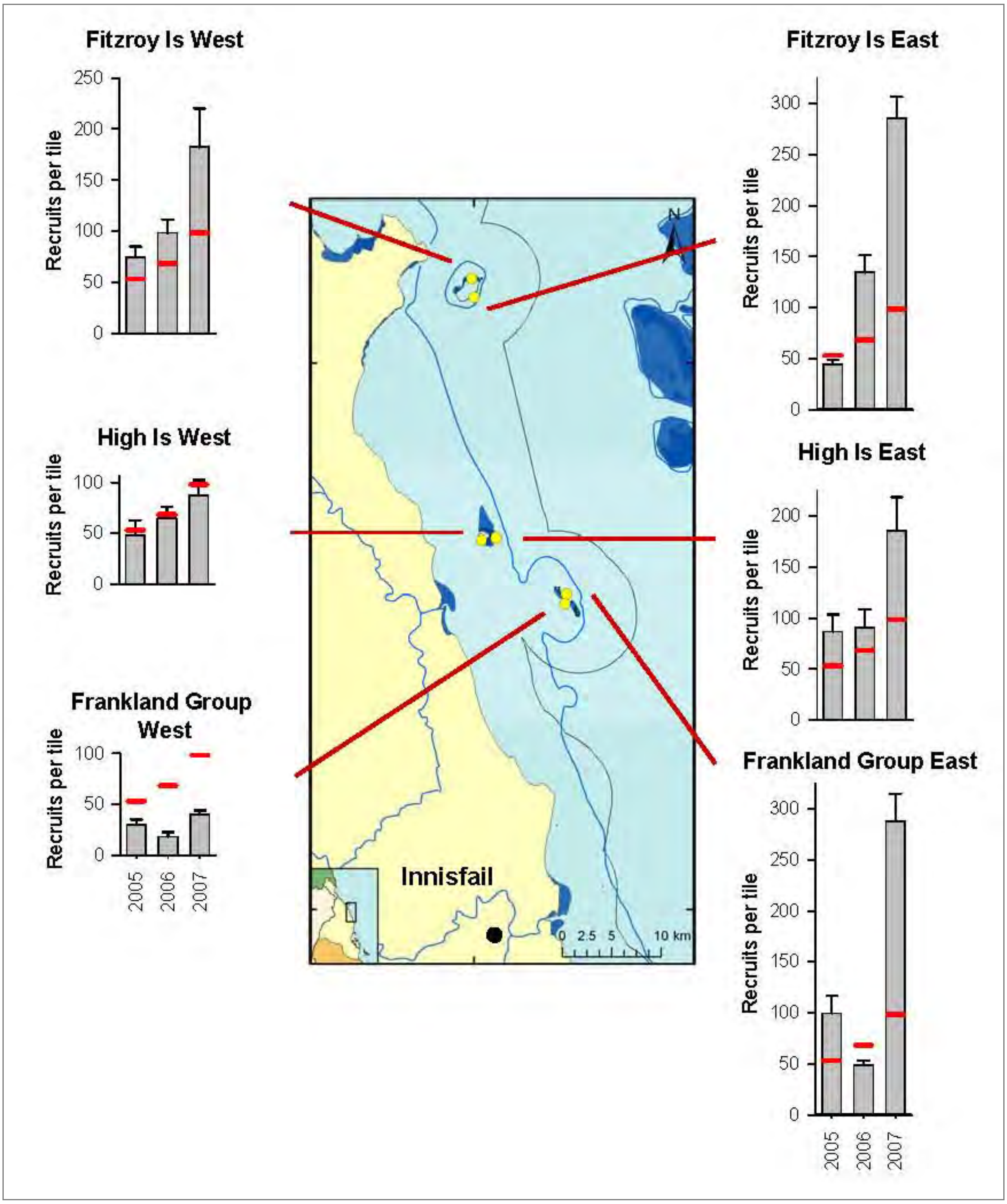


Figure 4.15: Average number of coral recruits per tile on reefs in the Johnstone Russell-Mulgrave sub-region of the Wet Tropics region. Data are from five metres' depth tile deployments. Average values from all reefs and regions sampled in each year are indicated by red lines. It should be noted that comparison of over all means (red lines) over time is not possible as the regions sampled vary among years (2005 includes reefs from the Wet Tropics and Mackay Whitsunday regions, in 2006 sampling also included reefs from the Fitzroy region and then 2007 included these and also reefs from the Burdekin region).

Between 2005 and 2007, changes in hard coral species richness were evident in the Tully Herbert sub-region where the average number of genera per site declined from 16 to 10. It is likely that this ongoing reduction represents an interaction between the physical impact of Cyclone Larry and the effect water quality from the Burdekin River has on coral recovery. In contrast, the average richness in the adjacent Johnstone and Russell Mulgrave sub-regions, where only one of the six reefs was impacted by Cyclone Larry, has increased from 12 to 14 genera per site over the same period.

From 2005 to 2007 most of the monitored Wet Tropics reefs had higher abundances of juvenile corals, increasing coral cover and also high and increasing rates of larval settlement except the Tully Herbert subregion, compared to averages over all reefs, which may be associated with low rainfall events in these subregions.

Pesticide concentrations

Pesticide monitoring was undertaken in the Tully River using passive samplers deployed from February to March 2007 and from February to May 2008. The pesticide profile included diuron, simazine, atrazine and hexazinone with occasional detections of atrazine breakdown products and tebuthiuron (Table 3.3, Figure 4.16). Simazine dominated during the wet season of 2006/07 and the dry season of 2007, whereas diuron dominated during the wet season of 2007/08. The Tully River was the only site that showed elevated water concentrations of simazine (e.g. max: 120 ngL^{-1}; median 91 ngL^{-1}) although it is acknowledged that the sample number was low (n = 5). Chlorpyrifos was detected once during the dry season and once during the wet season in the Tully River (1.4 ngL^{-1}).

Routine monitoring in the Tully River revealed a wider range of pesticides and elevated water concentrations compared to inshore reef sites with water concentrations for dominant chemicals often exceeding 1000 ngL^{-1}. Event monitoring at the Tully River showed that the pesticide profiles were similar to previous year’s results.

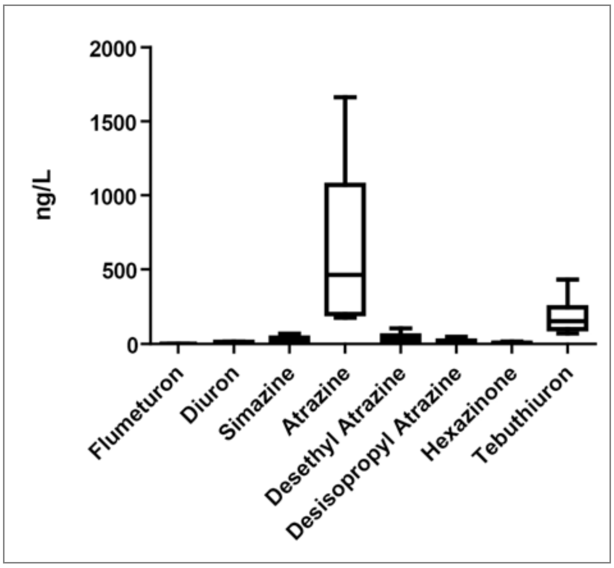


Figure 4.16: Box plots showing the range of water concentrations (ngL^{-1}) for pesticides detected in the Tully River using EDs. Maximum and minimum values represented by whiskers and the median represented by horizontal line within box.

The maximum water concentrations of individual pesticides in the marine waters of the Wet Tropics region were similar regardless of where samples were collected (e.g. maximum water concentration of diuron ranged from 12 to 15 ngL^{-1}). 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. This was most likely due to the fact that pesticide application generally occurs during the wet season, at a time when rainfall also increases the mobility of these chemicals. Within sites, there was general consistency between the wet and dry seasons in the percentage contribution of the major herbicides detected.

Detailed pesticide results are available in Section 3.1.4, including a table of all results; Table 3.3.

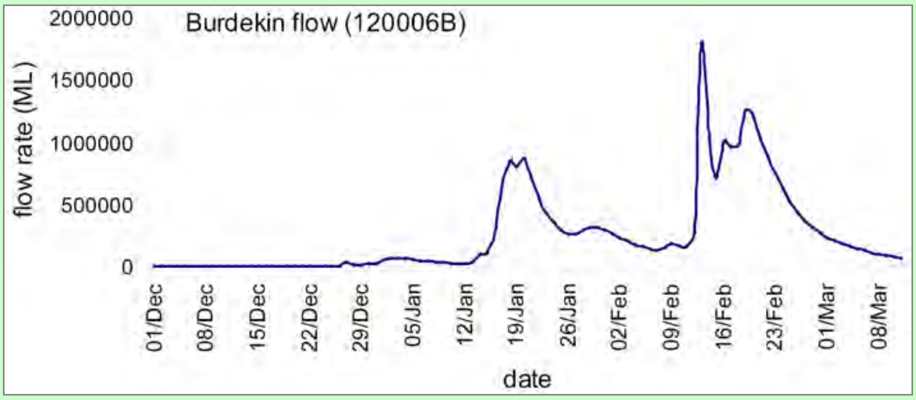
4.3 Burdekin region

During the early months of 2008, there was heavy rainfall throughout the Burdekin catchment. Interestingly, the heavy and prolonged rainfall was not associated with a specific cyclone, but rather a number of low pressure systems moving across the Coral Sea over the Queensland coast through January and February 2008.

Water quality

Box 4.1 Case Study: Burdekin River flood event 2007/08

The 2007/08 wet season produced the third largest flow discharge for the Burdekin River in the 87 year end-of-catchment gauged record (Burdekin River at Clare Weir) with a total discharge of 26.4 million ML (see figure below). Broadly, two separate discharge events occurred in the Burdekin River over 2007/08 wet season with the first event peaking on 18 January 2008 and the second on 13 February 2008. Large river flow events occurred in all tributaries of the Burdekin catchment including 6.1 million ML discharged from the upper Burdekin (Burdekin River at Sellheim), 2.3 million ML from the Cape River (Cape River at Taemas), 2.0 million ML from the Belyando River (Belyando River at Gregory Developmental Rd), 7.0 million ML from the Suttor River (Suttor at St Anns minus Belyando River) and 2.4 million ML from the Bowen River (Bowen River at Myuna). A total of 16.7 million ML of water spilled over the Burdekin Falls Dam in the 2007/08 wet season beginning on 29 December 2007.



Burdekin River daily flow rates measured at the Clare Weir (DNRW gauging station 120006B; http://www.nrw.qld.gov.au/water/monitoring/current_data/map_qld.php).

Wet season suspended sediment loads

Suspended sediment loads were measured during the wet season from December 2007 to May 2008 in the Burdekin River (located at Clare Weir) using a river logger deployed by AIMS to estimate wet season fine sediment exports.

The fine sediment discharge of the Burdekin River showed a clear ‘first flush’ signal in late December 2007 to early January 2008 with very high suspended solids concentrations at the first minor discharge event (Figure 4.17). During the major flood peaks the suspended solids concentrations were equally high (~3,000 mgL^{-1}), however, the total fine sediment export was obviously larger with the higher discharge volume during the two major flood peaks in January and February 2008. The water discharged during the 2007/08 wet season was almost three times the long-term average while the fine sediment discharge was eleven times the long-term average sediment export (Table 4.1; Furnas 2003).

The discharge-weighted fine sediment export in 2007/08 was comparable to the estimate from 2004/05 (Table 4.1), while the area-weighted export was significantly larger than the estimates since beginning of MMP monitoring as well as the long-term average (which does not include the 1991 flood; data from Furnas 2003). This indicates that major erosion has occurred during this event in the Burdekin catchment, which led to substantial fine sediment export per area of catchment under precipitation.

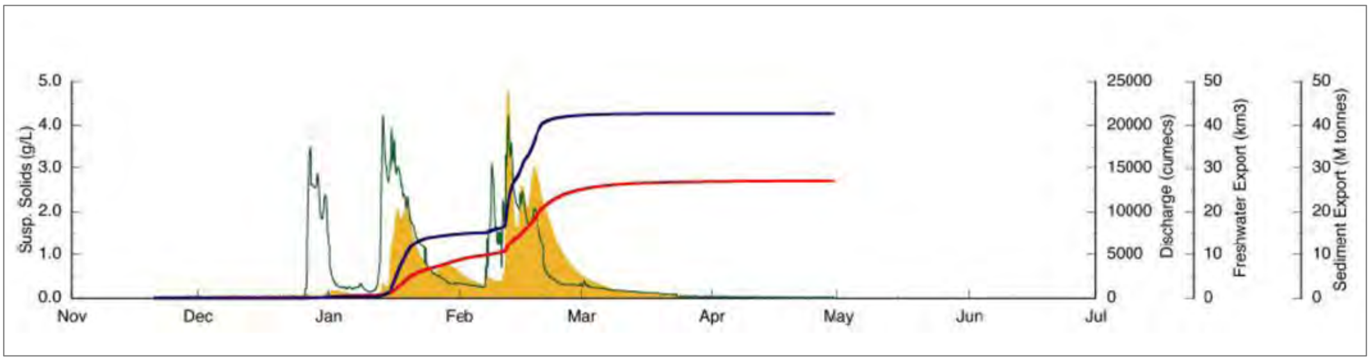


Figure 4.17: Time series of fine suspended solid concentrations (solid lines) in the Burdekin River at Clare over the 2007/08 wet season in relation to concurrent river flow (brown area), and integrations of cumulative freshwater discharge (red line, in km^3) and fine sediment export (blue line, in mega tonnes). River discharge data are the property and copyright of the State of Queensland (Department of Natural Resources and Water 2008).

Table 4.1: Estimates of fine sediment export from the Burdekin River during the 2004/05, 2005/06, 2006/07 and 2007/08 wet seasons. Long-term averages are given for comparison (annual river discharge: 1969-94; sediment export: 1989-2000, 1991 flood not included). Discharge data are the property and copyright of the State of Queensland (Department of Natural Resources and Water 2008).

Deployed	Retrieved	Freshwater discharge (km^3*)	Sediment export 10^6 tonnes	Discharge-weighted sediment export (10^3 tonnes km^{-3})	Area-weighted sediment export (tones km^{-2}) (from gauged catchment area)
30 Nov 2004	8 Jul 2005	4.09	7.1	1745	55
15 Dec 2005	6 Jun 2006	1.93	0.57	295	4
6 Dec 2006	2 May 2007	8.52	**	**	**
21 Nov 2007	26 May 2008	27.05	42.68	1578	329
Long-term average		10.29	3.77	366	29

* Measured freshwater discharge during the period of logger data collection (1 km^3 = 10^9 m^3 = 10^6 megalitres).

** No useful data recorded due to failure of the logger mounting structure under flood conditions.

Wet season chlorophyll and turbidity

Flood-specific analysis of chlorophyll and turbidity data was carried out using data from FLNTUSB instruments deployed in October 2007 at inshore reefs in the Burdekin region. Chlorophyll and turbidity measurements for the 2007/08 wet season are from three inshore reef sites in the Burdekin region (Pelorus Island, Geoffrey Bay Reef on Magnetic Island and Pandora Reef) with Pelorus Island exposed to Herbert River plume water, and Geoffrey Bay Reef and Pandora Reef exposed to the secondary Burdekin River plume. The maximum wet season chlorophyll and turbidity concentrations recorded by the fluorometers at these sites are shown in Figure 4.18.

During the 2007/08 wet season, Geoffrey Bay Reef had a mean chlorophyll concentration of 0.58 µgL^{-1} and a mean turbidity of ~3 NTU. Turbidity was more variable and elevated from late December to late March with a maximum value of ~24 NTU (Figure 4.18). Chlorophyll was above the Guideline trigger value from early February to mid March 2008, coinciding with the second major flood peak of the Burdekin River (Figure 4.18). Thirty percent of the daily means in the record exceeded the Guideline trigger values and sixteen percent exceeded the suggested 5 NTU limit for coral photo-physiological stress.

Pandora Reef had a mean chlorophyll concentration of 0.57 µgL^{-1}, and a mean turbidity of ~0.9 NTU. Maximum turbidity was ~4 NTU, reached during the February 2008 flood. Turbidity was more variable and slightly elevated from late December 2007 to late March 2008. Chlorophyll was above the Guideline trigger value from late January to late March 2008, coinciding with major flooding of the Burdekin River (Figure 4.18). 52% of the daily means in the record exceeded the Guideline trigger values but none exceeded the suggested 5 NTU limit for coral photo-physiological stress (Table 3.2).

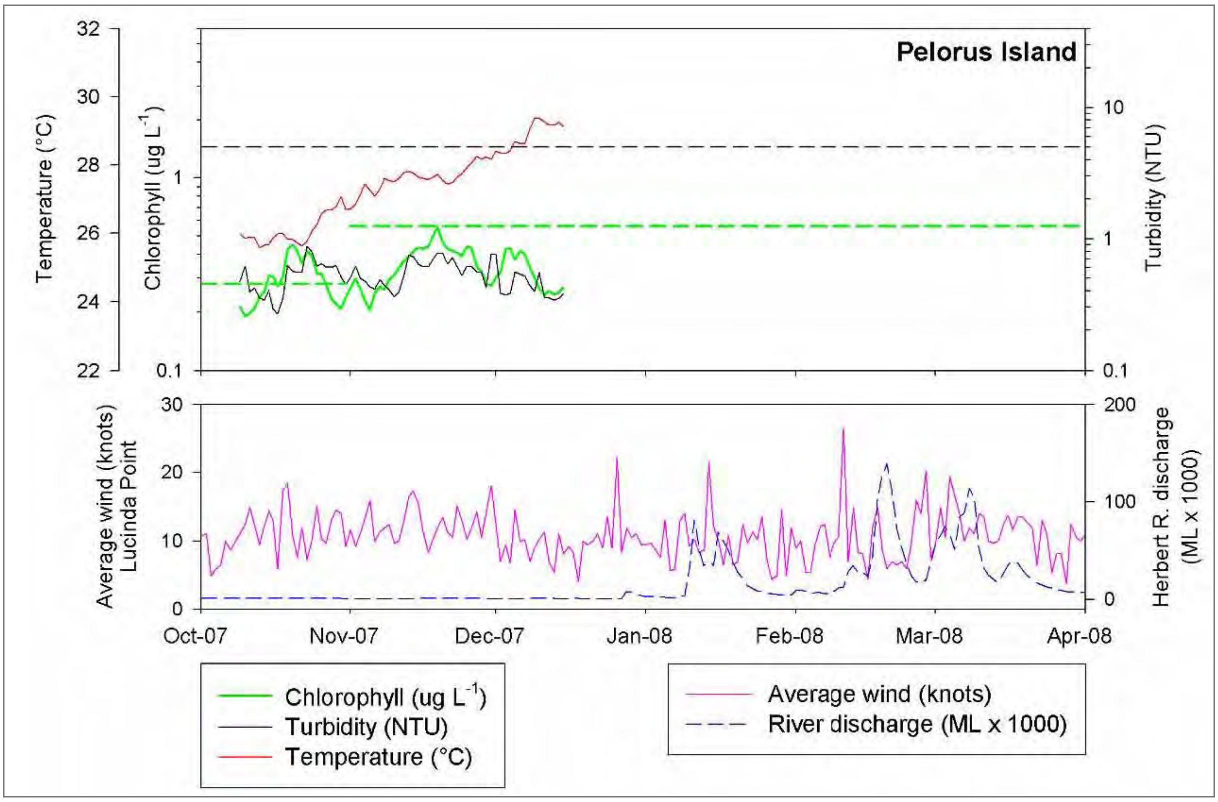


Figure 4.18 (continues to page 64): Time series of chlorophyll (µgL^{-1}, green line) turbidity (NTU, black line) and temperature (°C, red line) from field deployments of WET Labs Eco FLNTUSB combination fluorometer and turbidity sensors at Pelorus Island. Additional panels represent daily mean wind speeds (knots, pink solid line) and discharge volumes from the Burdekin River (ML x 1000, blue dashed line). Green dashed lines represent the chlorophyll trigger values in the Water Quality Guidelines (GBRMPA 2009), black dashed lines represent the suggested turbidity threshold of 5 NTU, beyond which corals may be severely light limited (Cooper *et al.* 2008).

