MARINE MONITORING PROGRAM

Annual Report for
INSHORE WATER QUALITY MONITORING
2017-18

JAMES COOK UNIVERSITY
AUSTRALIA

TropWATER

Australian Government
Great Barrier Reef
Marine Park Authority

Australian Government

AUSTRALIAN INSTITUTE
OF MARINE SCIENCE

Published by the Great Barrier Reef Marine Park Authority

ISSN: 2208-4096

A catalogue record for this publication is available from the National Library of Australia

This publication should be cited as:

Gruber, R., Waterhouse, J., Logan, M., Petus, C., Howley, C., Lewis, S., Tracey, D., Langlois, L., Tonin, H., Skuza, M., Costello, P., Davidson, J., Gunn, K., Lefevre, C., Shanahan, M., Wright, M., Zagorskis, I., Kroon, F., Neilen, A., 2019, *Marine Monitoring Program: Annual Report for Inshore Water Quality Monitoring 2017-18. Report for the Great Barrier Reef Marine Park Authority*, Great Barrier Reef Marine Park Authority, Townsville.

Front cover image: Aerial view of Myall Beach at Cape Tribulation in tropical North QLD.

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This project is supported by the Great Barrier Reef Marine Park Authority through funding from the Australian Government Reef Program, the Australian and Queensland governments Reef 2050 Integrated Monitoring and Reporting Program, Australian Institute of Marine Science and James Cook University.

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Commonly used acronyms, abbreviations and units

Abbreviations and acronyms

AIMS = Australian Institute of Marine Science

Authority = Great Barrier Reef Marine Park Authority

BOM = Bureau of Meteorology

CDOM = colour dissolved organic matter

Chl-*a* = chlorophyll *a*

CTD = Conductivity Temperature Depth profiler

CYWMP = Cape York Water Monitoring Partnership

DIN = dissolved inorganic nitrogen

DOC = dissolved organic carbon

DON = dissolved organic nitrogen

DOP = dissolved organic phosphorus

ENSO = El Nino – Southern Oscillation cycle

FU = Forel-Ule (toolbox and colour scale)

JCU = James Cook University

K_D = light attenuation coefficient

LOD = limit of detection

MMP = Marine Monitoring Program

Marine Park = Great Barrier Reef Marine Park

MODIS = Moderate Resolution Imaging Spectroradiometer

NH_3 = ammonia

NO_x = nitrogen oxides

NRM = natural resource management

PN = particulate nitrogen

PO_4 = phosphate (dissolved inorganic phosphorus)

PP = particulate phosphorus

QA/QC = Quality assurance/quality control

Reef = Great Barrier Reef

Reef 2050 WQIP = *Reef 2050 Water Quality Improvement Plan*

Reef Plan = Reef Water Quality Protection Plan

Reef 2050 Plan = *Reef 2050 Long-Term Sustainability Plan*

TSS = total suspended solids

WS colour scale = wet season colour scale

WQ Index = Water Quality Index

Units

km^3 = cubic kilometres

kt = kilotonnes

m = metre

mg L^{-1} = milligram per litre

ML = million litres

t = tonnes

µg L^{-1} = micrograms per litre

Acknowledgements

We acknowledge the Australian Government funding under the Australian Government Reef Program and specifically thank the Great Barrier Reef Marine Park Authority (the Authority) and the Department of the Environment and Energy for financial and technical support under this program. Thank you to Bronwyn Houlden and Carol Honchin from the Authority for their overall project management and program guidance.

We are grateful to all the people involved in the field work, particularly Jason Shearer and Bec Rowlands from Mission Beach Charters who have been involved in our long-term sampling of the Tully and Russell-Mulgrave marine waters, Andrew Mead from Barra Charters for the Burdekin region sampling and to the crew of the RV Cape Ferguson. Thank you to the TropWATER laboratory and the Australian Institute of Marins Science Analytical Technology staff who have analysed a large volume of samples for the programs.

We also thank several anonymous reviewers for their detailed reviews that improved earlier versions of this and previous reports.

Executive summary

The inshore water quality aspect of the Marine Monitoring Program reports on the annual condition and trend in water quality of the Great Barrier Reef (the Reef) with reference to previous data from 2005 to 2017. The program design includes the collection of water samples along transects in the Cape York, Wet Tropics, Burdekin and Mackay-Whitsunday focus areas year-round, with higher frequency sampling during the wet season to better characterise this period of episodic river discharge. Satellite imagery and modelling simulations are linked with *in-situ* monitoring data to estimate the exposure of inshore areas to end-of-catchment loads from rivers.

Trends in key water quality indicators

Key water quality indicators were used to derive a Water Quality Index which communicates the long-term trend (insensitive to year-to-year variability) and annual condition (sensitive to year-to-year variability) of water quality relative to guideline values (GVs). Trends were not assessed for the Cape York region due to insufficient long-term monitoring data.

The Index derived from monitoring showed that long-term inshore water quality (insensitive to year-to-year variability) has:

- declined in parts of the Wet Tropics region but remains **good** in general
- remained stable in the Burdekin region and is currently considered **good**
- declined in the Mackay-Whitsunday region over time and is currently considered **moderate**.

The annual condition Index showed that inshore water quality (sensitive to year-to-year variability) was:

- generally **poor** this year in the Wet Tropics and Burdekin regions, which was likely related to river discharge above or close to the long-term median in these regions
- **moderate** in the Mackay-Whitsunday region having improved from a very poor condition in 2016–17, which was likely related to this year's drier-than-average wet season following last year's wetter-than-average wet season.

Differences in scoring between versions of the Index are expected as they are designed to communicate different sources of variability in water quality.

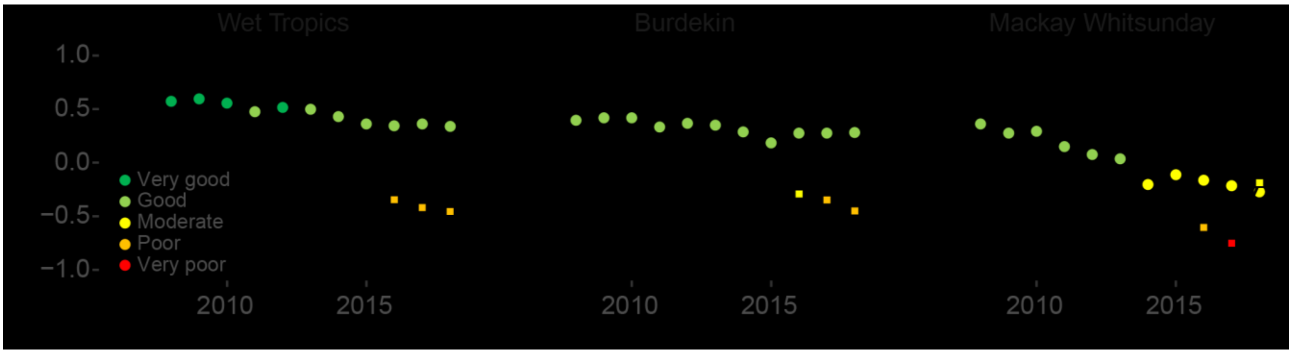

Figure i: Water Quality Index scores from 2006 to 2018 for the Wet Tropics, Burdekin and Mackay-Whitsunday regions. The Index is calculated to show the 'long-term' trend in water quality since the start of monitoring (circles) based on the initial program design. An updated version communicating annual condition is calculated from 2015 onwards (squares) that includes increased temporal and spatial sampling and relates water quality values to wet and dry season Reef water quality guidelines. The Index includes five variables: water clarity, concentrations of nitrate/nitrite, particulate nitrogen, particulate phosphorus, and chlorophyll *a*. Details of calculations can be found in Appendix D.

Changes in some water quality variables have been detected in most regions, including water clarity and concentrations of nutrients. The most notable overall trends in water quality were:

- **increasing** concentrations of particulate phosphorus, dissolved organic carbon and particulate organic carbon
- mean concentrations of chlorophyll *a*, total suspended solids and nitrogen oxides close to guideline values (GVs)
- **declining** Secchi depth (i.e. water clarity is worsening) across the inshore Reef, which is not meeting water quality GVs.

The causes of changes in nutrient concentrations are likely related to changes in nutrient inputs to the Reef lagoon and potentially changes in the rates of key ecological processes (such as primary production). The spatial and temporal variability in the *in-situ* water quality discussed in this report highlights the combination of complex factors, including river discharge, biogeochemical processes and physical forcing that act in concert to drive water quality.

Drivers and pressures

Environmental conditions over the 2017–18 summer were relatively benign. No cyclones crossed the coast in 2017–18; however, cyclone Iris tracked off the coast between Cairns and Rockhampton from mid-March to early April 2018, resulting in extensive flooding of the Herbert River (and the township of Ingham) and the Burdekin River flowed over the dam.

Rainfall was above-average in the Wet Tropics catchments; however, the total wet season rainfall for the Reef catchments in 2017–18 continued to be just below the long-term wet season averages. Total river discharges this year (and since 2013–14) have been around or below the long-term median. This year, the regions had annual discharges close to their long-term medians, with the exception of the Burnett-Mary region, which was between two and three times higher than the long-term median, and the Mackay-Whitsunday region, which had below median discharge.

End-of-catchment sediment and nutrient loads showed distinct variations between the focus areas, with the Tully-Murray-Herbert basins dominating the dissolved inorganic nitrogen exports, followed by the Russell-Mulgrave-Johnstone and Burdekin-Haughton basins. Loads of total suspended solids and particulate nitrogen were dominated by the Burdekin-Haughton basins.

Model simulations showed that sites in enclosed coastal waters had many days of exposure to river discharge, especially for the Normanby, Russell-Mulgrave, Tully, and Burdekin Rivers. Sites in open coastal and mid-shelf waters were also exposed to river plumes, especially in the Wet Tropics. In Cape York (Normanby River), plume exposure reached offshore waters for short periods. Dispersion modelling of dissolved inorganic nitrogen and total suspended solids loads showed dispersion similar to previous years with river discharge near the long-term median. Comparison with modelling of pre-European conditions identified the Wet Tropics as the dominant area of anthropogenic influence for dissolved inorganic nitrogen, and the Burdekin region as the dominant area of anthropogenic influence for total suspended solids in the present day.

Satellite imagery showed a high frequency of the primary water type in the coastal areas, with mid-shelf to offshore areas most frequently exposed to the tertiary water type. Primary waters are brownish (enriched in sediment and dissolved organic matter), secondary waters are greenish (enriched in algae and dissolved organic matter), and tertiary waters have low risk of detrimental ecological effects.

Exposure maps from satellite imagery show that all the tertiary water type concentrations were under the wet season GVs. Total suspended solid concentrations were above the wet season GVs in the secondary water type; total suspended solids, chlorophyll *a*, particulate phosphorus and particulate nitrogen concentrations were above the wet season GVs in the primary water type. In 2017–18, approximately 20% of the total area of the Reef was exposed to a potential risk, which was much lower than the long-term average area.

This included:

- 25% of the total area of the Cape York region
- 37% of the total area of the Wet Tropics region
- 16% of the total area of the Burdekin region
- 24% of the total area of the Mackay-Whitsunday region.

Case studies

Annual case studies are conducted every year. Case study one investigated the variability in time-series of chlorophyll and turbidity from the Marine Monitoring Program logger network. Long-term monitoring data was decomposed using signal analysis. A detectable amount of variability in chlorophyll and turbidity occurred over short time periods (every ~12 and ~6 hours), and was likely the result of tidal influence on the inshore region. This method can be extended to identify sources of variability in many types of time-series data from monitoring programs.

Case study two assessed continuity between satellite-derived water colour monitoring products. It found that it is feasible to transition the methods from historical MODIS to the new Sentinel-3 satellites and from the wet season colour scale to the historical Forel-Ule colour scale using a freely available toolbox that includes a smartphone application for the future and continuous mapping of Reef waters.

1. Introduction

1.1 The Great Barrier Reef

The Great Barrier Reef (the Reef) is the most extensive reef system in the world, comprising over 2900 km^2 of coral reefs (Figure 1-1). It also includes large areas of seagrass meadows, estimated to be over 43,000 km^2 or ~12.5% of the total area of the Great Barrier Reef Marine Park (the Marine Park). The Reef catchment is divided into six natural resource management (NRM) regions (Figure 1-1), each with differing land use, biophysical and socio-economic characteristics.

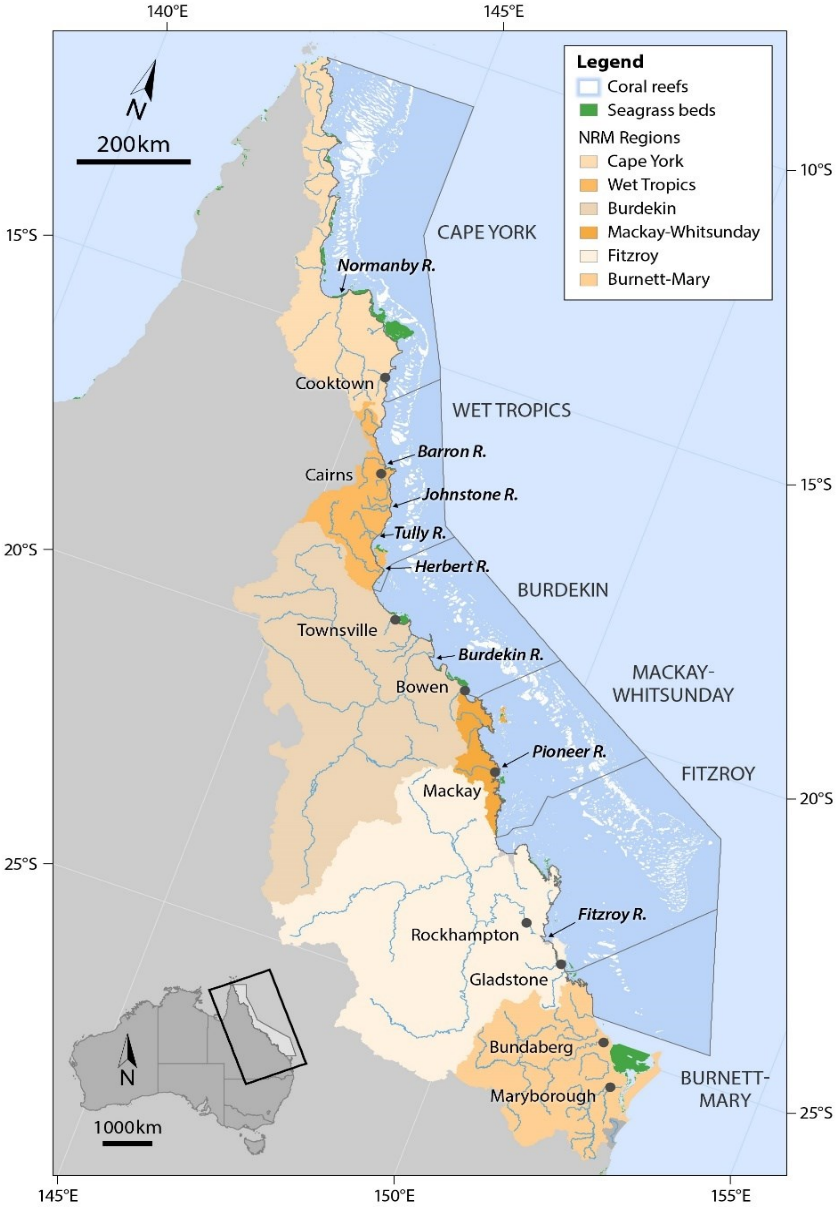

Figure 1-1: Locations of major marine ecosystems (coral reefs and surveyed seagrass beds) in the Marine Park, NRM regions, marine NRM regions (delineated by dark grey lines) and major rivers.

1.2 Water quality monitoring in the Marine Monitoring Program

The management of water quality remains a priority for the Great Barrier Reef Marine Park Authority (the Authority) because good water quality aids the resilience of coastal and inshore ecosystems of the Reef (Great Barrier Reef Marine Park Authority, 2014a, b).

In response to concerns about the impact of land-based run-off on water quality, the *Reef 2050 Water Quality Improvement Plan* (Reef 2050 WQIP; Australian and Queensland governments, 2018a) was recently updated by the Australian and Queensland governments, and integrated as a major component of the Reef 2050 Long-Term Sustainability Plan (Commonwealth of Australia, 2015)[1], which provides a framework for the integrated management of the Great Barrier Reef World Heritage Area.

A key deliverable of the Reef 2050 WQIP is the *Paddock to Reef Integrated Monitoring, Modelling and Reporting Program* (Australian and Queensland governments, 2018b), which is used to evaluate the efficiency and effectiveness of the implementation of the Reef 2050 WQIP, and report on progress towards goals and targets. The Marine Monitoring Program (MMP) forms an integral part of the *Paddock to Reef Integrated Monitoring, Modelling and Reporting Program.* The MMP encompasses the following three components: inshore water quality, coral and seagrass. Ecological components of the MMP (seagrass and coral health) publish separate annual reports detailing the condition and trend of these ecosystems in relation to multiple stressors, including water quality data presented in this report (e.g. McKenzie et al., 2017; Thompson et al., 2017). Inshore pesticide monitoring is also discussed in a separate report (e.g. Grant et al. 2017).

The overarching objective of the inshore water quality monitoring program is to '*Assess temporal and spatial trends in inshore marine water quality and link pollutant concentrations to end-of-catchment loads'.* The specific objectives of the program (Australian and Queensland governments, 2018b) are to:

- monitor, assess and report the three-dimensional extent and duration of flood plumes and link concentrations of suspended sediment and nutrients to end-of-catchment loads
- monitor, assess and report trends in inshore concentrations of total suspended solids (TSS), chlorophyll *a* (Chl-*a*) and nutrients against Water Quality Guidelines for the Great Barrier Reef Marine Park (or other water quality guidelines if appropriate)
- monitor, assess and report trends in turbidity and light attenuation for key Reef inshore habitats against established thresholds and/or guidelines
- monitor, assess and report the extent, frequency and intensity of potential for impact on inshore seagrass meadows and coral reefs from flood plumes and link to end-of-catchment loads.

Our capacity to comprehensively report on the link between concentrations of water quality parameters and end-of-catchment loads (objective 1) and the ability to make conclusions regarding the intensity of potential impacts of flood plumes on reef ecosystems (objective 4) is currently constrained by the spatial and temporal extent of water quality condition and trend data, and the ability to differentiate water quality influences from confounding factors such as climate change, and the impact of severe storms and disease. However, as predictive tools including the eReefs hydrodynamic and biogeochemical model are further progressed for practical applications such as these, the ability to report on these objectives will continue to improve.

The inshore water quality monitoring program has been delivered by the Australian Institute of Marine Science (AIMS), James Cook University (JCU) and the Authority since 2005.

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[1] http://www.environment.gov.au/marine/gbr/reef2050

1.3 Structure of the report

The next Section presents a summary of the program's methods. Section 3 describes the factors influencing marine water quality, referred to as drivers and pressures in the Driver-Pressure-State-Impact-Response (DPSIR) framework (Figure 1-2).

This year's results on the monitoring of the condition and trend of water in the Great Barrier Reef lagoon (i.e. the state of water quality) are presented in summary in Section 4, and described by region in Section 5. More detailed data are included in Appendix E.

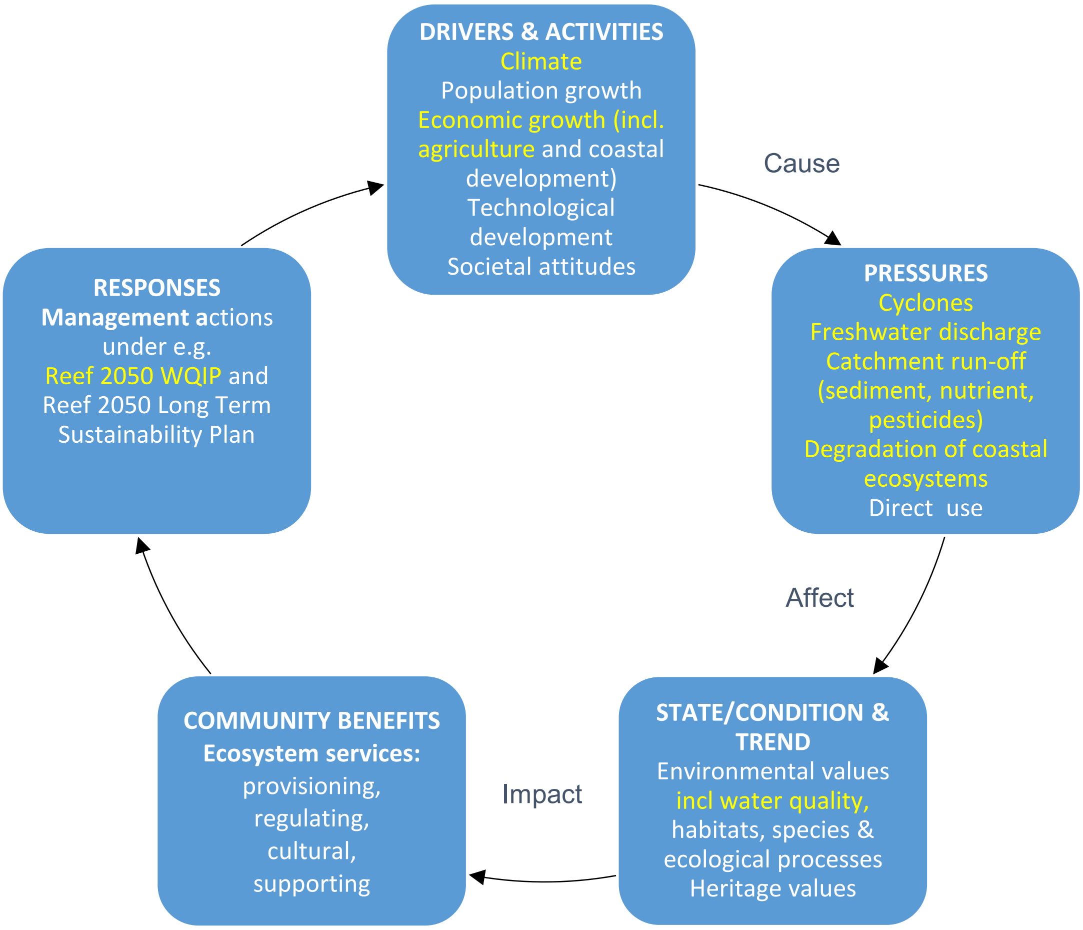


Figure 1-2: DPSIR framework used to guide the structure of the MMP, derived from the Great Barrier Reef Strategic Assessment (Great Barrier Reef Marine Park Authority, 2014a). The aspects highlighted in yellow are included in this report.

2. Methods summary

This Section provides an overview of the sampling design and indicators that are monitored as part of the MMP. More details are presented in the Appendices and in a separate quality assurance/quality control (QA/QC) report published annually (Great Barrier Reef Marine Park Authority, 2019). The QA/QC report covers the objectives and principles of analyses, step-by-step sample analysis procedures, instrument performance, data management systems and quality control measures.

2.1 Sampling design

The MMP inshore water quality monitoring is designed to quantify temporal and spatial variation in inshore water quality conditions. The current design was implemented in February 2015 and includes four focus areas—the Russell-Mulgrave, Tully, Burdekin, and Mackay-Whitsunday regions. The focus areas were targeted for intensive sampling and were chosen as priority areas based on water quality risk assessments (Brodie et al., 2013). Sites were selected along expected water quality gradients related to exposure to terrestrial runoff. This was largely determined by increasing distance from a river mouth in a northerly direction to reflect the predominantly northward flow of surface water driven by the prevailing south-easterly winds (Brinkman et al., 2011).

Most of the sampling sites that have been routinely monitored from 2005 to 2014 are included in the current sampling design, allowing for the continuation of the long-term time-series. Sites are now sampled more frequently (typically between five and 10 times annually) compared to only three times annually in the previous design (Kuhnert et al., 2015). The Tully focus area adds value to the long-term dataset collected in this area from 1994 to 2012 (Devlin and Schaffelke, 2009), and the Cairns Transect in the Barron-Daintree sub-region of the Wet Tropics is one of the world's longest tropical water quality datasets (beginning in 1989).

In January 2017, monitoring began in the Cape York region at four transects from the Pascoe, Normanby-Kennedy, Annan-Endeavour and Stewart Rivers. These transects are monitored by the Cape York Water Monitoring Partnership (CYWMP) coordinated by Howley Environmental Consulting.

The map in Figure 2-1 shows the geographical locations of the current sampling sites. Appendix C describes all stations included in the MMP, distinguishing between the routine and event-based sampling sites.

The list of parameters sampled in the program is provided in Table 2-1 and includes:

- continuous measurement of salinity and temperature at eight stations
- continuous measurement of chlorophyll and turbidity at 15 stations
- 60 routinely-sampled stations with more frequent sampling during the wet season (86 sites in total)
- 27 event-based stations sampled during flood conditions.

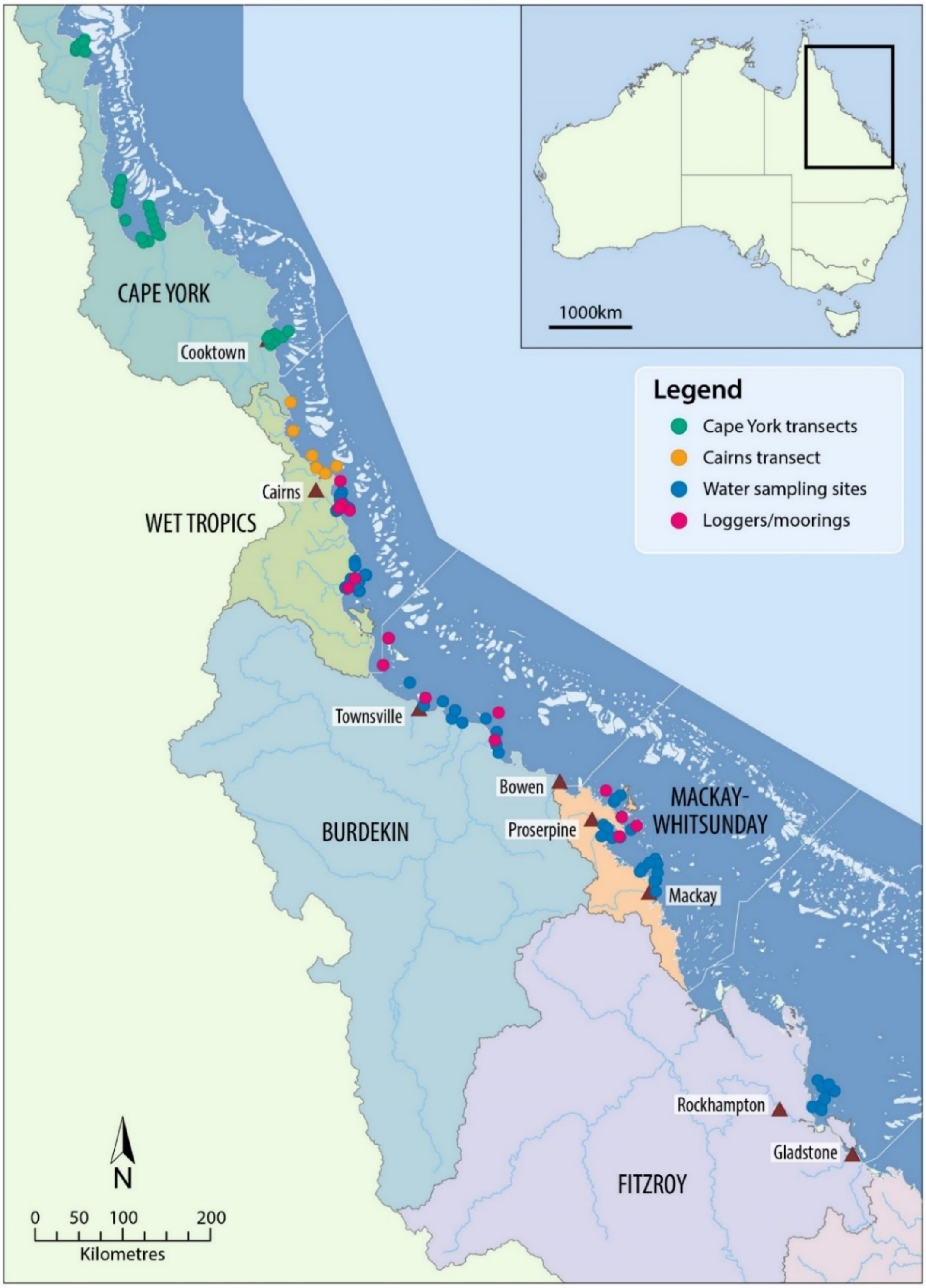


Figure 2-1: Sampling locations of the water quality monitoring sampled from 2015 onwards. Note that the Cape York transect was added in 2017. NRM region boundaries are represented by coloured catchment areas with grey lines extending these boundaries into the Reef.

Table 2-1: List of parameters measured during the routine and event-based water quality monitoring. Note that +/- signs identifying the charge of the nutrient ions were omitted for brevity.

Condition	Parameter	Abbreviation	Units of Measure
Physico-chemical	Salinity	Salinity	
	Temperature	Temperature	Celsius degree
	Light attenuation coefficient*	K_D	m^{-1}
	Total suspended solids	TSS	mg L^{-1}
	Coloured dissolved organic matter	CDOM	m^{-1}
	Turbidity	Turb	NTU
Nutrients	Ammonia	NH_3	µg L^{-1}
	Nitrite[1]	NO_2	µg L^{-1}
	Nitrate[1]	NO_3	µg L^{-1}
	Dissolved inorganic phosphorus	PO_4	µg L^{-1}
	Silica	Si	µg L^{-1}
	Particulate nitrogen	PN	µg L^{-1}
	Particulate phosphorus	PP	µg L^{-1}
	Total dissolved nitrogen	TDN	µg L^{-1}
	Total dissolved phosphorus	TDP	µg L^{-1}
	Particulate organic carbon	POC	µg L^{-1}
	Dissolved organic carbon	DOC	µg L^{-1}
Biological	Chlorophyll-*a*	Chl-*a*	µg L^{-1}

[1] note that NO_x is the sum of NO_2 and NO_3
**Derived from vertical profiles of photosynthetically active radiation and not sampled at all sites*

2.2 Water quality sampling

At each of the sampling locations (Figure 2-1, Appendix C), vertical profiles of water salinity and temperature were measured with a Conductivity Temperature Depth (CTD) profiler (Sea-Bird Electronics SBE19plus). CTD profiles are used to characterise the water column and to identify its state of vertical mixing. Some CTD profiles included measurements of photosynthetically active radiation (PAR), which were used to derive the light attenuation coefficient (K_D). See the QA/QC report for a detailed description of CTD data processing (Great Barrier Reef Marine Park Authority, 2019).