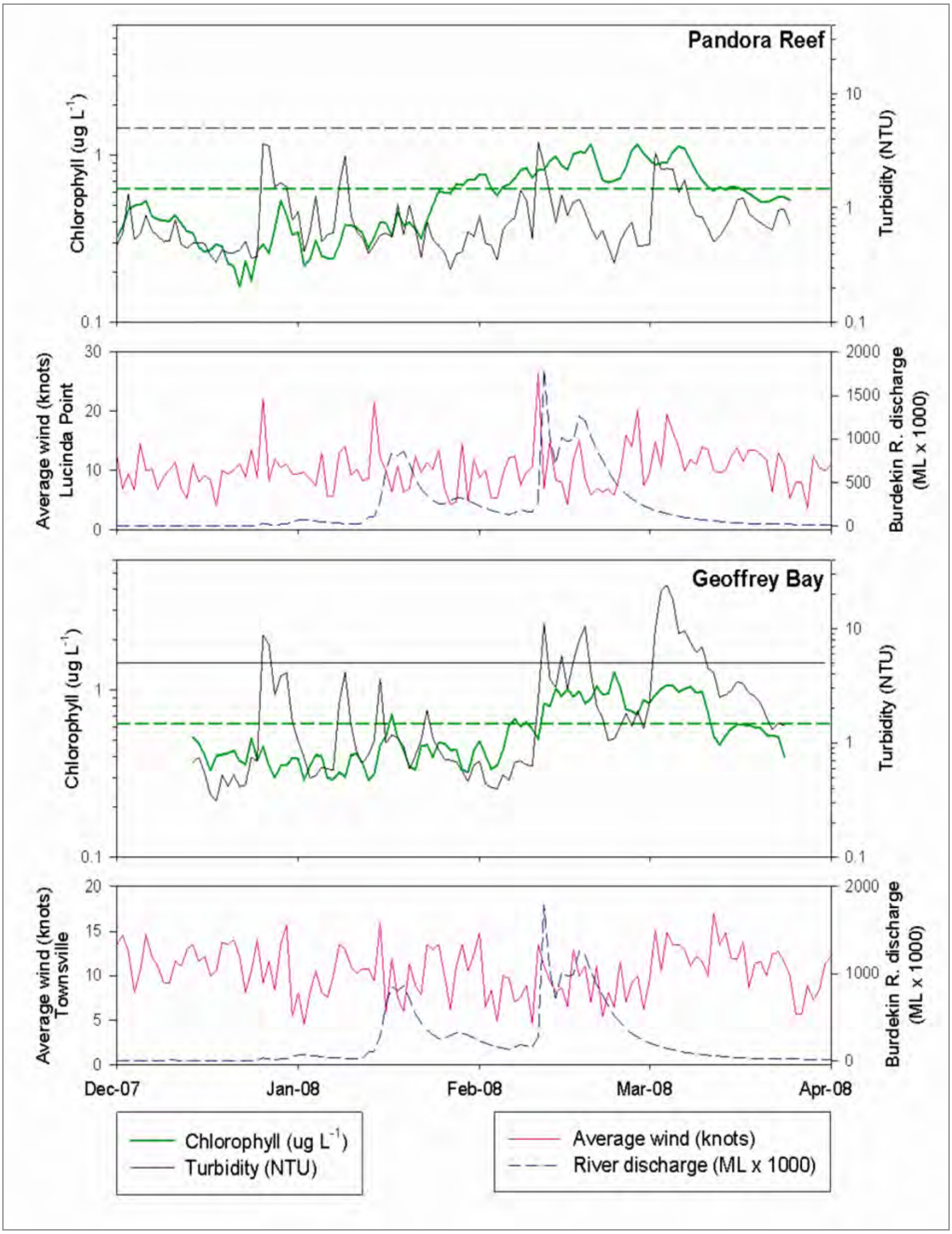


Figure 4.18 (continued from page 63): Time series of chlorophyll ($\mu g L^{-1}$, green line) turbidity (NTU, black line) and temperature (°C, red line) from field deployments of WET Labs Eco FLNTUSB combination fluorometer and turbidity sensors at Pandora Reef and Geoffrey Bay Reef in the Burdekin region. Additional panels represent daily mean wind speeds (knots, pink solid line) and discharge volumes from the Burdekin River (ML x 1000, blue dashed line). Green dashed lines represent the chlorophyll trigger values in the Water Quality Guidelines (GBRMPA 2009), black dashed lines represent the suggested turbidity threshold of 5 NTU, beyond which corals may be severely light limited (Cooper *et al.* 2008).

Burdekin River flood plume monitoring

Water sampling was undertaken in the Burdekin River flood plume over three time periods (Figure 4.19).

The concentration of chlorophyll, suspended particulate matter, dissolved and particulate nutrients were plotted against salinity, as mixing profiles (Figure 4.20). Suspended sediment was substantially elevated at the river mouth and declined rapidly in the initial mixing zone (0 to 10 ppt). Suspended sediment reduced slower over the lower salinity range than in previous years (Devlin *et al.* 2002), which could be indicative of a higher proportion of fine particulate transporting out in the initial event. Suspended sediment remained elevated through the plume waters however, there was a substantial drop in sediment concentrations as the water moved into reef waters, signifying that coarse sediment dropped out of the plume before it reached adjacent inshore reefs, for example Magnetic Island.

Particulate nitrogen and particulate phosphorus were in elevated concentrations in the initial mixing zone and declined in higher salinity waters (past 5 ppt). Both particulate species were substantially lower later in the plume (25-35 ppt) indicating limited transport of the particulate fraction into reef waters.

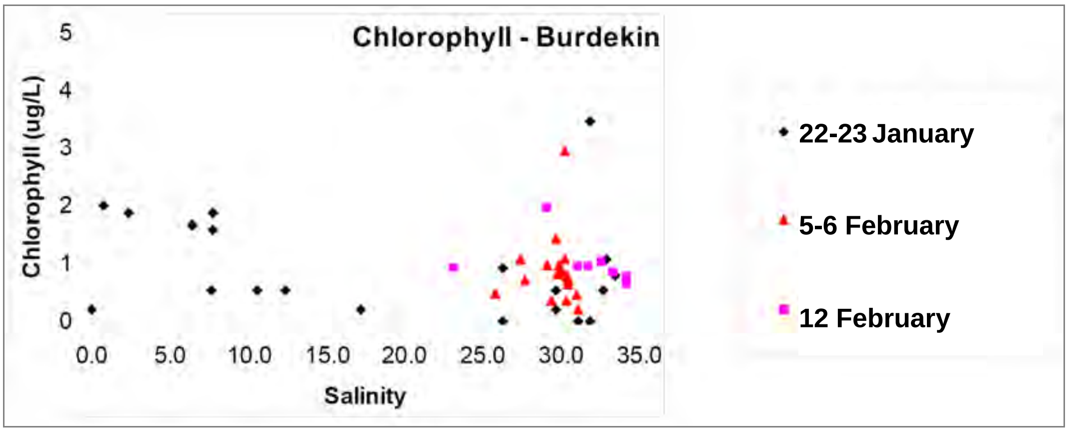


Figure 4.19: Mixing profiles for chlorophyll for the three different sampling events in the Burdekin River plume taken over three different sampling periods (22-23 January; 5-6 February and 12 February 2008).

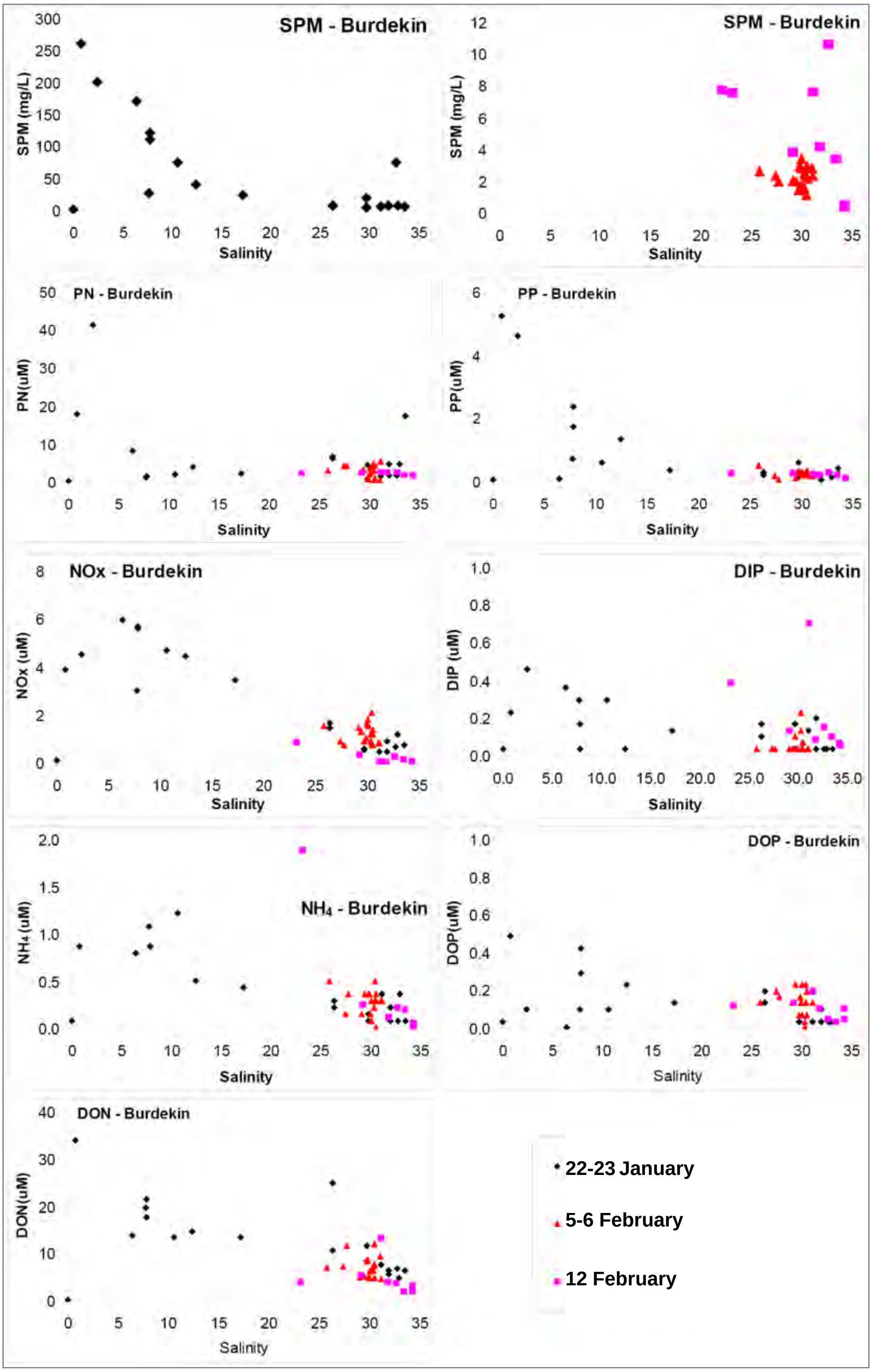


Figure 4.20: Mixing profiles for all nutrient species for the three different sampling events in the Burdekin River plume taken over three different sampling periods (22-23 January; 5-6 February and 12 February 2008).

The highest concentrations of NO_X occurred at 5 ppt within the plume, and generally diluted with distance away from the river mouth. In the second sampling event, all NO_X values were substantially lower at the higher salinities, but were still elevated in comparison to baseline values (Furnas 2005). NH_4 concentrations at 30 ppt were elevated in the first sampling event and the second sampling event, indicating that plume waters transported dissolved nutrients in a northerly direction past the Palm Islands. Chlorophyll (as an indicator of phytoplankton growth) was elevated in both sampling events, with high concentrations occurring in both low salinities, indicating some intrusion of freshwater phytoplankton, and in higher salinities, indicating favourable growth conditions for marine phytoplankton in non light limiting waters.

Flood plume water quality

The general extent of the 2007/08 Burdekin River flood plume was estimated based on remote sensing, modelling and field observations conducted as part of the MMP (Figure 4.21). The flood plume, water quality data logger, intertidal seagrass and inshore coral reef monitoring sites are also shown within Figure 4.11.

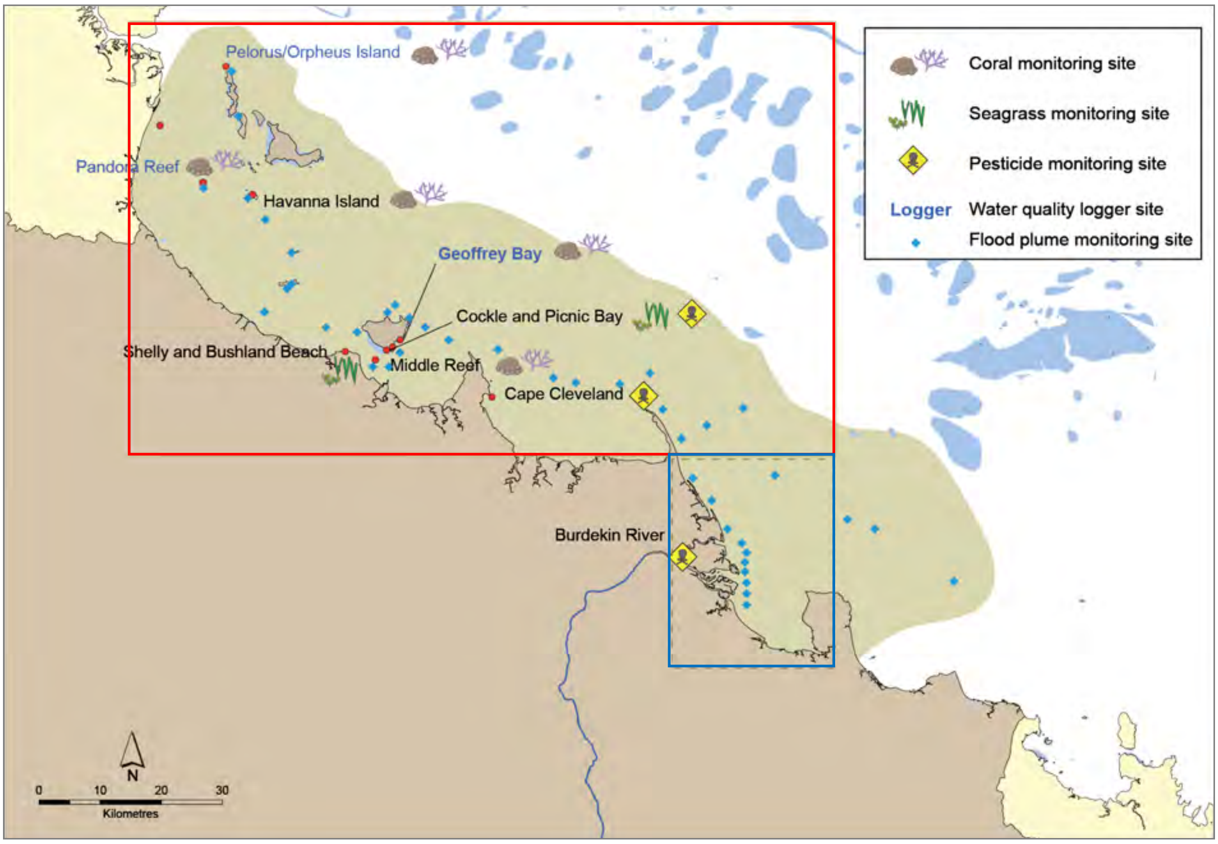


Figure 4.21: Map of the primary (red box) and secondary (blue box) Burdekin River plume extent, showing monitoring sites within the region.

In an attempt to understand the linkages between primary and secondary flood plumes and their associated impacts on inshore coral reef and seagrass ecosystem health, water samples collected as part of the flood plume monitoring within each of the boxed focus areas (Figure 4.22) were collated (approximately representative of the primary and secondary Burdekin River plumes). The maximum, minimum, median and 25th and 75th percentiles of the samples collected within the approximate primary and secondary plume are shown in Figure 4.22. In the primary plume, the suspended particulate matter and particular nitrogen and phosphorus were high with the majority of samples exceeding the relevant Water Quality

Guidelines (GBRMPA 2009). Within the secondary plume the concentrations were more variable, with suspended sediments still relatively high and elevated concentrations of nutrients and chlorophyll *a* detected within this area. These results indicate that the first flush of floodwaters deliver a major portion of the terrestrial pollutants that impact on inshore marine environments, and concentrations of these pollutants decrease with distance and time.

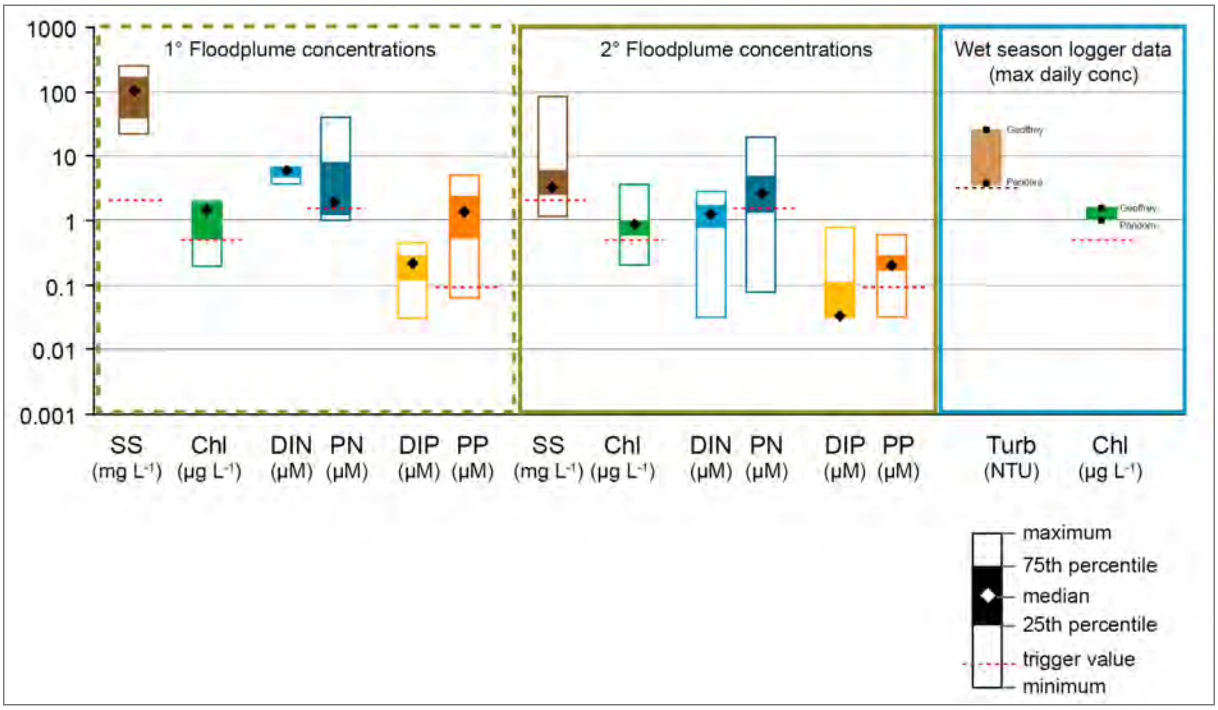


Figure 4.22: Primary (1°) and secondary (2°) flood plume water quality parameters (SS, Chl, DIN, PN, DIP and PP) and the maximum wet season turbidity and chlorophyll concentrations from field deployments of WET Labs Eco FLNTUSB combination fluorometer and turbidity sensors at Pandora Reef and Geoffrey Bay in the Burdekin region. Red dashed lines represent the trigger values in the Water Quality Guideline (GBRMPA 2009), the dark red dashed line represents the suggested turbidity 'threshold' of 5 NTU, beyond which corals may be severely light limited (Cooper *et al.* 2008)

Pesticide residues were detected in the flood plume samples from the Burdekin River, with tebuthiuron residues detected up to fifty kilometres from the river mouth. A sample collected near the mouth of the Burdekin River had the highest tebuthiuron concentration of 0.03 µg/L. This concentration exceeded the locally derived Guideline trigger value (0.02 µg/L; GBRMPA 2009).

Seagrass habitats

Within the Burdekin region, coastal and reef seagrass sites are monitored, with Bushland and Shelly Beach, near Townsville and Cockle and Picnic Bays on Magnetic Island being within the Burdekin River secondary plume zone.

Coastal sites are located on naturally dynamic intertidal sand flats and are subject to sand waves and erosion blowouts moving through the meadows. The Bushland Beach and Shelley Beach area is a sediment deposition zone, so the meadow must also cope with incursions of sediment carried by long shore drift. Sediments within this habitat are mud and sand that have been delivered to the coast during the episodic peak flows of the creeks and rivers (notably the Burdekin River). 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 (Figure 4.23).

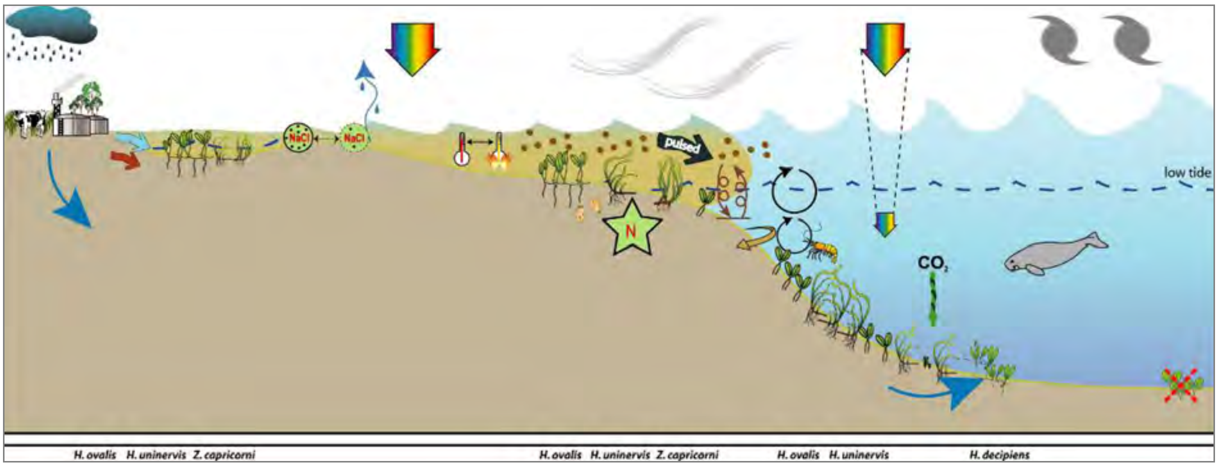


Figure 4.23: Seagrass coastal habitat in the Burdekin region – major control is wind and temperature extremes.

In the Burdekin region reef seagrass meadows are found associated with mainly fringing reefs around continental islands, growing on their intertidal flats. Nutrient supply to these meadows is by terrestrial inputs via riverine discharge, re-suspension of sediments and groundwater supply (Figure 4.24). The meadows are typically composed of zones of seagrass. *Cymodocea serrulata* and *Thalassia hemprichii* often occupy the lower intertidal/subtidal area, blending with *Halodule uninervis* (wide leaved) in the middle intertidal region. *Halophila ovalis* and *Halodule uninervis* (narrow leaved) inhabit the upper intertidal zone.

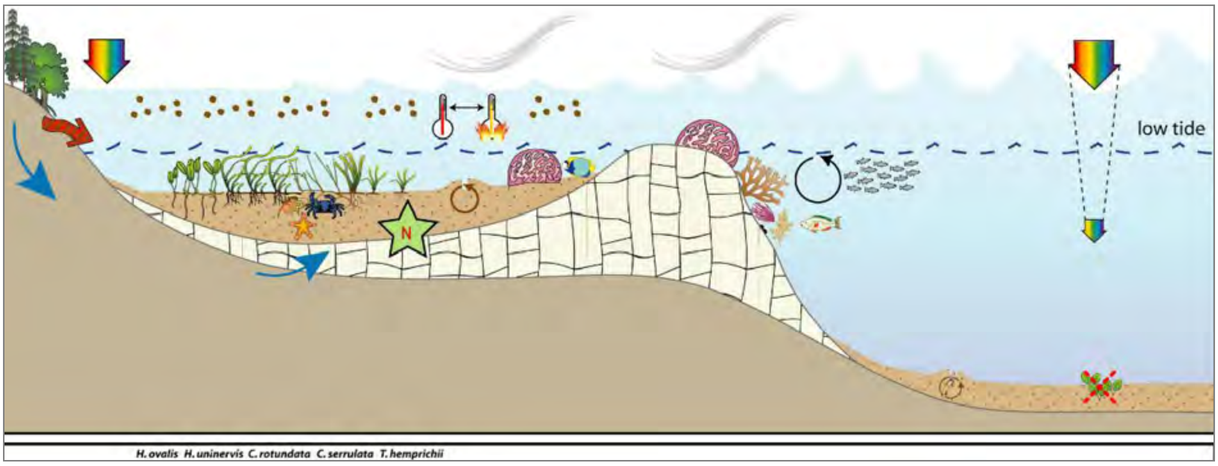


Figure 4.24: Seagrass fringing reef habitats in the Burdekin region – major control is nutrient supply (groundwater), light and shelter.

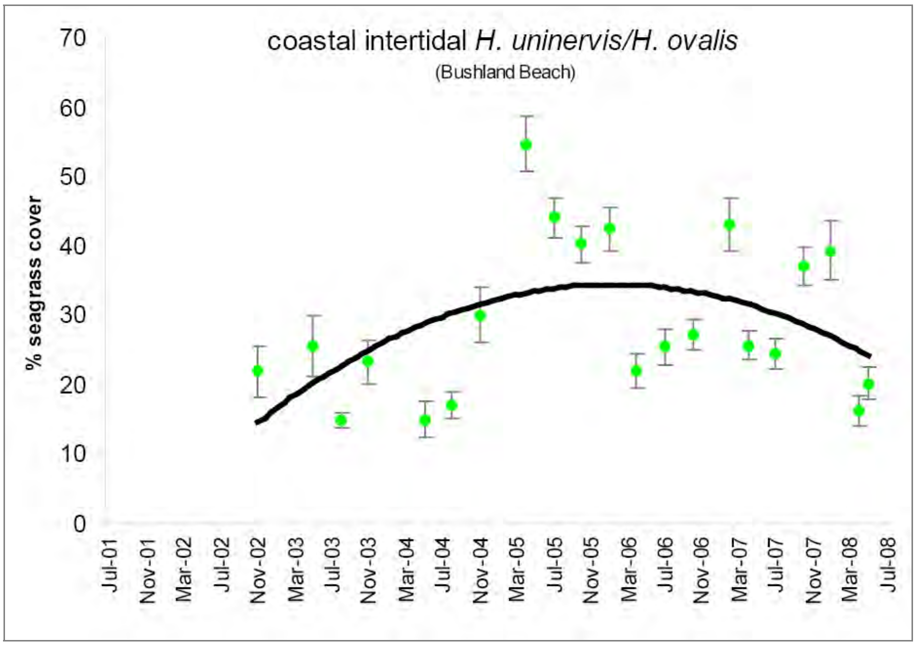
A summary of the status of intertidal seagrass meadows in the Burdekin region is provided in Table 4.2.

Table 4.2: Summary of condition and overall trend at each seagrass monitoring location, Burdekin region. Values are for October 2007 – April 2008 with long-term average in parentheses. Red = poor, Green = good; Yellow = fair; White = ambiguous or insufficient data.

Location	Seagrass cover (%)	Seagrass seeds (No. m^{-2})	Reproductive effort (No. core^{-1})	Meadow (area)	Epiphytes (%)	Macro-algae (%)
Townsville	24 – 14 (19) decline	4793 – 7388 (3227) increase	increase (high)	decline	7 – 23 (17) decline	6 – 1 (4) decline
Magnetic Island	43 – 56 (35) increase	14 – 8 (34) decline	stable	stable	51 – 54 (42) stable	21 – 6 (8) stable

Seagrass cover has fluctuated both within and between years at Bushland Beach (Figure 4.25). Shelley Beach appeared to follow a similar trend, until 2006, when the cover decreased and has not shown significant recovery (Figure 4.25). These meadows do, however have a high presence of seeds and reproductive effort, thus these meadows may be able to recover from disturbances such as flood plumes.

Offshore reef habitat seagrass meadows are monitored on the fringing reef flats of Magnetic Island (Picnic Bay and Cockle Bay). Seagrass cover at both sites appears to have increased since monitoring was established in 2005 (Figure 4.26). Seagrass abundance at both locations appears to follow a seasonal pattern, which is clearer at Cockle Bay.



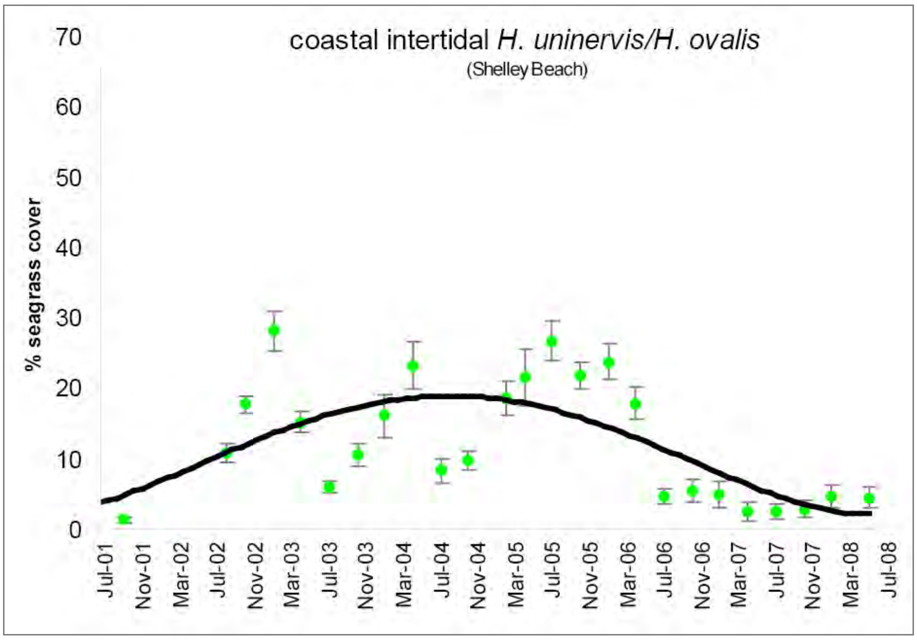
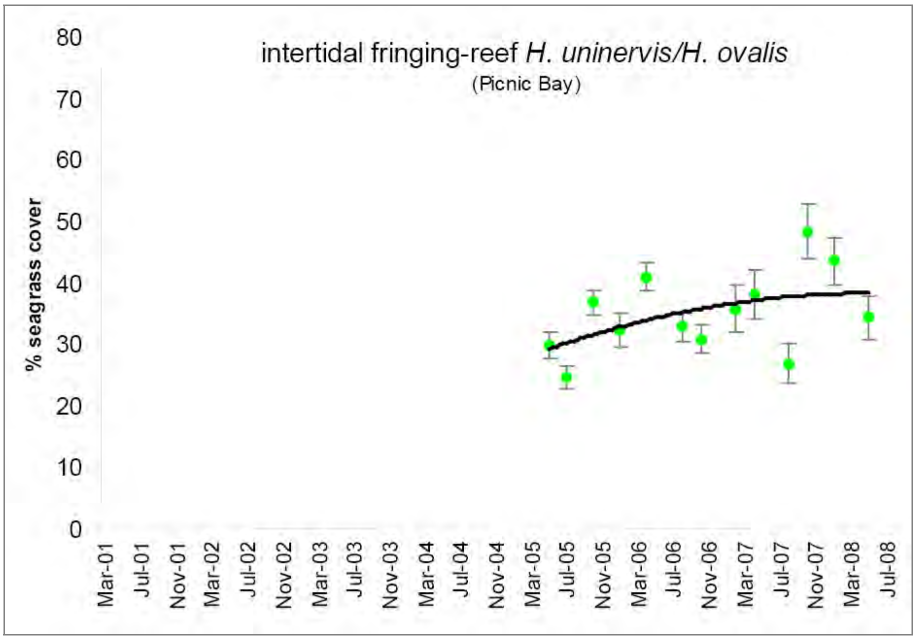


Figure 4.25: Change in seagrass abundance (percentage cover) at coastal intertidal meadows in the Burdekin region. NB: Polynomial trendline.



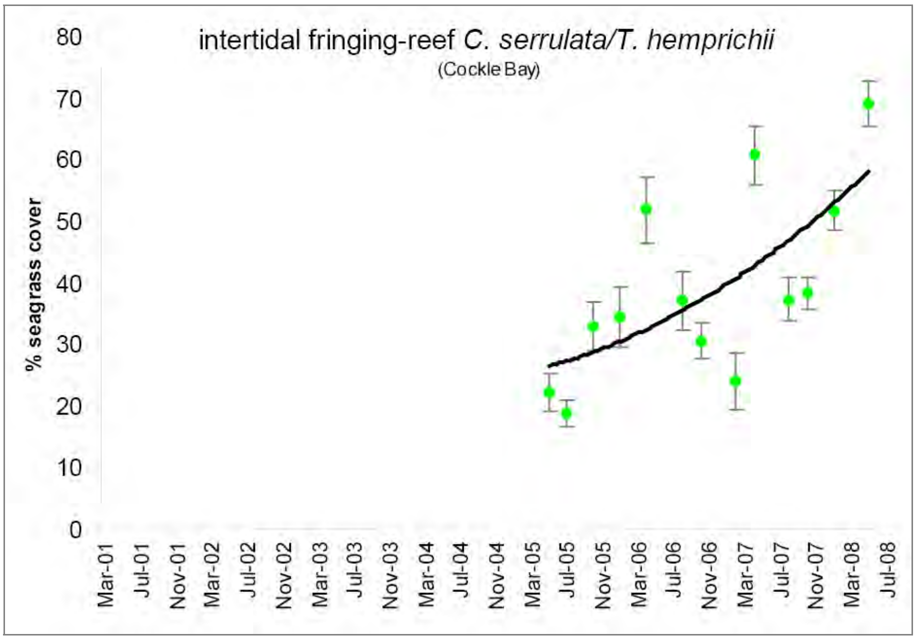
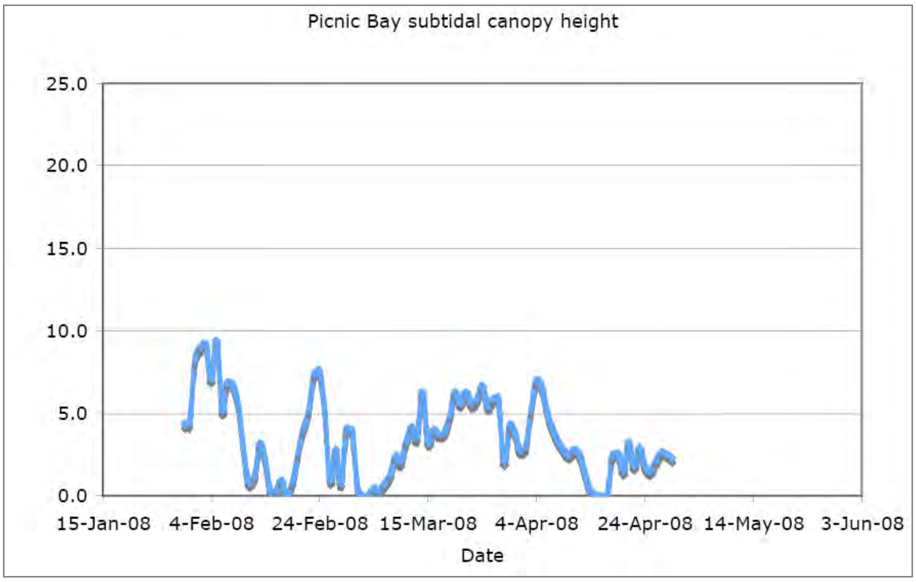


Figure 4.26: Change in seagrass abundance (percentage cover) at intertidal meadows on fringing reef platforms in the Burdekin region. NB: Polynomial trendline.

Seagrass response to light

Light loggers were trialed at intertidal and subtidal seagrass meadows at Picnic Bay to investigate underwater light availability as a driver of seagrass meadows (as part of a MTSRF research project, supported by the MMP). Associated seagrass parameters monitored included percent cover, above and below ground biomass, leaf length, leaf width, leaf thickness, leaves per shoot, carbohydrates, leaf growth and chlorophyll concentration.

Monitoring showed that the Picnic Bay subtidal site had extended low light periods of less than 1 $mol.m^{-2}.day^{-1}$ throughout February and early March 2008, coinciding with the flood plume of the Burdekin River (Figure 4.27). On average light was 3.5 $mol.m^{-2}.day^{-1}$. Light at the intertidal site was consistently higher than at the subtidal site with an average daily light of 10.7 $mol.m^{-2}.day^{-1}$ and a maximum total daily light of 21.7 $mol.m^{-2}.day^{-1}$. Work is continuing to elucidate the relationship between light and other variables that affect seagrass.



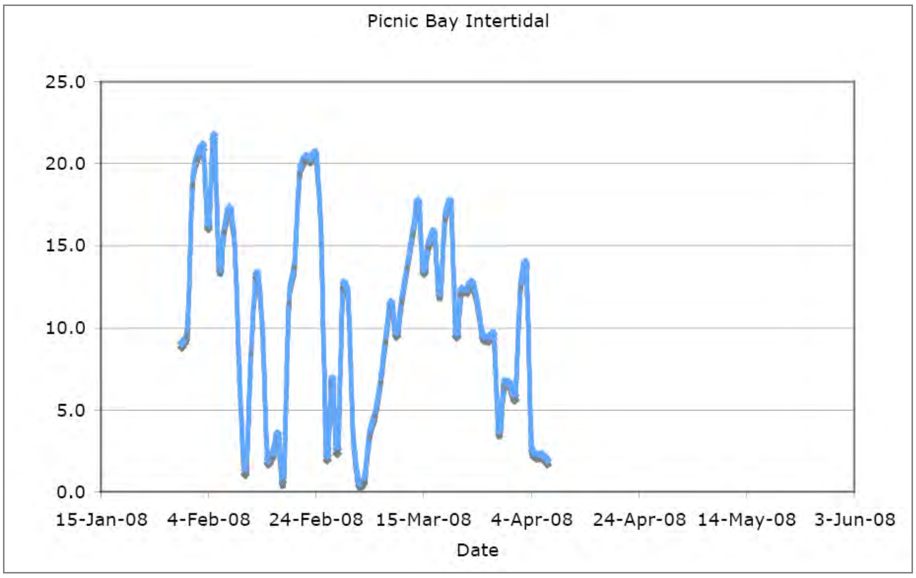


Figure 4.27: Daily light at the subtidal (upper) and intertidal sites (lower) at Picnic Bay from 30/01/2008 to 15/05/2008.

Inshore coral reefs

Historical monitoring of the reefs in the Burdekin region highlights the intense and frequent nature of disturbance to some reefs (Ayling and Ayling 2005, Sweatman *et al.* 2007). During the period 1991-1999 flood plumes extended to most reefs in 1994, 1997 and 1998 (Devlin *et al.* 2001). The largest single disturbance since monitoring began was coral bleaching in 1998, which affected all coral communities on monitored reefs in this region. In 2002 bleaching was less severe than 1998 but still affected the majority of coral communities. Cyclonic disturbances in 1990 (Cyclone Joy), 1996 (Cyclone Justin) and 2000 (Cyclone Tessi) impacted some reefs, and a large decrease in coral cover attributed to Cyclone Tessi at Havannah Island may also include the effects of a local COTS outbreak at that site in the same year.

Monitoring studies (Ayling and Ayling 2005, Sweatman *et al.* 2005) found no discernable direct effects of these flood plumes on the coral communities at the depths monitored. However, surveys on Pandora Reef after the major flooding event of 1998 found that around eighty percent of the corals were bleached to a depth of about ten metres. This indicates that the effects of the flood plume may have exacerbated the impacts of high temperature during this period (Devantier and Fabricius unpublished). Even though disturbance has been severe and frequent on the majority of reefs monitored in this sub-region, there has been evidence of increasing coral cover between disturbances. This increase has, however been slow; particularly when cover was reduced to very low levels as occurred on most reefs monitored in Halifax Bay as a result of bleaching in 1998 and 2002 (Sweatman *et al.* 2007).

Given the frequency and severity of disturbances to reefs in this region over the preceding decade it is not surprising that the regional average hard coral cover was significantly lower and macroalgae cover higher than all other regions (Figures 3.16 and 3.18) and coral cover has been consistently low over the period 2005-2007 (Figure 4.28). There were no substantial disturbances between surveys in 2005 and 2007, nor however, were there substantial indications of recovery of the coral communities with the cover of the major benthic groups relatively stable on most reefs (Figure 4.28).

The Burdekin River flood plumes of 2008 were an additional disturbance to the already disturbed environment of the Burdekin region. Elevated concentrations of chlorophyll and turbidity were recorded in the 2007/08 flood plume, with particularly elevated turbidity levels recorded at Geoffrey Bay (sixteen percent of the wet season daily means exceeded the suggested 5 NTU limit for coral photosynthesis).

The relatively low density of juvenile colonies coupled (Figure 4.29) with low hard coral cover potentially limits increase in coral cover. Both the high levels of macroalgae present on these reefs (Figure 4.28) and the relatively low supply of larvae (as measure by number of spat settling to tiles; Figure 4.30) are likely to be influencing the low density of juvenile colonies and hence recovery potential of the coral communities in this region.

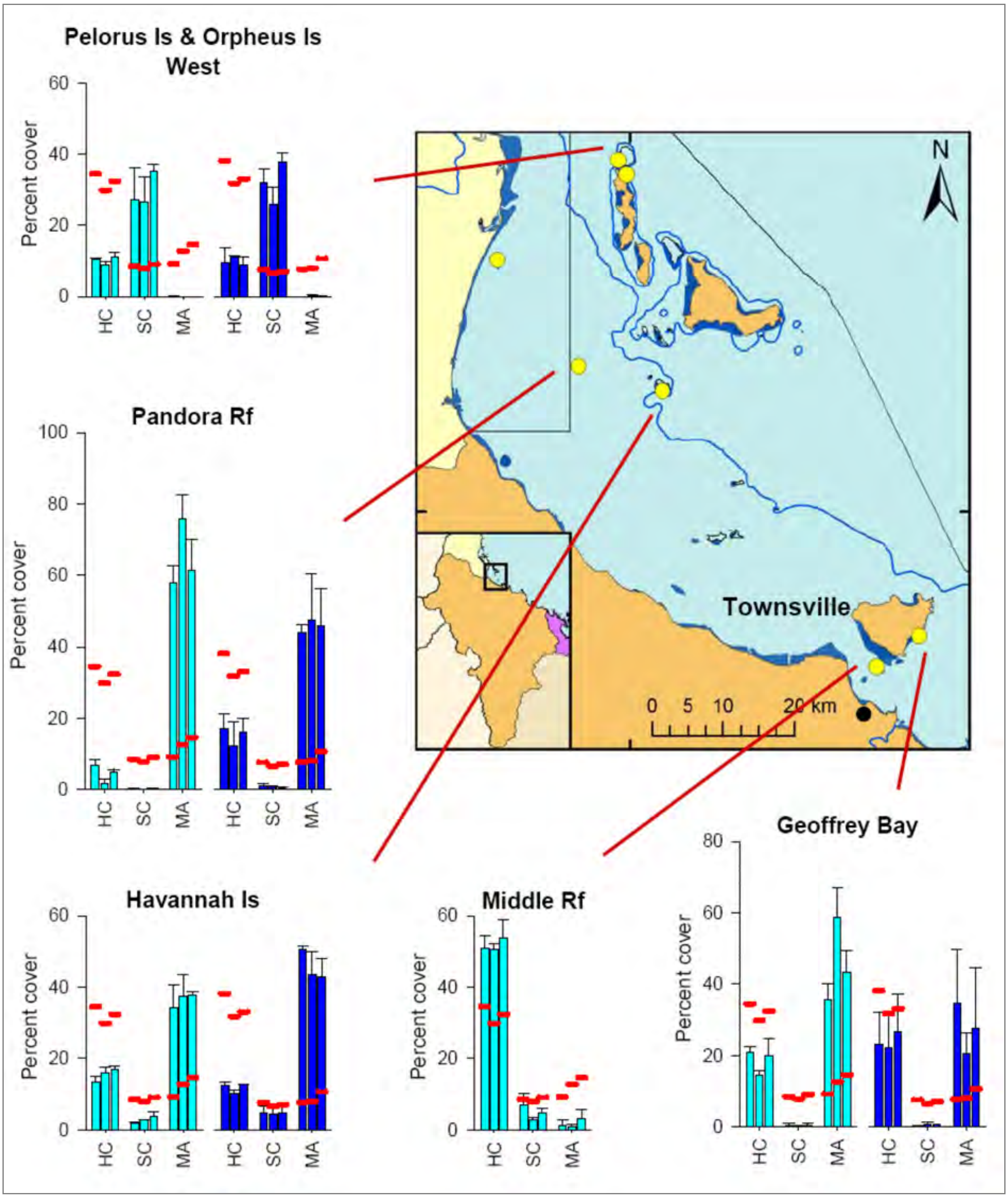


Figure 4.28: Percent cover estimates of major benthic groups, hard coral (HC), soft coral (SC) and macroalgae (MA) on reefs in the Burdekin region. Pale blue bars represent values for two metres' depth and dark blue bars for five metres' depth. Average values for each group and depth from all reefs and regions combined are indicated by red lines. For each benthic group the three bars represent, from left to right, data from 2005, 2006 and 2007.