Immediately following the CTD cast, discrete water samples were collected with Niskin bottles. Samples collected at routine stations were from the surface (~0.5 m below water surface) and bottom (~1 m above the seabed) of the water column, whereas for some event-based sampling only surface water samples were collected. Samples from the Niskin bottles were taken in duplicate and were analysed for a broad suite of water quality parameters (Table 2-1). Detailed descriptions of analytical chemistry techniques can be found in the QA/QC report (Great Barrier Reef Marine Park Authority, 2019). Values of water quality variables presented in this report are depth-weighted means calculated using surface and bottom samples.

Below is a brief description of each of the main water quality variables measured as part of the MMP. These definitions are not all-encompassing but are meant to provide a short description of what aspects of water quality they measure and what processes influence the variables:

- **Turbidity** is a measure of light scattering caused by fine suspended particles, such as clay and silt, detritus, microbes and phytoplankton and zooplankton. Turbidity is affected by a wide range of factors, including natural ones such as wind, waves and currents, as well as anthropogenic ones such as dredging and increased land-based run-off.
- **Chl-*a*** concentration is a measure of phytoplankton biomass in a water body and in coastal waters this can reflect changes in river nutrient loads.
- **Dissolved inorganic nutrients (NH_3, NO_X, PO_4 and $Si(OH)_4$)** measure the amount of readily available nutrients for plankton growth in water samples. Inorganic nitrogen (NH_3, NO_x) and phosphate (PO_4) contain around 1% of the nutrient pools in the Reef. The inorganic nutrient pools are affected by a complex range of production and uptake processes including both natural (e.g. plankton uptake/production, upwelling and nitrogen fixation) and anthropogenic (e.g. dredging, changed land use) processes.
- **Particulate nutrients (POC, PN and PP)** are a measure of the suspended material retained on a filter with a pore size of approximately 0.7 µm. This material consists of a minor fraction of living biomass (e.g. bacteria, phytoplankton) and a major fraction of detritus (e.g. dead cells, faecal pellets). The PN and PP pools in this report contain both inorganic and organic parts. The particulate matter pool is affected by primary production, microbial and sunlight degradation, and by factors such as wind, waves and currents, as well as sources such as dredging and land-based run-off.
- **Dissolved organic carbon (DOC)** is, in this report, a measure of the organic material passing a filter with a pore size of 0.45 µm. This pool is mainly lifeless and has a complex chemical composition. The DOC pool is affected by a complex range of production and degradation pathway. The sources include sediment resuspension events, river runoff and primary production. The main sinks are linked with microbial and sunlight degradation.

2.3 In-situ loggers

Continuous *in-situ* Chl-*a* fluorescence and turbidity were measured using WET Labs ECO FLNTUSB Combination Fluorometer and Turbidity Sensors located at 15 stations (Appendix C), which were deployed 5 m below the surface and sampled at 10 min intervals. Water samples for analyses of Chl-*a* and TSS were collected three times per year to calibrate logger fluorescence and turbidity to *in-situ* conditions. Diver-operated Niskin bottles were used to sample close to the moored loggers and samples were preserved and analysed in the same manner as ship-based water samples.

Daily averages of the chlorophyll and turbidity collected by the ECO FLNTUSB instruments are presented as time-series graphs in Appendix E (Figure E-1). Annual means and medians of turbidity were also calculated for each site based on the DERM ‘water year’ (1 October to 30 September) and compared with the guideline value (GV) (Table E-4).

Salinity and temperature loggers (Sea-Bird Electronics SBE37) were deployed at eight locations, with three of these being placed on fixed moorings near the Russell-Mulgrave, Tully and Burdekin River mouths (Figure 2-1Figure 2-1: Sampling locations of the water quality monitoring sampled from 2015 onwards., Appendix C). See the QA/QC report (Great Barrier Reef Marine Park Authority, 2019) for detailed descriptions of logger pre- and post-deployment procedures. Site-specific time-series from these loggers can be found in Appendix E (Figure E-2).

2.4 Data analyses – ambient water quality

Generalised additive mixed effect models were fitted to key water quality variables for each focus region and sub-region to identify long-term trends in inshore water quality (details in Appendix D-2).

The Water Quality Index (WQ Index) is an interpretation tool developed by AIMS to visualise trends in the suite of water quality variables measured, and to compare monitored water quality to existing

Water Quality Guidelines (Department of Environment and Resource Management, 2009; Great Barrier Reef Marine Park Authority, 2010). The WQ Index uses a set of five key indicators:

- water clarity (TSS concentrations, Secchi depth and turbidity measurements by FLNTUSB instruments, where available)
- Chl-*a* concentrations
- PN concentrations
- PP concentrations
- NO_x concentrations.

For each monitoring site, these indicators are compared to GVs, scored based on performance relative to guidelines, and aggregated to give an overall site-specific score. Sites are then aggregated within a region or sub-region to give a regional score (see Section 4).

The WQ Index is calculated using two different methods due to changes in the MMP design that occurred in 2015, as well as concerns that the Index was not responsive to changes in environmental pressures of each year. The changes in design included increased number of sites, increased sampling frequency and a higher sampling frequency during December to April to better represent wet season variability. Thus, statistical comparisons between MMP data from 2005–15 to 2015–onwards must account for these changes. The two versions of the WQ Index have different purposes:

1. **Long-term trend**: This version is based on the pre-2015 MMP sampling design and uses only the original sites and three sampling dates per year. This sampling design had low temporal and spatial resolution and was aimed at detecting long-term trends in inshore water quality. Key aspects of this version are:
    - annual water quality GVs are used for comparison with monitoring data
    - only AIMS monitoring data are used
    - a four-year running mean is applied to data to reduce the effect of sampling time on the Index
    - the Index is an average of scores for 5 indicators.

2. **Annual condition:** This version is based on the post-2015 MMP sampling design and uses all sites and sampling dates per year. Key aspects of this version are:
    - seasonal water quality GVs are used for comparison with monitoring data (i.e. wet season data are compared to a wet season GV and dry season data are compared to a dry season GV)
    - both AIMS and JCU monitoring data are used
    - a running mean is not applied
    - the Index is a hierarchical combination of scores for 5 indicators.

Details of Index calculation can be found in Appendix D-3.

2.5 Data analyses – wet season water quality

The wet season water quality data were used for several purposes:

- to characterise water quality gradients during the wet season and during high flow conditions
- to investigate the transport and/or transformation of key pollutants when they are discharged into the Reef lagoon
- to identify where measured values were above the water quality GVs
- to assess the exposure of coral reefs and seagrass ecosystems to land-sourced pollutants.

For the mapping, a simple data extraction was performed (see method in Appendix D-4); therefore, the water quality parameters measured during the wet season could be associated with each wet season water type (and colour class), i.e. to primary (colour classes 1 to 4), secondary (colour class 5) or tertiary (colour class 6) water types (Appendix D-4 and following Section for description of the wet season water types). The transport and/or transformation of water quality parameters as well as the pollutant concentration relative to the GVs were investigated by plotting the mean water quality concentrations (long-term and 2017–18) against their water type and colour class categories.

The mean water quality concentrations have been calculated for 2017–18 using all surface data (< 0.2 m) collected between November and April by JCU, AIMS and the CYWMP. During the previous wet seasons, the mean water quality concentrations were calculated using the JCU dataset only, assuming it was representative of high flow conditions.

2.6 Remote-sensing modelling – wet season water type and exposure maps

Several satellite-derived products were produced and are illustrated in Figure 2-2 (Devlin et al., 2015, modified). These products included weekly panel maps of environmental and marine wet season conditions, frequency maps of occurrence of wet season water types and exposure maps, as well as tabling the area (km^2) and percentage (%) of coral reefs and seagrass meadows potentially affected by different categories of exposure (or potential risk). Details are included in Appendix D-5.

Wet season water type maps were produced using MODIS-Aqua (hereafter, MODIS) quasi true colour (hereafter true colour) imagery (see Appendix B) reclassified to six distinct colour classes defined by their colour properties (Álvarez-Romero et al., 2013) and typical of colour gradients existing across coastal waters, including river plumes during the wet season (Figure 2-3). To complement this dataset, MODIS-Terra true colour images are also occasionally downloaded from the National Aeronautics and Space Administration (NASA)'s EOSDIS worldview website and processed to daily water type maps. MODIS-Terra are only used when MODIS data are too cloudy or unavailable, and when satellite information are required in near-real-time (rapid response mapping of flood events). The MODIS-Terra data are not included in the processing of the weekly, frequency and exposure composite maps.

Colour classes are assigned to plume waters that are characterised by different colour and concentrations of optically active components (e.g. TSS, CDOM, and Chl-*a*), which influence light attenuation (Petus et al., 2018), as well as different pollutant concentrations. These characteristics vary the impact on the underlying ecological systems.

Wet season colour classes were further grouped into three wet season water types:

- primary—classes 1 to 4
- secondary—class 5
- tertiary—class 6.

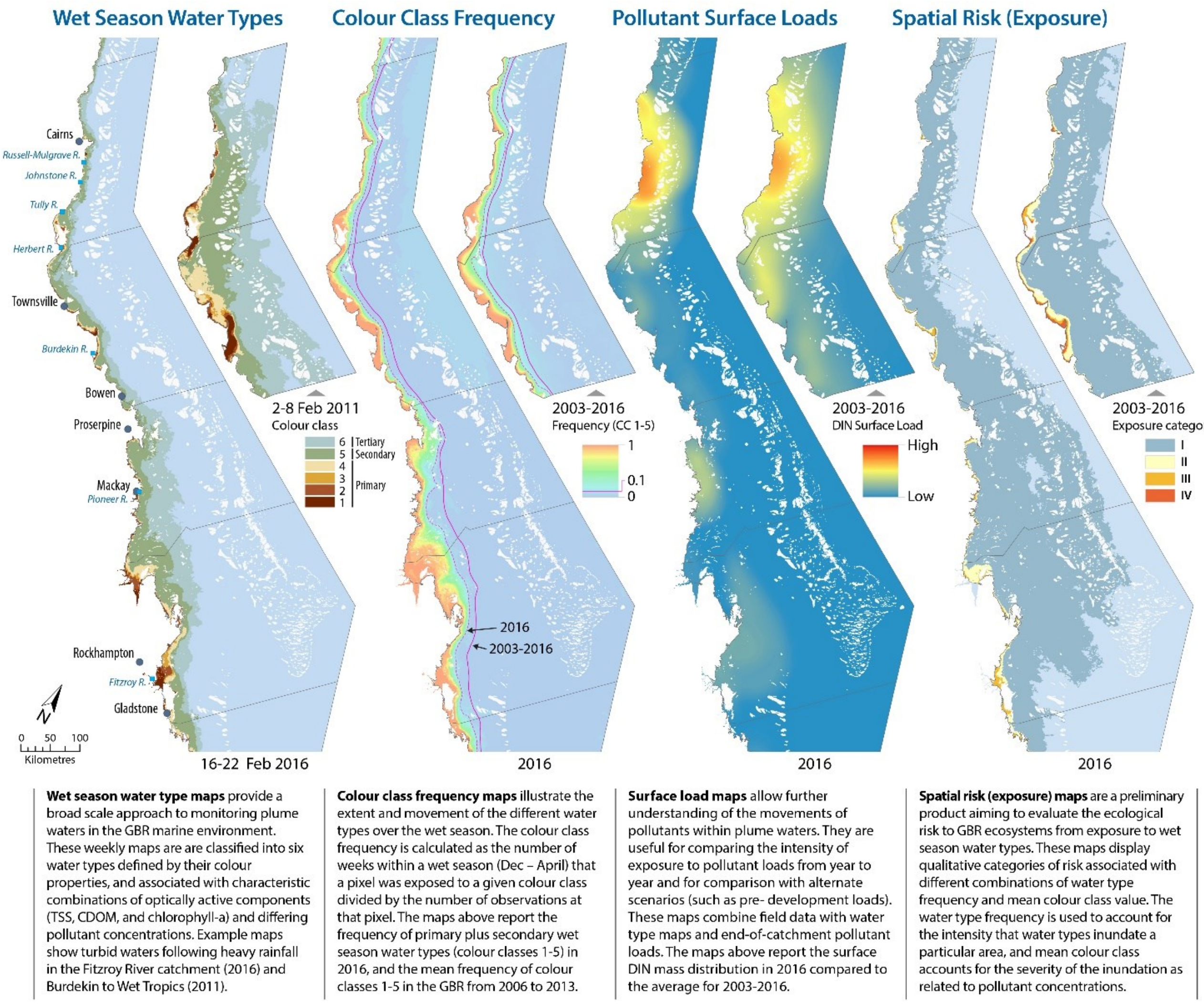
The brownish to brownish-green turbid waters (colour classes 1 to 4 or primary water type) are typical of inshore regions of the Reef that receive terrestrial discharge and have high concentrations of resuspended sediments during the wet season (Figure 2-3). These water bodies in flood waters typically contain high nutrient and phytoplankton concentrations but are also enriched in sediment and dissolved organic matter resulting in reduced light levels. The greenish to greenish-blue turbid water (colour class 5 or secondary water type) is typical of coastal waters rich in algae (Chl-*a*) and containing dissolved organic matter and fine sediment. This water body is found in open coastal waters of the Reef as well as in the mid-water plumes where relatively high nutrient availability and increased light levels due to sedimentation favour coastal productivity (Bainbridge et al., 2012). Finally, the greenish-blue waters (colour class 6 or tertiary water type) correspond to waters with above ambient water quality concentrations. This water body is typical of areas towards the open sea or offshore regions of river flood plumes.

Panels summarising weekly environmental (wind, rainfall and river discharge) and marine (wet season colour classes) conditions as well as water quality samples collected *in situ* were produced for each focus region to illustrate the link between environmental drivers and marine conditions across the wet season.

Frequency maps were produced and predicted the areas affected by the three wet season water types (primary, secondary and tertiary) combined or individually (i.e. of the brownish, greenish and greenish-blue waters, respectively). Frequency maps were produced over the seasonal (2017–18 wet season) and long-term (2002–03 to 2017–18 wet seasons) time frames (

Figure 2-2). The extent of the secondary and tertiary water type frequencies is rarely attributed to an individual river and is usually merged into one heterogeneous area. Results for 2011 (very wet), 2016 and 2017 (dry) years and 2018 were processed using true colour data from the Bureau of Meteorology (BOM) and the slightly modified cloud mask (2017 case study), while all other years were processed using previous methods.

The presence and spatial extent of each wet season water type is the result of the complex physico-chemical transformations occurring within river plumes, but also of resuspension, transport and other hydrodynamic processes.



Wet season water type maps provide a broad scale approach to monitoring plume waters in the GBR marine environment. These weekly maps are are classified into six water types defined by their colour properties, and associated with characteristic combinations of optically active components (TSS, CDOM, and chlorophyll-a) and differing pollutant concentrations. Example maps show turbid waters following heavy rainfall in the Fitzroy River catchment (2016) and Burdekin to Wet Tropics (2011).

Colour class frequency maps illustrate the extent and movement of the different water types over the wet season. The colour class frequency is calculated as the number of weeks within a wet season (Dec – April) that a pixel was exposed to a given colour class divided by the number of observations at that pixel. The maps above report the frequency of primary plus secondary wet season water types (colour classes 1-5) in 2016, and the mean frequency of colour classes 1-5 in the GBR from 2006 to 2013.

Surface load maps allow further understanding of the movements of pollutants within plume waters. They are useful for comparing the intensity of exposure to pollutant loads from year to year and for comparison with alternate scenarios (such as pre- development loads). These maps combine field data with water type maps and end-of-catchment pollutant loads. The maps above report the surface DIN mass distribution in 2016 compared to the average for 2003-2016.

Spatial risk (exposure) maps are a preliminary product aiming to evaluate the ecological risk to GBR ecosystems from exposure to wet season water types. These maps display qualitative categories of risk associated with different combinations of water type frequency and mean colour class value. The water type frequency is used to account for the intensity that water types inundate a particular area, and mean colour class accounts for the severity of the inundation as related to pollutant concentrations.

Figure 2-2: Summary description of the wet season water quality products derived from remote sensing information in the MMP illustrated using the 2016 map outputs as examples. Modified from Devlin et al. (2015).

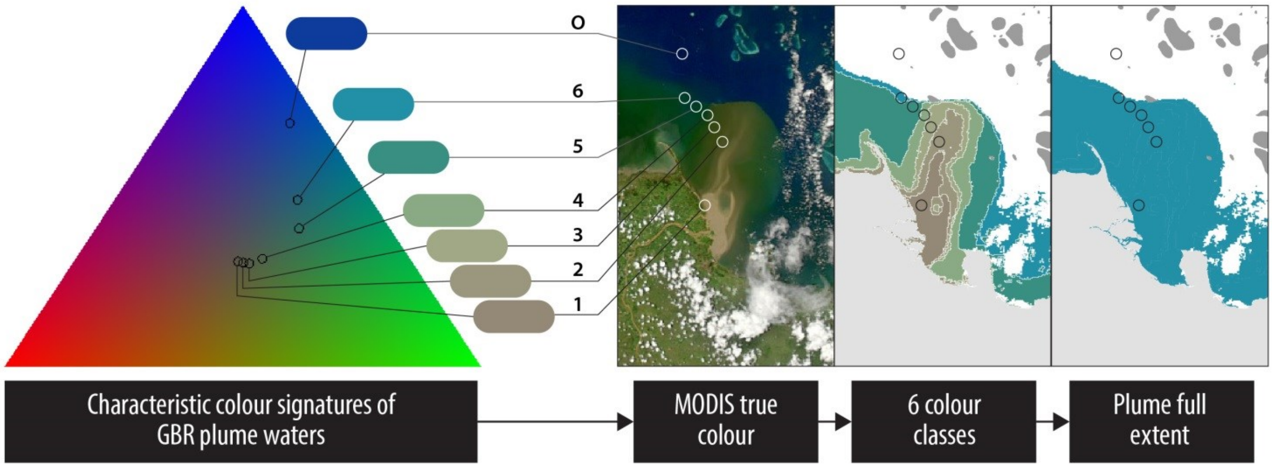


Figure 2-3: Triangular colour plot showing the characteristic colour signatures of the wet season water types in the Red-Green-Blue (RGB or true colour) space. Álvarez-Romero et al. (2013) developed a method to map these characteristic coastal water masses in the Reef using a supervised classification of MODIS true colour data (modified from Devlin et al., 2015). A comparison of the colour classes and approximate RGB colour of the Forel-Ule scale are also presented in Appendix D-4 (Figure D-1).

Exposure maps were produced for the whole of the Reef and for all focus regions over the seasonal (2017–18 wet season) and long-term (2002–03 to 2017–18 wet seasons) time frames. They were produced using the exposure assessment framework as presented in 2015–16, developed through a collaborative effort between the MMP monitoring providers (JCU water quality and seagrass teams and the AIMS coral monitoring team) and modified from Petus et al. (2016).

In this *magnitude* × *likelihood* framework, the ‘potential risk’ corresponds to an exposure to above guideline concentrations of land-sourced pollutants during the wet season and focuses on TSS, Chl-*a*, PP and PN concentrations. The *‘magnitude of the exposure’* corresponds to the mean wet season concentration of pollutants (proportional exceedance of the GV) mapped through the primary, secondary and tertiary water types. The *‘likelihood of the exposure’* is estimated by calculating the frequency of occurrence of each wet season water type. The exposure for each of the water quality parameters defined is the proportional exceedance of the GV multiplied by the likelihood of exposure in each of the wet season water types. Seasonal overall exposure scores are categorised into four equally-distributed potential risk categories, and the area (km^2) and percentage (%) of coral reefs and seagrass meadows affected by the different categories of exposure (I to IV) calculated as a relative measure between regions and years.

The methods are described in further detail in Appendix D-5.

2.7 River discharge

River flow is reported annually and can be derived from several sources. In many cases, river flow gauges that measure discharge (and constituent loads) are located well upstream of the river mouth and only capture a certain proportion of the catchment/basin area. Such disparities mean that river gauge data should not be directly compared across basins and NRM regions. For example, the Daintree and Barron Basins within the Wet Tropics region contain a similar area (2100–2200 km^2); however, the Daintree River at Bairds gauge only measures 43% of the Daintree Basin whereas the Barron River at Myola gauge captures 89% of the Barron Basin. If gauge data are used to compare discharge between these basins, the gauge on the Barron Basin is covering around double the area compared to the gauge on the Daintree Basin. A scaling factor is used on these data so that discharge (and constituent loads) can be directly compared across basins and NRM regions.

To account for these differences, the relevant discharge data for each basin were compiled, where available (Table 2-2; Department of Natural Resources and Mines [DNRM], 2017). The total annual discharge for each gauge was then up-scaled using the difference between the gauged area and the total basin area to estimate flow for each basin. The key assumption for this calculation is that rainfall was spread relatively evenly over the entire basin for each year. This assumption was tested further by comparing our mean annual basin discharge with those produced by the Source Catchments model (Waters et al., 2014) over the common period. The data showed reasonable agreement (generally within 10%) for most basins, although adjustments to the correction factor were made for some basins to account for areas of the basin that were gauged in wetter or drier parts of the basin. Where a flow gauge did not exist in a basin (e.g. Jacky Jacky Creek, Lockhart River, Jeannie River, Proserpine River, Styx River, Shoalwater Creek and Boyne River—marked with an asterisk), the gauge from the nearest neighbouring basin was used coupled with the relevant area adjustment.

Table 2-2. The 35 basins of the Reef catchment, the gauges used to examine flow and the corrections required to upscale flows to provide annual discharge estimates.

NRM region	Basin	AWRC No.	Basin area (km^2)	Relevant gauges	Percentage of Basin covered by key gauges	Correction factor
Cape York	Jacky Jacky Creek	101	2963	Pascoe River at Garraway Creek*	0	2.4
	Olive Pascoe River	102	4180	Pascoe River at Garraway Creek	31	3.0
	Lockhart River	103	2883	Pascoe River at Garraway Creek*	0	1.9
	Stewart River	104	2743	Stewart River at Telegraph Road	17	5.8
	Normanby River	105	24,399	Normanby River at Kalpowar Crossing	53	1.9
	Jeannie River	106	3638	Endeavour River at Flaggy*	0	10.0
	Endeavour River	107	2182	Endeavour River at Flaggy	15	6.5
Wet Tropics	Daintree River	108	2107	Daintree River at Bairds	43	2.3
	Mossman River	109	473	Mossman River at Mossman	22	4.5
	Barron River	110	2188	Barron River at Myola	89	1.1
	Mulgrave-Russell River	111	1983	Mulgrave River at Peets Bridge + Russell River at Bucklands	42	2.4
	Johnstone River	112	2325	South Johnstone River at Upstream Central Mill + North Johnstone at Tung Oil	57	1.8
	Tully River	113	1683	Tully River at Euramo	86	1.2
	Murray River	114	1107	Murray River at Upper Murray	14	7.1
	Herbert River	116	9844	Herbert River at Ingham	87	1.1
Burdekin	Black River	117	1057	Black River at Bruce Highway	24	4.1
	Ross River	118	1707	Haughton River at Powerline*	0	0.8
	Haughton River	119	4051	Haughton River at Powerline	44	2.3
	Burdekin River	120	130,120	Burdekin River at Clare	100	1.0
	Don River	121	3736	Don River at Reeves	27	3.7
Mackay Whitsunday	Proserpine River	122	2494	O'Connell River at Staffords Crossing*	0	7.8
	O'Connell River	124	2387	O'Connell River at Staffords Crossing	14	7.0
	Pioneer River	125	1572	Pioneer River at Dumbleton Weir T/W	95	1.1
	Plane Creek	126	2539	Sandy Creek at Homebush	13	7.8
Fitzroy	Styx River	127	3013	Waterpark Creek at Byfield*	0	2.9
	Shoalwater Creek	128	3601	Waterpark Creek at Byfield*	0	3.3
	Water Park Creek	129	1836	Waterpark Creek at Byfield	12	8.7
	Fitzroy River	130	142,552	Fitzroy River at The Gap	95	1.0
	Calliope River	132	2241	Calliope River at Castlehope	57	1.7
	Boyne River	133	2496	Calliope River at Castlehope*	0	0.43
Burnett-Mary	Baffle Creek	134	4085	Baffle Creek at Mimdale	34	2.9
	Kolan River	135	2901	Kolan River at Springfield	19	2.0
	Burnett River	136	33,207	Burnett River at Figtree Creek	92	1.1
	Burrum River	137	3362	Gregory River at Leesons	19	5.3
	Mary River	138	9466	Mary River at Home Park	72	1.4

* Gauges used that are not in the basin area

2.8 Load mapping

An ocean colour-based model has been used to estimate the dispersion of dissolved inorganic nitrogen (DIN = NH_4^+ + NO_2^- + NO_3^-) and TSS delivered by river discharge to the Reef waters (da Silva et al., in prep. reproduced in Waterhouse et al., 2017b). This model, built on a method by Álvarez-Romero et al. (2013), combines *in situ* data, MODIS satellite imagery and modelled annual end-of-catchment DIN and TSS loads from the Reef catchments. In the ocean colour model, monitored and modelled end-of-catchment loads provide the amount of DIN or TSS delivered to the Reef, *in-situ* data provides the DIN or TSS mass in river plumes and satellite imagery provides the direction and intensity of the DIN or TSS mass dispersed over the Reef lagoon. The eReefs hydrodynamic model also provides an estimate of the boundary of the plume extent during the wet season. This model produces annual maps of average DIN and TSS concentrations in reef waters.

The model is described in detail in Appendix D-6.

The difference between the estimated wet season DIN and TSS concentrations in the Reef lagoon for the 2018 water year (1 October 2017 to 30 September 2018) was calculated and compared to the pre-development loads. This can be interpreted as ‘anthropogenic’ DIN or TSS concentrations, highlighting the areas of greatest change with current land use characteristics.

The contribution of DIN and TSS load from rivers to the waters of each NRM region was determined by the load exported from each river that reaches a particular NRM region, divided by the total load of DIN or TSS in that region. If a river presents a load contribution of 100% to a particular NRM region, this means that no other river included in the model contributes load to that NRM region. Two periods were considered, pre-development and current (2017–18) water years.

2.9 Zones of influence for river discharge

Hydrodynamic models provide a tool for identifying, quantifying and communicating the spatial impact of discharges from various rivers into the Reef lagoon. The cumulative exposure was estimated for the entire water year (October 2017 to September 2018) for the Normanby, Barron, Russell-Mulgrave, Tully and Burdekin Rivers.

The eReefs (http://ereefs.org.au/ereefs) hydrodynamic model output was used for the year, which incorporates measured wind, pressure, and tide to provide improved estimates of river plume movement in coastal waters. Simulated river-tagged passive tracers were released from each of the major gauged rivers discharging into the Reef. The discharge concentration of each river’s unique tracer was set at 1.0 at the river mouth, whereas the starting tracer concentration in the Reef lagoon was set at 0.

Details of the methods used for the eReefs tracer study are presented in Appendix D-7.

3. Drivers and pressures influencing water quality during 2017–18

3.1 Coastal development including agriculture

The Wet Tropics, Burdekin, Mackay Whitsunday, Fitzroy and Burnett-Mary regions are characterised by a variety of land uses including agricultural (sugarcane, grazing, cropping and other horticulture), mining and urban development. The Cape York region is less developed than these Reef catchments; therefore, land-based activities in this region are considered to have a relatively small impact on marine ecosystems (Waterhouse et al., 2017b). However, even in the Cape York region, grazing land use, roads, mining and other vegetation clearing have significantly increased sediment erosion (Brooks et al., 2013). Specifically:

- Cape York
    - The Endeavour and Annan River Basin has an area of 2186 km^2 and a relatively high proportion of nature/conservation land use (52% as of 2015) and closed grazing (40%) (Queensland Land Use Mapping Program [QLUMP], 2015). Additional grazing land has been converted to conservation land use since 2015 and approximately 80% of the Annan catchment is now under conservation or Aboriginal freehold. Sources of pollution (e.g. sediment, nutrients and toxicants) in the Endeavour catchment include urban run-off from the township of Cooktown located at the mouth of the Endeavour River, cattle grazing, horticulture and road erosion upstream. Historical mining disturbances, cattle grazing impacts (current and past) and road erosion are the primary sources of pollution to the Annan River (Shellberg et al., 2015).
    - The Normanby Basin has an area of 24,550 km^2 and a relatively high proportion of nature/conservation land use (46%) and grazing (52%) (QLUMP, 2015). Additional lands have shifted from grazing to conservation since 2015, resulting in approximately 53% conservation land use and 47% grazing. Horticulture accounts for only 1% of land use but has been expanding in the Laura and West Normanby sub-catchments. Current and former cattle grazing, large-scale land clearing for agricultural development, and road construction and maintenance are the primary pressures affecting water quality (sediment and associated nutrient loads) across the Normanby Catchment (Cape York NRM and South Cape York Catchments, 2016). Horticulture in the Laura sub-catchment has also increased nutrient concentrations in the Laura River (Howley, 2010).
    - The Pascoe River has an area of 2088 km^2 with a high proportion of nature/conservation land use (84%) with some closed grazing (15%) according to QLUMP (2015). However, locals advise that there is no longer any active grazing within the Pascoe catchment (Polglase pers. comm. November 2018). Feral cattle and pigs, fire (previous years but not the current year) and road erosion are the main pressures affecting water quality. These impacts are considered to be minimal in this sub-region relative to other Reef catchments and marine waters are considered to be of high Environmental Value (Cape York NRM and South Cape York Catchments, 2016).
- Wet Tropics
    - The Barron Daintree sub-region is primarily influenced by discharge from the Daintree, Mossman and Barron catchments and, to a lesser extent, by other Wet Tropics rivers south of the sub-region (Brodie et al., 2013; Waterhouse et al., 2017b). The Daintree catchment has an area of 2107 km^2 and has a high proportion of protected areas (56% natural/minimal use lands and 32% forestry). The remaining area consists of 7% grazing and, to a lesser extent, sugarcane and urban areas. The Mossman catchment has an area of 479 km^2 and consists of 76% natural/minimal use lands, 10% sugarcane and smaller areas of grazing and urban land uses. The

  Barron catchment has an area of 2189 km^2 and consists of 29% natural/minimal use lands, 31% grazing, 18% forestry, 11% cropping including bananas and sugarcane, and smaller areas of dairy and urban land uses (Terrain NRM, 2015). The Barron River is the most hydrologically modified river in the Wet Tropics region and is heavily regulated by water supply infrastructure.
  - The Russell-Mulgrave Basins contain a high proportion of upland National Park and forest (72%), with 13% of the area used for sugarcane production on the coastal floodplain (Terrain NRM, 2015). The Johnstone Basin has an area of 2326 km^2 and has a relatively high proportion of natural/minimal use lands (55%). The remaining area has 16% grazing, 12% sugarcane and smaller areas of dairy (in the upper catchment), bananas and other crops, and urban land uses (Terrain NRM, 2015).
  - The Tully River Basin has an area of 1685 km^2 and has a high proportion of natural/minimal use lands (75%). The remaining area is comprised of 12% sugarcane, 4% bananas, 5% grazing, and smaller areas of forestry, other crops and urban land uses. The Murray River Basin has an area of 1115 km^2 and has a high proportion of natural/minimal use lands (64%). The remaining area is comprised of 14% sugarcane, 10% forestry, 6% grazing and smaller areas of bananas, other crops and urban land uses. The Herbert River Basin has an area of 9842 km^2 and consists of 27% natural/minimal use lands, 56% grazing, 8% sugarcane and smaller areas of forestry.
- The Burdekin region is one of the two large dry tropical catchment regions adjacent to the Reef, with cattle grazing as the primary land use on over 95% of the catchment area (NQ Dry Tropics, 2016). There is also intensive irrigated sugarcane on the floodplains of the Burdekin and Haughton Rivers. Fluctuations in climate and cattle numbers greatly affect the state and nature of vegetation cover and, therefore, the susceptibility of soils to erosion and off-site transport of suspended sediments and associated nutrients.
- The climate in the Mackay-Whitsunday region is wet or mixed wet and dry tropical with the catchment land use dominated by agriculture broadly divided into grazing in the upper catchments and sugarcane cultivation on the coastal plains (Folkers et al., 2014). In addition, there are expanding urban areas along the coast.

3.2 Climate and cyclone activity

Climate is a major driver of the condition of water quality and ecosystems and can vary substantially between years. It is heavily driven by the El Nino – Southern Oscillation (ENSO) cycle. Climate models predict continued warming; increasing intensity of extreme rainfall events, resulting in freshwater floods; fewer but more intense tropical cyclones; and more frequent and extreme La Niña and El Niño events (Schaffelke et al., 2017).

No cyclones crossed the coast in 2017–18 but cyclone Iris tracked off the coast between Cairns and Rockhampton from mid-March to early April 2018 (Figure 3-1), resulting in extensive flooding in the Herbert River (and the township of Ingham) and the Burdekin River flowed over the dam.

In the 11 years since the MMP began, 10 cyclones have been Category 3 or above and have affected the health of the Reef.

3.2.1Wet season rainfall for the Reef, NRM regions and basins

Queensland rainfall, and resulting river flows into the Reef, is highly seasonal and highly variable from year to year and on decadal timescales. Wet season rainfall for the Cape and Mackay-Whitsunday catchments continued to be below the long-term averages in 2017–18 (Figure 3-2 and Figure 3-3). The Wet Tropics catchments had above average rainfall, largely associated with a strong convergence weather system (early March) and cyclone Iris (end of March/early April) (Figure 3-2 and Figure 3-3). Wet season rainfall in the Burdekin, Fitzroy and Burnett-Mary regions was less than the long-term average but not substantially so. Rainfall events prior to the wet season are important, with reasonably large rainfall events occurring in mid-October 2017 in the Baffle, Kolan, Burnett, Burrum, and Mary catchments.

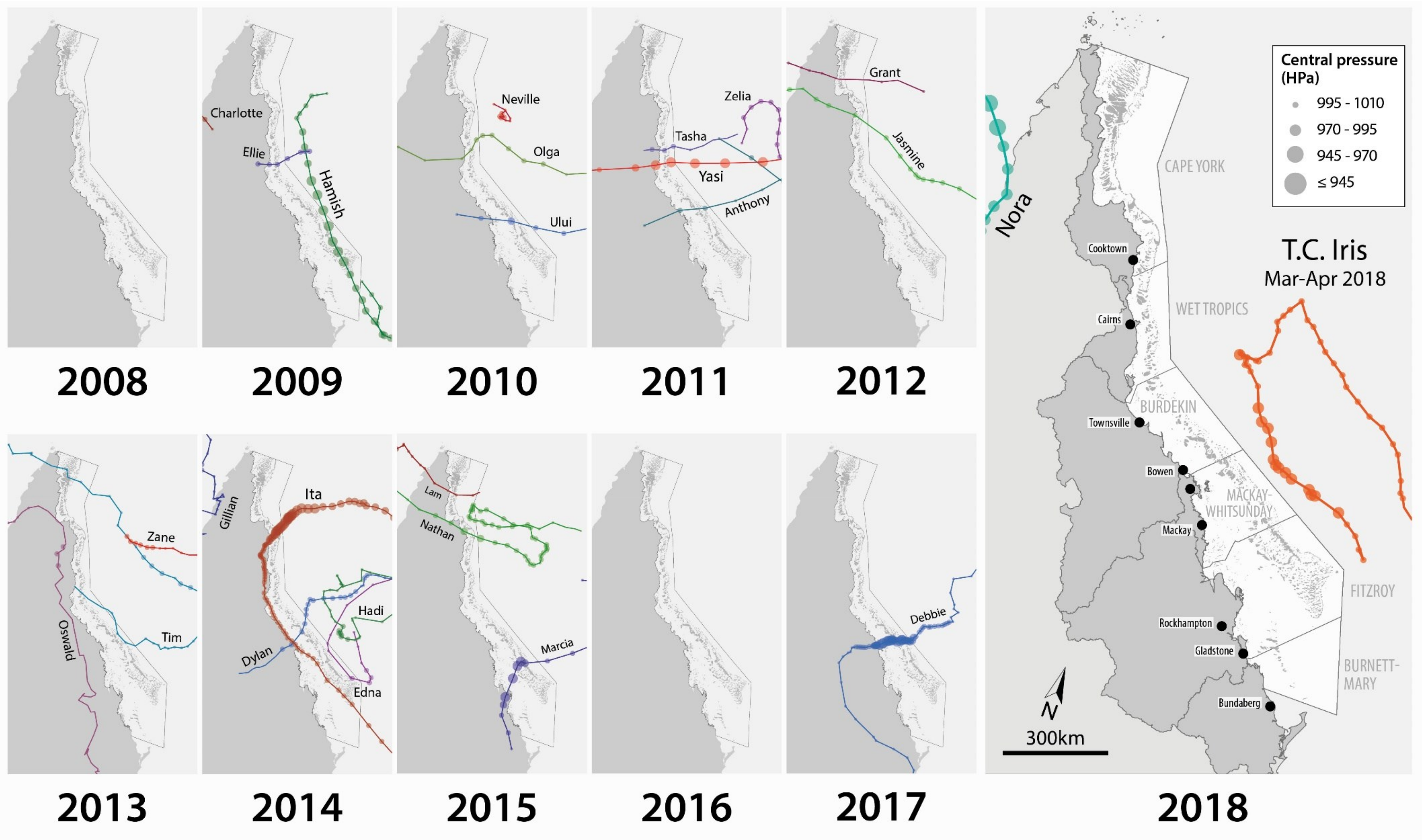


Figure 3-1: Trajectories of tropical cyclones affecting the Reef in 2017–18 and in previous years (2007 to 2017).

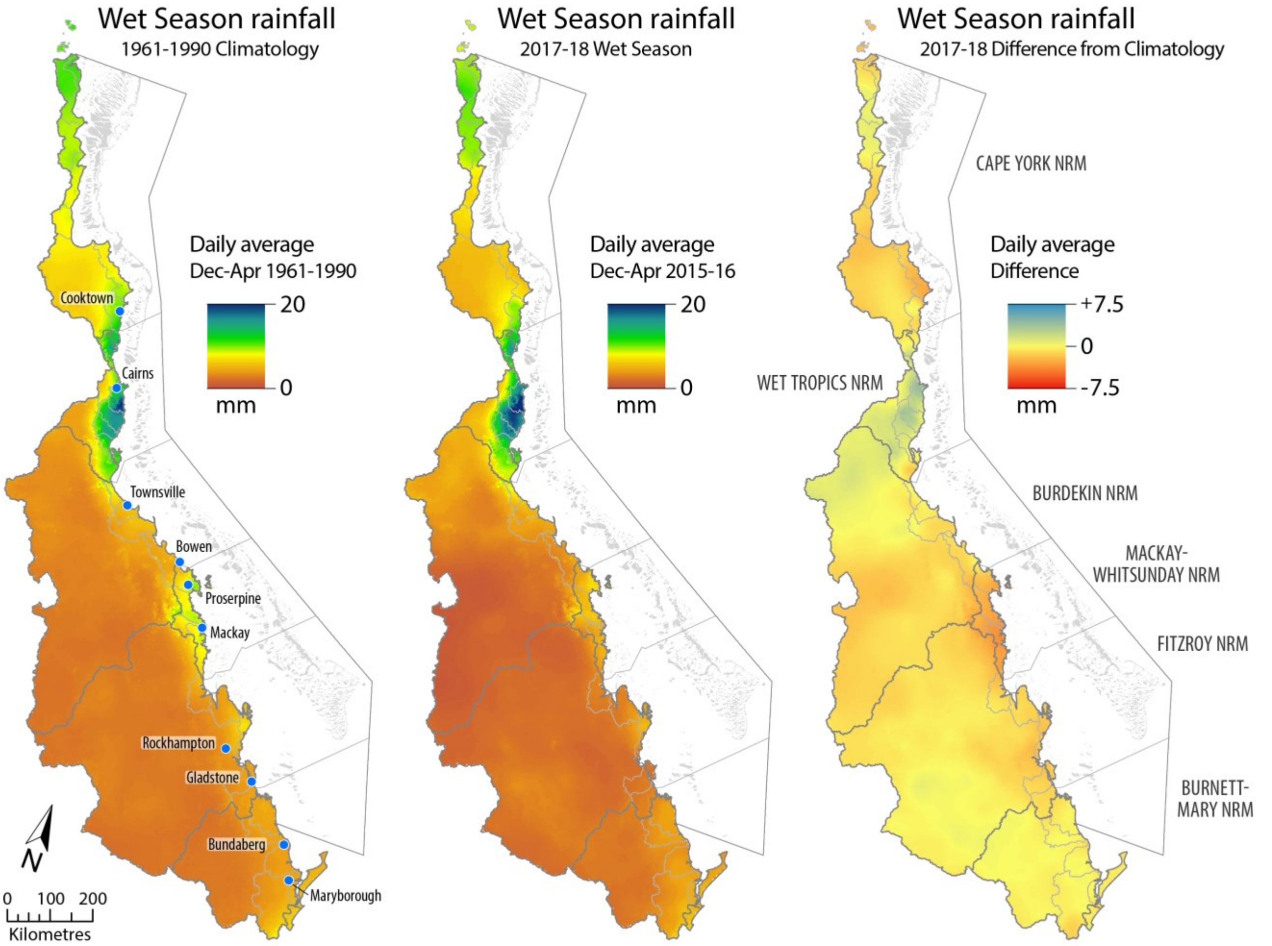


Figure 3-2: Average daily wet season rainfall (mm/day) in the Reef catchment: (left) long-term annual average (1961–90; time period produced by BOM), (centre) 2017–18 and (right) the difference between the long-term annual average and 2017–18 rainfall patterns.

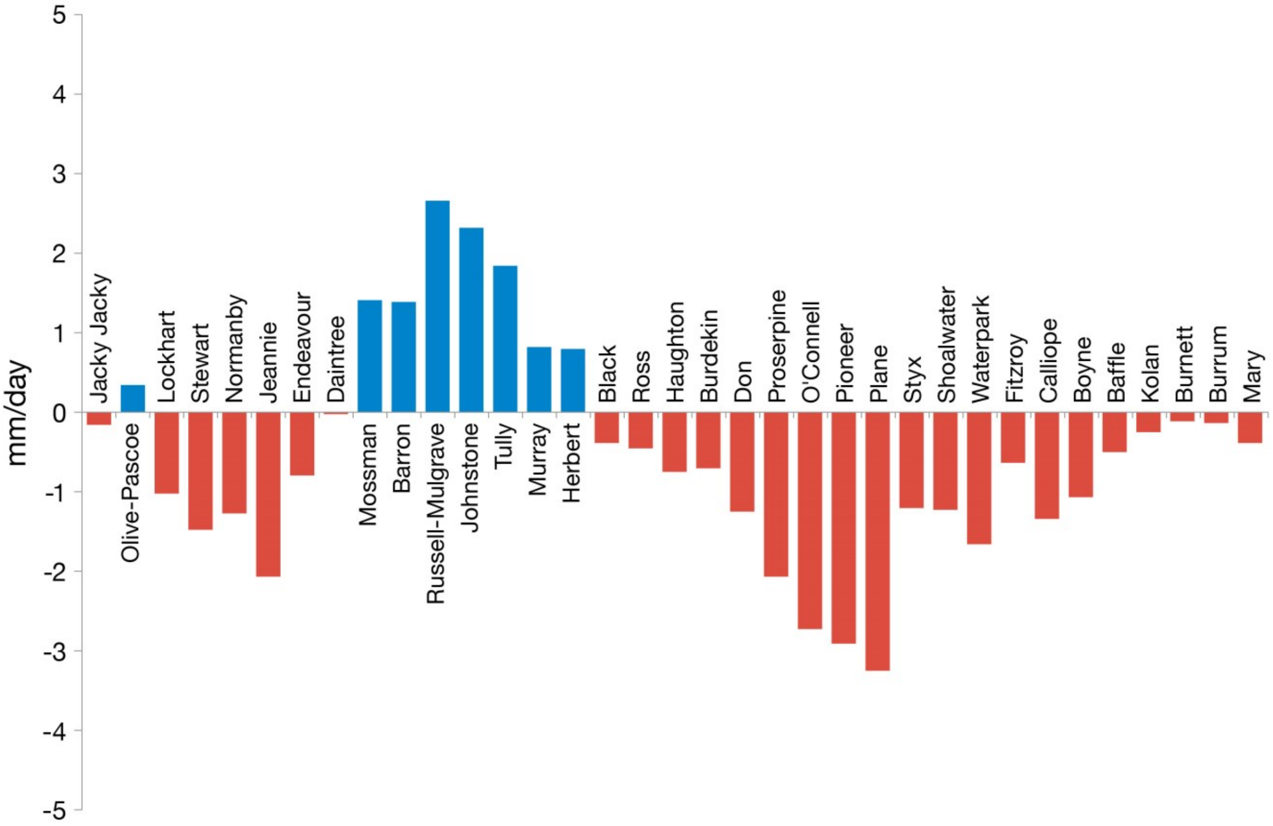


Figure 3-3: Difference between annual average wet season rainfall (December 2017–April 2018) and the long-term wet season rainfall average (1961–90). Red and blue bars denote catchments with rainfall below and above the long-term average, respectively. Note that the catchments are ordered from north to south (left to right).

3.2.2 Annual freshwater discharge for the Reef, NRM regions and basins

The trends in freshwater discharge have a significant influence on water quality. The total annual freshwater discharge for all of the Reef catchments relative to long-term medians (based on hydrological year, calculated using the methods described in Section 2.7) is shown in Figure 3-4 (supported by Appendix E, Table E-1). Discharge at the regional level is shown in Figure 3-5.

In 2017–18, most regions had annual discharges close to the long-term median, with the exception of the Burnett-Mary region (two and three times the long-term median) and the Mackay-Whitsunday region (below the long-term median) river discharge. The 2013 water year (October 2012 to September 2013) was the last in a sequence of years with total river discharge above the long-term median (2007 to 2013). Total river discharge from the 2013–14 to 2017–18 water years was around or below the long-term median. As noted above, the high discharge in the Burnett-Mary region was associated with heavy rainfall events in October 2017. The annual discharges in the Cape York, Wet Tropics and Burdekin regions were amongst the highest discharge recorded in these locations over the past 3 to 5 years.

Annual discharge for the 35 Reef catchment basins in 2017–18 is shown in Table 3-1 and compared to long-term median annual flow for that basin.

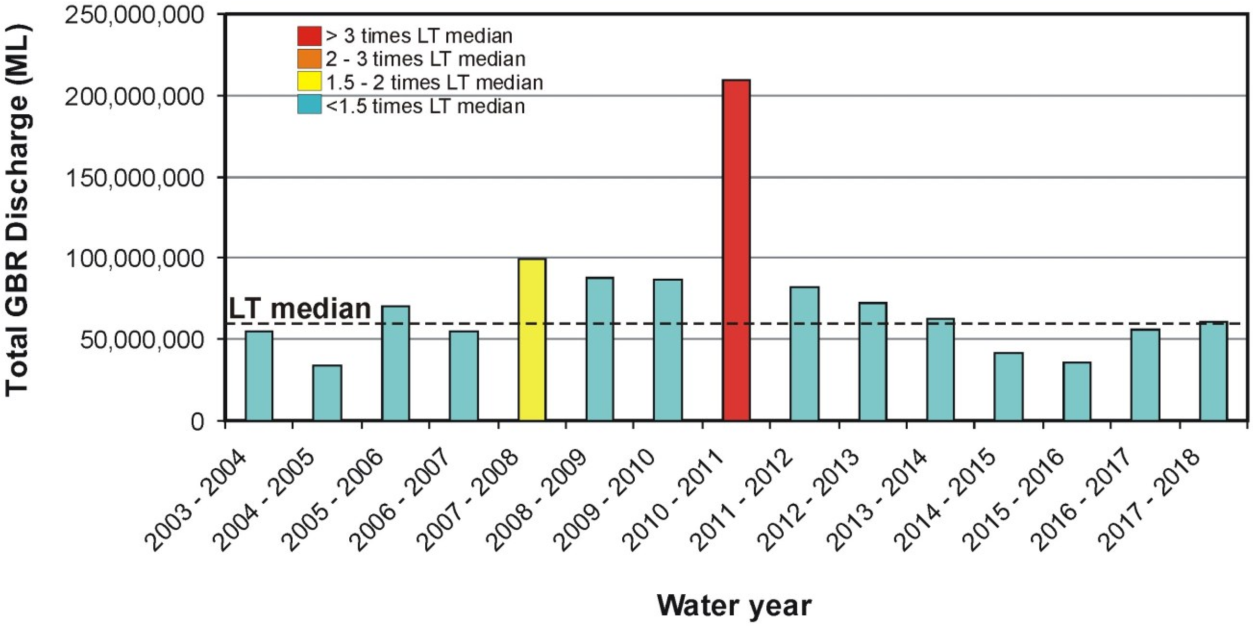


Figure 3-4: Long-term total discharge in ML (hydrological year: 1 October to 30 September) for the 35 main Reef rivers. Source: DNRM, http://watermonitoring.dnrm.qld.gov.au/host.htm.

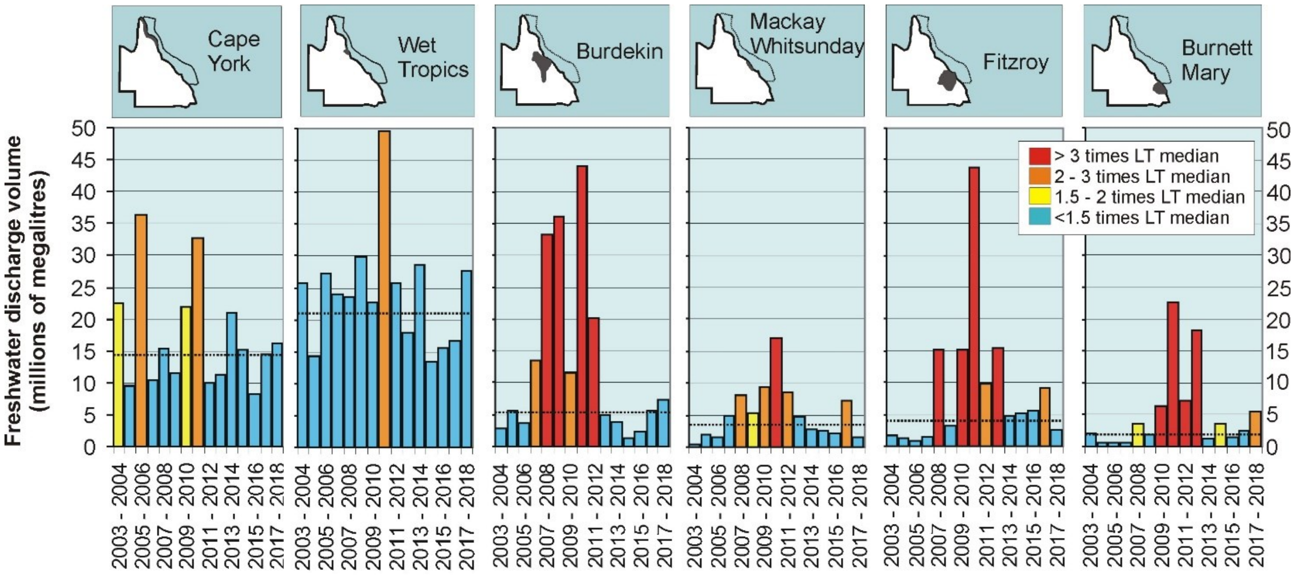


Figure 3-5: Corrected annual water year (1 October to 30 September) discharge from each NRM region (using the correction factors in Table 2-2) for 2002–03 to 2017–18 in (ML per year. Data derived from DNRM (2018).

Table 3-1: Annual water year discharge (GL) of the main Reef rivers (1 October 2017 to 30 September 2018, inclusive) and long-term (LT) median discharge (1986–87 to 2017–18). Colours indicate levels above the long-term median: yellow for 1.5 to 2 times, orange for 2 to 3 times and red greater than 3 times. (– = data not available).

Basin	LT median	2010—11	2011—12	2012—13	2013—14	2014—15	2015—16	2016—17	2017—18
Jacky Jacky Creek	2192	4735	1820	1987	3791	1498	631	2383	2740
Olive Pascoe River	2740	5919	2276	2484	4739	3932	788	2979	3425
Lockhart River	1735	3749	1441	1573	3001	1186	499	1887	2169
Stewart River	689	2181	616	523	1312	299	312	685	826
Normanby River	4097	11,333	2182	3462	5060	2915	3407	3781	4333
Jeannie River	1508	2825	1048	695	1870	1434	1581	1747	1721
Endeavour River	980	1836	681	452	1215	932	1028	1136	1119
Daintree River	1723	3936	2397	1668	5137	1905	1623	1932	1312
Mossman River	1207	2015	1526	1147	1919	874	1245	1143	1504
Barron River	527	2120	852	328	664	380	183	288	868
Mulgrave-Russell River	4458	7893	5697	3530	5421	3146	3254	3016	5760
Johnstone River	4744	9277	5339	3720	5404	3045	3416	4018	5940
Tully River	3536	7443	3425	3342	4322	2660	2943	3099	4237
Murray River	1228	4267	2062	1006	1531	366	974	948	1683
Herbert River	3556	12,594	4545	3190	4282	1095	1896	2248	6386
Black River	229	1424	747	188	419	18	130	65	457
Ross River	355	2093	1325	277	1177	3	24	12	343
Haughton River	553	2416	1756	517	574	121	268	338	827
Burdekin River	4407	34,834	15,568	3425	1459	881	1807	4165	5542
Don River	342	3136	803	578	324	171	102	921	135
Proserpine River	888	4583	2171	852	720	157	317	1684	543
O'Connell River	797	4113	1949	764	647	141	284	1511	488
Pioneer River	777	3630	1568	1163	635	2029	597	1389	250
Plane Creek	1053	4809	2855	1949	738	241	833	2613	274
Styx River	205	906	275	968	544	376	344	508	264
Shoalwater Creek	233	1031	313	1102	619	428	391	578	300
Water Park Creek	616	2718	826	2904	1632	1128	1032	1524	791
Fitzroy River	2852	37,942	7993	8530	1579	2682	3589	6170	955
Calliope River	153	1000	346	1558	284	480	149	406	141
Boyne River	39	253	87	394	72	121	38	103	36
Baffle Creek	465	3650	1776	2031	276	710	257	829	1845
Kolan River	56	779	308	810	45	214	111	146	273
Burnett River	286	9422	643	7582	218	853	381	536	849
Burrum River	72	114	118	91	62	150	335	457	670
Mary River	1145	8719	4340	7654	595	1652	481	583	1903
Sum of basins	**50,443**	**209,696**	**81,674**	**72,445**	**62,285**	**38,225**	**35,249**	**55,825**	**60,906**

Notes for the river discharge data: Values were obtained from DNRM (http://watermonitoring.dnrm.qld.gov.au/host.htm) and up-scaled using the methodology presented in Appendix D.

4. Modelling and mapping marine water quality

This Section presents results of monitoring inshore Reef water quality during the 2017–18 ‘water year’ (October 2017–September 2018); monitoring results from the duration of the MMP (since 2005) are used to provide context for interpreting recent monitoring. It integrates the results of the AIMS and JCU (including the CYWMP) inshore water quality monitoring.

4.1 Satellite monitoring of wet season water types

To illustrate wet season influence on marine conditions and identify potential risk to marine ecosystems, several satellite-derived map products were produced for the Reef, including frequency maps predicting the areas affected by the three wet season water types (primary, secondary or tertiary water types) combined (Figure 4-1) and individually (Figure 4-2).

4.1.1 Areas affected

The 2017–18 water type frequency maps and the long-term water type frequency map showed similar trends for most of the Reef. The frequencies of occurrence of combined wet season water types measured across the Tully-offshore, Herbert-offshore and Pioneer-offshore transects in 2017–18 were similar to the long-term frequencies and lower than the 2010–11 frequencies (wettest wet season monitored) (inset Figure 4-1).

The extent and frequency of the occurrence of each of the three wet season water types was variable across regions, cross-shelf and wet seasons, reflecting the constituent concentrations and intensity of the river discharge and/or resuspension events (Figure 4-2). The maps illustrate a well-documented inshore to offshore spatial pattern (e.g. Devlin et al., 2013, 2015), with coastal areas experiencing the highest frequency of occurrence of primary water types and offshore areas less frequently exposed to primary waters and, when exposed, more frequently reached by the tertiary water type (Figure 4-2).

The total area of the Reef affected by wet season water types was similar to the long-term area affected and lower than the 2011 area (includes waters of Hervey Bay, south of the Marine Park boundary, Reef+HB); Table 4-1). However, the primary waters in 2017–18 covered much less area than in 2011 or in the long-term. Similarly, secondary waters covered less area than in 2011 or in the long-term. Tertiary waters covered more area than in the long-term, but still less than in 2011.

Table 4-1: Areas (km^2) and percentages (%) of the Reef lagoon (and Hervey Bay waters) affected by the wet season water types during the 2017–18, 2010–11 and long-term wet season (the Reef+HB).

Water type	2017–18		2010–11		Long-term	
	Area (km^2)	% of Reef+HB	Area (km^2)	% of Reef+HB	Area (km^2)	% of Reef+HB
Combined	266,076	70%	320,089	84%	258,483	68%
Primary	21,886	6%	50,871	13%	48,335	13%
Secondary	92,144	24%	137,486	36%	108,924	29%
Tertiary	245,634	64%	298,403	78%	223,294	59%

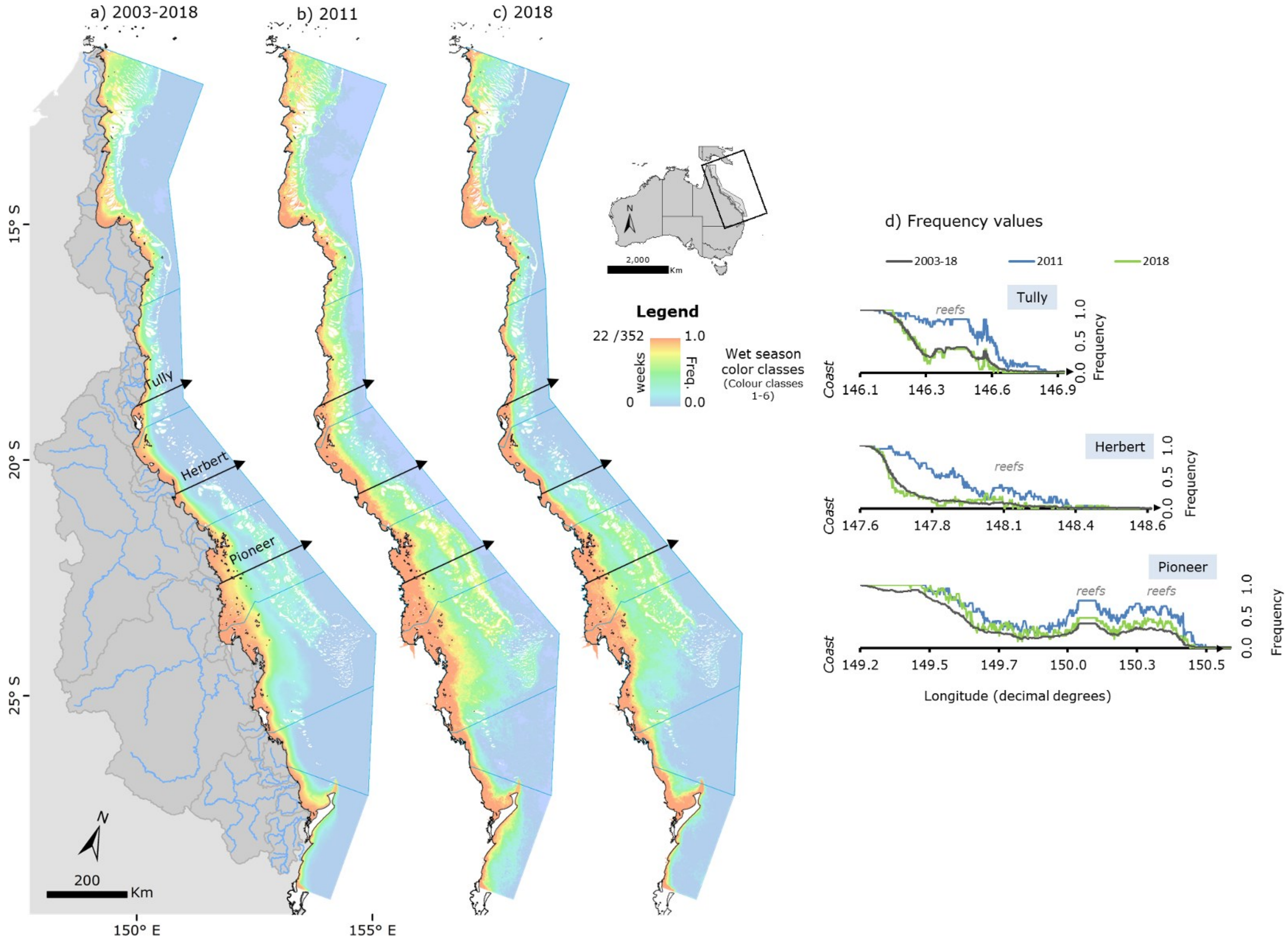


Figure 4-1: Map showing the frequency of wet season water types (primary, secondary and tertiary water types combined) in the a) long-term (2002–03 to 2017–18: 333 weeks), b) 2010–11 wet season (22 weeks) and c) 2017–18 wet season (22 weeks), where the highest frequency is shown in orange and the lowest frequency is shown in blue. Plots on the right show the frequency values recorded along three transects extending from the Tully, Herbert and Pioneer Rivers to the external boundaries of the Marine Park and illustrate the differences in the spatial distribution and frequency of occurrence existing between dry and wet years. Wet seasons 2011, 2016, 2017 and 2018 have been produced using MODIS true colour data processed by BOM. Other wet seasons were produced using MODIS true colour data processed by JCU.