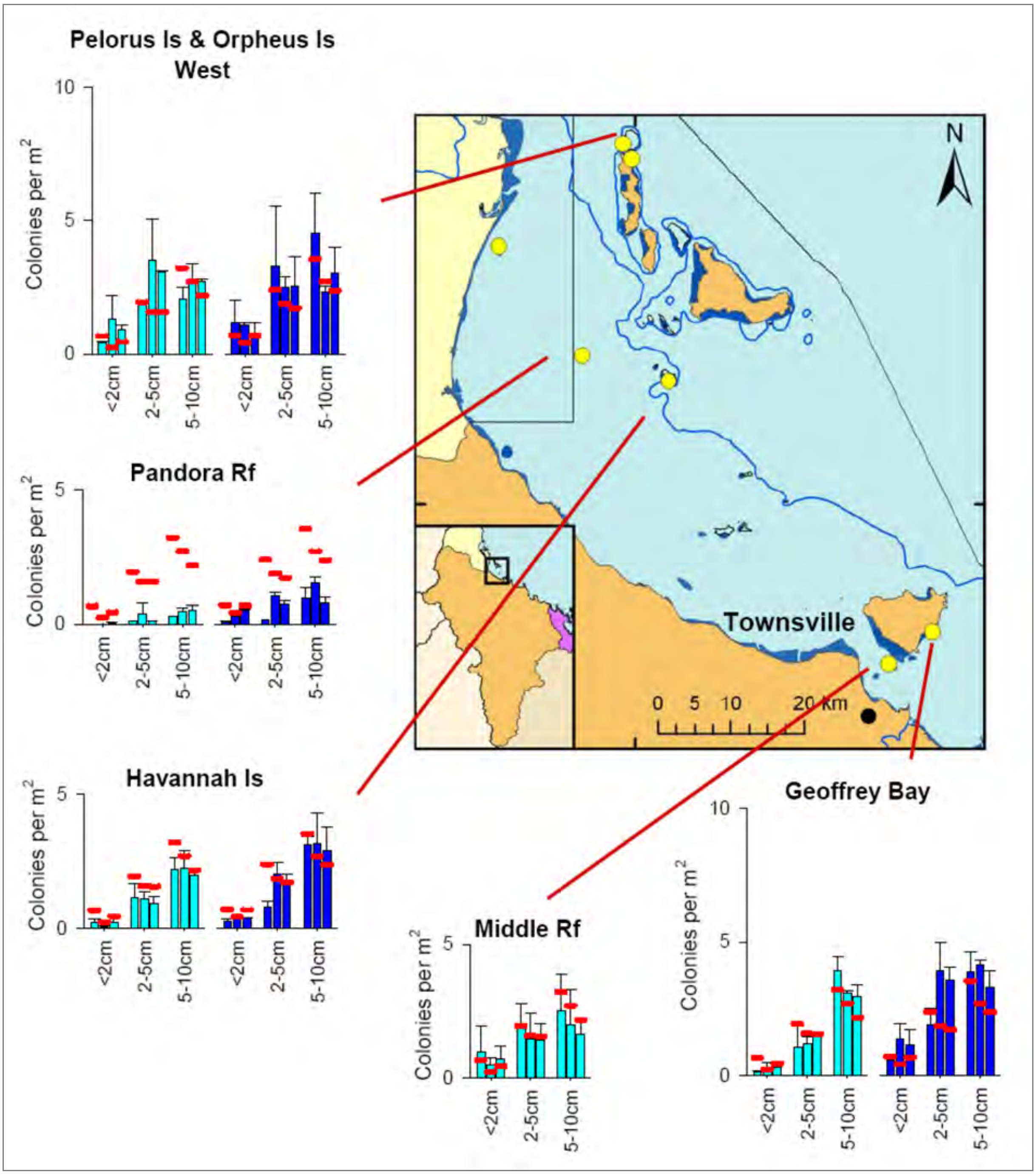


Figure 4.29: Number of juvenile hard coral colonies by size class for reefs in the Burdekin region. Pale blue bars represent values for two metres' depth and dark blue bars for five metres' depth. Average values for each size class and depth from all reefs and regions combined are indicated by red lines. For each size class the three bars represent, from left to right, data from 2005, 2006 and 2007.

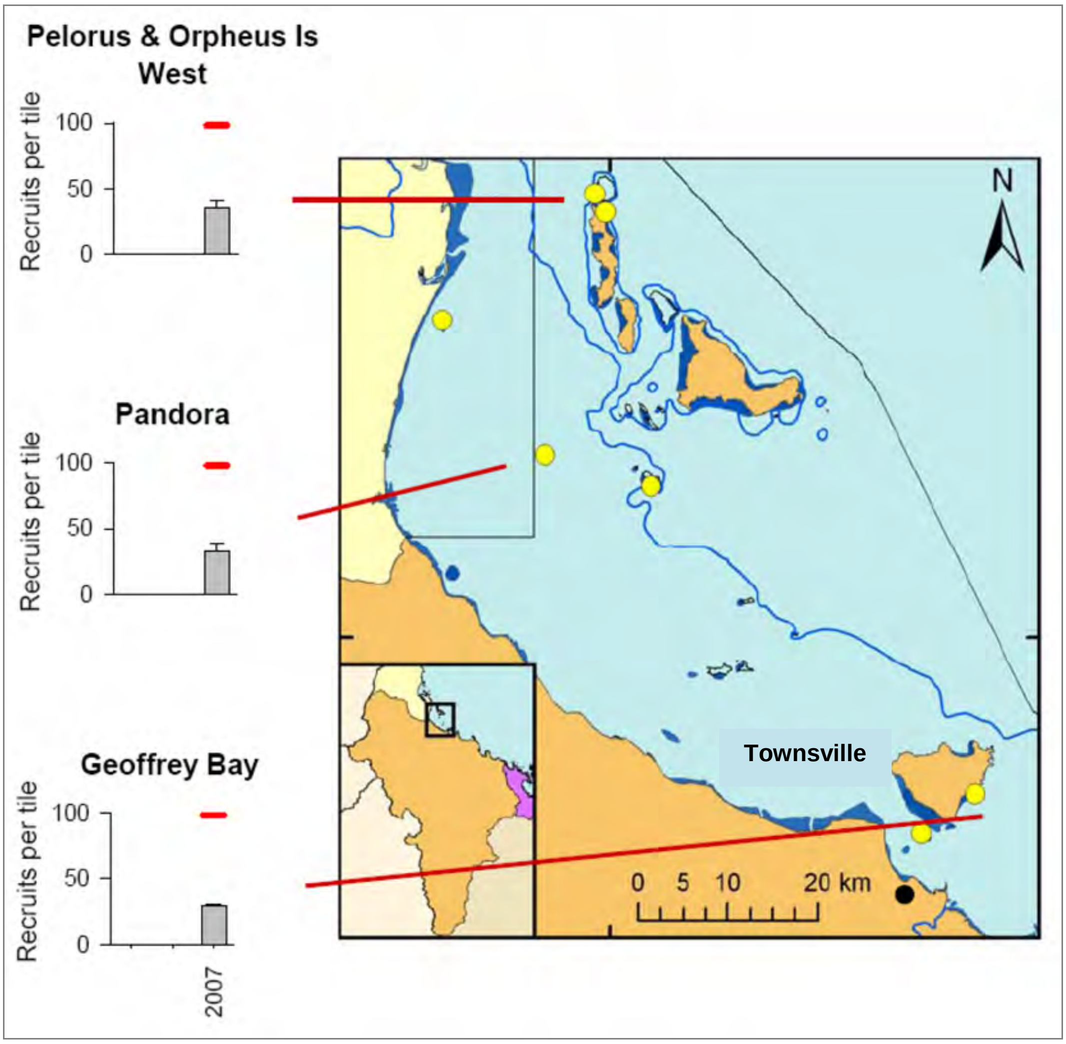


Figure 4.30: Average number of coral recruits per tile on reefs in the Burdekin region. Average values from all reefs and regions sampled in that year are indicated by red lines.

4.4 Mackay Whitsunday region

Ambient water quality

During the 2007/08 sampling period, temperature, chlorophyll and turbidity were measured at three sites in the Mackay Whitsunday region; Double Cone, Daydream and Pine Islands (Figure 4.31) all of which can be exposed to Pioneer River plume waters. Annual and seasonal means of chlorophyll *a* concentrations were exceeded in the Mackay Whitsunday region during 2007-2008, coinciding with the Pioneer River flood events during 2007/08. The wet season Guideline trigger value (GBRMPA 2009) for PP was exceeded at Pine Island, the location closest to the Pioneer River mouth. This site also recorded the highest chlorophyll *a* and turbidity values. Chlorophyll was above the Guideline trigger value for most of the record with 91% of daily means exceeding this value and a mean chlorophyll *a* concentration of 0.73 μgL^{-1}, also above the Guideline trigger value (Table 3.1). Maximum turbidity was ~7 NTU and was variable and slightly elevated from late December to mid February, and the mean turbidity was ~1.7 NTU, both the highest values in this region (Table 3.2). Four percent of daily turbidity means exceeded the suggested 5 NTU limit for coral photo-physiological stress.

The depth-profile for Double Cone Island showed a thermocline in both the wet and dry seasons, unlike other sub-regions where the water column was generally well-mixed. Double Cone Island had a mean chlorophyll concentration of 0.69 μgL^{-1}, which was above the Guideline trigger value from mid January to mid February coinciding with the two major flood peaks of the Pioneer River, and 54% of the daily means in the record exceeded the trigger values. Maximum turbidity was ~6 NTU (mean turbidity was ~1.3 NTU) and four percent of daily means exceeded the suggested 5 NTU limit for coral photo-physiological stress.

Daydream Island had a mean chlorophyll concentration of 0.48 µg L-1, which was just above the Guideline trigger value and the lowest value in the region, and exceeded the trigger value for most of October but show very little response to the Pioneer River flood. Twenty-five percent of the daily means in the record exceeded the Guideline chlorophyll trigger values. Maximum turbidity was ~8 NTU, reached briefly mid February, coinciding with the second major flood peak of the Pioneer River, and the mean turbidity was ~1.3 NTU and two percent of daily means exceeded the suggested 5 NTU limit for coral photo-physiological stress (Table 3.2).

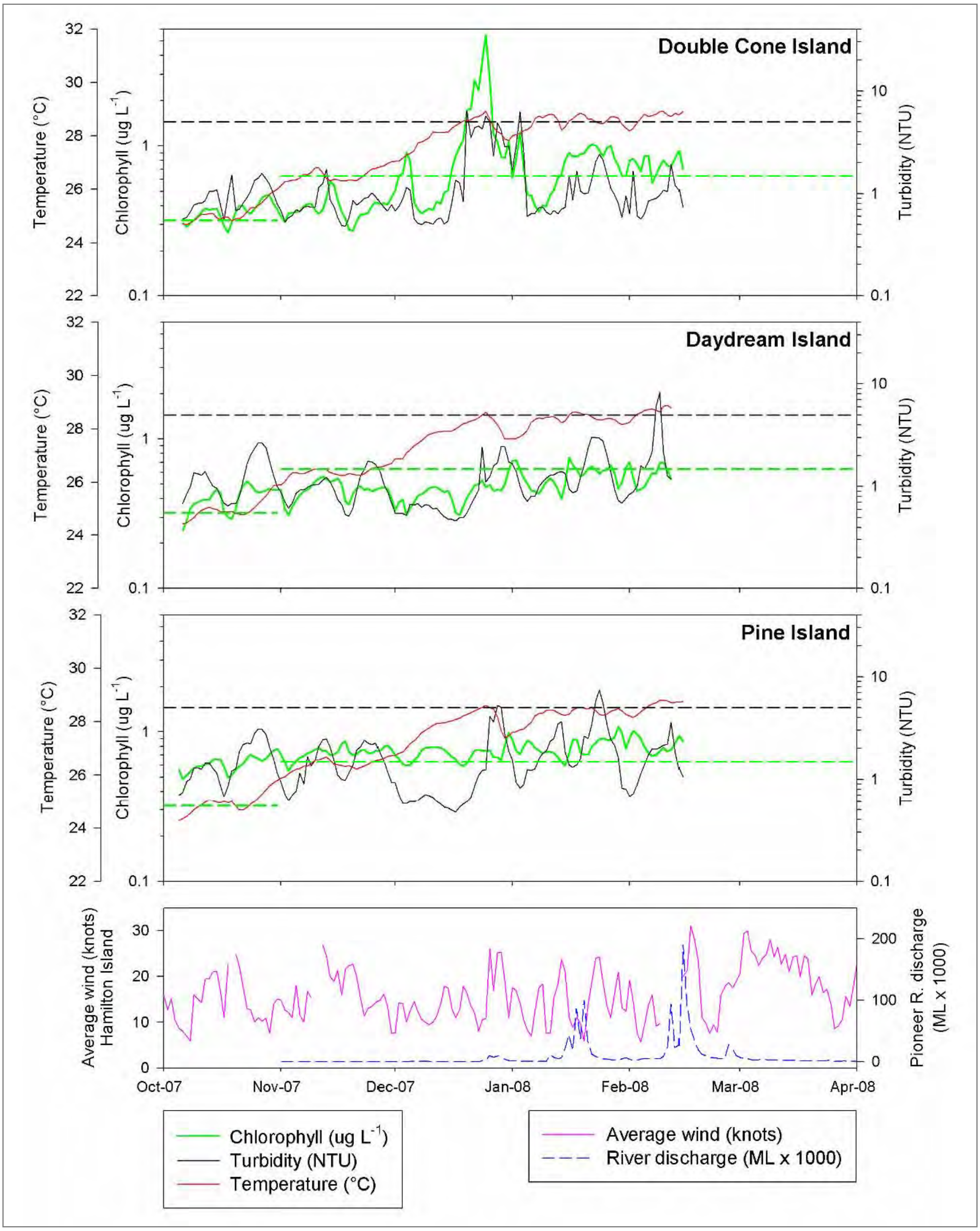


Figure 4.31: Time series of chlorophyll (µg L-1, green line) turbidity (NTU, black line) and temperature (°C, red line) from field deployments of WET Labs Eco FLNTUSB combination fluorometer and turbidity sensors at Double Cone, Daydream and Pine Islands in the Mackay Whitsunday region.

Seagrass habitats

Estuarine, coastal and reef seagrass habitats are monitored in the Mackay Whitsunday region. Estuarine seagrass monitoring is in Sarina Inlet, and monitored meadows are typically intertidal on the large sand/mud banks of sheltered estuaries. Run-off through the catchments connected to these estuaries is variable, though the degree of variability is moderate compared to the high variability of the Burdekin River and the low variability of the Tully River (Brodie 2004). Seagrass in this habitat must cope with extremes of flow, associated sediment and freshwater loads from December to April when eighty percent of the annual discharge occurs (Figure 4.32).

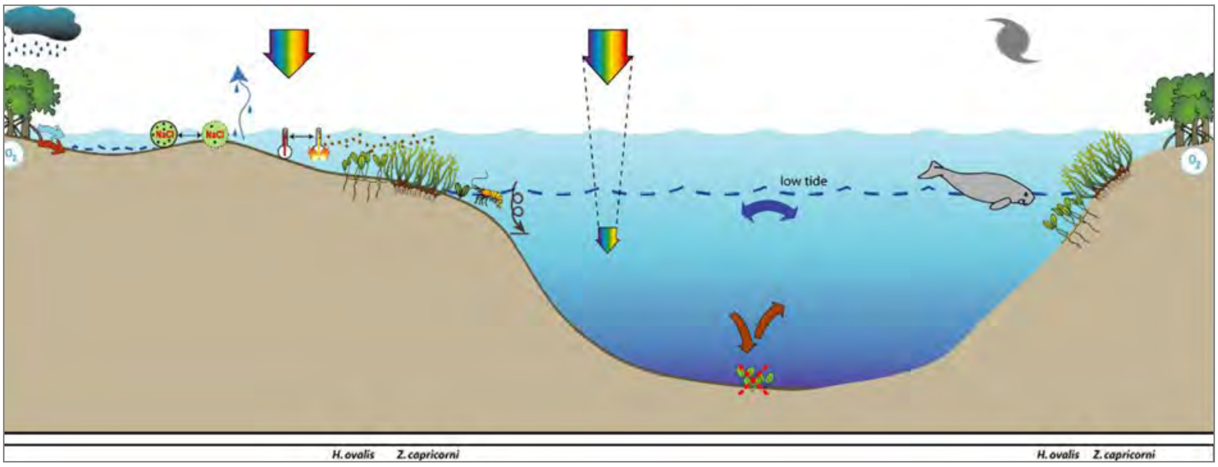


Figure 4.32: Seagrass estuarine habitat in the Mackay Whitsunday region.

Monitoring of intertidal coastal seagrass habitats is on the sand/mud flats adjacent to Cannonvale in southern Pioneer Bay. Coastal seagrass habitats are found in the leeward side of inshore continental islands and in north opening bays. These areas offer protection from the south-easterly trades. Potential impacts to these habitats are declines in water quality associated with urban, marina development and agricultural land use (Figure 4.33).

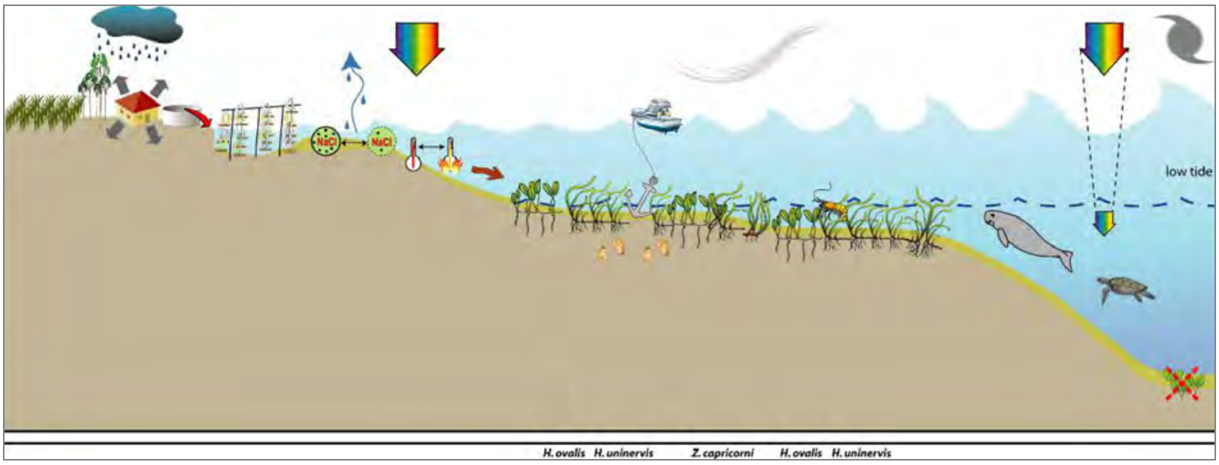


Figure 4.33: Seagrass coastal habitat in the Mackay Whitsunday region – major control is shelter and temperature extremes.

Reef habitat seagrass meadows are found in the intertidal zone on the top of the coastal fringing reefs or fringing reefs associated with the many islands in this region, with monitoring undertaken at Hamilton Island. Habitat drivers for reef seagrass meadows are exposure to air, and desiccation (Figure 4.34). Major threats include physical damage or removal due to increased tourism activities and coastal developments, such as marinas.

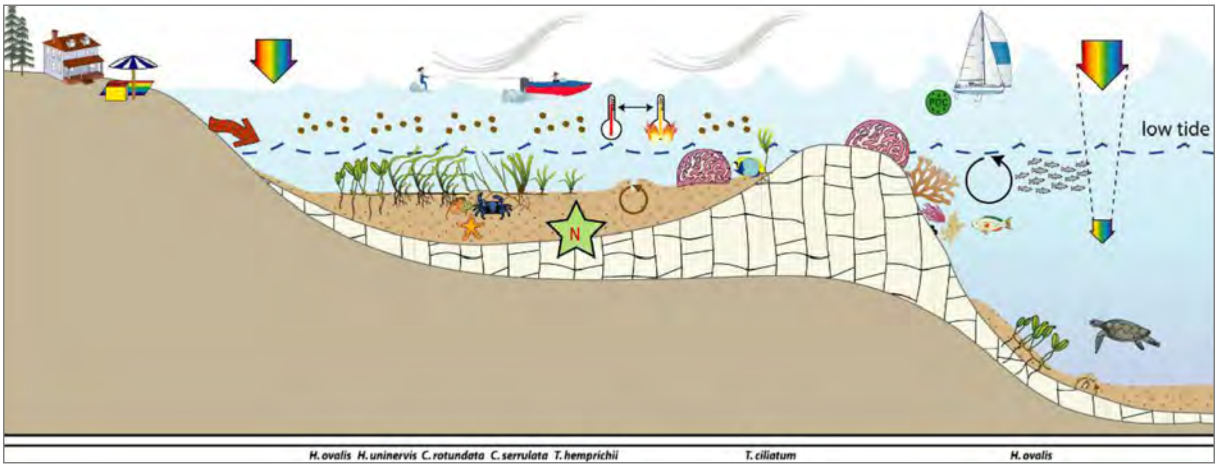


Figure 4.34: Conceptual diagram of seagrass reef habitat in the Mackay Whitsunday region – major control is light and temperature extremes.

In the Mackay Whitsunday region, coastal sites are replete or phosphorus limited, suggesting saturating levels of nitrogen. Seagrass abundance showed a dramatic decline in the late 2008 monsoon, possibly a consequence of the flooding in the region, but this is not significant compared to similar declines in previous wet seasons. The highest concentrations of the herbicide diuron were detected in the Mackay Whitsunday region at Pioneer Bay and Sarina Inlet, 0.48 and 0.32 $\mu g kg^{-1}$ respectively. These figures are well below the maximum concentrations recorded by Haynes *et al.* (2000b; 1.7 $\mu g kg^{-1}$ in intertidal sediments at Cardwell).

Coral reef habitats

Hard coral cover remained relatively high in the Mackay Whitsunday region from 2005 to 2007 at 41 to 42.5% respectively (Figure 4.35). There were no substantial changes to the cover of either soft corals or macroalgae, both remained stable at around 8% and 6% respectively (Figure 4.35). Coral species richness of reefs in the Mackay Whitsunday region increased significantly from 2006 to 2007 and was significantly higher than all other regions and sub-regions in the GBR at ~30 genera.

Between 2005 and 2006 there was an unexplained decline in the density of juvenile colonies regionally. This decline did not continue through to 2007 with densities very similar between 2006 and 2007 on most reefs (Figure 4.36). The density of juvenile colonies in 2007 was at or slightly below the overall average for all reefs surveyed. The density of juvenile colonies was lowest at Double Cone Island however this is likely to be due to the lack of substrate available to coral recruits as there is very high coral cover at this site.

Settlement of coral recruits was moderate and variable in the Mackay Whitsunday region, with generally low numbers of juvenile colonies and negligible change in coral cover over the survey period (Figure 4.37). The number of spat recorded in 2005 at Double Cone Island was very low, and in 2007 the highest number recorded regionally was at Daydream Island. While coral cover on some reefs in this region was high it is unclear how resilient to disturbance these communities would prove.