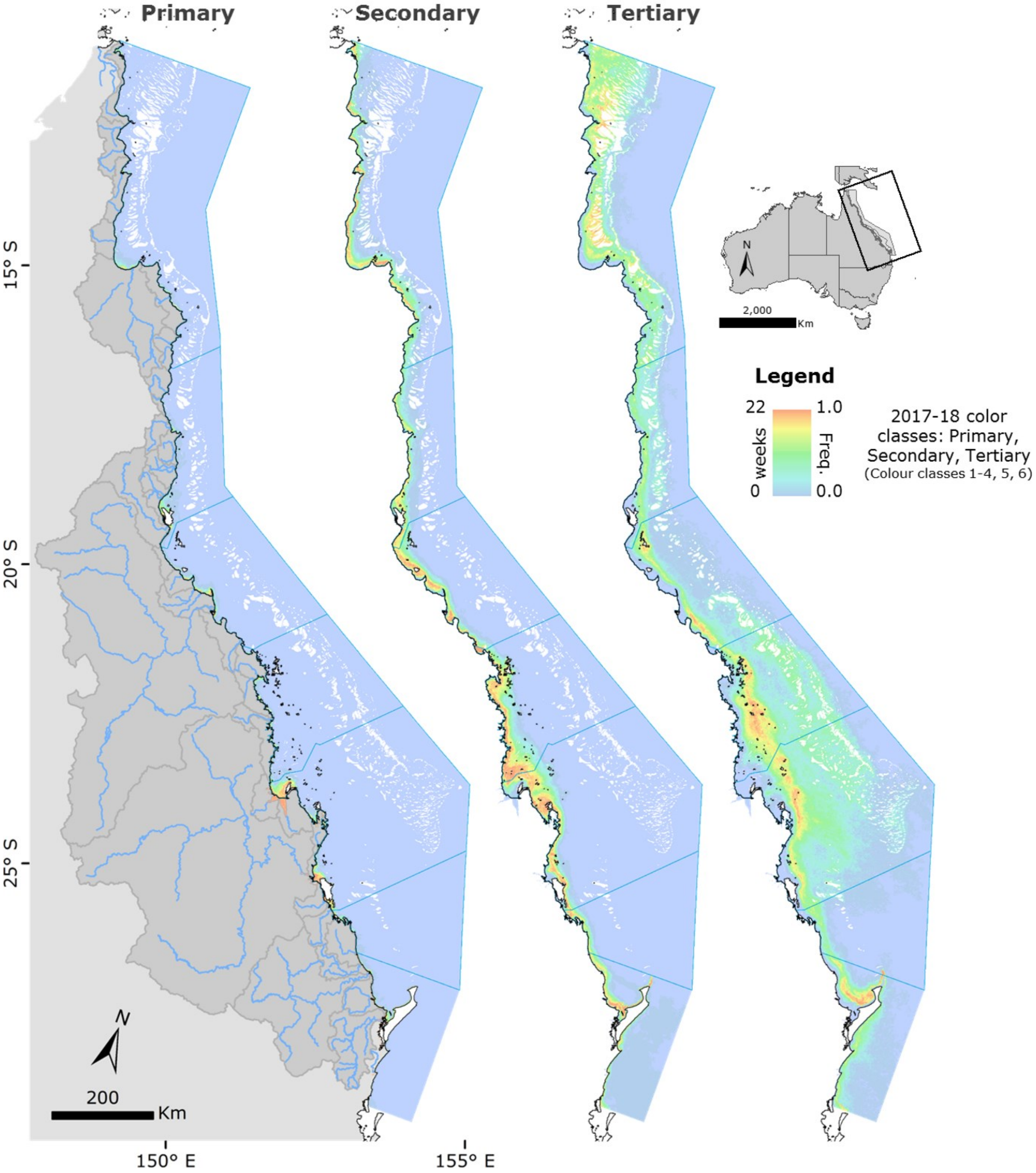


Figure 4-2: Map showing the frequency of primary, secondary and tertiary wet season water types in the 2017–18 wet season (22 weeks), where the highest frequency is shown in orange and the lowest frequency is shown in blue.

4.1.2 Composition of water types

A summary of water quality parameters in the six colour classes in 2017–18 is shown in Figure 4-3 and Figure 4-4 and detailed characteristics are provided in Appendix E.

Most of the key water quality parameters in both the long-term dataset (2003 to 2018) and in the reporting year 2017–18 followed long-term and published trends, i.e. decreasing values of constituents from the primary (colour classes 1 to 4) to the tertiary (colour class 6) water type (and, inversely, increasing trends for Secchi depth).

The mean concentration of water quality parameters measured across the wet season water types and colour classes in 2017–18 were all below the long-term average concentrations, especially PO_4 that was three times below the long-term average concentration for the primary water type (Figure 4-3 and Figure 4-4). The following trends were found:

- primary water type: the long-term and 2017–18 mean TSS, Chl-*a*, PP and PN concentrations were above the wet season GVs
- secondary water type: the long-term mean TSS, Chl-*a*, PP and PN concentrations were above the wet season GVs. The 2017–18 mean TSS concentration was above the wet season GV; however, the 2017–18 mean Chl-*a*, PP and PN concentrations were below their respective wet season GVs.
- tertiary water type: the long-term mean TSS concentration was above the wet season GV; however, the 2017–18 mean TSS concentration was below the wet season GV. The long-term and 2017–18 mean Chl-*a*, PP and PN concentrations were below their respective wet season GVs.

Except for the 2017–18 tertiary water type, the long-term and 2017–18 TSS concentrations were above the wet season GVs (Great Barrier Reef Marine Park Authority, 2010) in each respective wet season water type (Figure 4-3). It is however important to note the high variability of TSS in these waters, as follows:

- $TSS_{primary}$ = 13.1 ± 35.6 mg L^{-1}
- $TSS_{secondary}$ = 4.5 ± 10.3 mg L^{-1}
- $TSS_{tertiary}$ = 2.2 ± 1.7 mg L^{-1} in 2017–18.

All tertiary waters in the 2017–18 wet season met the GVs. Only an annual mean Secchi depth GV has been derived (10 m) and no seasonal GV is currently available (and hence is not indicated on Figure 4-3 and Figure 4-4). The 2017–18 Secchi depth values (7.6 m) did not meet the annual mean value, although the ecological significance of this is not clear.

While Devlin et al. (2012a) reported higher Chl-*a* concentration in the secondary water type than in the primary water type, the 2017–18 wet season was characterised by higher mean Chl-*a* concentrations in the primary water type (1 ± 0.6 µg L^{-1}) than in the secondary water type (0.6 ± 0.4 µg L^{-1}), similar to observations in 2015–16 and 2016–17. Chl-*a* concentrations were, higher in colour class 3 (1.3 ± 0.2 µg L^{-1}) than in colour classes 1 and 2 (0.8 to 0.9 µg L^{-1}) (Figure 4-4). Thus, the sub-classification into colour classes may better describe fine-scale coastal processes in coastal waters and supports the findings of Devlin et al. (2013) that a peak of Chl-*a* concentration is located in transition zones between the primary and secondary water types This peak in Chl-*a* concentration is hypothesised to be driven by a reduction in both TSS and light attenuation, and is measured by increased Secchi depth values, regular nutrient inputs, and the increase in salinity because the growth rate of marine phytoplankton can be inhibited by lower salinity (Carstensen et al., 2015).

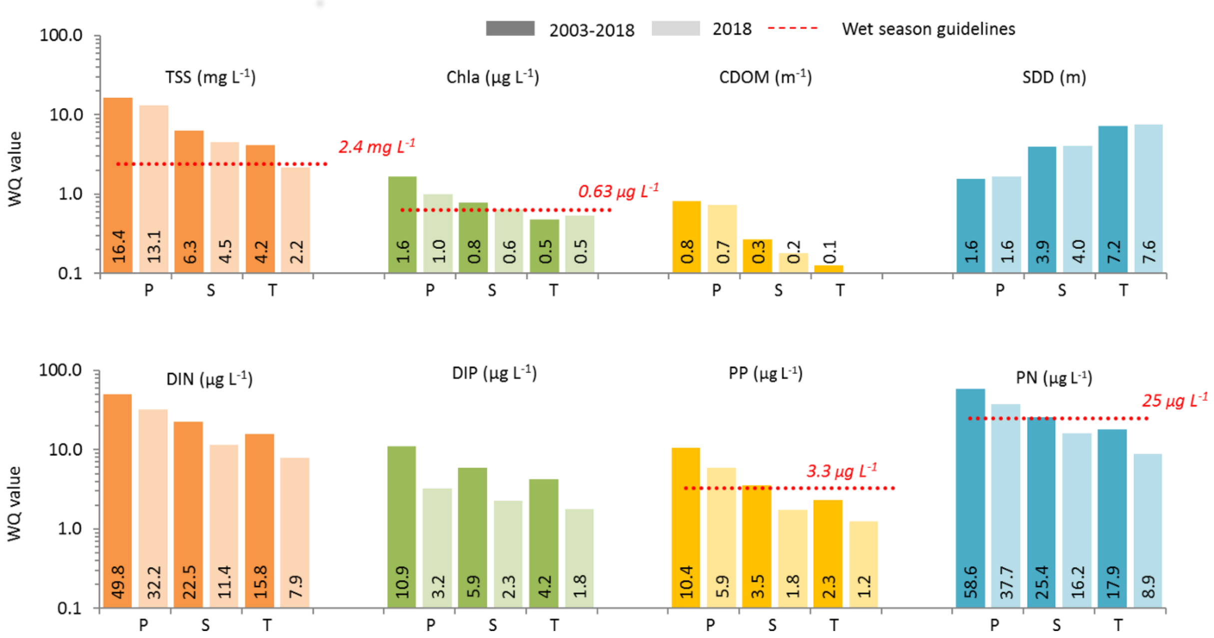


Figure 4-3: Mean water quality concentrations across the three wet season water types: comparison between the mean multi-annual values (2002–03 to 2017–18; dark shaded), the 2017–18 values (light shaded) and wet season GVs for the open coastal and mid-shelf waters (dotted red lines).

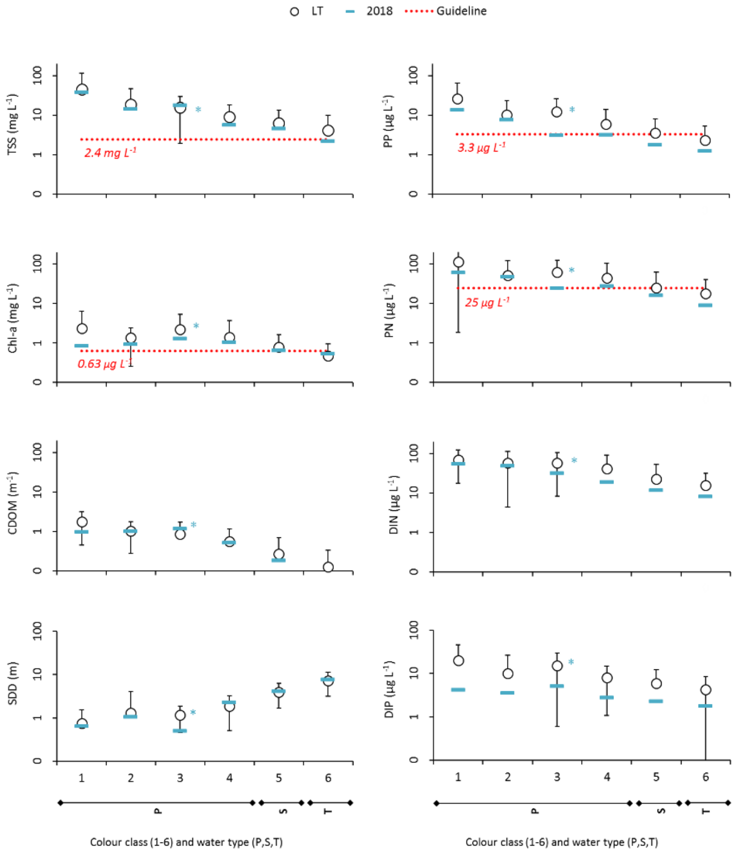


Figure 4-4: Mean water quality concentrations and standard deviation across the six colour classes: comparison between the mean multi-annual values (2002–03 to 2017–18; circles with error bars) and the 2017–18 values (blue rectangles). Blue dots indicate that the number of data was ≤3.

Mean concentrations of water quality parameters across the three 2017–18 wet season water types showed similar trends between the focus regions, with maximum concentrations measured in the primary water type and minimum concentrations in the tertiary water types. However, there were distinct differences in the concentrations of individual pollutants across regions (Figure 3-5).

For example, the Burdekin region had the greatest TSS, Chl-*a*, PO_4, PP and PN concentrations in the primary and secondary water types, whereas maximum mean CDOM and DIN concentrations were measured in the primary water type of the Wet Tropics region. Maximum Chl-*a* concentrations were measured in the primary water type of the Burdekin and Wet Tropics regions. The Mackay-Whitsunday and Cape York regions showed the lowest concentrations of water quality parameters of all regions. However, no water quality data were collected in the primary water type in the Mackay-Whitsunday region and no CDOM were collected in the primary water type in the Cape York region. In addition, the frequency of sampling in flood events was higher in the Wet Tropics region (Russell-Mulgrave three events and Tully 11 events) compared to the other focus areas (three to four in the Cape York transects, two in the Burdekin and none in the Mackay-Whitsunday regions), which is likely to influence the results. To provide context for these results, regional weekly mean concentrations across colour classes were calculated and are presented in the weekly panels in the regional reports of this section (Sections 4.4 to 4.7).

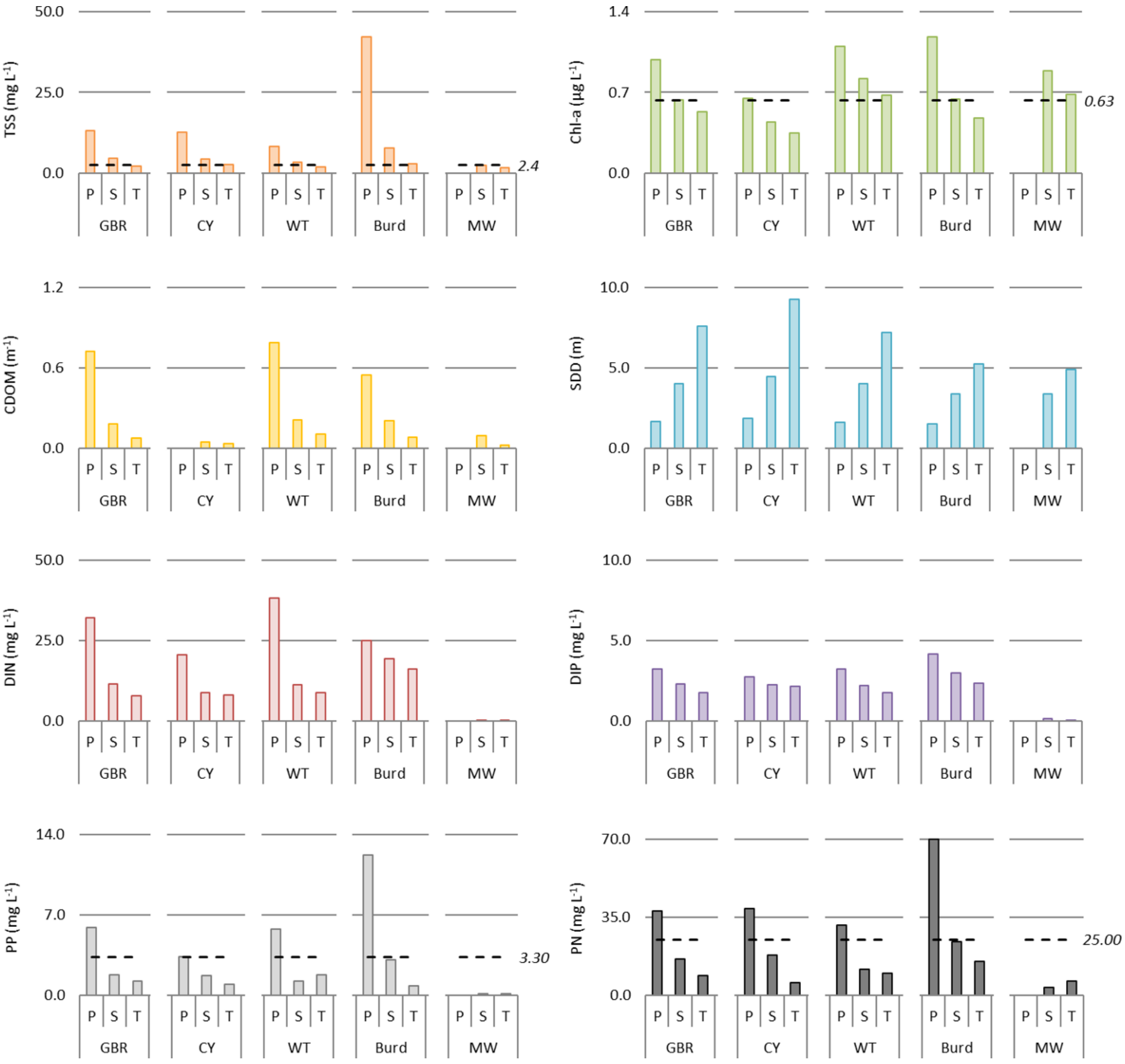


Figure 4-5: Mean 2017–18 water quality concentrations across the three wet season water types: comparison across the focus regions.

4.1.3 Potential exposure risk to Reef ecosystems

The area (km^2) and percentage (%) of coral reefs and seagrass meadows potentially affected by different categories of exposure (or potential risk) based on satellite-derived wet season water types is presented.

The long-term and wet season mean concentrations of water quality parameters (Reef-wide) measured across the wet season water types described above were assessed against the water quality GV for the open coastal and mid-shelf waters (Great Barrier Reef Marine Park Authority, 2010), and used in combination with the seasonal and long-term frequency maps to derive wet season and long-term surface exposure maps, respectively. These assessments incorporate data from all the surface samples collected between December and April by AIMS, JCU and the CYWMP.

Exposure maps were produced (Section 4.1.3) and overlaid with information on the spatial distribution of Reef ecosystems to help identify ecosystems that may experience acute or chronic high exposure to pollutants during the wet season (exposure assessment, Table 4-2).

Figure 4-6 presents the exposure map of the 2017–18 wet season and Table 4-2 presents the areas (km^2) and percentage (%) of total area, coral reef and seagrass area, affected by different exposure categories within the Reef. The maps, areas and percentage are presented in the context of the long-term exposure (2003–18).

In 2017–18, approximately 20% of the total area of the Reef lagoon was exposed to a potential risk, which was much lower than the long-term total area (Table 4-2– 62% exposed). The Reef lagoon was mostly influenced by the lowest exposure categories (categories I and II), in agreement with the long-term trends, but smaller areas were exposed to exposure category I (18% in 2017–18 versus 60% in the long-term). This characteristic was related to the relatively low mean TSS, Chl-*a*, PP and PN concentrations measured in 2017–18 (Figure 4-4) where all the concentrations were under the wet season GVs in the tertiary water type, only TSS was above the wet season GVs in the secondary water type, and TSS, Chl-*a*, PP and PN were above the wet season GVs in the primary water type. Only 0.5% of the Reef lagoon was in the exposure category III and there were no areas of the Reef in the exposure category IV, but these areas are typically low (long-term areas shown in Table 4-2—1% category III and 1% category IV). Regional reports are presented later in Section 5.

The incorporation of the full wet season dataset (including all AIMS, JCU and CYWMP data) in the last two years of analysis, rather than only the results obtained by JCU during flood events in previous years, may have partially contributed to the generally lower exposure values, although the same approach was adopted in 2016–17 and did not result in any comparable differences. It is recommended that the influence of the combination of datasets is investigated further during the next period of reporting.

Coastal areas have the highest frequency of occurrence of primary waters, and thus coastal ecosystems have the greatest potential to be affected by the highest exposure categories (categories III and IV). Inversely, offshore areas are less frequently exposed to wet season water types and, when exposed, are more likely reached by the tertiary water type. Thus, offshore ecosystems are most affected by the lower exposure categories. Inshore ecosystems are located in transitional zones that experience an alteration of water types and frequencies depending on the wet season characteristics and resuspension events.

In 2017–18, it was estimated that:

- A total of 24% of coral reefs were exposed to a potential risk. However, no corals were in the highest exposure category (IV) and only 0.1% of corals were in category III.
- A total of 95% of seagrass area was exposed to a potential risk. No seagrasses were in the highest exposure category (IV) and 13% were in category III.

- The coral and seagrass areas in the highest category of exposure in 2017–18 were lower than the long-term areas (Table 4-2: 0.1% and 0.1% of reefs and 8% and 10% of seagrasses exposed to category III and IV, respectively) and were logical with the characteristic of a relatively dry (close to long-term median) wet season in most regions.

Table 4-2: Areas (km^2) and percentages (%) of the Reef lagoon affected by different categories of exposure within the Reef during the 2017–18 wet season (and long-term values in brackets). Surface areas south of the Marine Park boundary (Hervey Bay) are not included.

Area		**Total**	**Potential Risk category**				**Total area exposed**	**Total area not exposed**
			Lowest		**Highest**			
			I	**II**	**III**	**IV**		
Surface area	area	348,839	63,685	3722	1577	*nil*	68,984	279,856
			(208,111)	(4878)	(2599)	(2369)	(217,957)	(130,882)
	%	*100%*	18%	1%	0.5%	*ne.*	20%	80%
			(60%)	(1%)	(1%)	(1%)	(62%)	(38%)
Coral reefs	area	24,149	5617	42	28	*nil*	5687	18,461
			(22,900)	(109)	(27)	(32)	(23,067)	(1082)
	%	*100%*	23%	0.2%	0.1%	*nil*	24%	76%
			(95%)	(0.4%)	(0.1%)	(0.1%)	(96%)	(4%)
Surveyed seagrass	area	4640	3574	569	277	*nil*	4420	220
			(3,082)	(669)	(352)	(469)	(4572)	(69)
	%	*100%*	77%	12%	6%	*nil*	95%	5%
			(66%)	(14%)	(8%)	(10%)	(99%)	(1%)

4.2 Mapping the dispersal of DIN and sediment from rivers to the Reef

An improved understanding of dispersal of the plume components—DIN and sediment—has been developed using a combination of modelling and *in-situ* monitoring. The process involves dispersing modelled load over individual wet season river plumes, which is corrected for DIN uptake, and then DIN or sediment dispersal from each river plume is summed to represent the total DIN or sediment dispersed over the lagoon in that year. A detailed description of the methodology and maps and their potential applications and limitations are presented in Appendix D-6.

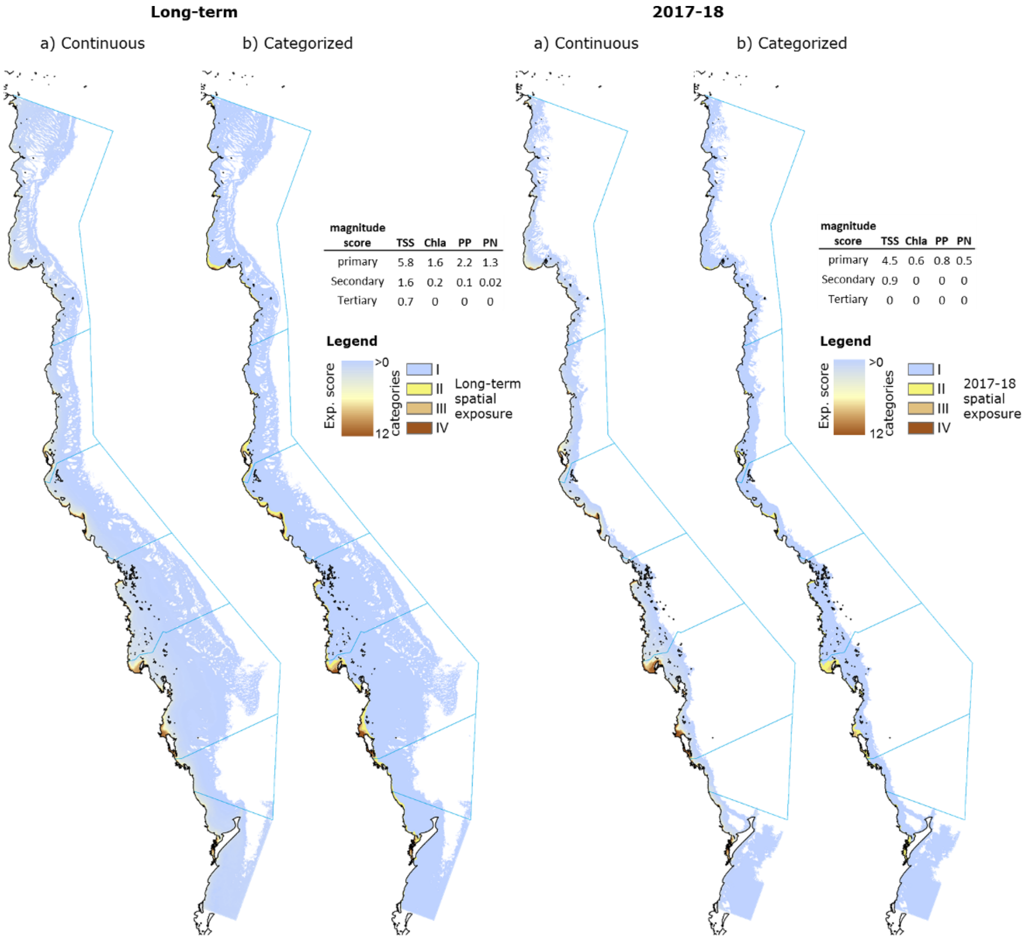


Figure 4-6: Long-term (2003–18) and 2017–18 maps of potential risk exposure produced using the proportional exceedance of the guideline (magnitude score) multiplied by the likelihood of exposure in each of the wet season water types: a) continuous exposure scores and b) categorised exposure scores: [>0–3] = cat. I, [3–6] = cat. II, [6–9] = cat III and [>9] = cat IV.

4.2.1 DIN dispersal in the 2018 water year

The preferential northward movement of the river plumes in the model can result in increased model-predicted DIN concentration into distant water bodies. The river contributions (x-axis) to the DIN loading to the six NRM regions in 2017–18 are shown in Figure 4-7. Overall, rivers located within a marine NRM region were the main contributors to the presence of DIN in its waters, although this varied between regions. For example:

- The Burdekin had minimal (<1%) contribution to the Wet Tropics DIN loading
- The Daintree, Mossman, Barron, and Russell-Mulgrave Wet Tropics Rivers contributed to the Cape York region (8% total)
- The Herbert River contributed around 30% to the Burdekin NRM region DIN loading in 2017–18 and, to a much lesser extent, the Proserpine (3%) and O'Connell (2%) Rivers.

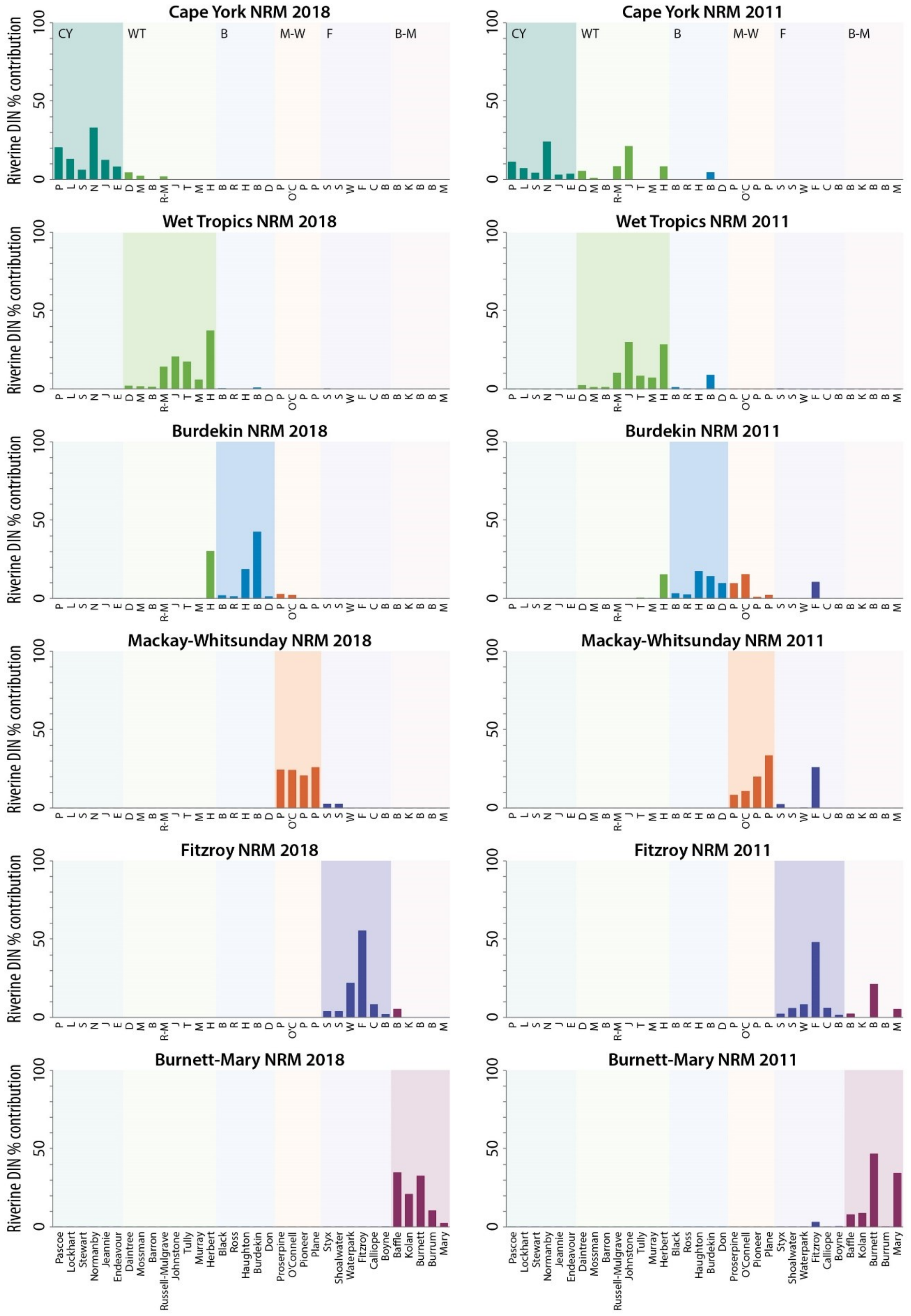


Figure 4-7: River contributions (x-axis) to the DIN loading in the six NRM regions. The shading groups rivers in the same NRM region: Cape York – dark green, Wet Tropics – light green, Burdekin – blue, Mackay-Whitsunday – orange, Fitzroy – purple, Burnett-Mary – maroon. The left panels show data for the 2010–11 water year (1 October to 30 September) and right panels for the 2017–18 water year.

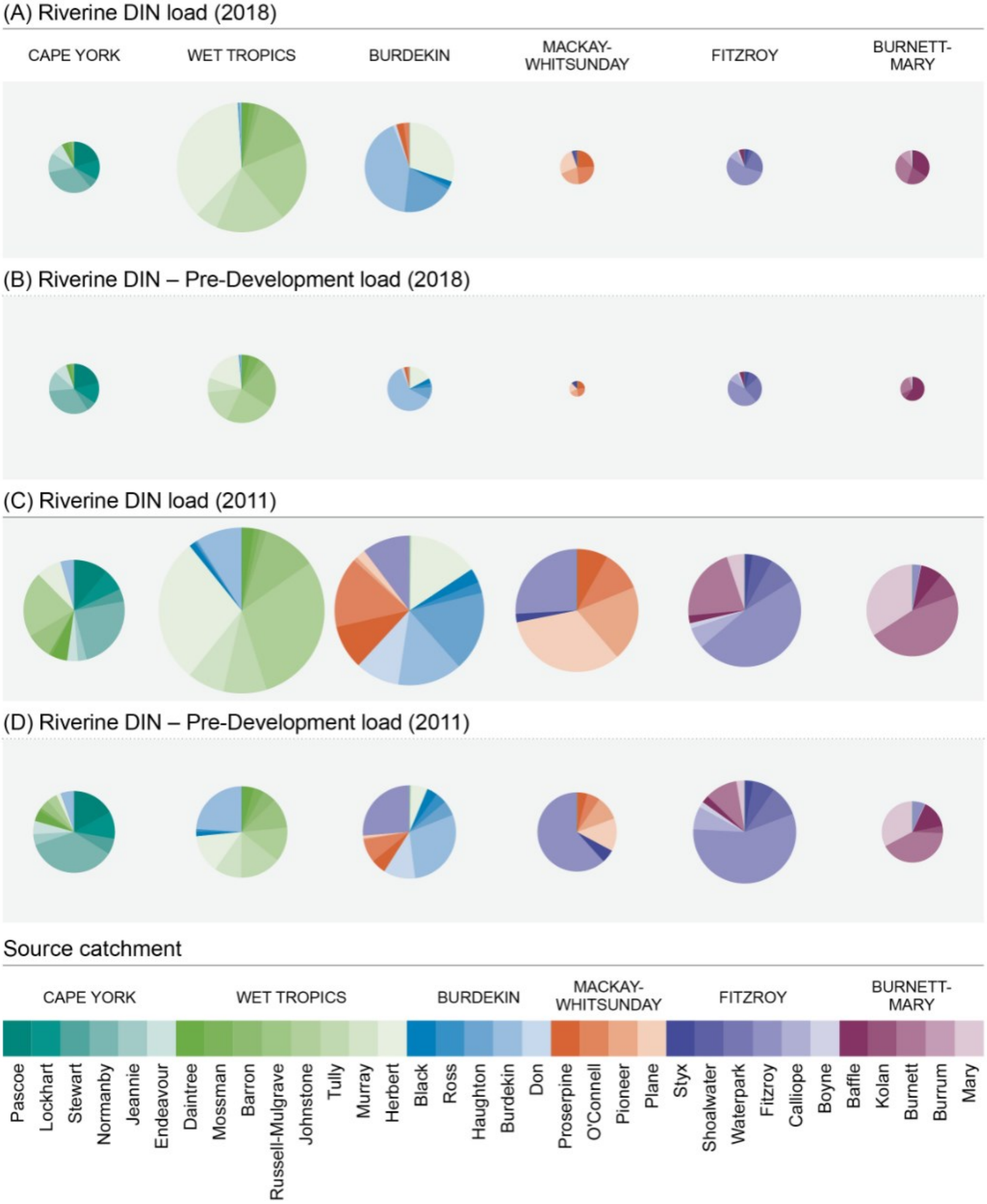


Figure 4-8: River contributions to modelled DIN loading in the six NRM regions. The area of the pie charts is scaled relative to the loading (mass) of DIN in each of the NRM regions. Pie charts are shaded according to the river source catchment. Panels A and B show data for the 2017–18 water year (1 October to 30 September). Panels C and D show data for the 2010–11 water year.

These cross-regional influences are also evident in satellite imagery in the 2017–18 events.

Modelled DIN mass loads are also presented in Figure 4-8, which shows river contributions in the six NRM regions shaded according to the river source catchment, and the relative contribution to the total loading of DIN in each of the NRM regions (shown by scaling the size of the pie charts). Data for the 2017–18 water year (1 October to 30 September) (Panel A) is compared to pre-development loads (Panel B). The results highlight the large DIN loadings from the Wet Tropics region (Panel A) and the large changes between current (Panel A) and pre-development loadings (Panel B), including in the catchment-based contributions, which are linked to land use change and land management practices.

The resulting map of the estimated wet season DIN concentration in the Reef lagoon for the 2018 water year (1 October to 30 September) (Figure 4-9 left panel) was compared to the pre-development loads (Figure 4-9 centre panel) and the difference between them (Figure 4-9 right panel). The difference is interpreted as the ‘anthropogenic’ DIN concentrations, which highlight the areas of greatest change with current land use and land management practices. The Wet Tropics is the dominant area of anthropogenic influence in the 2017–18 wet season and, to a lesser extent, the Burdekin region. Anthropogenic influence is also evident in the Burnett-Mary region.

4.2.2Trends in annual DIN concentration in the Reef during 2005–18

The model-predicted DIN export to the Reef lagoon (based on its annual concentration in µg L^{-1} over 14 years), provides an estimate of the dispersion of river-derived DIN in Reef waters and the resulting map highlights spatial and temporal variation in DIN concentration ().

The time series from 2005 to 2018 () shows distinct differences between years, driven by river flow and pollutant loads, and region. The areas of influence in 2017–18 are comparable to those years with river discharge close to or below the long-term median, e.g. 2013–14. The greatest extent of the highest concentrations of model-predicted DIN concentration was observed in 2011 (associated with tropical cyclone Yasi), with large areas of high DIN values estimated in all areas except for Cape York.

The areas presenting higher DIN concentrations were relatively constant over the years, with higher DIN values observed in the Wet Tropics and Mackay-Whitsunday NRM regions than in the other regions. The greatest incidence of high DIN values occurred in the Wet Tropics region in all years including 2018 and, within the Wet Tropics, the greatest areas of high values were correlated with large river discharge events in 2006, 2007, 2009, 2011, 2014 and 2018. High values were also observed in each region during different years. For example, high values in the Mackay-Whitsunday region in 2008, each year in 2010 to 2013 and in 2017 (Figure 4-10).

Even though the Burdekin River is responsible, on average, for over 36% of the DIN load accounted for in the model, it is also responsible for 60% of the total discharge. The periodically large Burdekin River discharge results in large plumes and, consequently, dilutes DIN concentrations.

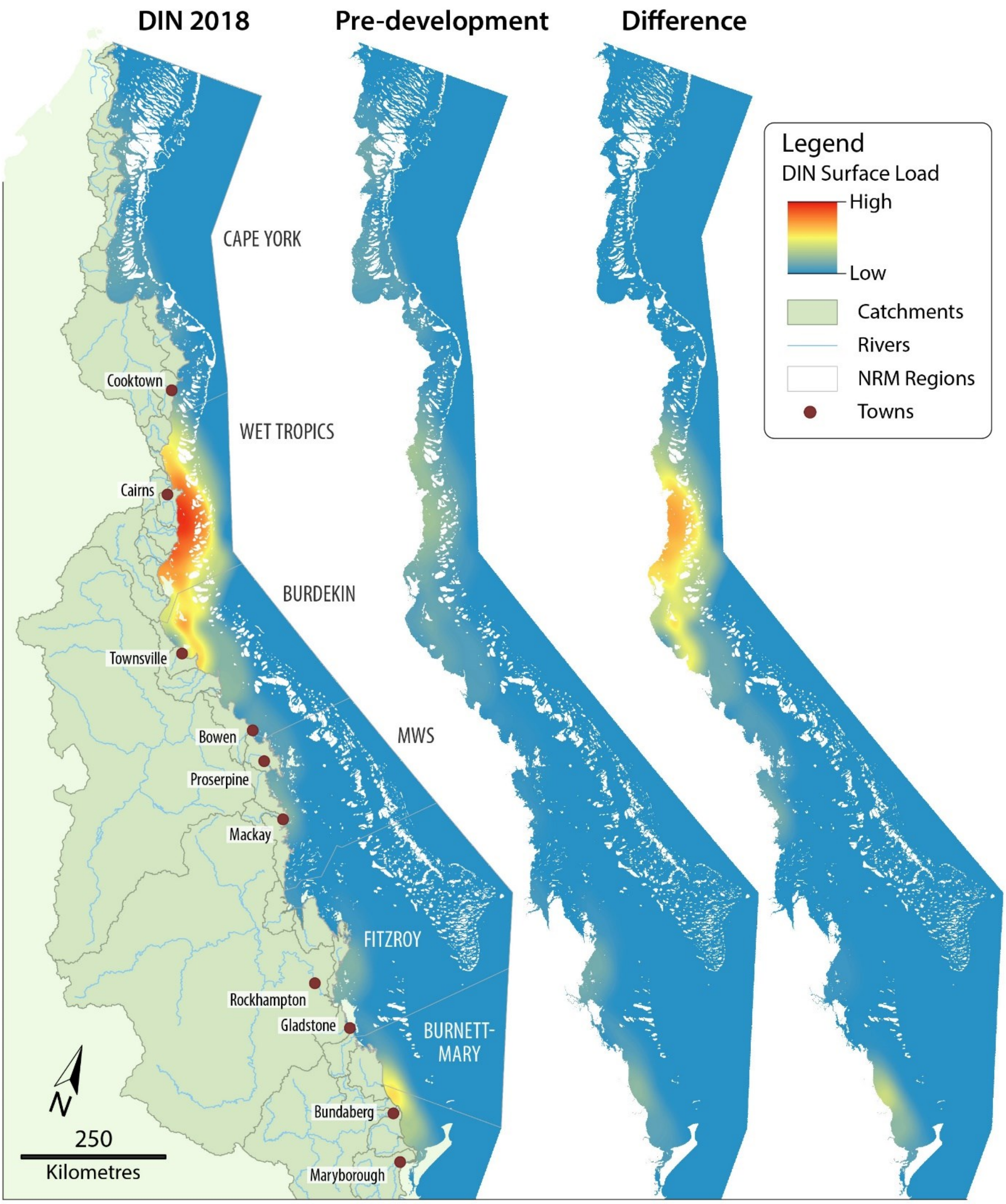


Figure 4-9: DIN concentration in the Reef lagoon, modelled for the (left panel) 2018 water year (1 October to 30 September), (centre panel) pre-development loads and (right panel) difference between the DIN concentration with pre-development end-of-catchment DIN load estimates and the 2018 estimates.

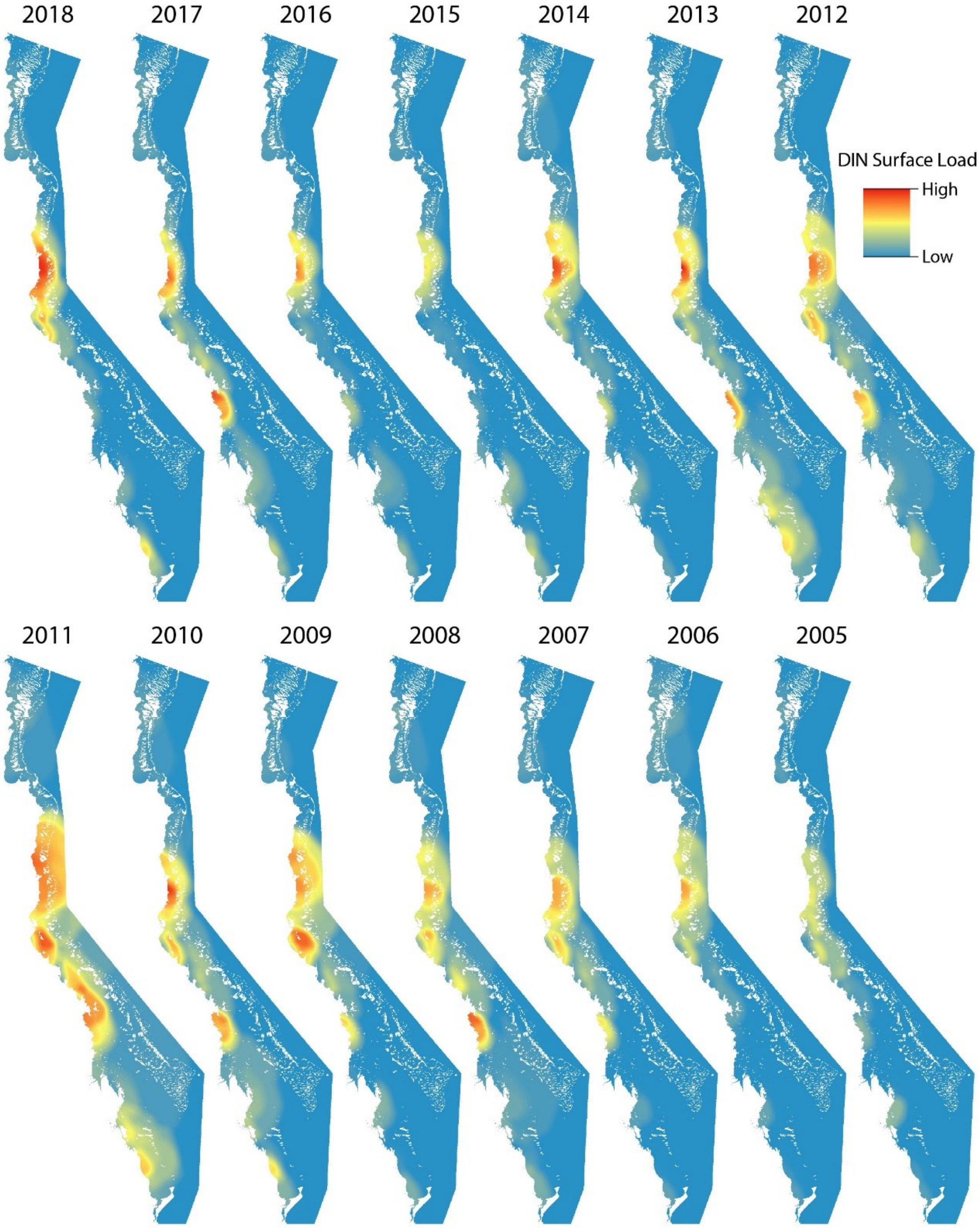


Figure 4-10: DIN over the Reef lagoon for the 2005 to 2018 water years (1 October to 30 September).

4.3 Mapping annual average TSS concentrations 2005–18

The same model developed for DIN dispersion was used to produce maps for the river-derived TSS in the Reef, except that the decay function was not included.

4.3.1 TSS dispersal in the 2018 water year

The preferential northward movement of the river plumes in the model can result in increased model-predicted TSS concentration in areas that may not directly receive high loads from their catchments. Figure 4-11 shows the river contributions (x-axis) to the TSS loadings for the six NRM regions in 2017–18. Rivers located within a marine NRM region were the main contributors to the presence of river-derived TSS in its waters, although this varied between regions. For example:

- In 2017–18 only the Daintree (4%), Mossman (3%) and Russell-Mulgrave (1%) Rivers contributed to the Cape York region TSS loading
- The influence of the Burdekin River extended to the Wet Tropics region in 2017–18 (5%), and the Herbert (5%), Don, Proserpine and O'Connell Rivers all had minor (<1%) contributions to the TSS loading in the Burdekin region
- The cross-regional influence between the Fitzroy and Burnett-Mary regions and rivers occurred in the Fitzroy from the Baffle River (9%) in 2017–18.

These cross-regional influences are also evident in satellite imagery during the 2017–18 events. As with DIN, these results further support the conclusion that the northward plume transport has the potential to increase the TSS load impact into zones outside of the NRM region.

Another way of presenting this information is provided in Figure 4-12, which shows river contributions to modelled TSS loading (mass) in the six NRM regions shaded according to the river source catchment, and the relative contribution to the total loading of TSS in each of the NRM regions (shown by scaling the size of the pie charts) for the 2017–18 water year (1 October to 30 September). These panels highlight the large overall TSS loadings from the Burdekin region (Figure 4-12 Panel A) and the large changes between current (Panel A) and pre-development loadings (Figure 4-12 Panel B) in most regions with notably less change in the Cape York region.

Figure 4-13 shows the difference between the estimated wet season TSS concentration in the Reef lagoon for the 2018 water year (1 October to 30 September) (Figure 4-13 left panel), compared to the pre-development loads (Figure 4-13 centre panel) and the difference between them (Figure 4-13 right panel). This can be interpreted as 'anthropogenic' TSS concentrations, highlighting the areas of greatest change with current land use and land management practices. This highlights the Burdekin region as the dominant area of anthropogenic influence in the 2017–18 wet season and, to a lesser extent, the Burnett-Mary and Wet Tropics regions.

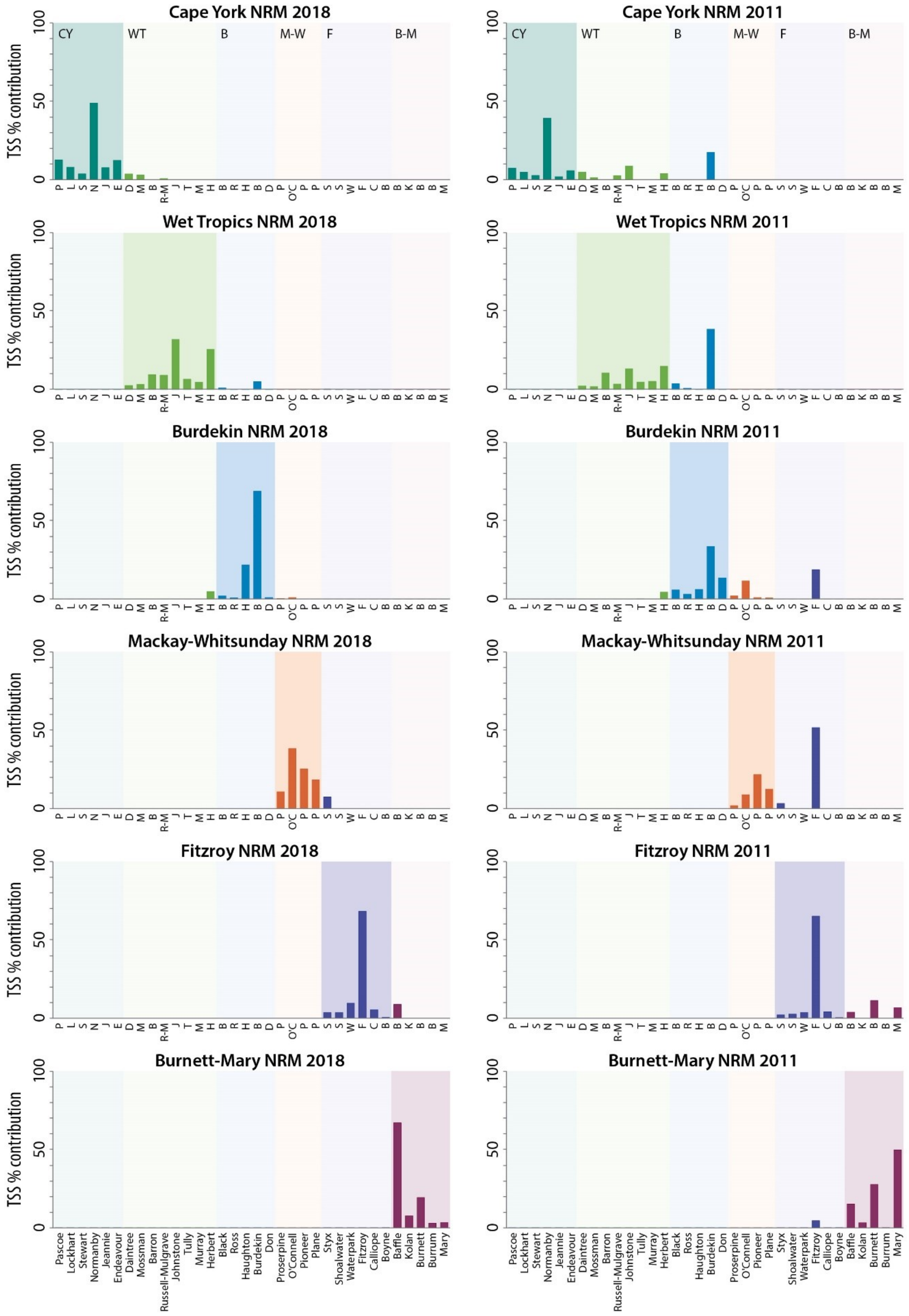


Figure 4-11: River contributions (x-axis) to the TSS loading in the six NRM regions. The shading groups rivers in the same NRM region: Cape York – dark green, Wet Tropics – light green, Burdekin – blue, Mackay-Whitsunday – orange, Fitzroy – purple, Burnett-Mary – maroon. The left panels show data for the 2010–11 water year (1 October to 30 September) and right panels for the 2017–18 water year.

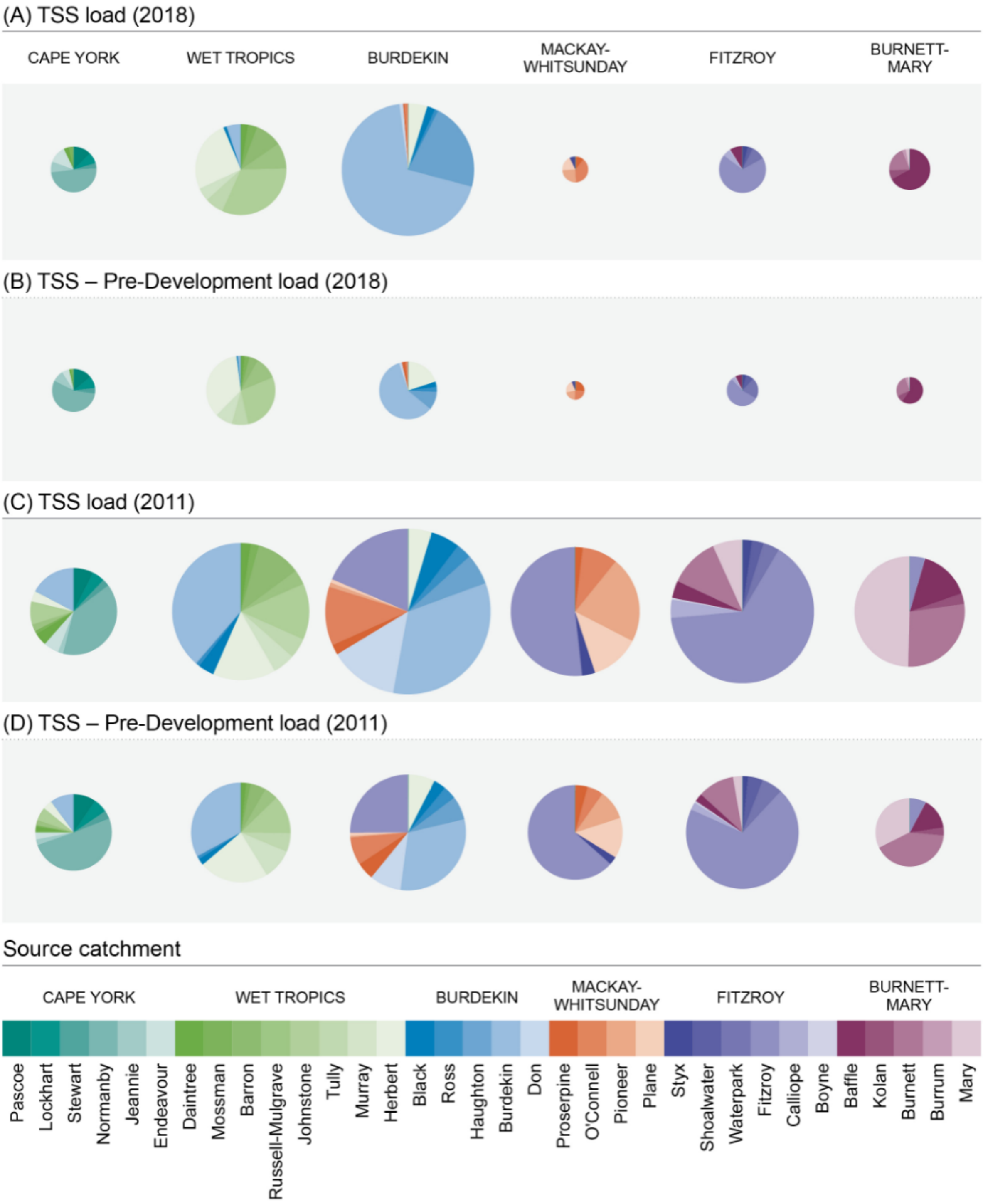


Figure 4-12: River contributions to modelled TSS loading in the six NRM regions. The area of the pie charts is scaled relative to the loading (mass) of TSS in each of the NRM regions. Pie charts are shaded according to the river source catchment. Panels A and B show data for the 2017–18 water year (1 October to 30 September). Panels C and D show data for the 2010–11 water year.

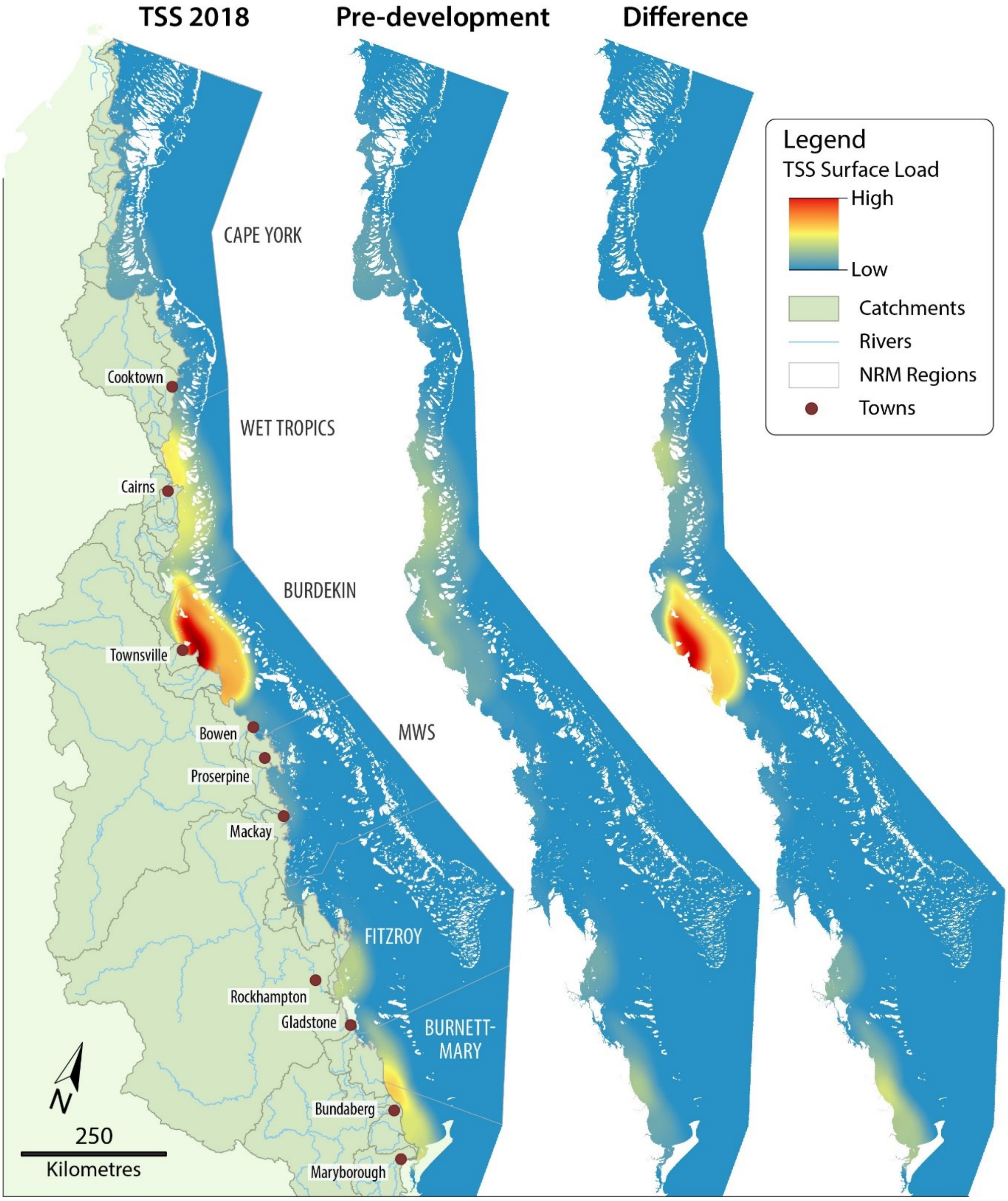


Figure 4-13: TSS (mg L^{-1}) in the Reef lagoon, modelled for the (left panel) 2018 water year (1 October to 30 September), (centre panel) pre-development loads and (right panel) the difference between TSS concentration with pre-development end-of-catchment TSS load estimates and the 2018 estimates.