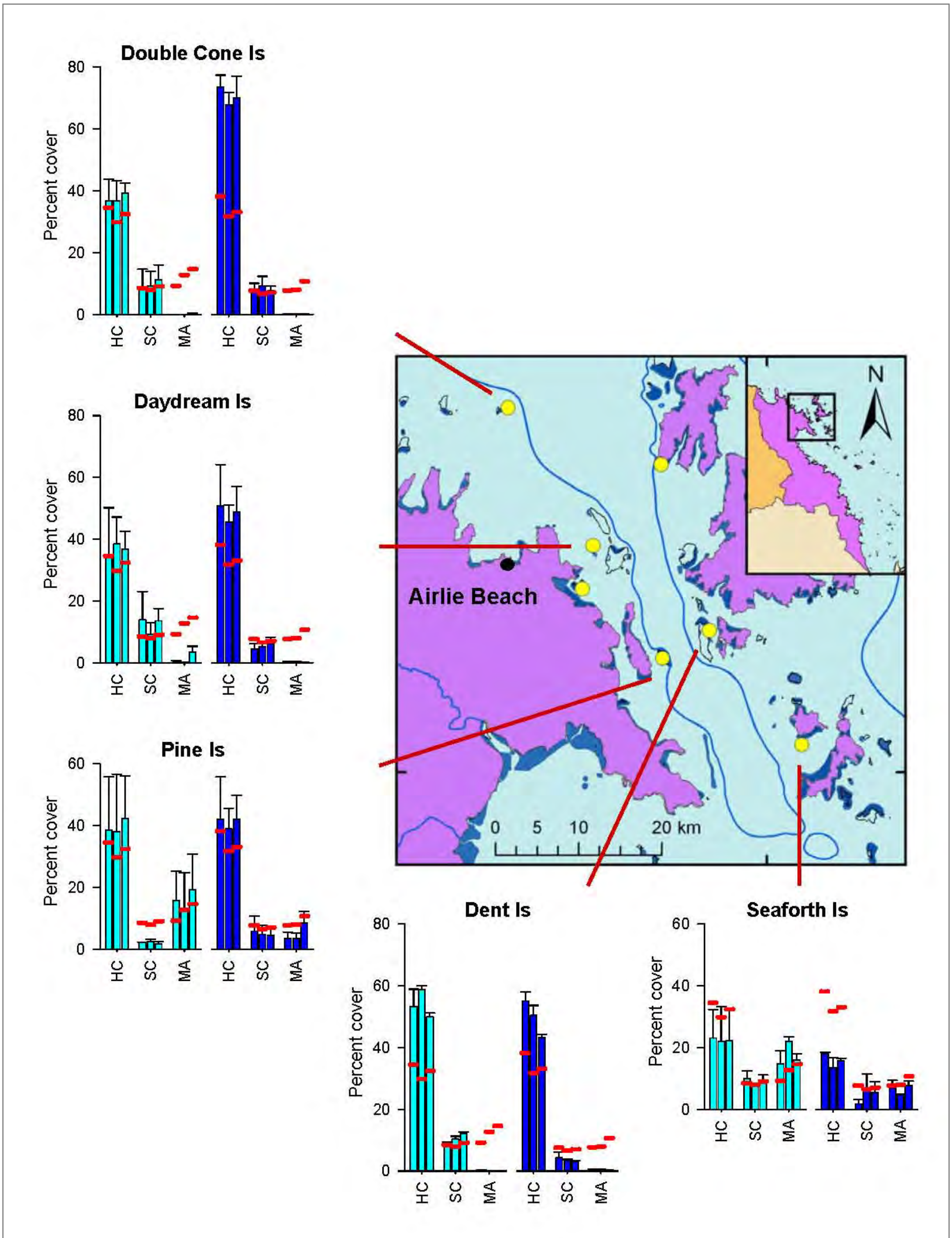


Figure 4.35: Percent cover estimates of major benthic groups, hard coral (HC), soft coral (SC) and macroalgae (MA) on reefs in the Mackay Whitsunday region. Pale blue bars represent values for two metres' depth and dark blue bars for five metres' depth. Average values for each group and depth from all reefs and regions combined are indicated by red lines. For each benthic group the three bars represent, from left to right, data from 2005, 2006 and 2007.

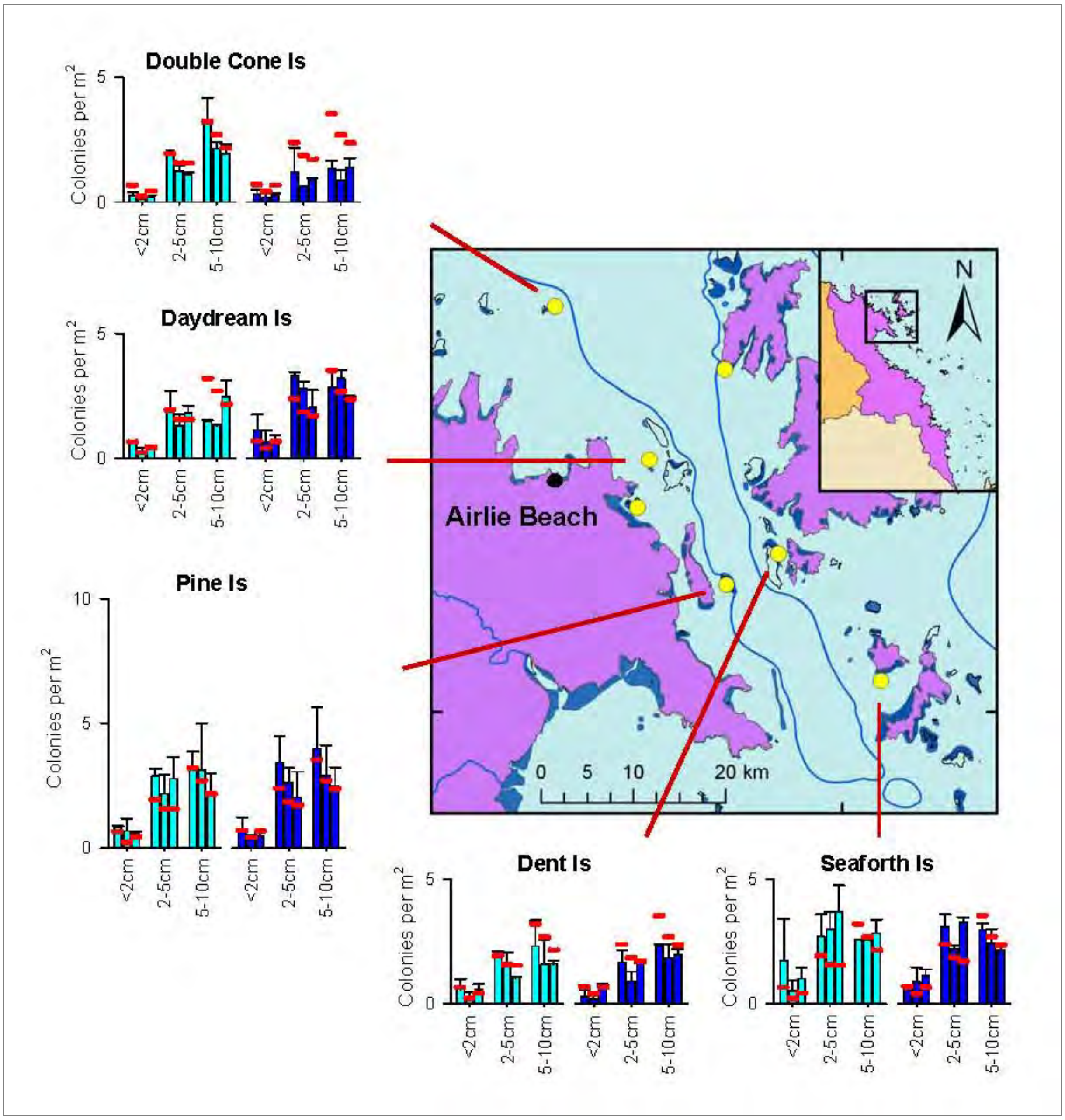


Figure 4.36: Abundance of juvenile hard coral colonies by size class for reefs in the Mackay Whitsunday region. Pale blue bars represent values for two metres' depth and dark blue bars for five metres' depth. Average values for each size class and depth from all reefs and regions combined are indicated by red lines. For each size class the three bars represent, from left to right, data from 2005, 2006 and 2007.

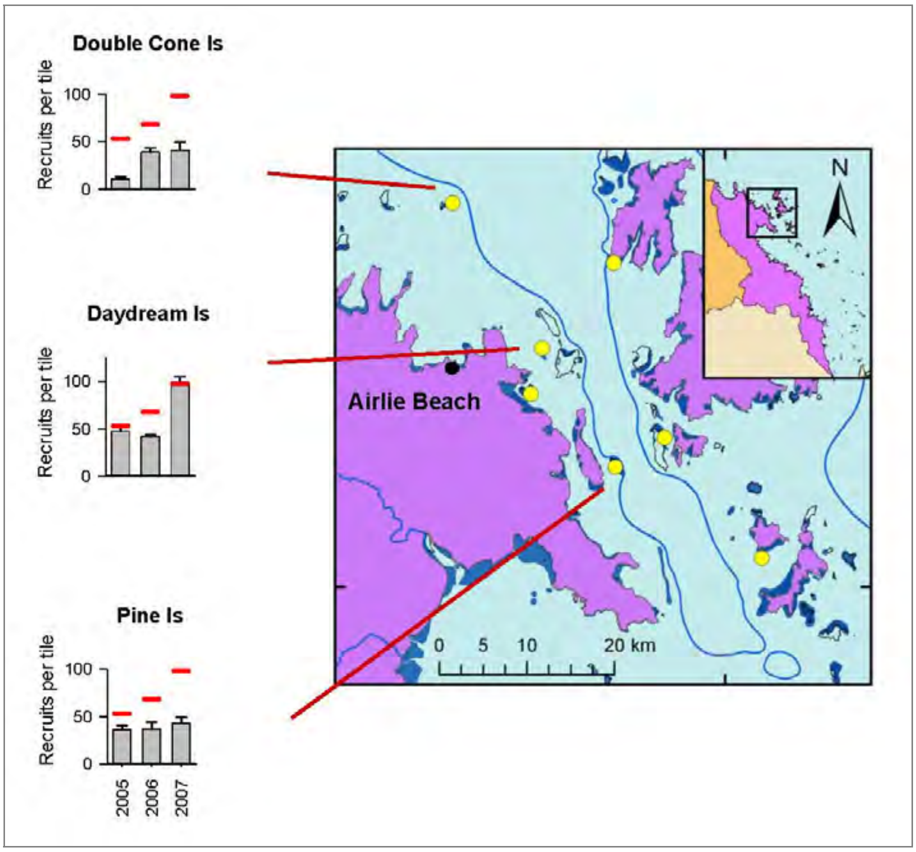


Figure 4.37: Average number of coral recruits per tile on reefs in the Mackay Whitsunday region. Data are from five-metre tile deployments. Average values from all reefs and NRM regions sampled in each year are indicated by red lines. It should be noted that comparison of over all means (red lines) over time is not possible as the regions sampled vary among years (2005 includes reefs from the Wet Tropics and Mackay-Whitsunday regions, in 2006 sampling also included reefs from the Fitzroy region and then 2007 included these and also reefs from the Burdekin region).

Pesticide concentrations

Routine pesticide monitoring in the Pioneer River revealed a wider range of pesticides and elevated water concentrations compared to inshore reef sites. The pesticide profile was dominated by atrazine and diuron, followed by hexazinone, atrazine breakdown products, ametryn, tebuthiuron and simazine (Figure 4.38).

Event monitoring at the Pioneer River detected a range of pesticides with atrazine and diuron present at the highest concentrations followed by hexazinone, ametryn, flumeturon, tebuthiuron, simazine and prometryn (Table 4.3). The water concentrations of atrazine, diuron and hexazinone varied over a large range and were on several occasions close to or in excess of 1,000 ngL^{-1}. Tebuthiuron, prometryn and simazine were in most cases <1 ngL^{-1}. The pesticide profile at the Pioneer River did not vary significantly between seasons or over time. Both atrazine and diuron dominated followed by hexazinone and ametryn. Elevated concentrations of most chemicals measured in 2006/07 and 2007/08 coincided with high flow events. For example, the water concentration of diuron increased from approximately 1 ngL^{-1} to almost 10 ngL^{-1} during high flow periods.

Monitoring at the Inner Whitsunday Islands detected diuron, hexazinone, atrazine, tebuthiuron and ametryn. Diuron dominated the chemical profile with median water concentrations of all other pesticides just at the detection limit. Across seasons, diuron dominated followed by hexazinone and atrazine. Overall, peak water concentrations for diuron were one to two magnitudes lower than levels measured during similar periods in the Pioneer River. Chlorpyrifos was detected in the Inner Whitsundays (0.04 ngL^{-1}) and Pioneer River (0.04 ngL^{-1}) once during the dry season.

Monitoring at the Outer Whitsunday Islands detected diuron, hexazinone, atrazine, tebuthiuron, ametryn and desethyl atrazine. Diuron dominated the chemical profile followed by hexazinone and atrazine.

Seven non-polar pesticides – metolachlor (3-14 ngL^{-1}), phosphate tri-n-butil (1-13 ngL^{-1}), pendimethalin (1-11 ngL^{-1}), dieldrin (0.6-5 ngL^{-1}), chlorpyrifos (1-3 ngL^{-1}), chlorfenvinphos (3 ngL^{-1}) and trifluralin (1-2 ngL^{-1}) – were detected in the Pioneer River.

Table 4.3: Summary of event monitoring maximum, median and minimum water concentrations (ngL^{-1}) for pesticides detected at Pioneer River using Empore Disks from 2005-2008.

Pesticide	Maximum	Median	Minimum
Diuron	1700	130	nd
Atrazine	1500	61	1.6
Simazine	7.0	nd	nd
Hexazinone	730	45	nd
Tebuthiuron	11	nd	nd
Ametryn	72	5.0	nd
Flumetron	90	nd	nd
Prometryn	0.8	nd	nd
Desisopropyl atrazine	31	0.7	nd
Desethyl atrazine	110	7.2	nd

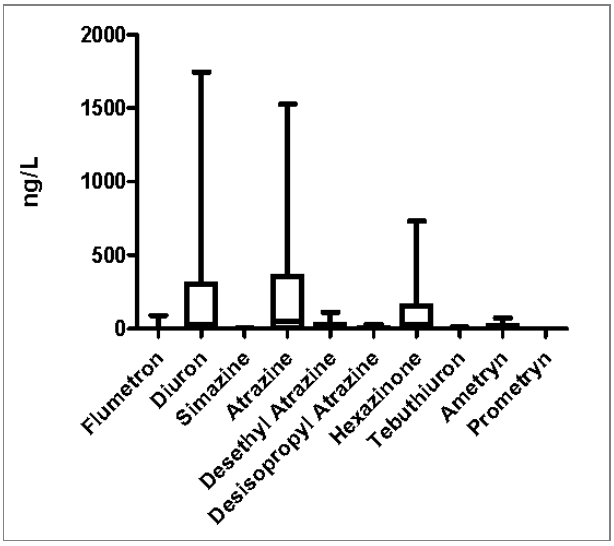


Figure 4.38: Box plots showing the range of water concentrations (ngL^{-1}) for pesticides detected at Pioneer River using Empore Disks. Maximum and minimum values represented by whiskers and the median represented by horizontal line within box.

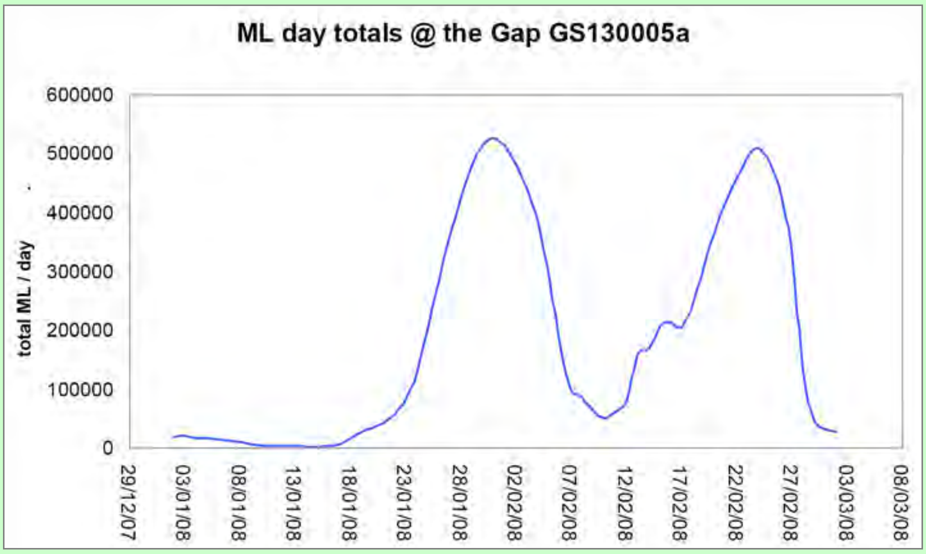
4.5 Fitzroy region

Water quality

Box 4.2 Case Study: Fitzroy River flood event 2007/08

Heavy rainfall created significant flooding in Fitzroy catchments in January/February 2008, although there was a distinct difference in when the sub-catchments flooded due to the local variability in rainfall location. The flood event in the Fitzroy River in 2008 was the largest within the last decade. Although the 1991 flood had almost double the peak flow rate of the 2008 event it should be noted that the 2008 event showed a double peak in flow, a short period of time (three weeks) and the total volume discharged was comparable to the 1991 event.

Flow data for the 2008 event is illustrated in the figure below. The event started on 18 January 2008 and leveled off around 2 March 2008, resulting in approximately 42 days of high flow. There were two distinct peaks, measuring greater than 500,000 ML per day, on 29 January and 25 February 2008 respectively. The resultant flood plumes in the marine environment generally moved in a northerly direction due to the strong, prevailing south-easterly wind. However, aerial images do show some movement offshore with variable wind direction and speed.



Fitzroy River flow rates (ML/day) measured at site The Gap DNRW gauging station (130005a) during the 2008 flood event (http://www.nrw.qld.gov.au/water/monitoring/current_data/map_qld.php).

Wet season chlorophyll and turbidity

Chlorophyll and turbidity measurements (from FLNTUSB instruments deployed at inshore reefs) are available for the 2007/08 wet season for three sites in the Fitzroy region – Barren Island, Humpy Island and Pelican Island. The maximum wet season chlorophyll and turbidity concentrations recorded at the inshore reef sites are shown in Figure 4.39.

Barren Island had a mean chlorophyll concentration of 0.52 μgL^{-1}, and a mean turbidity of ~0.5 NTU, both the lowest values in this region. Turbidity was slightly elevated and more variable from late December 2007 to late February 2008 with a maximum of ~3 NTU (Figure 4.40). Chlorophyll was highest after the second flood peak of the Fitzroy River mid to late February. Twenty-eight percent of the daily means in the record exceeded the Guideline chlorophyll trigger values (GBRMPA 2009) but none exceeded the suggested 5 NTU limit for coral photo-physiological stress. Humpy Island had a mean chlorophyll concentration of 0.6 μgL^{-1}, and a mean turbidity of 1.5 NTU.

Chlorophyll *a* was above the Guidelines trigger value in mid February 2008, coinciding with the second major flood peak of the Fitzroy River, when the maximum turbidity of ~6.5 NTU was briefly reached (Figure 4.40). Twenty percent of the daily means in the record exceeded the Guidelines trigger values and only two percent exceeded the suggested 5 NTU limit for coral photo-physiological stress.

Pelican Island had a mean chlorophyll concentration of 0.9 μgL^{-1}, which was above the Guidelines trigger value, and a mean turbidity of ~10 NTU, both the highest values in this region and, for turbidity, of all fourteen locations. Daily means of chlorophyll were above the Guidelines trigger value on 75% of the days, during the flood event for 77 days in a row. Maximum turbidity was ~37 NTU and values were very variable for most of the record with more elevated values from late December 2007 to late March 2008, encompassing the major flood of the Fitzroy River (Figure 4.40). Sixty-one percent of daily means exceeded the suggested 5 NTU limit for coral photo-physiological stress, with thirty days above this threshold during the flood event.

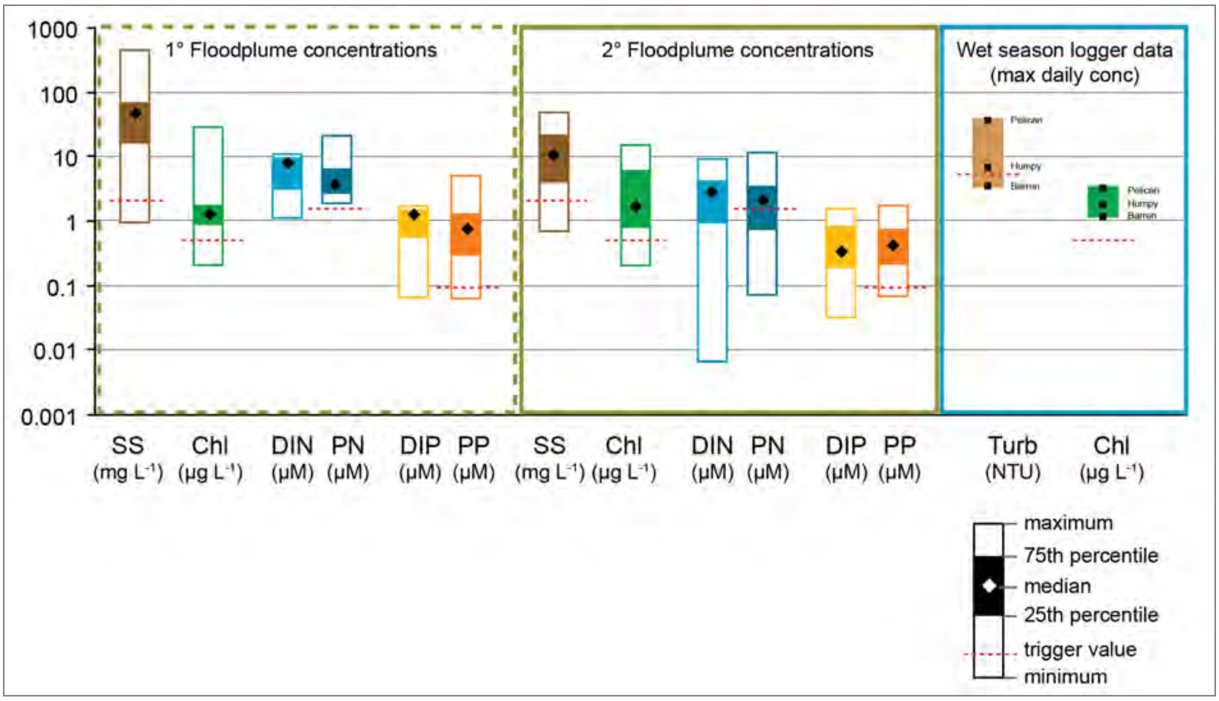


Figure 4.39: Primary (1°) and secondary (2°) floodplume water quality parameters (SS, Chl, DIN, PN, DIP and PP) and the maximum wet season turbidity and chlorophyll concentrations from field deployments of WET Labs Eco FLNTUSB combination fluorometer and turbidity sensors in the Fitzroy region. Red horizontal dashed lines represent the trigger values in the Water Quality Guidelines (GBRMPA 2008), the dark red dashed line represents the suggested turbidity 'threshold' of 5 NTU, beyond which corals may be severely light limited (Cooper *et al.* 2008).

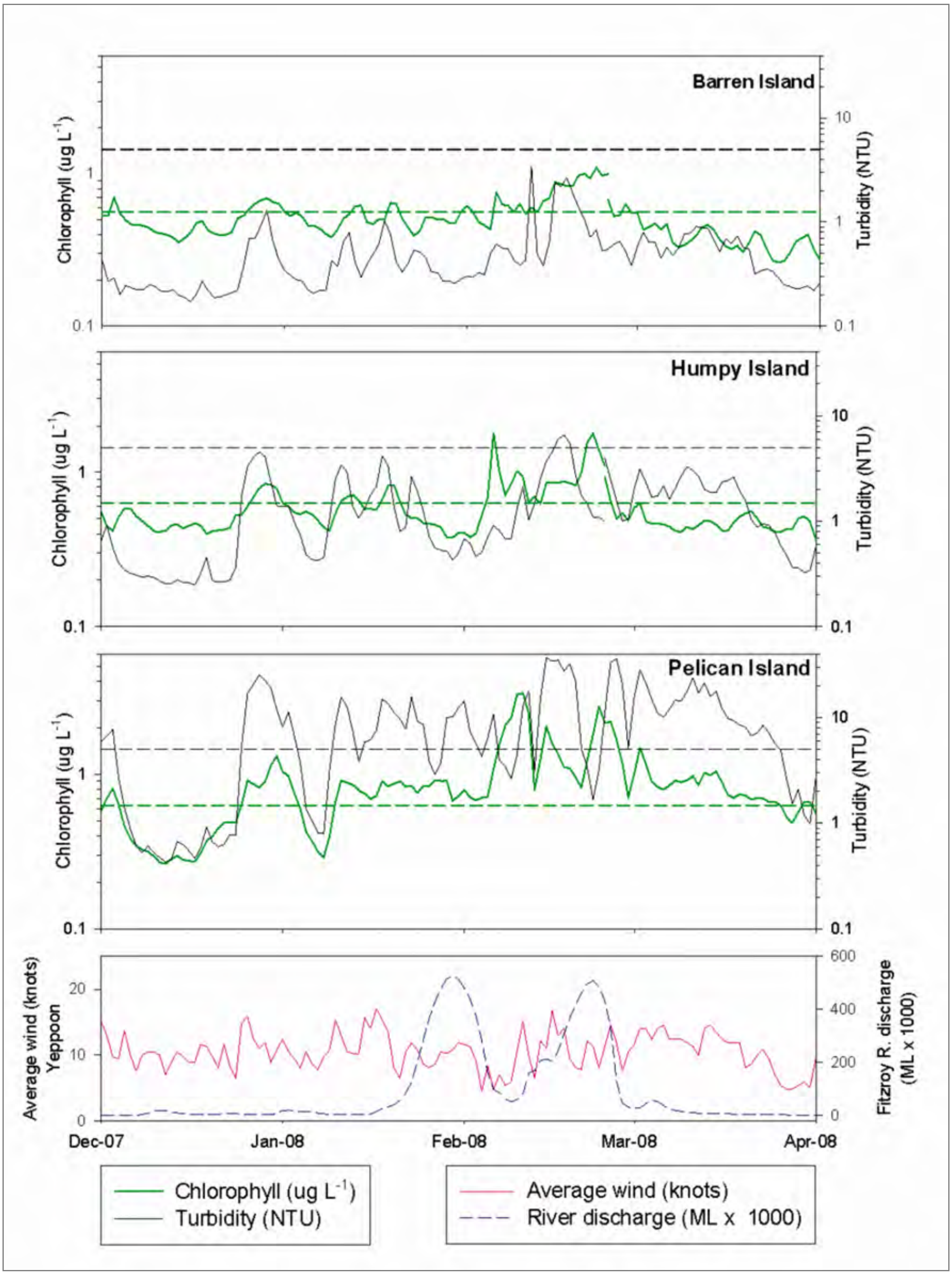


Figure 4.40: Time series of chlorophyll (µg L^{-1}, green line) turbidity (NTU, black line) and temperature (°C, red line) from field deployments of WET Labs Eco FLNTUSB combination fluorometer and turbidity sensors at Barren Island, Humpy Island and Pelican Island in the Fitzroy region. Additional panels represent daily mean wind speeds (knots, pink solid line) and discharge volumes from the Fitzroy River (ML x 1000, blue dashed line). Green horizontal dashed lines represent the Guideline chlorophyll trigger values (GBRMPA 2009); black dashed lines represent the suggested turbidity threshold of 5 NTU, beyond which corals may be severely lightlimited (Cooper *et al*. 2008).

Pesticide concentrations

Pesticide monitoring was undertaken in the Fitzroy River over the two peak events using passive samplers (Figure 4.41). These flow event included inflows from both cropping and grazing areas. Results from passive Empore Disk (ED) samplers showed that atrazine dominated the polar pesticides with a maximum water concentration of 1663 ngL^{-1}. Tebuthiuron was the second highest polar pesticide, with a maximum of 431 ngL^{-1} (for conversion to water concentrations see Bartkow *et al.* 2008). These results are different to event monitoring in the previous year which detected tebuthiuron in higher concentrations than atrazine. Land use appears to have a substantial effect on the type of pesticides in flood waters from the Fitzroy River Basin. The 2007 seasonal floods originated from lands used for grazing. Other polar pesticides and degradation products present at significant concentrations included desethly atrazine, simazine, desisopropyl atrazine, diuron, and hexazinone. Prometryn, flumeturon and ametryn were also present, mostly below 1-2 ngL^{-1}.

PDMS samplers (for monitoring more non-polar chemicals) were also deployed during the 2007/08 flood. Results showed that metalochlor was present at the highest concentrations with a maximum water concentration of 98 ngL^{-1} followed by phosphate tri-n-butyl with a maximum concentration of 32 ngL^{-1}. Other non-polar pesticides present at low concentration were diazinon, chlorpyrifos, prometryn, fenitrothion, fipronil, dieldrin and piperonyl butoxide (Figure 4.27).

Detailed pesticide results are available in Section 3.1.4, including individual site results in Table 3.3.

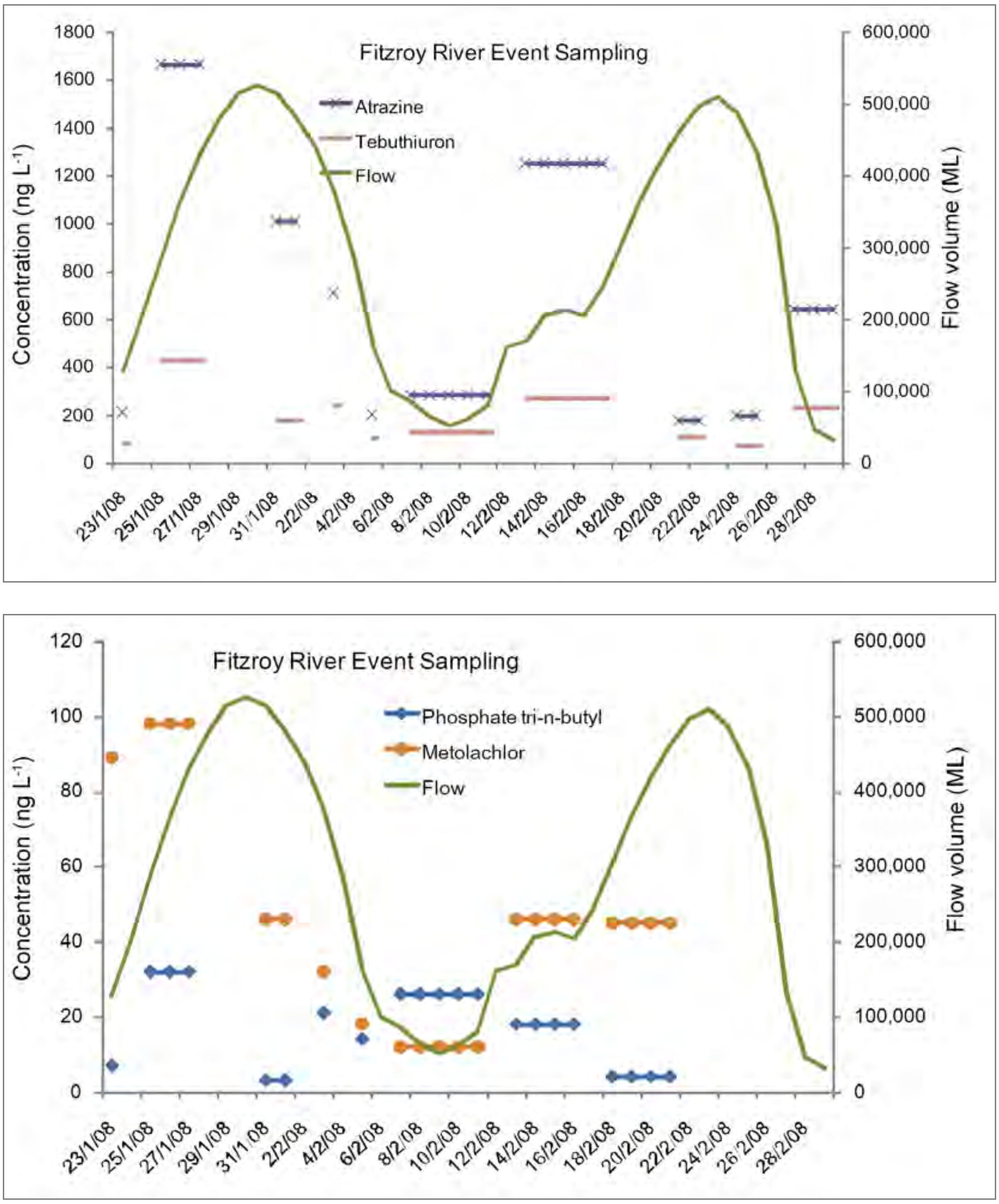


Figure 4.41: Flow rates (ML/day) and water concentrations (ngL^{-1}) of pesticides measured during Fitzroy River flow events.

Fitzroy River flood plume monitoring

Figures 4.42 shows the location of the sampling sites in the Fitzroy River plume waters. Figure 4.43 shows the sites as defined by the agency responsible for collection of the samples, and sampling sites selected based on observations of plume movement and colour on the day and operational constraints.

All data were integrated into the dilution curves. Figure 4.44 shows the mixing profiles for suspended particulate matter (or suspended sediments), particulate nitrogen and phosphorus, dissolved inorganic phosphate (DIP), dissolved inorganic nitrogen (DIN - nitrate + nitrite (NOX) and ammonium (NH4)), dissolved organic nitrogen (DON), dissolved organic phosphorus (DOP) and chlorophyll along the salinity gradient.

Suspended sediments (SPM) were substantially elevated in the river mouth and declined rapidly in the initial mixing zone (0 to 10 ppt). SPM remained elevated through the plume waters, with values of greater than 10 mgL^{-1} measured in reef waters further north and offshore of the Fitzroy River mouth. The mixing profiles of the particulate nutrients also show elevated concentrations in the low salinity samples however concentrations reduced with increasing distance from the initial mixing zone.

DIP and DIN mixed conservatively, diluting with distance away from the river mouth. However both nutrient elements showed elevated concentrations at lower salinities, signifying some uptake or desorption processes occurring through the plume waters.

Chlorophyll concentrations were very high in the river mouth sample, which most likely represents freshwater phytoplankton growth in the riverine plume. As the freshwater phytoplankton dies, and the increased turbidity limits phytoplankton growth, there is a fall in chlorophyll concentrations in the low salinity waters. However, there are two distinct peaks of chlorophyll from 10 to 20 ppt, from sites some distance away from the river mouth (Figure 4.44), related to the corresponding higher nutrient secondary plume waters and higher light levels.

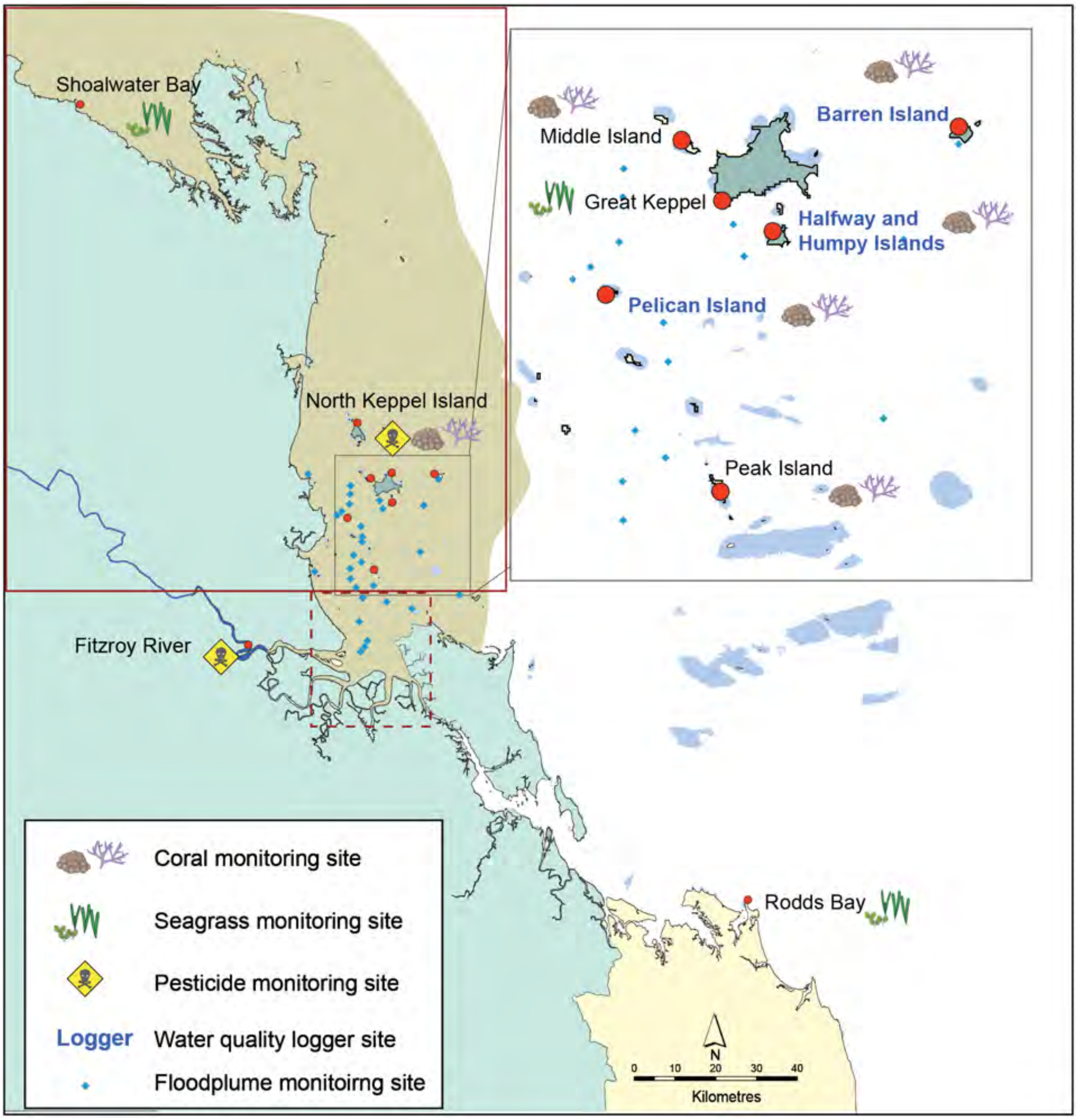


Figure 4.42: Map of the primary (red line) and secondary (red dotted line) Fitzroy River plume extent showing monitoring sites within the region. Inset (grey box) shows types of sites monitored.

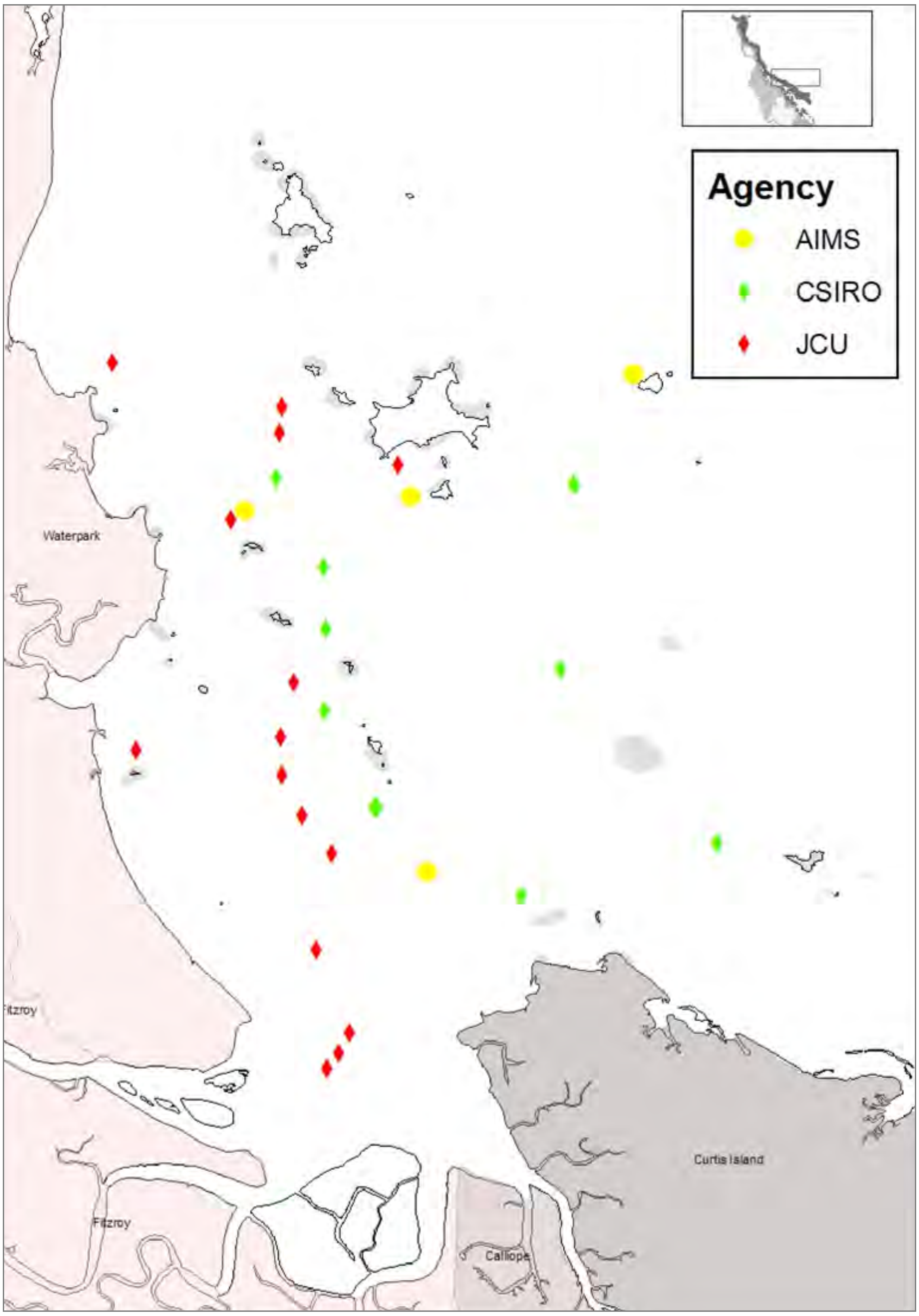


Figure 4.43: Sites monitored within the floodplume of the Fitzroy River during January and February 2008, undertaken by the Australian Institute of Marine Science (AIMS), the CSIRO and James Cook University (JCU).