4.3.2 Trends in annual TSS concentration in the Reef during 2005–18

The annual concentration of model-predicted TSS export to the Reef lagoon was examined over 14 years (Figure 4-14). The greatest extent of the higher model-predicted TSS concentration was observed in 2011, followed by 2007 and 2008. The areas with the highest TSS concentration were more variable over the years than for the DIN assessment.

The greatest incidence of the highest TSS values occurred in the Burdekin region and were correlated with large river discharge events in 2005, 2007, 2008, 2009, 2010, 2011, 2013, 2017 and 2018. High values were also observed in each region in different years. For example, high values occurred in the Fitzroy region in each year between 2010 and 2013; in the Mackay-Whitsunday region in 2008, 2010 and 2011; and in the Wet Tropics region in 2008, 2009 and 2011 (Figure 4-14).

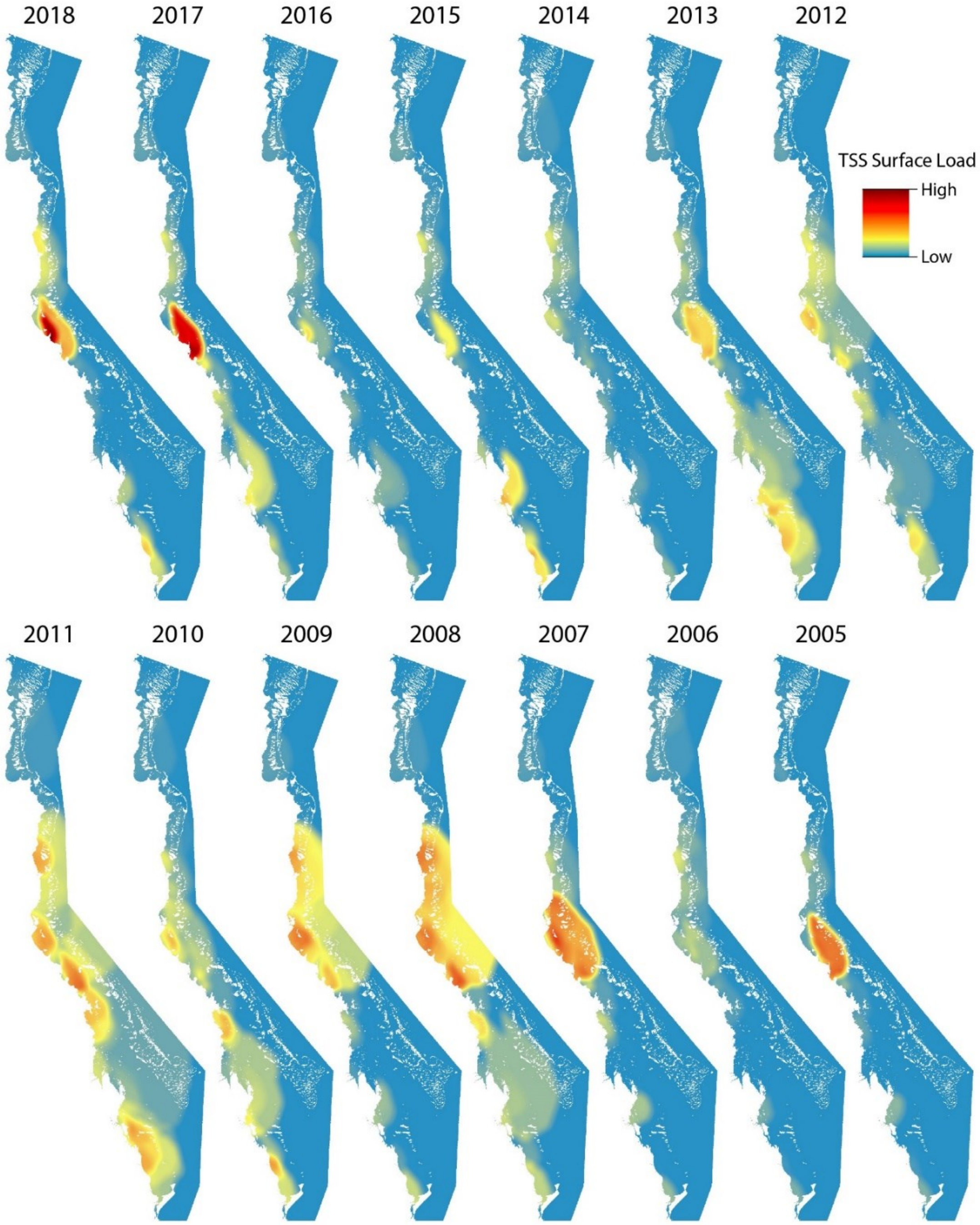


Figure 4-14: TSS over the Reef lagoon for the 2005 to 2018 water years (1 October to 30 September).

4.4 Cape York

The cumulative exposure of marine ecosystems to discharge from the Normanby River was estimated for the first time using a passive tracer in the eReefs hydrodynamic model. Results showed relatively high exposure to river discharge in the enclosed coastal zone during the 2017–18 water year (Figure 4-15), although model resolution near the Kennedy and Bizant River mouths is not sufficient to capture the extent of exposure. Exposure to river-derived material also occurred in the open coastal and mid-shelf water bodies. Model output suggests that Normanby River plumes may actually be transported closer to the centre of Princess Charlotte Bay rather than along the axis of the current MMP sampling transect (NR01 – NR06; Figure 5-11), which may require consideration in future monitoring years.

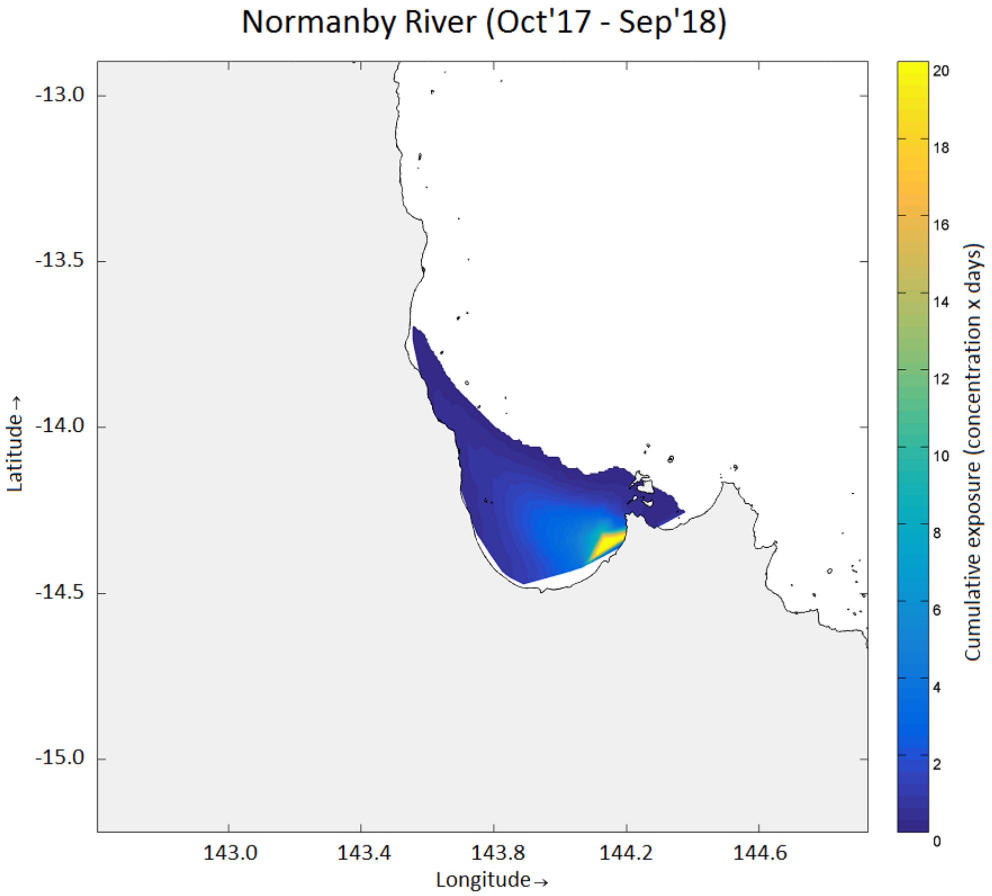


Figure 4-15: Cumulative exposure index for the Normanby River from October 2017to September 2018. The colour bar indicates the calculated cumulative exposure (concentration x days) above 1% of the incoming concentration. The colour bar is capped at 20 concentration days.

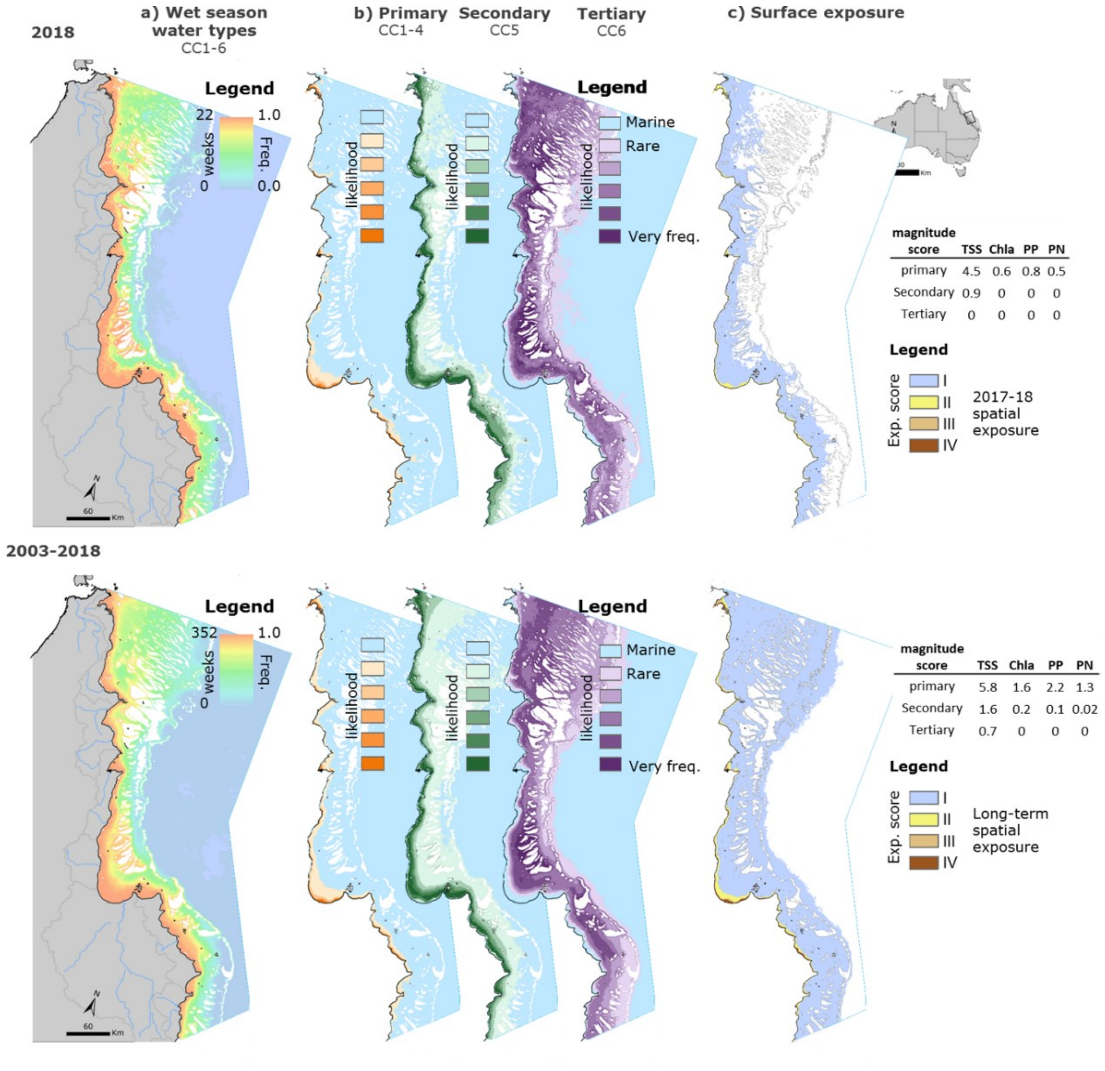
As described for the Reef, a number of mapping products were generated to represent wet season water quality conditions in the Cape York region. The *in-situ* data collected by the CYWMP during the wet season, including high flow periods, is used to characterise and validate these products. This data are presented in Figure 4-16 and in a panel of weekly characteristics throughout the 22 week wet season period (Figure 4-17 and Figure 4-18).

Details in the panels include:

- *in-situ* water quality characteristics including TSS, Secchi depth, Chl-*a* and DIN within each colour class
- weekly river discharge

- wind speed and direction
- weekly wet season water type maps showing the six wet season colour classes.

Figure 4-16 (top) presents the frequency of the combined wet season water types (primary, secondary and tertiary), the frequency of primary, secondary and tertiary wet season water types individually, and the exposure map in the 2017–18 wet season.



magnitude score	TSS	Chla	PP	PN
primary	4.5	0.6	0.8	0.5
Secondary	0.9	0	0	0
Tertiary	0	0	0	0

magnitude score	TSS	Chla	PP	PN
primary	5.8	1.6	2.2	1.3
Secondary	1.6	0.2	0.1	0.02
Tertiary	0.7	0	0	0

Figure 4-16: Maps showing the a) frequency of combined wet season water types (primary, secondary and tertiary), b) the frequency of primary, secondary and tertiary wet season water types and c) the exposure maps for the Cape York region in the long-term (bottom) and 2017–18 wet season (top).

Table 4-3presents the area (km^2) and percentage (%) of total area, coral reefs and seagrasses (surveyed) affected by different exposure categories corresponding to different potential risk for the seagrass and coral reef ecosystems within the Cape York region. The term ‘potential’ is used as the exposure maps have not been yet validated against ecological health data to confirm the ecological consequences of the risk. The maps are presented in the context of the long-term exposure (2003–18) in Figure 4-16 (bottom) with the areas and percentage of exposure summarised in Table 4-3 (numbers in brackets).

In 2017–18, the Cape York region was most affected by the lowest exposure categories (categories I and II), in agreement with the long-term trends. Approximately 25% of the total area of the Cape York region was exposed to a potential risk (Table 4-3). This area was smaller than the long-term area (55% exposed to a potential risk) primarily due to a smaller total area exposed to the lower exposure category I (24% in 2017–18 versus 53% in the long-term). Only 0.1% of the Cape York region was exposed to exposure category III and no area to exposure category IV. These areas were slightly smaller than long-term areas, which are small anyway (0.4% exposed to category III and 0.3% to category IV).

In 2017–18, it was estimated that:

- A total of 40% of Cape York coral reefs were exposed to a potential risk, which was smaller than the long-term exposure (Table 4-3: 97% of Cape York coral reefs). Only 0.01% of corals were in exposure category III and no corals were in the highest exposure category IV.
- A total of 94% of the Cape York seagrasses were exposed to a potential risk. No seagrasses were in the highest exposure category IV and 2% were in exposure category III.
- The areas of coral reefs and seagrasses exposed to category III were slightly smaller than long-term areas (0.1% and 0.02% of reefs and 5% and 4% of seagrasses were exposed to categories III and IV, respectively). These results are consistent with the characteristic of an average wet season for this region
- Tertiary water exposure, generally represented by category I, is expected to have low or no detrimental ecological effects, assuming that the duration of exposure is not long-term.

Table 4-3: Areas (km^2) and percentages (%) of the Cape York marine NRM region affected by different categories of exposure during the 2017–18 wet season (and *long-term values in brackets*).

Area		**Total**	**Potential Risk category** **Lowest ------------------------ highest**				**Total exposed**	**Total non-exposed**
			I	**II**	**III**	**IV**		
Surface area	area	96,316	22,972	579	130	*nil*	23,681	72,635
			(51,489)	(1152)	(418)	(266)	(53,325)	(42,991)
	%	*100%*	24%	1%	0.1%	*nd.*	25%	75%
			(53%)	(1%)	(0.4%)	(0.3%)	(55%)	(45%)
Coral reefs	area	10,375	4147	16	1	*nil*	4164	6211
			(10,022)	(33)	(8)	(3)	(10,066)	(309)
	%	*100%*	40%	0.2%	0.01%	*nd.*	40%	60%
			(97%)	(0%)	(0.1%)	(0.02%)	(97%)	(3%)
Surveyed seagrass	area	2655	2259	190	57	*nil*	2506	149
			(2,077)	(310)	(129)	(112)	(2629)	(26)
	%	*100%*	85%	7%	2%	*nil*	94%	6%
			(78%)	(12%)	(5%)	(4%)	(99%)	(1%)

Figure 4-17 and Figure 4-18 illustrate the changes in water quality and environmental conditions in the Cape York region and focus on surface data collected by CYWMP between December 2017 and April 2018. The 2017–18 wet season was characterised by below average river discharges for the first quarter of the wet season (until early February – week 9), then most weeks were characterised by above average weekly river discharges except for weeks 11–12, and 19–22.

The maximum wet season water quality surface concentrations were measured during week 8 (19 January 2017: 370.0 mg L^{-1} for TSS, 78.0 μg L^{-1} for DIN). However, cloud cover prevented obtaining clear satellite imagery of the flood plumes for this week. Using only sites with a satellite colour class category (i.e. no cloud), the highest weekly average concentrations were:

- week 17 in colour class 1 for TSS (33.5 mg L^{-1})
- week 8 for Chl-*a* in class 4 (1.4 µg L^{-1})
- week 11 for DIN in colour class 2 (45 µg L^{-1}, no data was available in colour class 1).

This is approximately 14 and 2 times the wet season TSS and Chl-*a* GVs, respectively, for the open coastal and mid-shelf waters. The GV, however, is a seasonal mean and the ecological effect of the acute concentration peak is not known. No week had *in-situ* samples collected across all colour classes (1 to 6), which did not allow the depiction of a full description of water quality changes across the colour gradients.

Using only sites with a satellite colour class category (i.e. no cloud), the mean seasonal TSS concentrations measured across the primary and secondary water types were 12.6 and 4.3 mg L^{-1}, i.e. approximately 5 and 2 times the wet season TSS GVs of 2.4 mg L^{-1}, respectively (Table E-6). The mean seasonal Chl-*a* concentrations in the primary water type was 0.65 µg L^{-1}, i.e. just above the Chl-*a* GV of 0.63 µg L^{-1}. The mean seasonal PP concentration in the primary water type was 3.4 µg L^{-1} just above the 3.3 µg L^{-1} GV and the mean seasonal PN concentration in the primary water type was 38.7 µg L^{-1}, i.e. approximately 1.5 times the wet season PN GV of 25 µg L^{-1}. Finally, the mean seasonal TSS concentration in the tertiary waters, Chl-*a*, PP and PN concentrations in the secondary and tertiary water types were all under their respective wet season GVs (Table E-6).

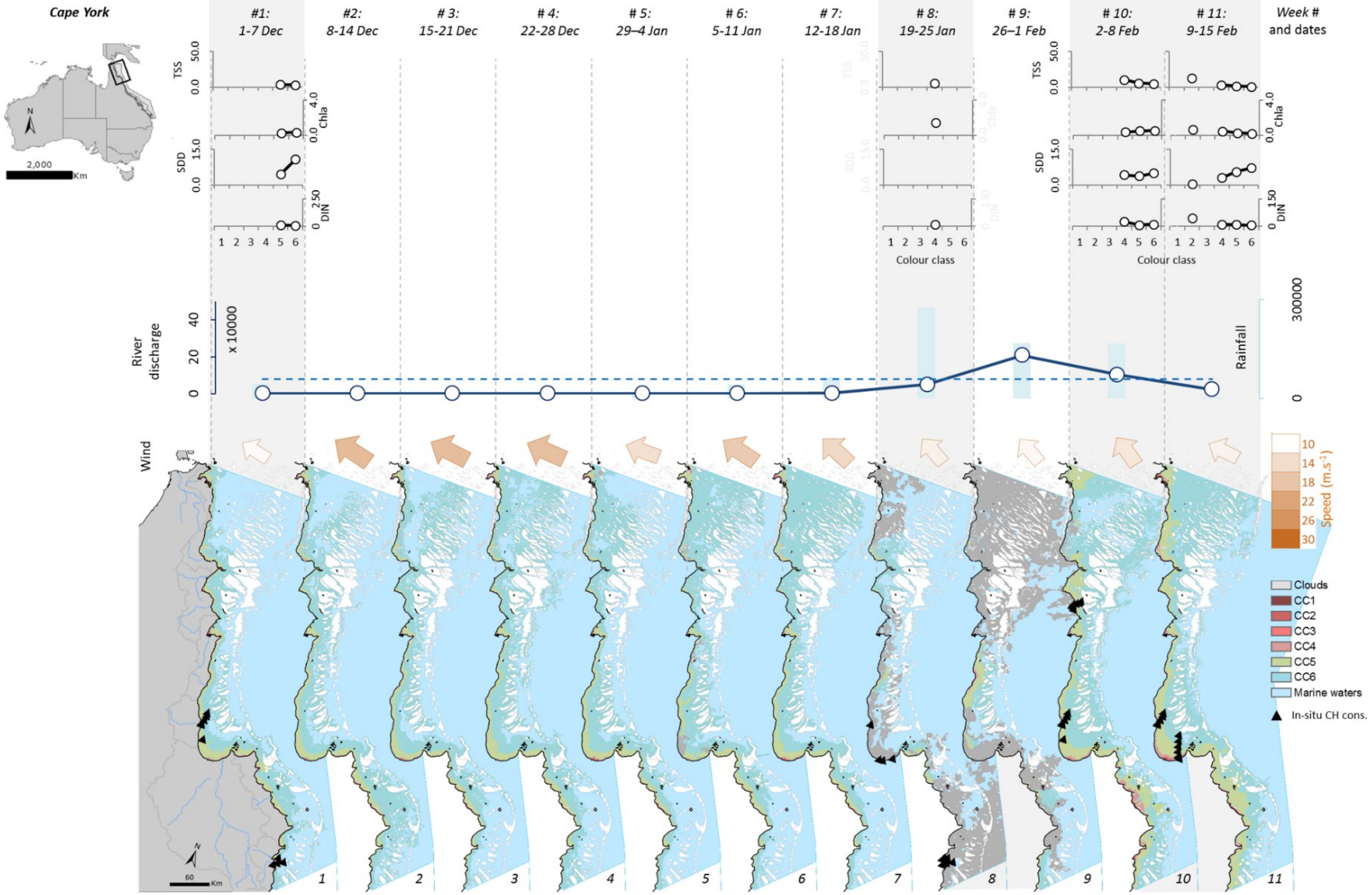


Figure 4-17: Panel of water quality and environmental characteristics in the Cape York region throughout the 2017–18 wet season period: weeks 1 to 11. Details included in the panels: mean TSS (mg L^{-1}), Secchi depth (SDD) (m), Chl-*a* (µg L^{-1}) and DIN (µg L^{-1}) within each colour class; weekly river discharge (ML/day) and rainfall (mm) (note different scales between regions); wind speed (m.s^{-1}) and direction; and the wet season water type maps showing the six wet season colour classes as well as the location of the *in-situ* data collected by CYWMP. The long-term mean weekly river discharge is indicated by a dotted blue line.

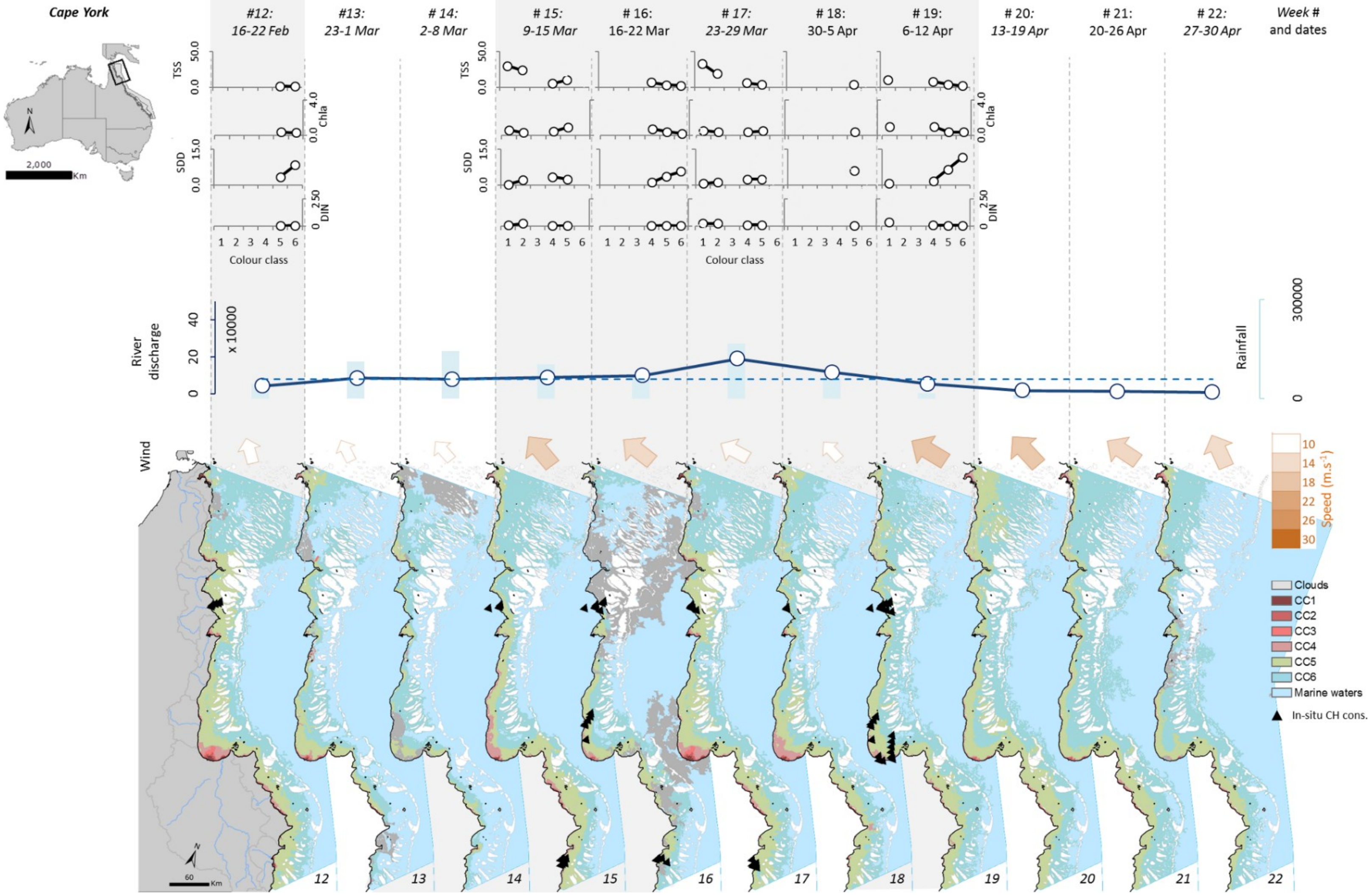


Figure 4-18: Panel of water quality and environmental characteristics in the Cape York region throughout the 2017–18 wet season period: weeks 12 to 22. Details included in the panels: mean TSS (mg L^{-1}), Secchi depth (SDD) (m), Chl-*a* (µg L^{-1}) and DIN (µg L^{-1}) within each colour class; weekly river discharge (ML/day) and rainfall (mm) (note different scales between regions); wind speed (m.s^{-1}) and direction; and the wet season water type maps showing the six wet season colour classes as well as the location of the *in-situ* data collected by CYWMP. The long-term mean weekly river discharge is indicated by a dotted blue line.

4.5 Wet Tropics

Cumulative exposure mapping derived from eReefs hydrodynamic model output showed that enclosed coastal, open coastal and some mid-shelf sites in the Barron-Daintree focus area were exposed to material derived from the Barron River during the 2017–18 monitoring year (Figure 4-19). Detectable levels of river discharge (>1% of input) from Barron River plumes extended ~90 km northward from the Barron River mouth.

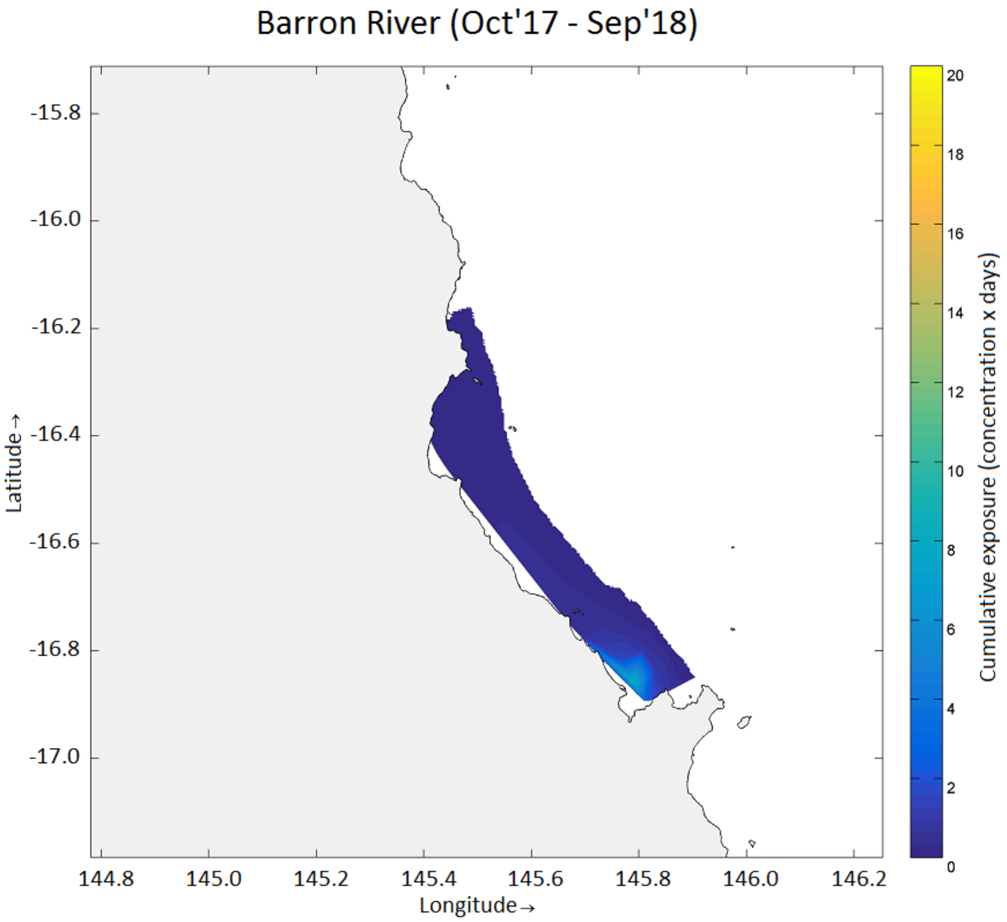


Figure 4-19: Cumulative exposure index for the Barron River from October 2017 to September 2018. The colour bar indicates the calculated cumulative exposure (concentration x days) above 1% of the incoming concentration. The colour bar is capped at 20 concentration days.