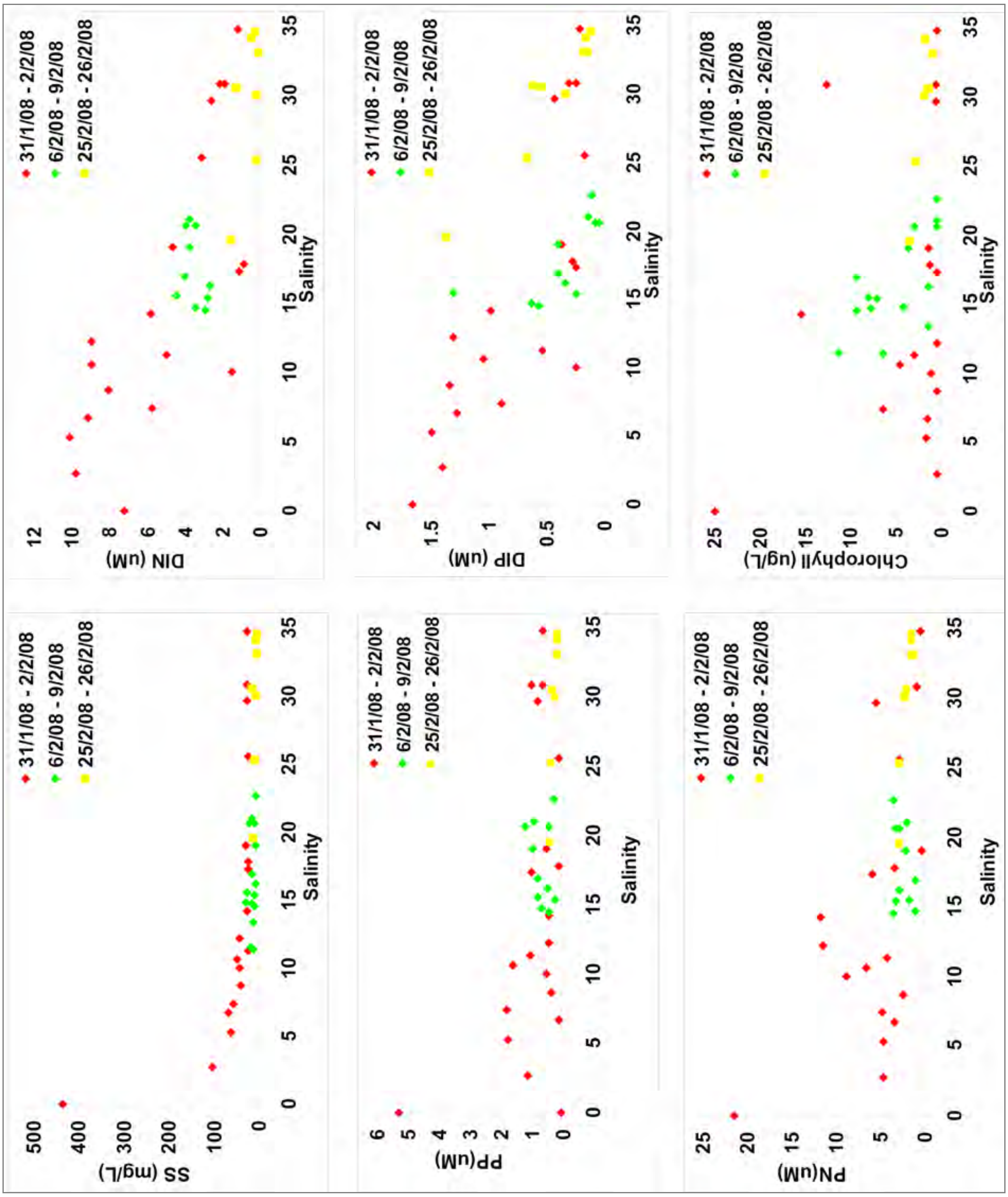


Figure 4.44: Mixing profiles of suspended sediment, particulate nitrogen and phosphorus for Fitzroy River plume sampling. Colours denote the timings of sampling.

Flood plume water quality

Water sampling in the Fitzroy River plume was undertaken in a collaborative effort by JCU, AIMS, CSIRO and Queensland Parks and Wildlife. The water quality concentrations in the two boxed areas in Figure 4.42 are approximately representative of the primary and secondary Fitzroy River plumes. In order to increase the knowledge on the exposure of the inshore coral reef and seagrass habitats within this region, samples collected as part of the flood plume monitoring within each of these areas have been collated. The maximum, minimum, median and 25th and 75th percentiles of the samples collected within the approximate primary and secondary plume are shown in Figure 4.39. In the primary plume, the suspended particulate matter and particular nitrogen and phosphorus were high, with the majority of samples exceeding the respective GBRMPA Water Quality Guidelines. Within the secondary plume the concentration of suspended sediments was still relatively high and elevated concentrations of nutrients and chlorophyll *a* were detected within this area.

Flood plume extent and exposure

The extent of the Fitzroy River plume in 2008 is presented for key dates to characterise the late January and mid February 2008 peak events as the pseudo true colour composites and the daily CDOM maps (Figure 3.6). The first image, 28 January 2008, shows the primary plume constrained to the coast and within a low salinity zone. The secondary plume moves northwards, still relatively close to the coast. The high CDOM concentrations retrieved from imagery captured on 21 and 22 February 2008 show that the offshore influence of the Fitzroy River flood was more significant in the second flow event, possibly due to the very high volumes of flow from the second event. By 8 March 2008, the CDOM signal was once again constrained to the shore and measured only north of the river mouth.

The extent of the flood event in the Fitzroy River in January-February 2008 was characterised by comparing maps of the 75th and 95th percentiles and the maximum retrieved CDOM values of the 2007/08 wet season to the previous year when no flow event occurred. The values of CDOM in the 75th percentiles map for 2008 are comparable in magnitude with the 95th percentiles of the 2007 wet season. The map of the maximum retrieved CDOM values for 2008 (Figure 3.6) clearly shows the lobes of high concentrations of dissolved materials that were observed from the daily imagery and in the field during the late January and mid February 2008 peak events. Values higher than 0.50 m^{-1} were observed in Keppel Bay for a radius of forty kilometres from the river mouth and in a costal band approximately twenty kilometres wide, up to fifty kilometres north of the river mouth.

Seagrass habitats

Monitoring sites within the Fitzroy region are located in coastal, estuarine or fringing-reef 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 Shoalwater Bay monitoring sites are located in a bay which is a continuation of an estuarine meadow that is protected by headlands. A feature of the region is the large tidal amplitudes and consequent strong tidal currents (Figure 4.45). As part of this tidal regime, large intertidal banks are formed which are left exposed for many hours. Pooling of water in the high intertidal results in small isolated seagrass patches one to two metres above MSL. Seagrass in the Fitzroy region show a dichotomy between habitat types in terms of nutrient availability.

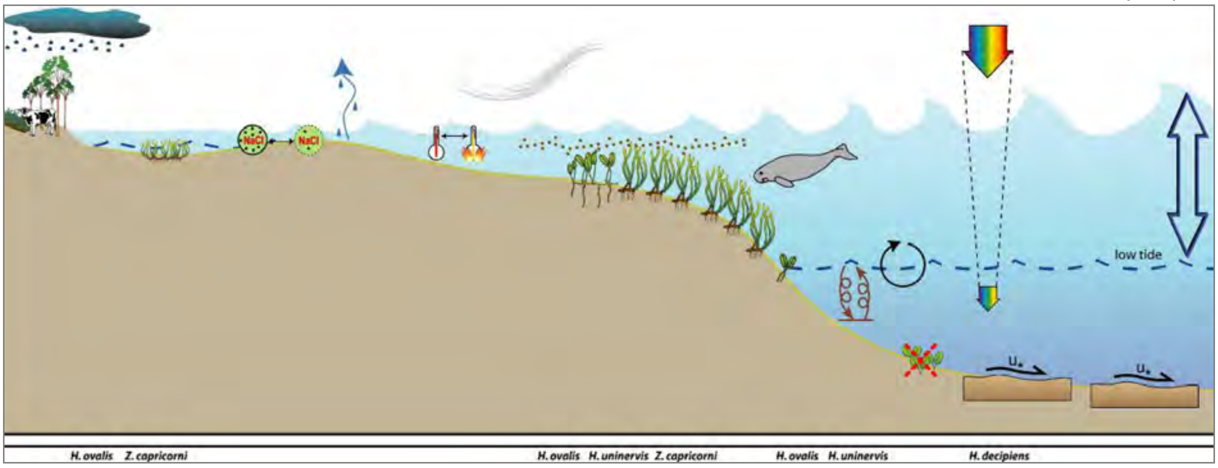


Figure 4.45: Seagrass coastal habitats in the Fitzroy region – major control is pulsed light, salinity and temperature extremes.

In contrast, the estuarine sites are located within Gladstone Harbour, a heavily industrialised port. Offshore reef sites are located in Monkey Beach at Great Keppel Island.

Estuarine seagrass habitats in the southern Fitzroy region tend to be intertidal, on the large sand/mud banks in sheltered areas of the estuaries. Tidal amplitude is not as great as in the north, and estuaries that are protected by coastal islands and headlands support meadows of seagrass. These habitats feature scouring, high turbidity and desiccation linked to this large tide regime, and are the main drivers of distribution and composition of seagrass meadows in this area (Figure 4.46). These southern estuarine seagrasses (Gladstone) are highly susceptible to impacts from local industry and inputs from the Calliope River.

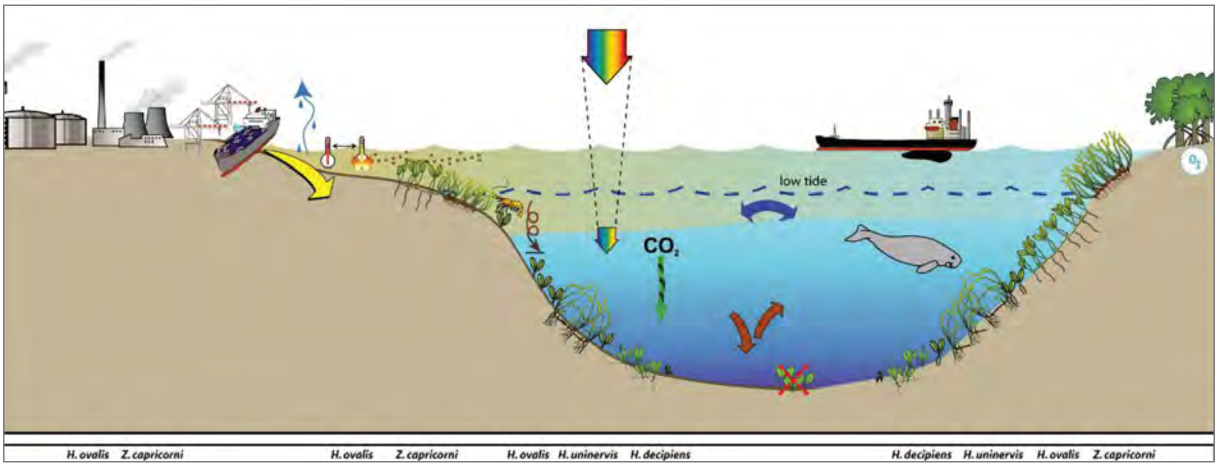


Figure 4.46: Seagrass estuarine habitats in the Fitzroy region – major control variable rainfall and tidal regime.

In the Fitzroy region, seagrass species composition differed greatly between coastal and offshore sites. Sites monitored in Shoalwater Bay were dominated by *Zostera capricorni* with some *Halodule uninervis* (Figure 4.47). Percent cover continued to increase, driven by a large increase in cover in late 2005, except at Shoalwater Bay where cover remained relatively stable (Figure 4.48). Gladstone Harbour sites are located in a large *Zostera capricorni* dominated meadow on the extensive intertidal Pelican Banks south of Curtis Island. Seagrass distribution decreased significantly in this location in early 2006 however the meadow has significantly recovered over the past 18 months.

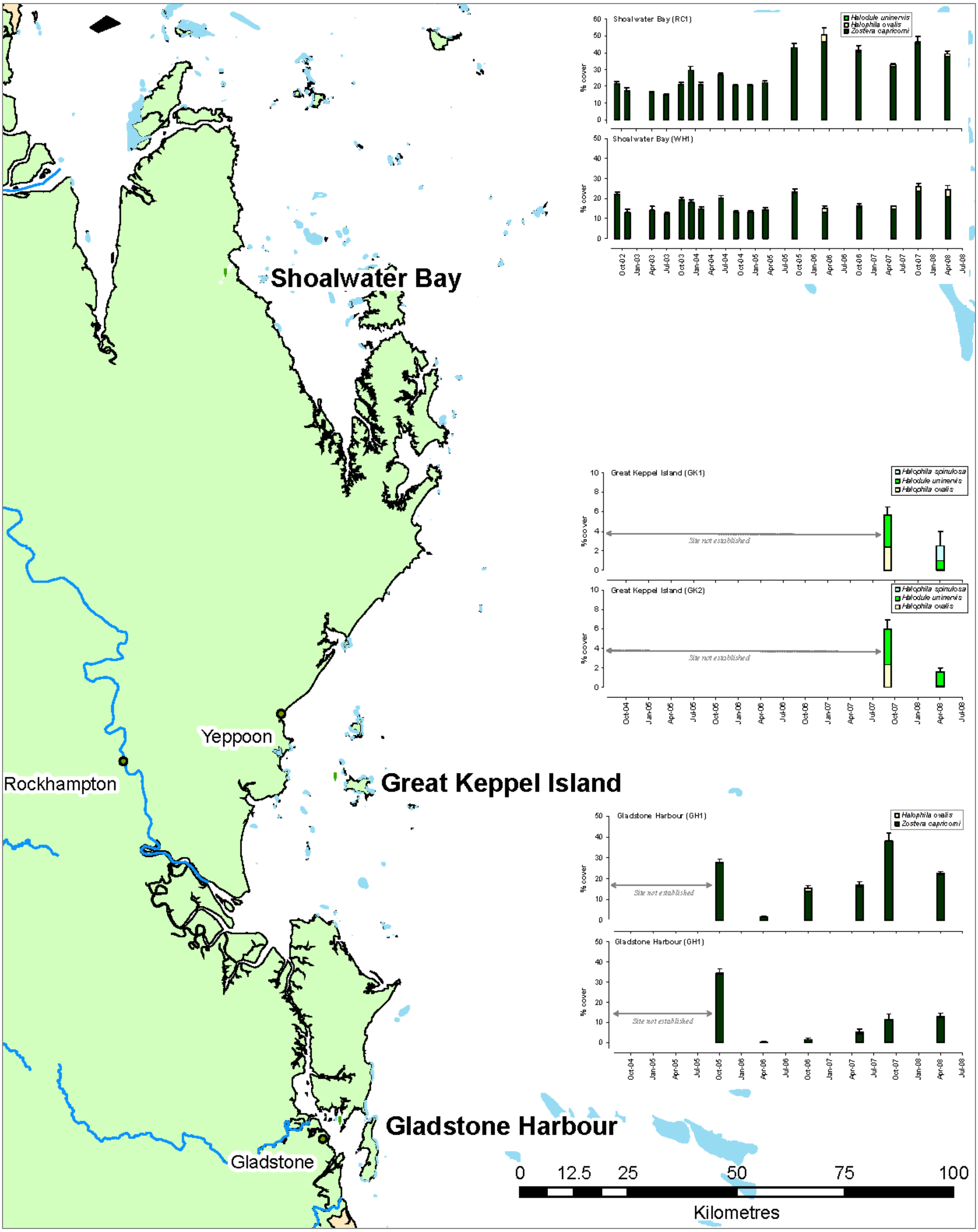


Figure 4.47: Mean percentage cover for each seagrass species at MMP long-term monitoring sites in the Fitzroy region (+ Standard Error). NB: if no sampling conducted then x-axis is clear.

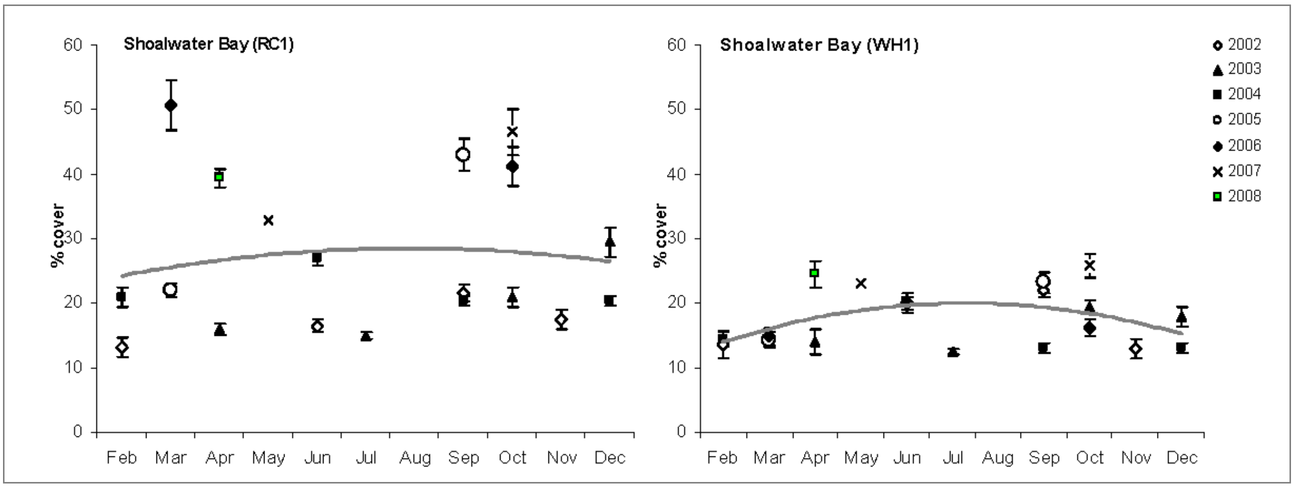


Figure 4.48: Mean percentage seagrass cover (all species pooled) (± Standard Error) at Shoalwater Bay long-term monitoring sites at time of year. NB: Polynomial trendline for all years pooled.

Evidence of reproductive effort was found at all sites but was very low on Great Keppel Island. Increasing reproductive effort was recorded at Shoalwater Bay and Gladstone Harbour, mostly due to meadow recovery from a decline in 2006. This recovery of reproductive effort demonstrates resilience to disturbance at this site. The increase in reproductive effort in Shoalwater Bay does not appear to correspond to any particular factor.

Seagrass tissue nutrients showed a separation between habitat type, coastal and reef in the Fitzroy region. Sediment pesticide sampling detected diuron during the late 2008 wet season. All concentrations were below levels reported to inhibit seagrass growth.

Edge mapping at all monitoring sites conducted in September/October 2007 and March/April 2008 showed that the coastal meadows in Shoalwater Bay have remained stable since monitoring began, while the estuarine meadow at Gladstone Harbour has fluctuated greatly over the same period, with some recent declines.

Seagrass epiphyte cover over the 2007/08 monitoring period was similar to previous monitoring periods and appears seasonal with higher abundance in each dry season. Percentage cover of macro-algae at coastal sites has decreased over the last monitoring period, but is very highly variable at estuarine sites.

Inshore coral reefs

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 as part of an impact study into the effects the 1991 Fitzroy River flood (Van Woesik 1991). Sites on these reefs have been monitored by Queensland Parks and Wildlife (QPW) from 1993 (Middle Island) or 1996 (Halfway Island) (Sweatman *et al.* 2007)

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

Hard coral cover declines in early 2006 as a result of coral bleaching was followed by significant increases in macroalgae (primarily of the genus *Lobophora*) that rapidly colonised the newly available substratum. On these reefs, the cover of macroalgae continued to increase through to 2007. Reefs re-surveyed in 2007 showed significantly lower richness of hard coral genera than in all other regions and sub-regions, with the exception of the Tully Herbert sub-region. The relatively low richness in the Fitzroy region has been a consistent pattern over the period 2005-2007 and most likely reflects a latitudinal decline in richness toward the southern GBR. In 2007, richness of juvenile hard coral genera was significantly lower in the Fitzroy region than all other regions and sub-regions, similar to the richness of adult hard corals.

The propensity for hard coral communities in this region to recover from disturbance was evident in 2007 with coral cover increasing at Barren Island and at the two-metre site at Humpy and Halfway Islands following declines in 2006 (Figure 4.49). These increases contrast with continued declines at five metres at Humpy and Halfway Islands and both depths at North Keppel Island (Figure 4.49) where marked increase in the cover of macroalgae (specifically the genus *Lobophora*) may be retarding the recovery of hard corals at least in the short term. The coral communities at Pelican Island were not impacted by bleaching in 2006 and at this site the hard coral community at two metres has shown a substantial increase in cover between 2005 and 2007 while the deeper community has remained stable (Figure 4.49).

Regionally the density of hard coral recruits is low (Figure 4.50). This along with the rapid increase in cover following disturbances indicates recovery of coral cover is largely due to the growth of colonies surviving disturbance rather than the recruitment and subsequent growth of new colonies. A possible exception is at two metres at Pelican Island where surveys in 2004 (Sweatman *et al.* 2007) and 2005 surveys indicated that the high numbers of small *Acropora* colonies observed in these surveys are largely responsible for the rapid increase in cover at this location.

It should also be noted that low estimates of settlement (Figure 4.51) in the Fitzroy region may have resulted, in part, as a result of spawning irregularity. In this region coral spawning following the November moon occurred as much as seven days later than expected (Alison Jones pers. comm). This delay was likely caused by unseasonably overcast and rough conditions over a prolonged period leading up to, and over, the expected spawning date. This delay would have resulted in a mismatch between peak settlement and the timing of tile deployments, hence underestimation of overall settlement.

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

Water quality monitoring during the flood indicates that the inshore reefs within the southern area of the Keppel Islands were exposed to adverse water quality for relatively long time periods. In particular, Peak and Pelican Islands would have received the highest exposure to the flood plumes. The reefs at Pelican Island experienced thirty days of turbidity at levels beyond which corals may be considered severely light limited (Cooper *et al.* 2008). To fully understand the impacts of the 2007/08 floods, coral monitoring after the 2008 event (surveyed mid-year 2008) will be reported in the coming year.

Reefs in the Fitzroy region have, to date, been resilient to disturbance, with hard coral cover recovering rapidly following past disturbance events (Sweatman *et al.* 2005). However, this rapid recovery has mainly been the result of the re-growth of surviving fragments of just a few species of *Acropora*. Current data show that the density of juvenile corals is very low on these reefs, even though larval settlement rates are high, which suggests limited recovery potential from disturbances that cause whole colony mortality over large areas.