Cumulative exposure mapping in the Russell-Mulgrave focus area (Figure 4-20) showed that enclosed coastal regions were heavily influenced by river-derived material over the 2017–18 monitoring year. Open coastal and mid-shelf sites were also exposed to river-derived material. Detectable levels of river discharge (>1% of background) from Russell-Mulgrave River plumes extended ~220 km northward from the river mouth, well beyond the spatial extent of the Barron River plumes (Figure 4-19). Russell-Mulgrave River plumes also extended southward ~80 km from the river mouth and southward plumes tended to be transported offshore reaching a number of mid-shelf reefs (Figure 4-20).

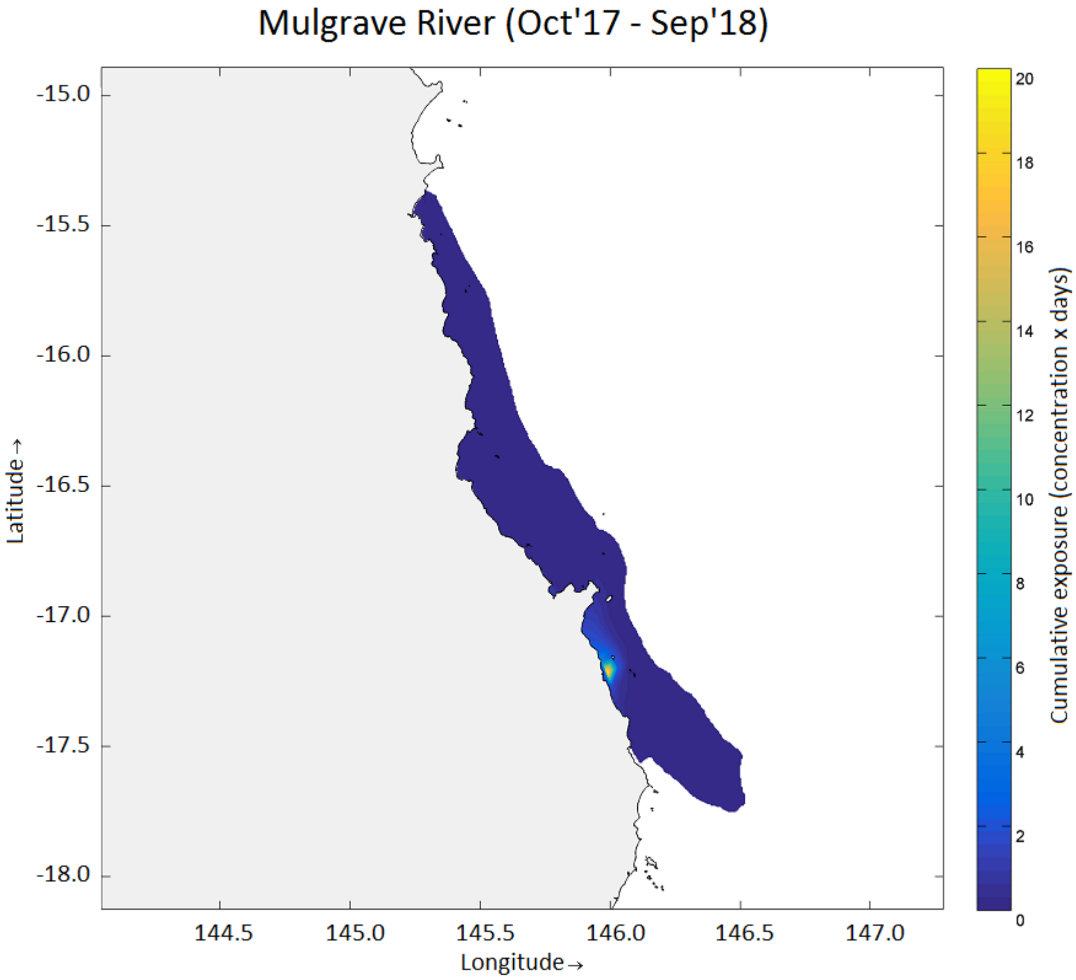


Figure 4-20: Cumulative exposure index for the Russell-Mulgrave River from October 2017 to September 2018. The colour bar indicates the calculated cumulative exposure (concentration x days) above 1% of the incoming concentration. The colour bar is capped at 20 concentration days.

Cumulative exposure mapping in the Tully focus area (Figure 4-21) showed that enclosed coastal regions were heavily influenced by river-plumes from the Tully River over the 2017–18 monitoring year. Open coastal and mid-shelf sites were also exposed to river-derived material. Detectable levels of river discharge (>1% of background) from Tully River plumes extended ~100 km northward from the river mouth, overlapping the spatial extent of southerly plumes from the Russell-Mulgrave River (Figure 4-20). Tully River plumes also extended southward ~40 km from the river mouth and southward plumes tended to be transported offshore (to the southeast) reaching Hinchinbrook Island (Figure 4-21).

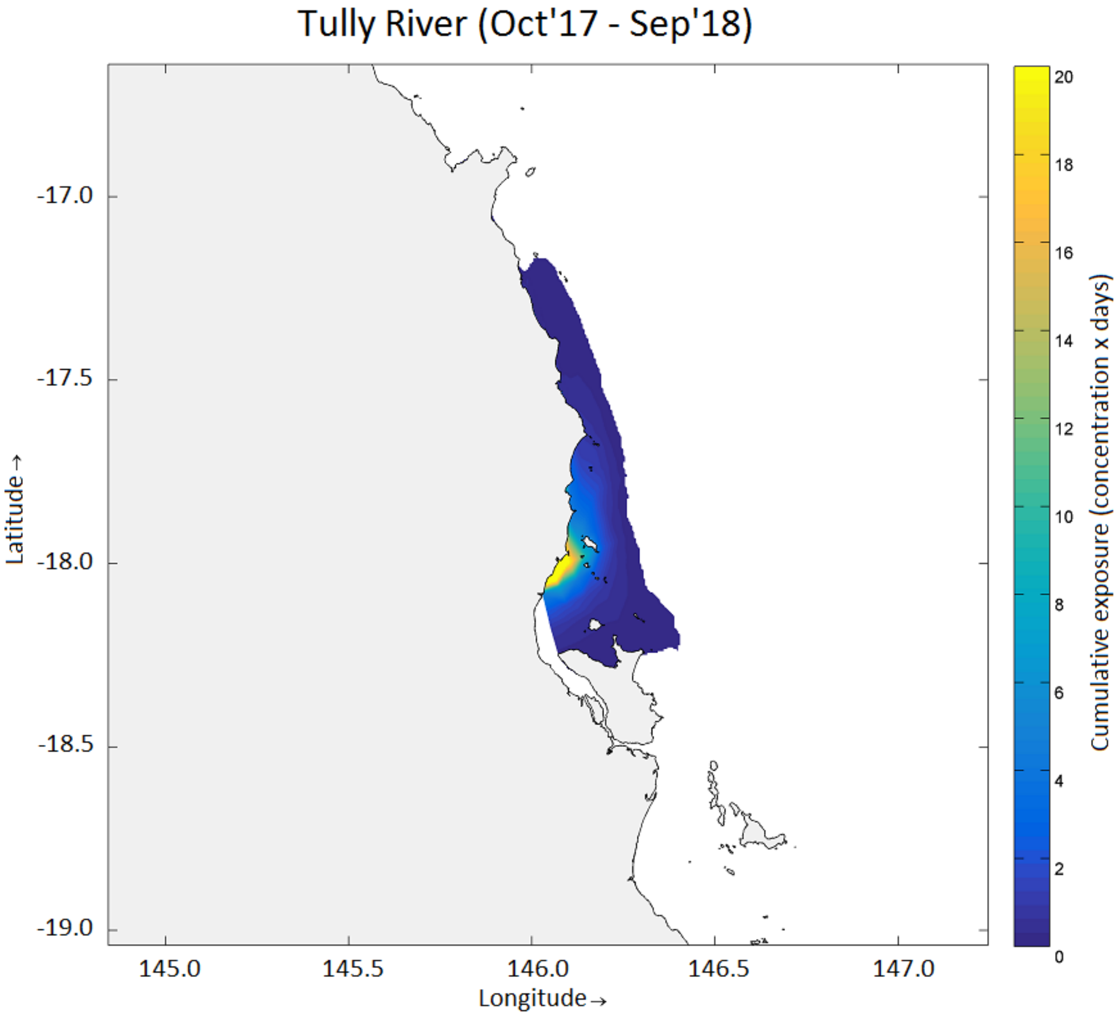


Figure 4-21: Cumulative exposure index for the Tully River from October 2017 to September 2018. The colour bar indicates the calculated cumulative exposure (concentration x days) above 1% of the incoming concentration. The colour bar is capped at 20 concentration days.

Mapping products were also generated to represent wet season water quality conditions in the Wet Tropics region. The surface *in-situ* data collected by JCU and AIMS during the wet season, including high flow periods, were used to characterise and validate these products. This data is presented in Figure 4-22 and in a panel of weekly characteristics throughout the 22-week wet season period (Figure 4-23 and Figure 4-24).

Details in the panels include:

- *in-situ* water quality characteristics including TSS, Secchi depth, Chl-*a* and DIN within each colour class
- weekly river discharge
- wind speed and direction
- weekly wet season water type maps showing the six wet season colour classes.

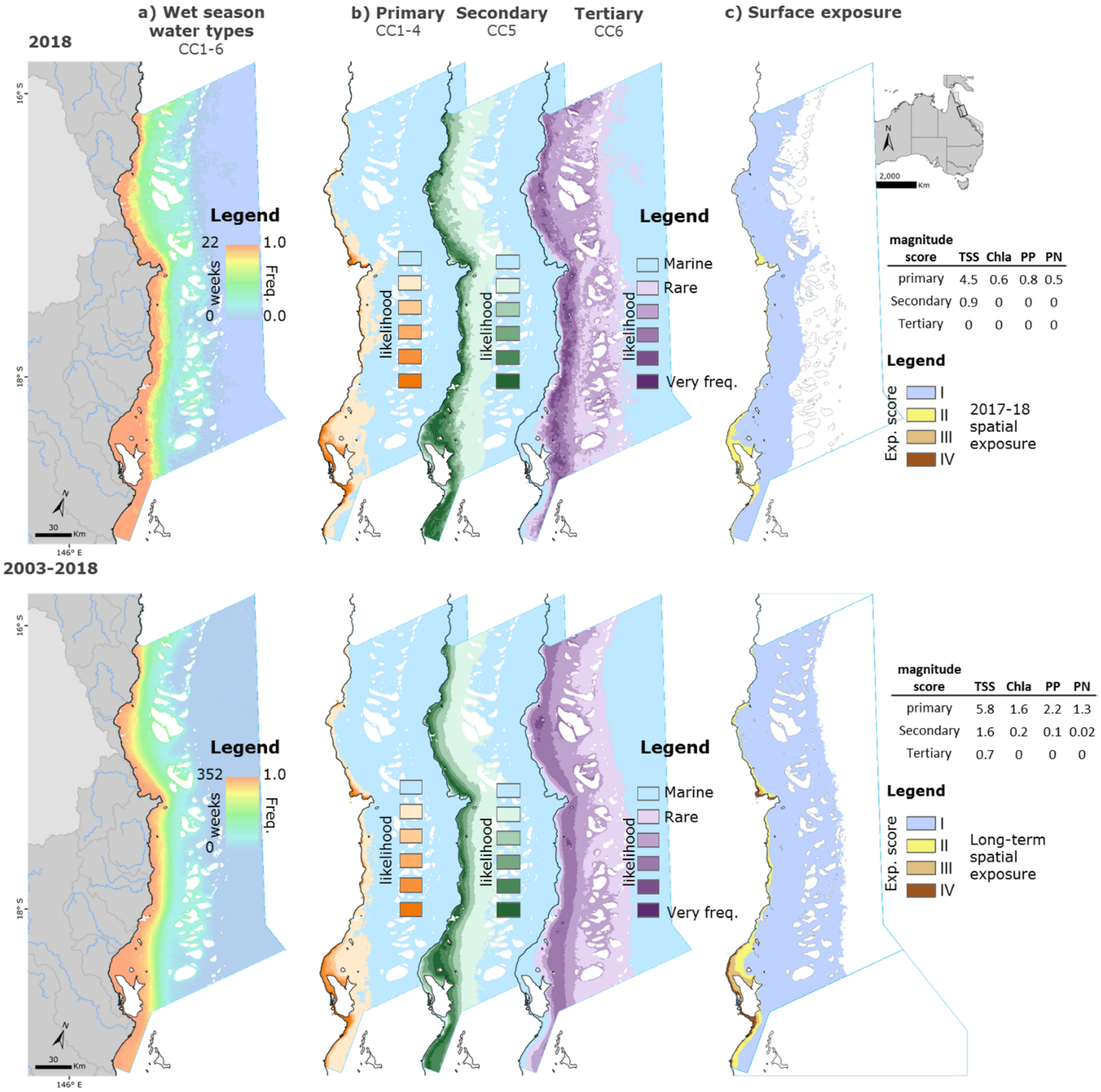


Figure 4-22: Maps showing the a) frequency of combined wet season water types (primary, secondary and tertiary), b) the frequency of primary, secondary and tertiary wet season water types and c) the exposure maps for the Wet Tropics region in the long-term (bottom) and 2017–18 wet season (top).

Figure 4-22 (top) presents the frequency of combined wet season water types (primary, secondary and tertiary), the frequency of primary, secondary and tertiary water types individually and the exposure map during the 2017–18 wet season. Table 4-4 presents the areas (km^2) and percentage (%) of total area, coral reefs and seagrasses (surveyed) affected by different exposure categories corresponding to different potential risk for the seagrass and coral reef ecosystems within the Wet Tropics region. The term 'potential' is used as the exposure maps have not been validated against ecological health data to confirm the ecological consequences of the risk. The maps, areas and percentage are presented in the context of the long-term exposure (2003–18, Figure 4-22 (bottom) and Table 4-4 (numbers in brackets).

In 2017–18, the Wet Tropics region was most affected by the lower exposure category (category I), in agreement with the long-term trends. Approximately 37% of the total area of the Wet Tropics region was exposed to a potential risk (Table 4-4). This area was smaller than the long-term area (59% exposed to wet season water types) and was due to a smaller total area exposed to the lower exposure category I (34% in 2017–18 versus 59% in the long-term). Only 0.3% of the Wet Tropics region was exposed to exposure category III and no area was exposed to exposure category IV. These areas were slightly smaller than long-term areas (0.3% exposed to category III and 1% to category IV).

In 2017–18, it was estimated that:

- A total of 43% of the Wet Tropics coral reefs were exposed to a potential risk. Only 0.01% of corals were in exposure category III and no reefs were in the highest exposure category IV.
- A total of 98% of the Wet Tropics seagrasses were exposed to a potential risk. A total of 13% of seagrasses were in exposure category III and no seagrasses were in the highest exposure category IV.
- These exposures indicate potential risk only because exposure maps have not yet been validated against ecological health data to confirm the ecological consequences of the risk
- In 2017–18, the coral and seagrass areas in categories III and IV were under the long-term areas (0.1% and 0.004% of reefs and 28% and 23% of seagrasses exposed to categories III and IV, respectively). The Wet Tropics region experienced an average wet season in 2017–18 and these results are consistent with the characteristics of an average wet season for this region (Table 3-1) in 2017–18.
- Tertiary water exposure, generally represented by category I, is expected to have low or no detrimental ecological effects, assuming that the duration of exposure is not long-term.

Table 4-4: Areas (km^2) and percentages (%) of the Wet Tropics region affected by different categories of exposure during the 2017–18 wet season (*and long-term values in brackets*).

NRM		Total	Potential Risk category Lowest ----------------------- Highest				Total exposed	Total non-exposed
			I	II	III	IV		
Surface area	area	31,976	10,903	851	92	*nil*	11,846	20,130
			(18,729)	(698)	(739)	(181)	(20,348)	(11,628)
	%	*100%*	34%	3%	0.3%	*nil*	37%	63%
			(59%)	(2%)	(2%)	(1%)	(64%)	(36%)
Coral reefs	area	2425	1039	5	0.2	*ne.*	1,044	1,382
			(2370)	(12)	(4)	(0.1)	(2385)	(40)
	%	*100%*	43%	0.2%	0.01%	*ne.*	43%	57%
			(98%)	(0.5%)	(0.1%)	(0.04%)	(98%)	(2%)
Surveyed seagrass	area	232	103	94	30	*nil*	227	6
			(38)	(70)	(65)	(54)	(227)	(5)
	%	*100%*	44%	41%	13%	*nil*	98%	2%
			(16%)	(30%)	(28%)	(23%)	(98%)	(2%)

Figure 4-23 and Figure 4-24 illustrate the changes in water quality and environmental conditions in the Wet Tropics region and summarise all *in-situ* surface data collected by JCU and AIMS between December 2017 and April 2018.

The Wet Tropics region was just above the long-term median in 2017–18 with major flooding occurring in many rivers including the Russell-Mulgrave, Herbert and Tully Rivers. The Wet Tropics region had two major flow events in March (weeks 15 and 17 of the wet season) and two moderate level flow events in January and February (weeks 8 and 10), This was measured by weekly river discharges above the long-term mean weekly discharge value during weeks 10 and 11 and weeks 13 to 18, with a maximum weekly discharge value measured during week 15 (4,182,953 ML).

The primary waters from the Tully and Herbert Rivers were largely confined to the enclosed coastal region of the Wet Tropics, but with evidence of some influence on parts of the open coastal and mid-shelf regions after the main flood events (weeks 14–15 and 17–18).

The weekly composites highlighted the influence of turbid flood waters on Dunk Island, especially during weeks 14–15 and 18. The open coastal region off the Tully River was nearly always exposed to the secondary water type during the 2017–18 wet season and the tertiary water type extended to the offshore coral reefs in seven of the 22 weeks of the wet season (after week 10) (see also case study in Appendix B and Petus et al., submitted).

An increase in water quality concentrations was observed following these flow events. The maximum TSS surface concentrations and minimum Secchi depth were measured during week 15 (13 March 2018) (51.0 mg L^{-1}); and was classified as colour class 2 in the weekly colour class map for this week. Using only sites with a colour class category (i.e. no cloud), the mean weekly TSS concentrations reached 19.0 mg L^{-1} (week 9) and 14.1 mg L^{-1} (week 15) in colour class 2. This is up to 8 times the wet season TSS GVs for the open coastal and mid-shelf waters. The GV, however, is a seasonal mean and the ecological effect of the acute concentration peak is not known.

The mean weekly Chl-*a* reached 2.9 µg L^{-1} during week 7 in colour class and 1.3 µg L^{-1} during week 15 in colour class 2. The lower mean weekly Secchi depth (0.3 m) was measured in colour class 2 during week 9. The maximum highest mean weekly DIN was measured during weeks 9 and 11 (154.3 and 132.0 µg L^{-1}, respectively) in colour class 2 and during week 15 (90.0 µg L^{-1}) in colour class 1. No week had *in-situ* samples collected across all colour classes (1 to 6), thus the water quality changes across colour gradients could not be fully described.

Using only sites with a satellite colour class category (i.e. no cloud), the mean seasonal TSS concentrations measured across the primary and secondary water types were 8.2 mg L^{-1} and 3.2 mg L^{-1}, respectively (i.e. approximately 3.4 and 1.3 the wet season TSS GVs of 2.4 mg L^{-1}) respectively. The mean seasonal Chl-*a* concentrations in the primary, secondary and tertiary water types were 1.1 µg L^{-1}, 0.8 µg L^{-1} and 0.7 µg L^{-1}, respectively, i.e. approximately 1.7, 1.3 and 1.1 times the wet season Chl-*a* GV of 0.63 µg L^{-1}, respectively. The mean seasonal PP concentration in the primary water type was 5.9 µg L^{-1} (1.8 times the 3.3 µg L^{-1} GV) and the mean seasonal PN concentrations in the primary water types was 31.6 µg L^{-1} (1.3 times the 25 µg L^{-1} GV). Finally, the mean seasonal TSS, PP and PN concentrations in the tertiary water type and the mean seasonal PP and PN concentrations in the secondary water type were all under their respective wet season GVs.

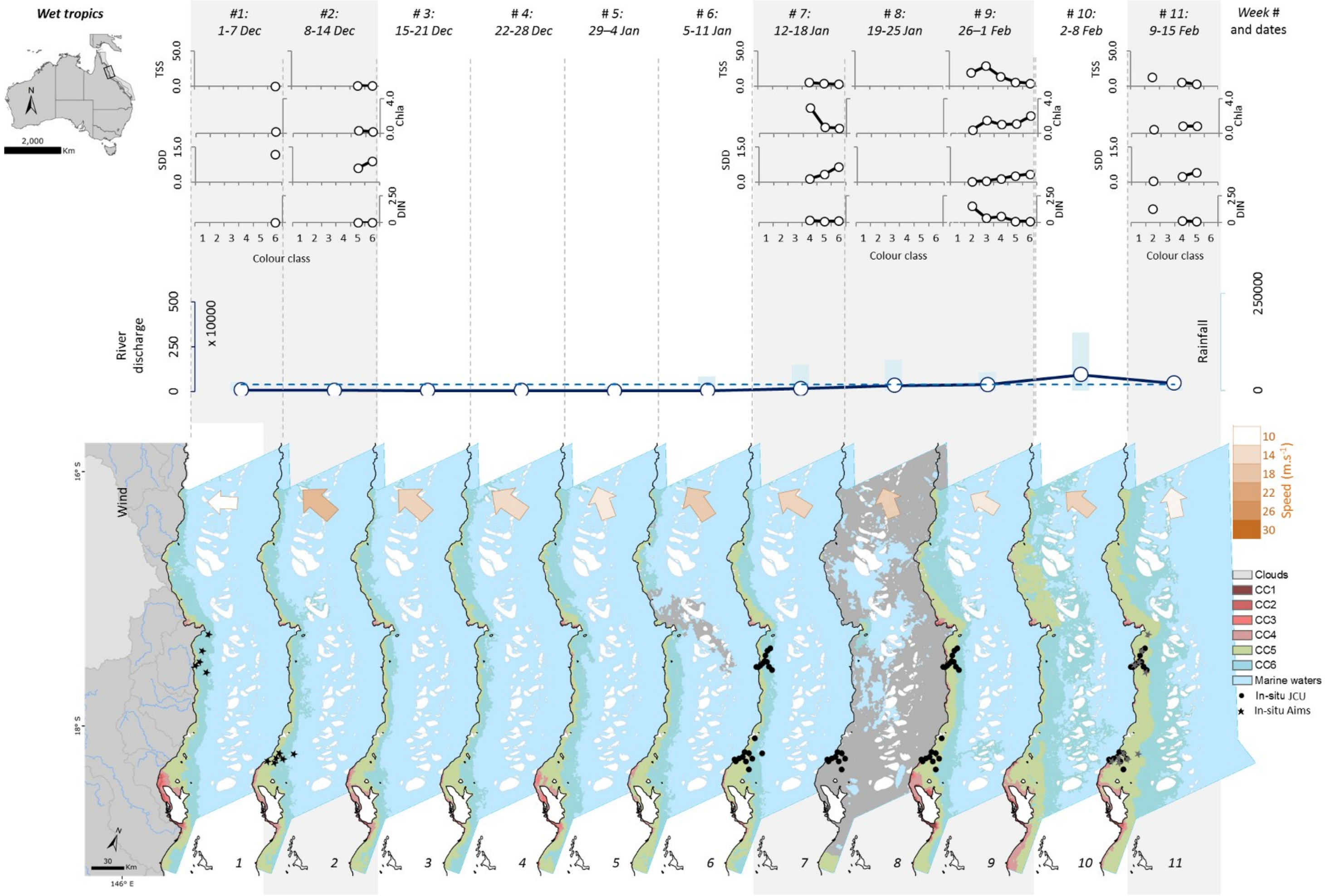


Figure 4-23: Panel of water quality and environmental characteristics in the Wet Tropics region throughout the 2017–18 wet season period: weeks 1 to 11. Details included in the panels: mean TSS (mg L^{-1}), Secchi depth (SDD) (m), Chl-*a* (µg L^{-1}) and DIN (µg L^{-1}) within each colour class; weekly river discharge (ML/day) and rainfall (mm) (note different scales between regions); wind speed (m.s^{-1}) and direction; and the wet season water type maps showing the six wet season colour classes as well as the location of the *in-situ* data collected by JCU and AIMS. The long-term mean weekly river discharge is indicated by a dotted blue line and correspond to cumulative weekly river discharge (megaliters) of the Barron, Daintree, Herbert, Mossman, Mulgrave, Murray, North Johnstone, Russell, South Johnstone and Tully Rivers.

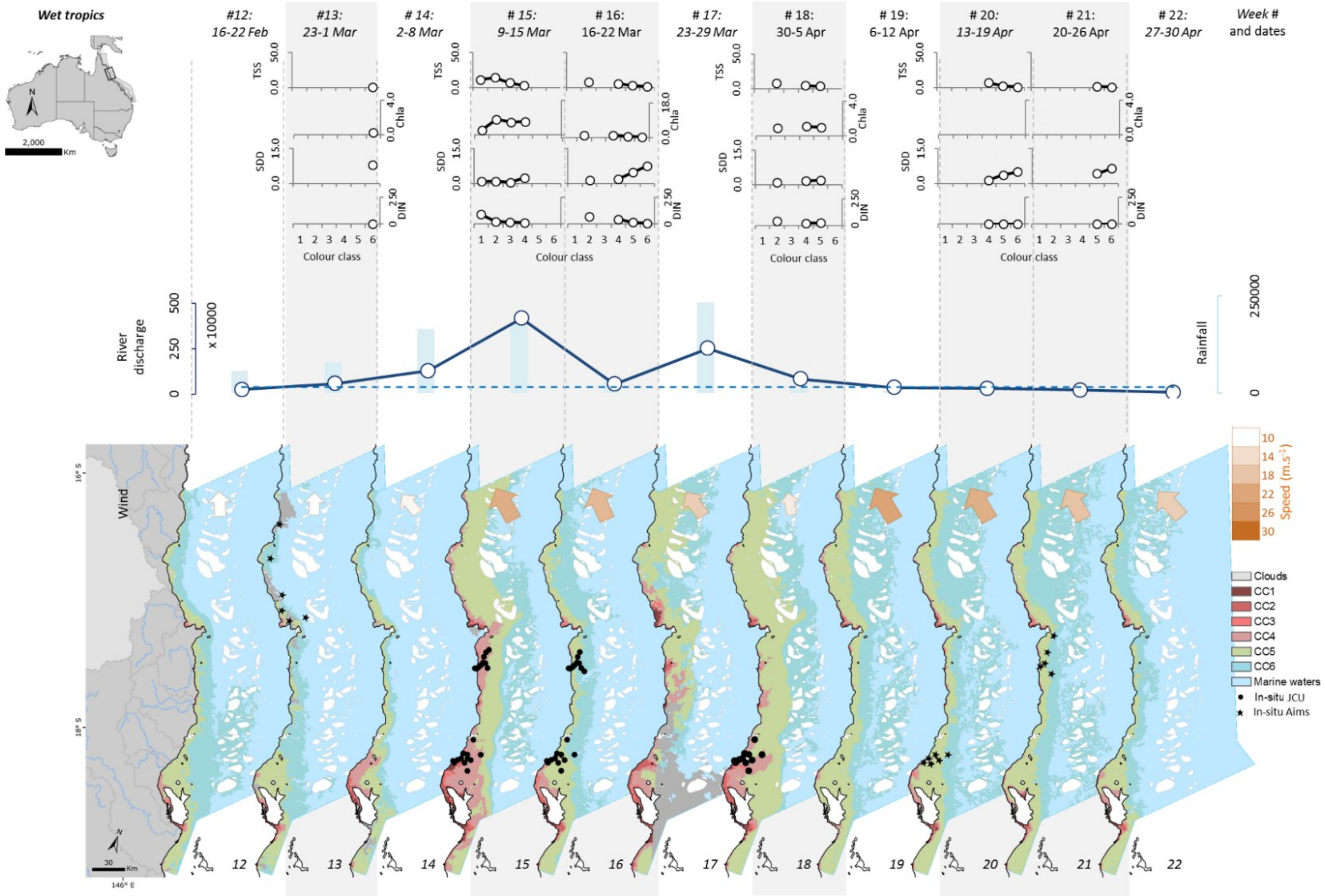


Figure 4-24: Panel of weekly water quality and environmental characteristics in the Wet Tropics region throughout the 2017–18 wet season period: weeks 12 to 22. Details included in the panels: mean TSS (mg L^{-1}), Secchi depth (SDD) (m), Chl-*a* (µg L^{-1}) and DIN (µg L^{-1}) within each colour class; weekly river discharge (ML/day) and rainfall (mm) (note different scales between regions); wind speed ($m.s^{-1}$) and direction; and the wet season water type maps showing the six wet season colour classes as well as the location of the *in-situ* data collected by JCU and AIMS. The long-term mean weekly river discharge is indicated by a dotted blue line.

4.6 Burdekin

Cumulative exposure mapping derived from eReefs hydrodynamic model output (Figure 4-25) showed that enclosed coastal regions were heavily influenced by river-plumes from the Burdekin River over the 2017–18 monitoring year. Open coastal and some mid-shelf sites were also exposed to river plumes. Detectable levels of river discharge (>1% of background) from the Burdekin River plumes extended ~170 km northwest from the river mouth, reaching reefs in the Palms. The Burdekin River plumes were also transported easterly ~60 km from the river mouth and tended to be transported seaward (Figure 4-25).