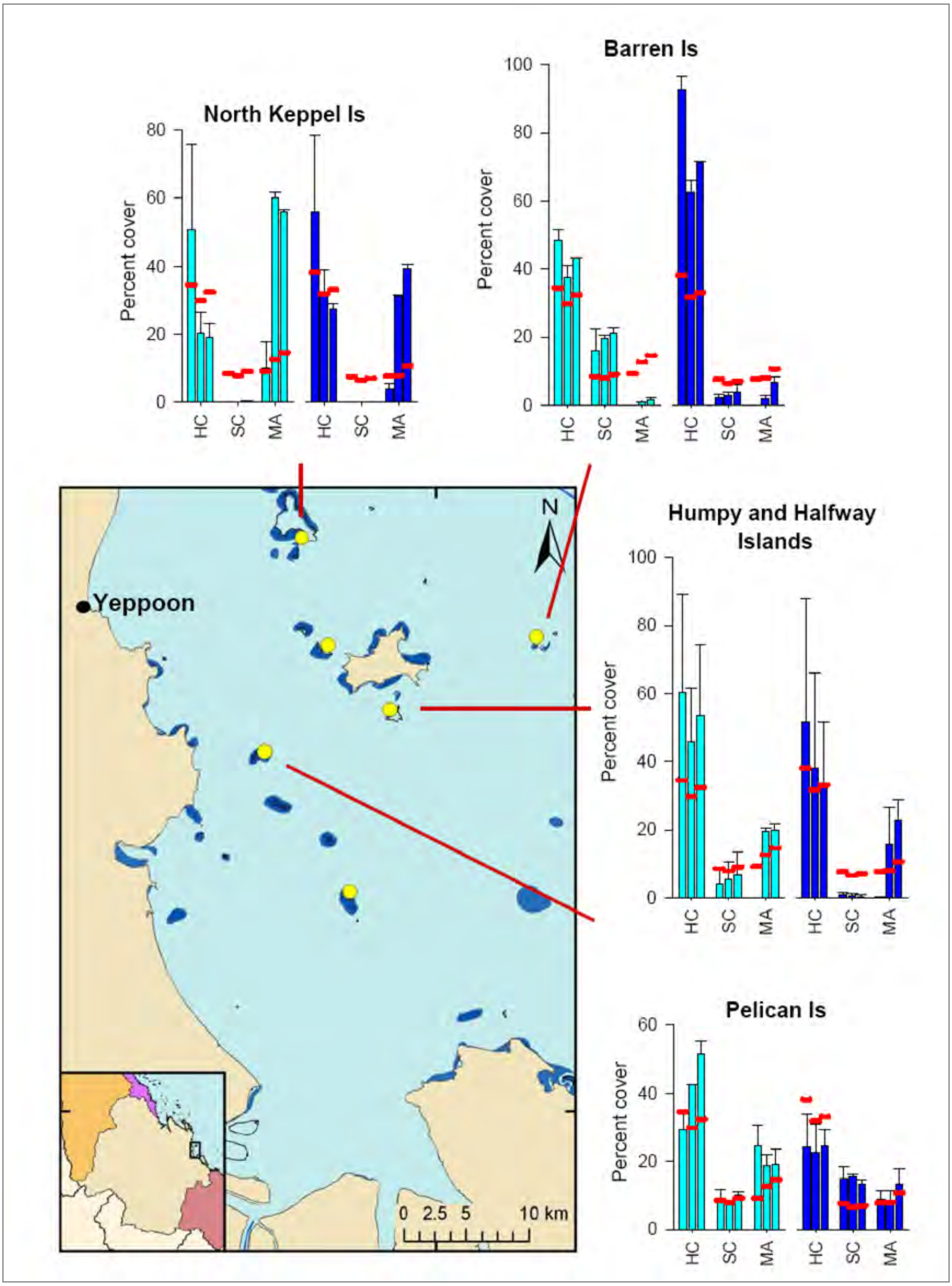


Figure 4.49: Percent cover estimates of major benthic groups, hard coral (HC), soft coral (SC) and macroalgae (MA) on reefs in the Fitzroy region. Pale blue bars represent values for two metres' depth, dark blue bars for five metres' depth. Average values for each group and depth from all reefs and regions combined are indicated by red lines. For each benthic group the three bars represent, from left to right, data from 2005, 2006 and 2007.

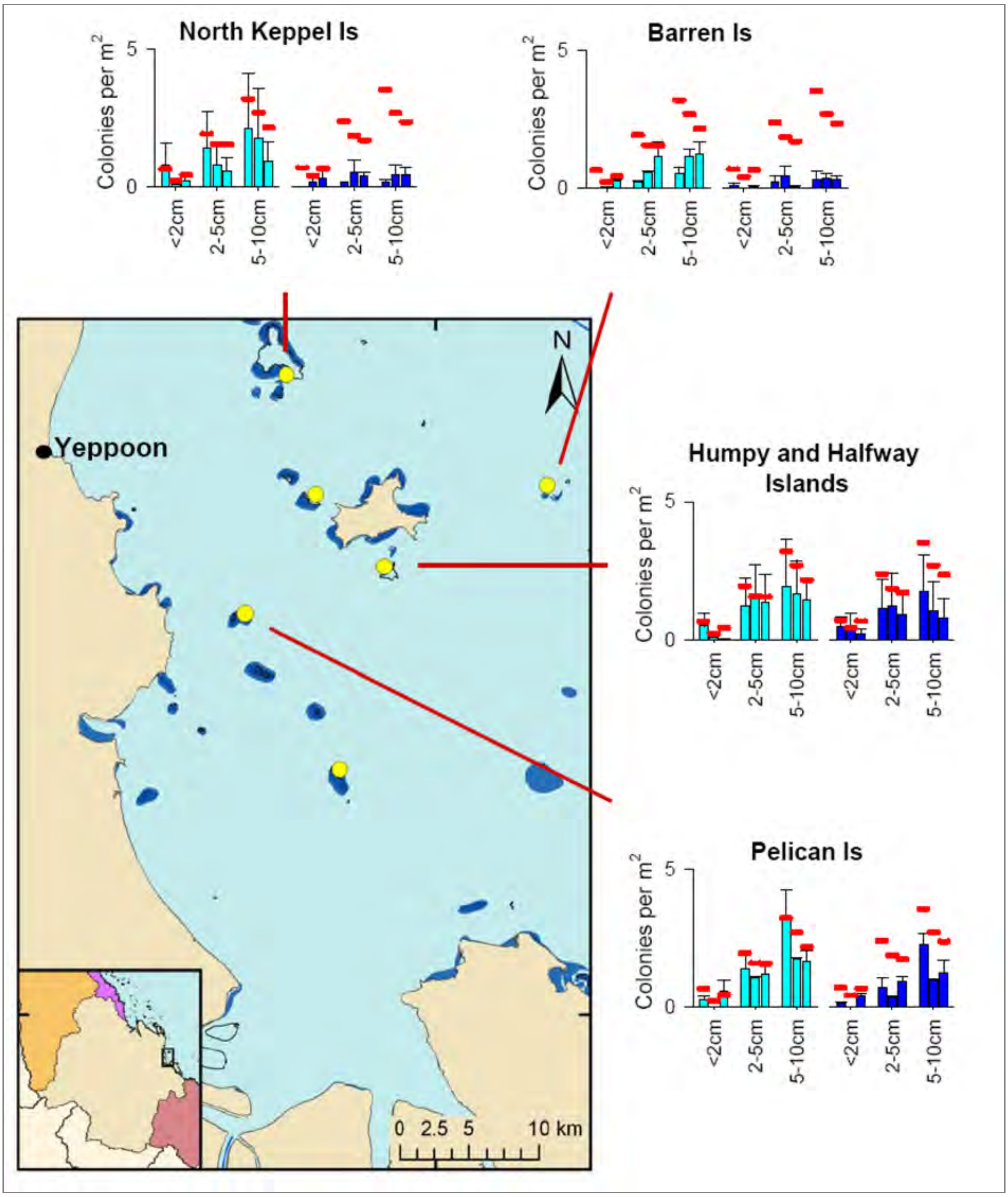


Figure 4.50: Number of juvenile hard coral colonies by size class for reefs in the Fitzroy region. Pale blue bars represent values for two metres' depth and dark blue bars for five metres' depth. Average values for each size class and depth from all reefs and NRM regions combined are indicated by red lines. For each size class the three bars represent, from left to right, data from 2005, 2006 and 2007.

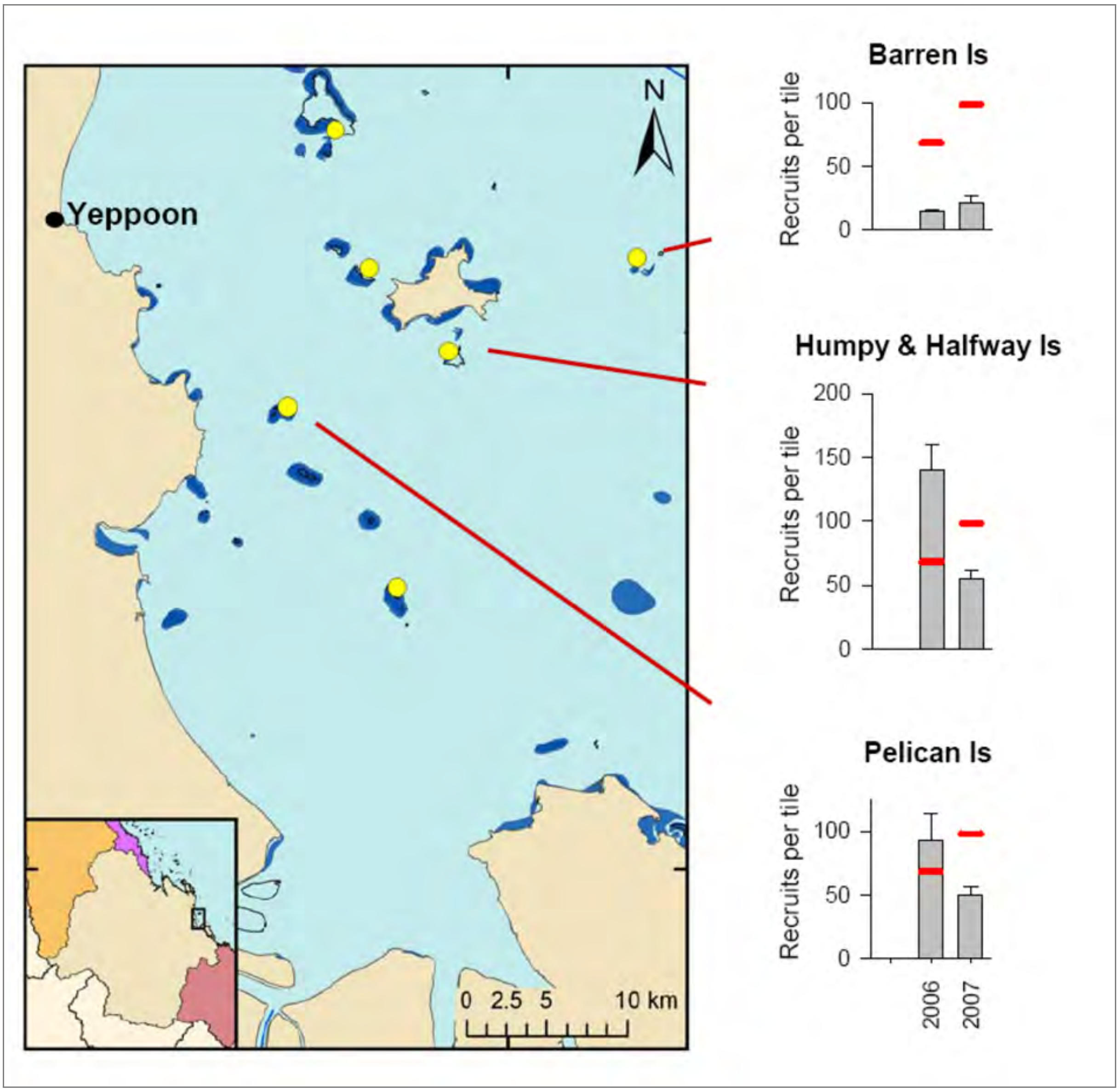


Figure 4.51: Average number of coral recruits per tile on reefs in the Fitzroy region. Average values from all reefs and regions sampled in that year are indicated by red lines.

4.6 Burnett Mary region

Water quality

During the 2007/08 wet season, the Burnett River was well below its long-term discharge average, similar to the last three dry years in this catchment. Regular monthly chlorophyll sampling detected dry season chlorophyll *a* concentrations of between 0.228-0.893 µg L^{-1}, and wet season concentrations of between 0.2-0.938 µg L^{-1}. The seasonal mean of chlorophyll *a* exceeded the Guideline trigger value (GBRMPA 2009). Annual median chlorophyll values were higher in the coastal and inshore zones.

Seagrass habitats

Seagrass meadows in the Burnett Mary region are typically exposed to low levels of anthropogenic influence. The main location that is monitored within this region is at Urangan (Hervey Bay), adjacent to the Urangan marina and in close proximity to the Mary River. Additional monitoring sites were recently established within Rodd's Bay, also within the Burnett Mary region.

Estuarine habitats occur in bays that are protected from the south-easterly winds and consequent wave action. The seagrass meadows in this area must survive pulsed events of terrestrial run-off, sediment turbidity and drops in salinity. Estuarine seagrass in the region are susceptible to temperature related threats and desiccation due to the majority being intertidal (Figure 4.52).

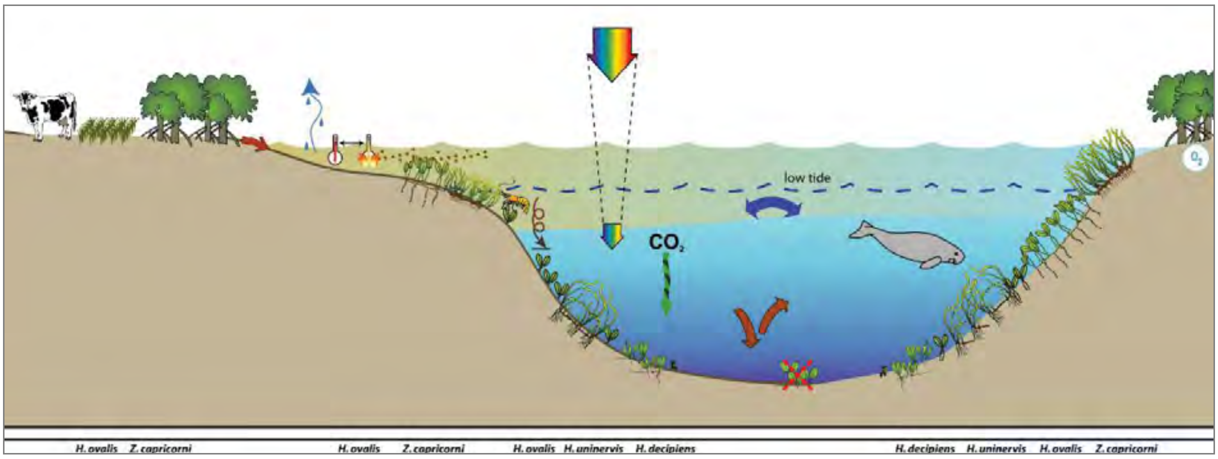


Figure 4.52: Seagrass estuarine habitats in the GBR section of the Burnett Mary region – major control is shelter from winds and physical disturbance.

In the Harvey Bay sites (Urangan) in early 2006 there was meadow decline and seagrass was absent until April 2007, when a few isolated plants were found on the intertidal banks. In the 2007 dry season, isolated patches of *Zostera capricorni* were scattered across the intertidal banks, with a few patches within the monitoring sites. By the late wet season, the patches had expanded in size and aggregated. Seagrass cover increased slightly over the twelve-month monitoring period, but mean cover still remained less than one percent (Figure 4.53). Since monitored was established at this location in 1998, the Urangan meadow has come and gone on an irregular basis and this appears to be a long-term pattern, with greater abundance in the late dry seasons. The seagrass cover at Rodds Bay was significantly lower in the late wet season compared to the 2007 dry season, however it is unknown if this change is seasonal.

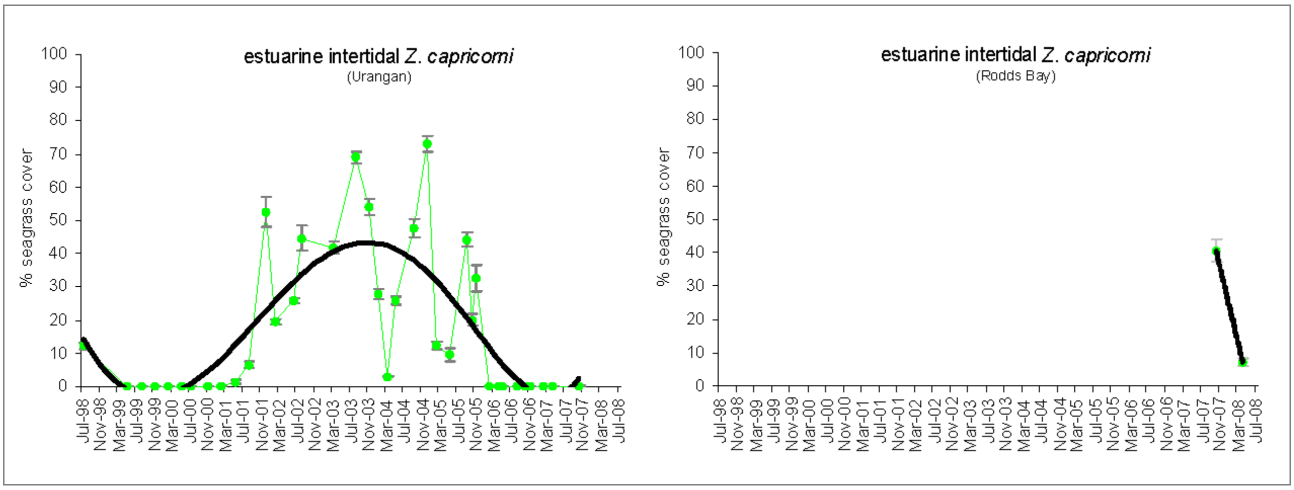


Figure 4.53: Change in seagrass abundance (percentage cover ±Standard Error) at estuarine (Urangan and Rodds Bay) intertidal seagrass meadows in Burnett Mary region.

Seagrass in both locations were observed to produce significant numbers of reproductive structures. Hervey Bay sites (Urangan) were recovering from seagrass loss and the increasing presence of reproductive structures is positive sign of resilience in this location.

Diuron was the only herbicide detected in the sediments at one coastal site (Urangan) in the Burnett Mary region post wet season 2008.

Seagrass edge mapping at Urangan has shown recovery since early 2006. In April 2007, only a few isolated plants were found scattered across the intertidal banks, however by April 2008 large aggregated patches of seagrass were located within the monitoring sites.

Epiphytes cover on seagrass leaf blades at Urangan have been highly variable over the years of monitoring, however was low over the 2007/08 monitoring period. Percentage cover of macro-algae has continued to remain low.

No coral monitoring is carried out in the Burnett-Mary region.

5. Conclusions

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

The 2007/08 monitoring period was unusual in that both dry tropical rivers experienced significant flood events – the Burdekin and Fitzroy Rivers – while the wet tropical regions had average or below-average riverflow. This makes this monitoring period somewhat anomalous, and interpretation of results in relation to previous years challenging.

Time-series (2007/08) chlorophyll and turbidity concentrations were monitored at fourteen inshore reef locations. Ten of these sites showed chlorophyll values above the GBRMPA trigger value and eight of these were south of the Palm Island Group, which agrees with the well-known southward increase of chlorophyll concentrations. Only one location (Pelican Island) had generally very turbid water, and during the summer floods the suggested photo-physiology threshold of 5 NTU was continuously exceeded for thirty days at this location. Three other locations (Snapper and Dunk Island in the Wet Tropics and Geoffrey Bay in the Burdekin region) were found to be regularly turbid with values around 2 NTU and high values (>5 NTU) for more than ten percent of the record.

Seasonal and annual means for chlorophyll, suspended solids, particulate nutrients and turbidity, averaged over all stations and three years of sampling, exceeded the GBRMPA Guideline trigger values as did the annual and wet season means for particulate phosphorus. On a regional basis, chlorophyll annual and seasonal means were mainly exceeded in the Burdekin, Mackay Whitsunday and Fitzroy regions all of which experienced significant flood events during 2007/08. These data provide additional evidence that nutrient concentrations and turbidity levels are significant water quality issues for the GBR.

Detectable concentrations of herbicides, in particular diuron, atrazine and hexazinone were present at all inshore monitoring locations. The results indicate that the herbicide diuron, is the highest contributor to the overall herbicide toxicity, due to the elevated concentrations detected and it greater relative ability to inhibit photosynthesis. In particular, sites adjacent to the Burdekin, Wet Tropics and Mackay Whitsunday regions are at risk from herbicide exposure.

The herbicide concentrations detected at inshore GBR sites were approximately ten times lower than concentrations observed to have acute effects; however few studies have invested the impact of long term exposure to these herbicides and synergistic effects with water quality.

Intertidal seagrasses on a GBR-wide scale are in a good to fair condition, although localised declines were observed at two locations. Reef seagrass habitats (which are generally nutrients limited) are showing increases in seagrass abundance. Coastal seagrass habitats are fairly stable and estuarine seagrass habitats are fluctuating greatly or showing signs of decline. Seagrass plant nutrient status at locations in the Burdekin (Townsville), Mackay Whitsunday (Pioneer Bay) and Fitzroy (Great Keppel) regions suggests these seagrasses are being affected by local water quality.

However, evidence of significant amount of reproductive effort across the majority of sites suggests that most seagrass sites appear to be resilient. Seed and reproductive structures in general were more common at coastal, compared to offshore locations. The region with the greatest seed banks and reproductive effort was the Burdekin region, followed by the Wet Tropics region, then the Mackay Whitsunday region.

The data collected through the MMP has improved the understanding of GBR coral and seagrass ecosystems; spatial patterns of community composition and the likely environmental factors shaping these communities. The results strengthened the view that the processes shaping biological communities are complex and are based on local interactions of water quality with other factors including climate change and physical disturbances. It is therefore important to understand and document the timing and intensity of disturbances and their consequences that are likely to interact with water quality and shape inshore GBR reef communities. One of the ways in which water quality is likely to shape seagrass and coral reef communities is through its effect on reproduction and recruitment, particularly following a disturbance event when recovery and future community composition depends on good reproductive capacity.

Inshore Wet Tropics reefs in the Johnstone, Russell Mulgrave sub-region have been severely impacted in the past decade by coral bleaching, poor water quality, crown of thorns starfish outbreaks and cyclones. However, the Wet Tropics reefs had a high abundance of juvenile corals, and increasing rates of larval settlement, which indicates that these reefs are currently improving and likely to have been resilient to past disturbances. Reef resilience is less evident in the Burdekin Region where bleaching in 1998 affected most reefs, was more severe and resulted in higher mortality (Sweatman *et al.* 2007). On the reefs monitored in the Burdekin Region, settlement of recruits was low; there were fewer juvenile colonies and a negligible increase in hard coral cover. Reefs in the Mackay Whitsunday region had a similar status with moderate, albeit variable, settlement of recruits, generally lower numbers of juvenile colonies and negligible change in coral cover. While coral cover on some reefs in this region was high it is unclear how resilient to disturbance these communities would prove. Reefs in the Fitzroy region have to date been resilient to disturbance, with hard coral cover recovering rapidly following past events (Sweatman *et al.* 2005). However, this rapid recovery has mainly been the result of the re-growth of surviving fragments of just a few species of Acropora. The MMP data shows that the density of juvenile corals is very low on these reefs, even though larval settlement rates are high, which suggests limited recovery potential from disturbances that would cause whole colony mortality over large areas.

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