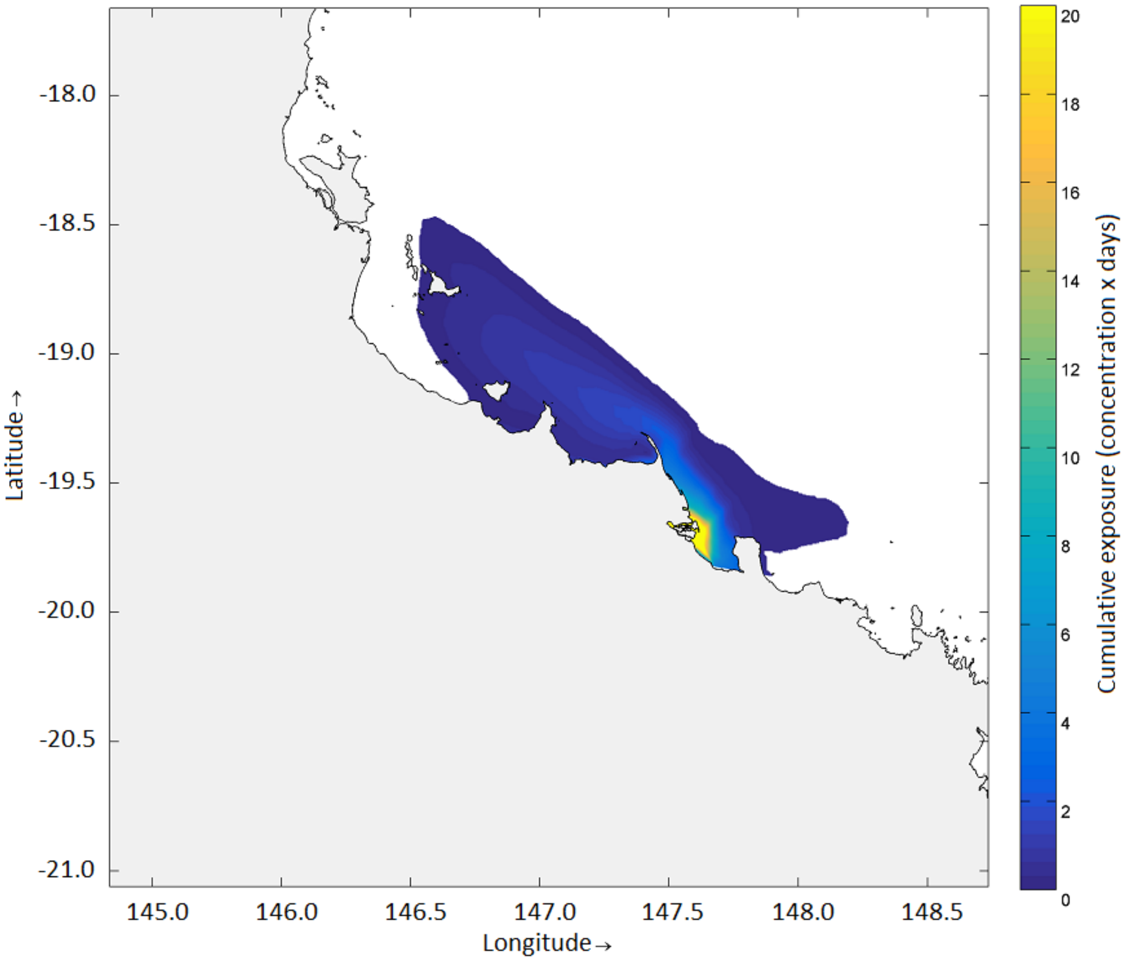


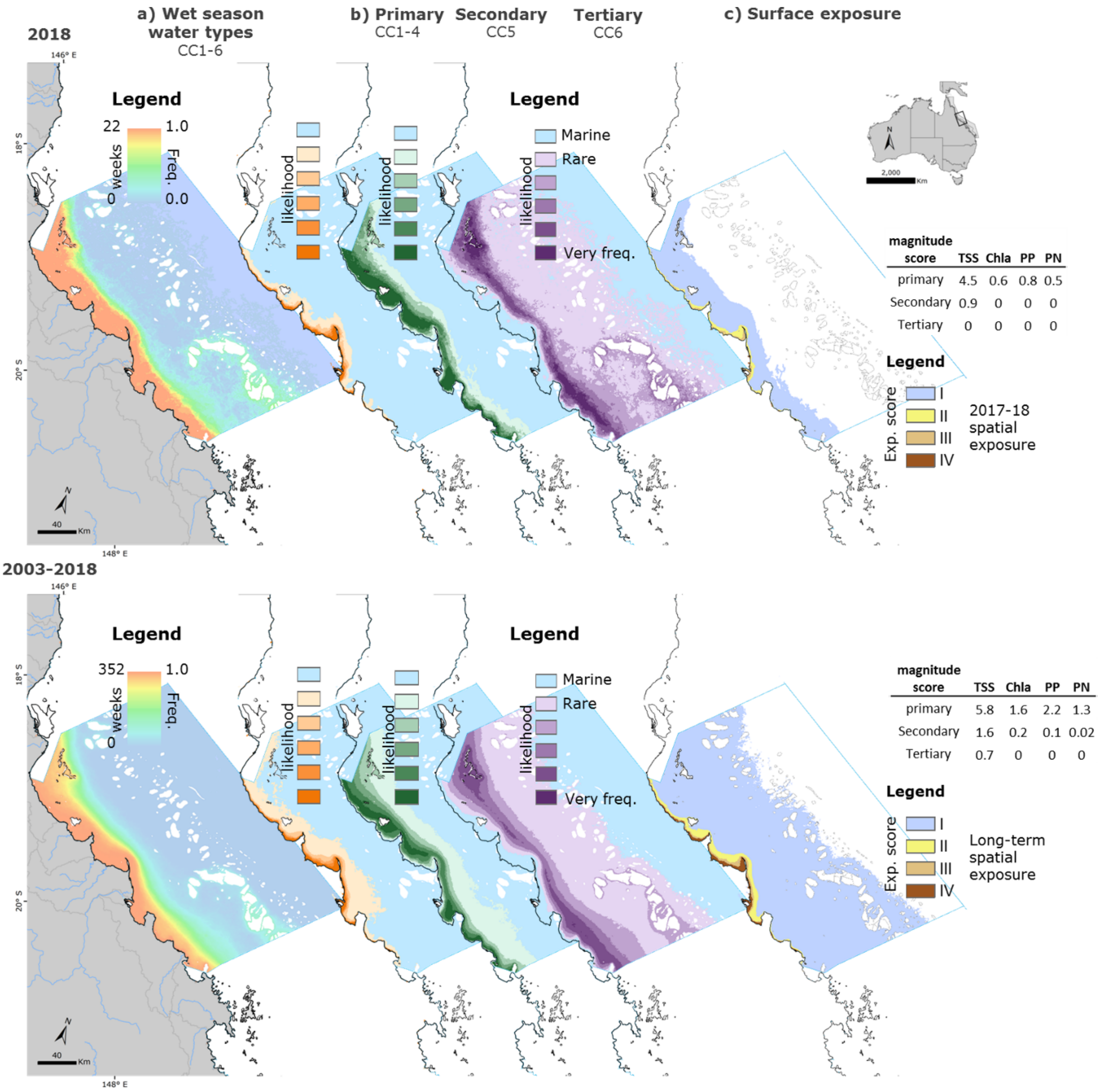
Figure 4-25: Cumulative exposure index for the Burdekin River from October 2017 to September 2018. The colour bar indicates the calculated cumulative exposure (concentration x days) above 1% of the incoming concentration. The colour bar is capped at 20 concentration days.

Mapping products were generated to represent wet season water quality conditions in the Burdekin region. The *in-situ* data collected by JCU and AIMS during the wet season, including high flow periods, is used to characterise and validate these products. These data are presented in Figure 4-26 and in a panel of weekly characteristics throughout the 22-week wet season period (Figure 4-27 and Figure 4-28).

Details in the panels include:

- *in-situ* water quality characteristics including TSS, Secchi depth, Chl-*a* and DIN within each colour class
- weekly river discharge

- wind speed and direction
- weekly wet season water type maps showing the six wet season colour classes.



magnitude score	TSS	Chla	PP	PN
primary	4.5	0.6	0.8	0.5
Secondary	0.9	0	0	0
Tertiary	0	0	0	0

magnitude score	TSS	Chla	PP	PN
primary	5.8	1.6	2.2	1.3
Secondary	1.6	0.2	0.1	0.02
Tertiary	0.7	0	0	0

Figure 4-26: Maps showing the a) frequency of combined wet season water types waters (primary, secondary and tertiary), b) the frequency of primary, secondary and tertiary water types and c) the exposure maps for the Burdekin region in the long-term (bottom) and 2017–18 wet season (top).

Figure 4-26 presents the frequency of combined wet season water types (primary, secondary and tertiary), the frequency of primary, secondary and tertiary plume water types individually, and the exposure map during the 2017–18 wet season. Table 4-5 presents the areas (km^2) and percentage (%) of total area, coral reefs and seagrasses (surveyed) affected by different exposure categories corresponding to different potential risk for the seagrass and coral reef ecosystems within the Burdekin region. The term ‘potential’ is used because the exposure maps have not been yet validated against ecological health data to confirm the ecological consequences of the risk. The results are presented in the context of the long-term exposure (2003–18) shown in Figure 4-26 (bottom), with the area and percentage of exposure presented in Table 4-5 (long-term exposure in brackets).

In 2017–18, the Burdekin region was most affected by the lowest exposure category (category I) in agreement with long-term trends. Approximately 16% of the total area of the Burdekin region was exposed to a potential risk (Table 4-5**)**. This area was smaller than the long-term area (62% exposed to wet season water types) and was due primarily to a smaller total area exposed to the lower exposure category I (14% in 2017–18 versus 59% in the long-term). Only 0.6% of the Burdekin region was exposed to exposure category III and no area was exposed to exposure category IV. These areas were smaller than long-term areas (1% exposed to category III and 1% to category IV).

In 2017–18, it was estimated that:

- A total of 2% of the Burdekin coral reefs were exposed to a potential risk. Only 0.01% of corals were in exposure category III and no reef were in the highest exposure category IV.
- A total of 98% of the Burdekin seagrasses were exposed to a potential risk. A total of 10% of seagrasses were in exposure category III and no seagrasses were in the highest exposure category IV.
- These exposures indicate the potential risk because exposure maps have not been yet validated against ecological health data to confirm the ecological consequences of the risk.
- In 2017–18, the seagrass and coral areas in exposure categories III and IV were smaller than in the long-term areas, except for the seagrass areas exposed to categories III and IV, which was slightly greater (0.03% and 0.01% of coral reefs and 7% and 16% of seagrass exposed to categories III and IV, respectively). The Burdekin region experienced an average wet season during 2017–18 and these results are consistent with the characteristic of an average wet season for this region.
- Tertiary water exposure, generally represented by category I, is expected to have low or no detrimental ecological effects, assuming that the duration of exposure is not long-term.

Table 4-5: Areas (km^2) and percentages (%) of the Burdekin region affected by different categories of exposure during the 2017–18 wet season (*and long-term values in brackets)*.

NRM		Total	Potential Risk category Lowest ------------------------ Highest				Total exposed	Total non-exposed
			II	II	III	IV		
Surface area	area	47,009	6799	412	259	*nil*	7470	39,539
			(27,561)	(949)	(312)	(423)	(29,245)	(17,765)
	%	*100%*	14%	1%	0.6%	*ne.*	16%	84%
			(59%)	(2%)	(1%)	(1%)	(62%)	(38%)
Coral reefs	area	2966	57	1	0	*nil.*	58	2908
			(2,706)	(16)	(1)	(0.2)	(2,723)	(243)
	%	*100%*	2%	0.03%	0.01%	*nil.*	2%	98%
			(91%)	(1%)	(0.03%)	(0.01%)	(92%)	(8%)
Surveyed seagrass	area	708	538	83	74	*nil*	695	13
			(340)	(190)	(53)	(114)	(697)	(11)
	%	*100%*	76%	12%	10%	*nil*	98%	2%
			(48%)	(27%)	(7%)	(16%)	(99%)	(1%)

Figure 4-27 and Figure 4-28 illustrate the changes in water quality and environmental conditions in the Burdekin region and focus area with surface data collected between December 2017 and April 2018. The Burdekin region experienced an average wet season in

2017–18, with flooding occurring at the end of the Burdekin River in early March. The flow events were mainly derived from the upper Burdekin tributary, which is one of the dominant contributors to sediment loads at the end of river (Bainbridge et al., 2014). In addition, it was one of only two large events that occurred in the last three years in the Burdekin region, together with tropical cyclone Debbie in March and April 2017. Weekly river discharges during the 2017–18 sampling period were below the long-term mean weekly discharge value, except for weeks 13 to 16 and week 18.

Weekly composites of the Burdekin region showed that the extent of the turbid flood waters was mainly confined in the enclosed coastal region of the Reef. Primary waters were confined next to the estuary mouth (Upstart Bay) during weeks 1 to 12 and began to extend into Bowling Green Bay after the main peak discharge (week 14). The next weekly composites (week 15) showed the primary water type extending northwards past Magnetic Island. The secondary and tertiary water types were largely confined in the open coastal and mid-shelf regions, respectively; however, the tertiary waters reached the offshore coral reefs after the main flood event.

Sampling of the Burdekin flood plume after the main flood event was restricted to short trips in Upstart Bay and off Magnetic Island (weeks 14–17) due to poor weather conditions. No week had *in-situ* samples collected across all colour classes (1 to 6); therefore, it was not possible to fully describe water quality changes across colour gradients. However, an increase in water quality concentrations was observed following the February/early March flood event. The maximum TSS surface concentrations (340 mg L^{-1}) and minimum Secchi depth (0.1 m) were measured during week 14 (5 March 2018), and was classified as colour class 1 in the weekly colour class map for this week. The highest weekly mean TSS and DIN values and the minimum Secchi depth were sampled during week 14, in the colour class 1 (118.2 mg L^{-1}, 66.6 µg L^{-1} and 0.4 m^{-1}, respectively). The highest weekly mean Chl-*a* was measured in weeks 9, 14 and 16 in colour classes 4, 1 and 3, respectively (1.5 µg L^{-1}). This is approximately 49 and 2.4 times that of the wet season TSS and Chl-*a* GVs, respectively, for the open coastal and mid-shelf waters.

Using only sites with a satellite colour class category (i.e. no cloud), the mean seasonal TSS concentrations measured across the primary, secondary and tertiary water types were 42.2, 7.6 and 2.5 mg L^{-1}, respectively, i.e. approximately 18 times, 3.2 times and just above the wet season TSS GVs of 2.4 mg L^{-1}, respectively (Table E-8). The mean seasonal Chl-*a* concentrations in the primary and secondary water types was 1.2 and 0.66 µg L^{-1}, respectively, i.e. approximately 2 times and just above the wet season Chl-*a* GVs of 0.63 µg L^{-1}. The mean seasonal PP and PN concentrations in the primary water type was 12.2 µg L^{-1} (3.7 times the 3.3 µg L^{-1} GV) and 70.0 µg L^{-1} (2.8 times the 25 µg L^{-1} GV). Finally, the mean seasonal Chl-*a* in the tertiary water type and PP and PN concentrations in the secondary and tertiary water types were all under their respective wet season GVs (Table E-8).

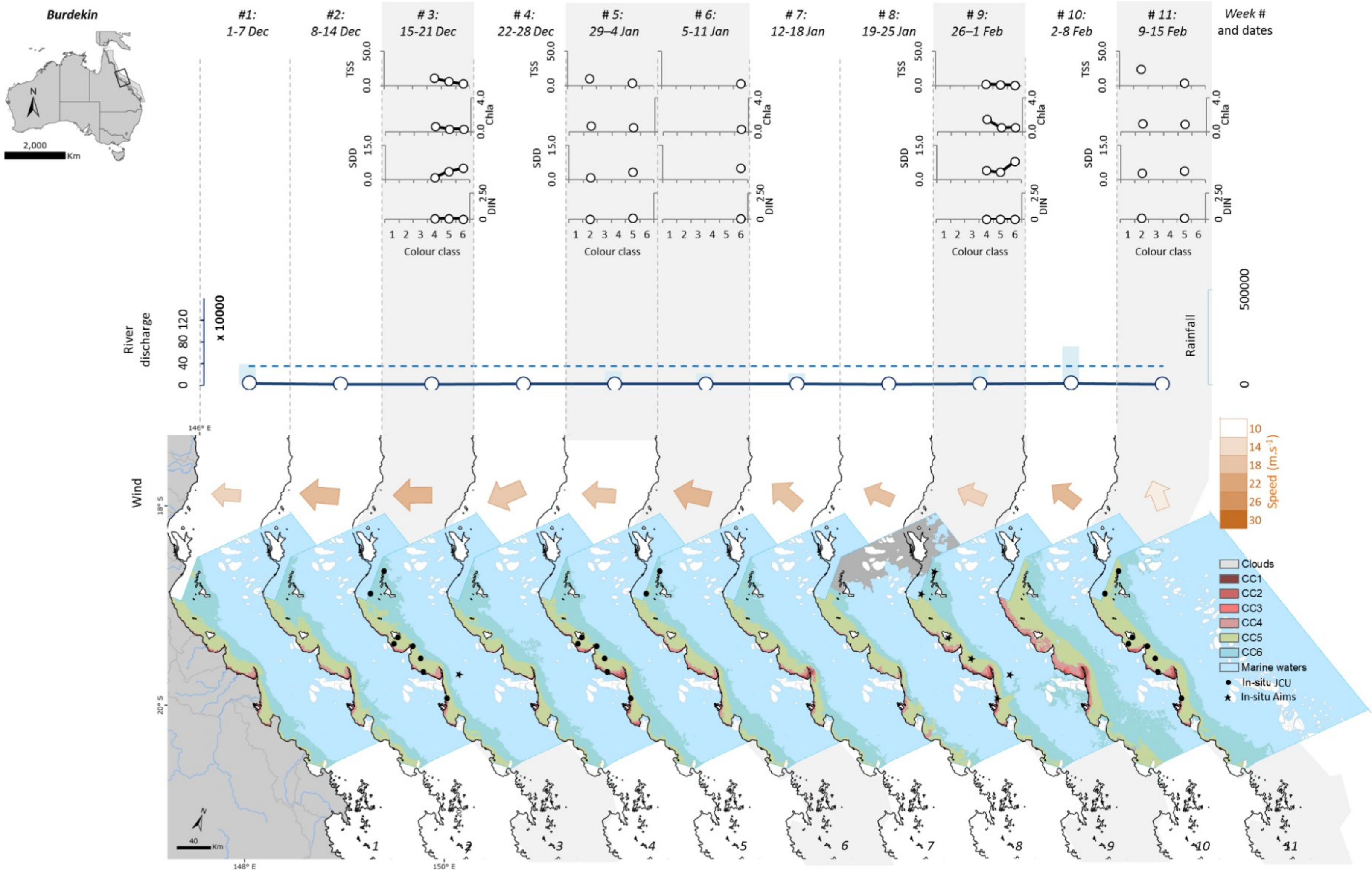


Figure 4-27: Panel of water quality and environmental characteristics in the Burdekin region throughout the 2017–18 wet season period: weeks 1 to 11. Details included in the panels include mean TSS (mg L^{-1}), Secchi depth (SDD) (m), Chl-*a* (µg L^{-1}) and DIN (µg L^{-1}) within each colour class; weekly river discharge (ML/day) and rainfall (mm) (note different scales between regions); wind speed ($m.s^{-1}$) and direction; and the wet season water type maps showing the six wet season colour classes as well as the location of the *in-situ* data collected by JCU and AIMS. The long-term mean weekly river discharge is indicated by a dotted blue line.

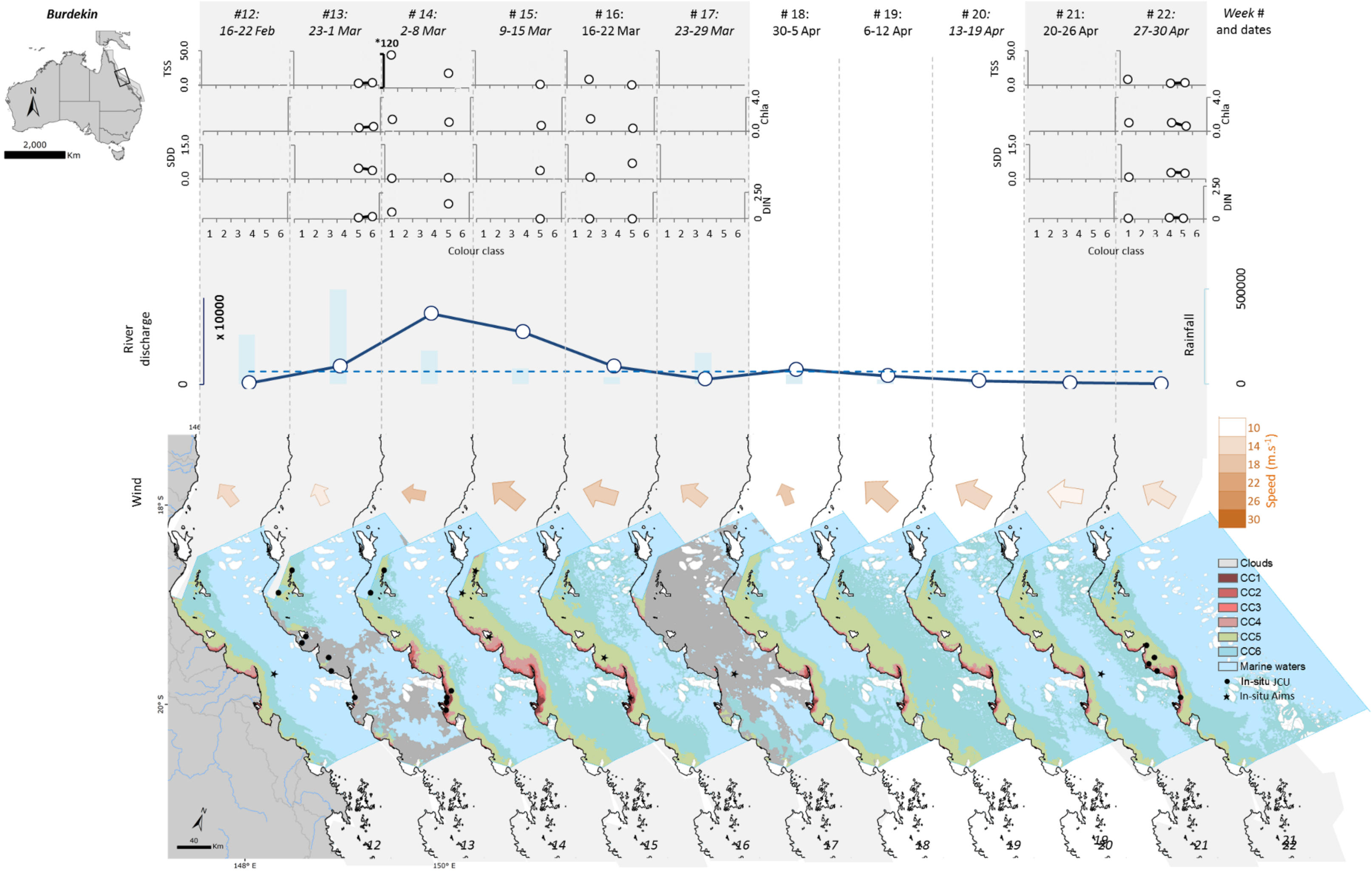


Figure 4-28: Panel of water quality and environmental characteristics in the Burdekin region throughout the 2017–18 wet season period: weeks 12 to 22. Details included in the panels include mean TSS (mg L^{-1}), Secchi depth (SDD) (m), Chl-*a* (µg L^{-1}) and DIN (µg L^{-1}) within each colour class; weekly river discharge (ML/day) and rainfall (mm) (note different scales between regions); wind speed (m.s^{-1}) and direction; and the wet season water type maps showing the six colour wet season classes as well as the location of the *in-situ* data collected by JCU and AIMS. The long-term mean weekly river discharge is indicated by a dotted blue line. Note that week 14 has a different TSS axis.

4.7 Mackay Whitsunday

Mapping products were generated to represent wet season water quality conditions in the Mackay-Whitsunday region. The *in-situ* data collected by JCU and AIMS during the wet season, including high flow periods, is used to characterise and validate these products. These data are presented in Figure 4-29 and in a panel of weekly characteristics throughout the 22-week wet season period (Figure 4-30 and Figure 4-31).

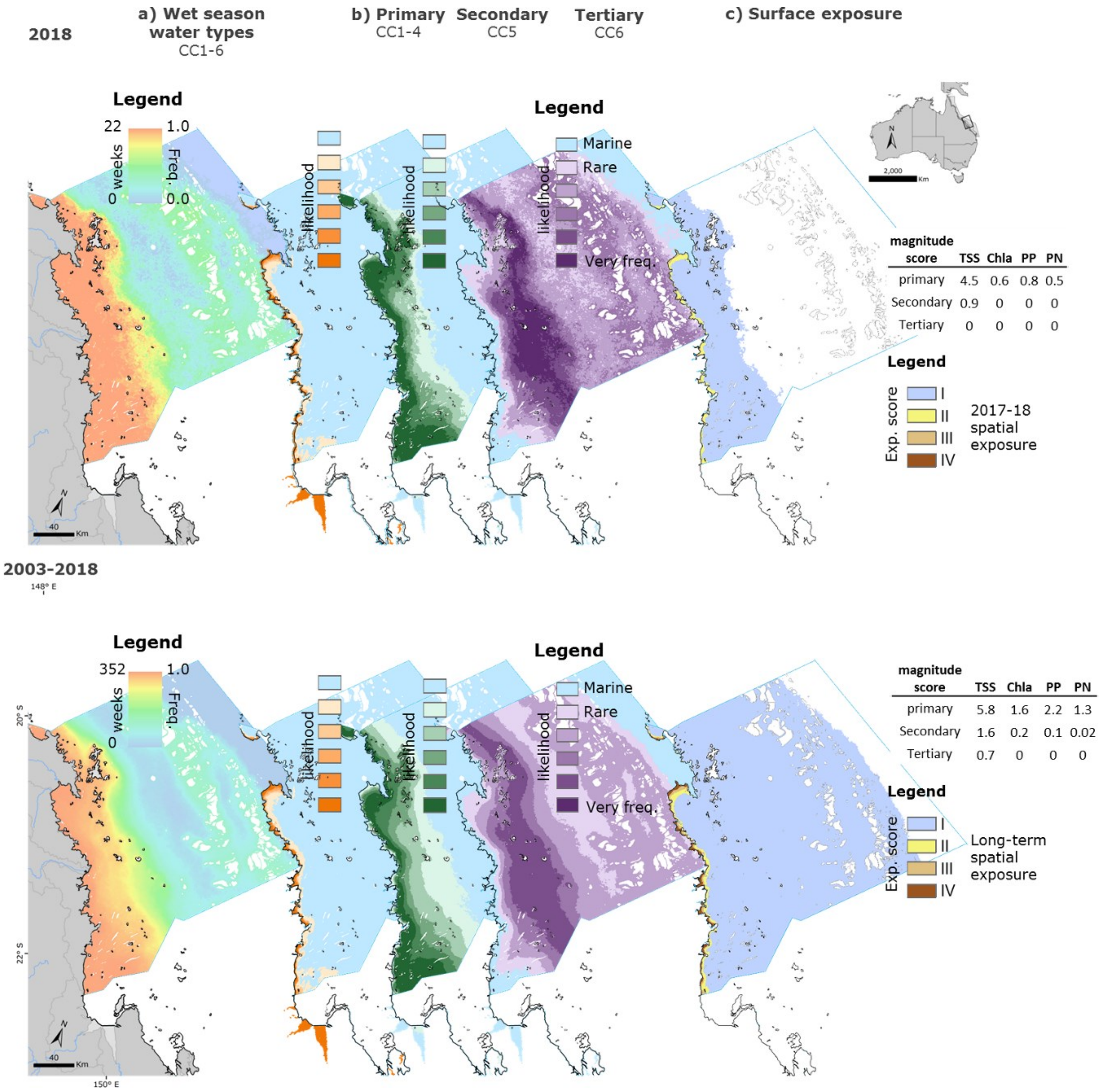
Details in the panels include:

- *in-situ* water quality characteristics including TSS, Secchi depth, Chl-*a* and DIN within each colour class
- weekly river discharge
- wind speed and direction
- weekly wet season water type maps showing the six wet season colour classes.

Figure 4-29 (top) presents the frequency of combined wet season water types (primary, secondary and tertiary), the frequency of primary, secondary and tertiary wet season water types individually and the exposure map in the 2017–18 wet season. Table 4-6 presents the areas (km^2) and percentage (%) of total area, coral reefs and seagrasses (surveyed) affected by different exposure categories corresponding to different potential risk for the seagrass and coral reef ecosystems within the Mackay-Whitsunday region. The term ‘potential’ is used because the exposure maps have not been yet validated against ecological health data to confirm the ecological consequences of the risk. The maps, areas and percentage are presented in the context of the long-term exposure (2003–18: Figure 4-29 (bottom) and Table 4-6 (numbers in brackets).

In 2017–18, the Mackay-Whitsunday region was most affected by the lowest exposure category (category I), in agreement with the long-term trends. Approximately 24% of the total area of the Mackay-Whitsunday region was exposed to a potential risk (Table 4-6). This area was smaller than the long-term area (85% exposed to wet season water types) and was due to a smaller total area exposed to the lower exposure category I (23% in 2017–18 versus 83% in the long-term). Only 0.3% of the Mackay-Whitsunday region was exposed to exposure category III and no area was exposed to exposure category IV. These areas were slightly smaller than long-term areas (0.5% exposed to category III and 1% to category IV). In 2017–18, it was estimated that:

- A total of 8% of the Mackay-Whitsunday coral reefs were exposed to a potential risk. Only 0.02% of corals were in exposure category III and no reefs were in the highest exposure category IV. A total of 96% of the Mackay-Whitsunday seagrasses were exposed to a potential risk. A total of 6% of seagrasses were in exposure category III and no potential risk because the exposure maps have not yet been validated against ecological health data to confirm the ecological consequences of the risk.
- In 2017–18, the areas of coral reefs and seagrasses exposed to exposure categories III and IV were similar under the long-term areas (0.1% and 0.04% of reefs and 14% and 15% of seagrasses exposed to categories III and IV, respectively). These results were logical with the characteristic of a below average wet season for this region.
- Tertiary water exposure, generally represented by category I, is expected to have low or no detrimental ecological effects, assuming that the duration of exposure is not long-term.



magnitude score	TSS	Chla	PP	PN
primary	4.5	0.6	0.8	0.5
Secondary	0.9	0	0	0
Tertiary	0	0	0	0

magnitude score	TSS	Chla	PP	PN
primary	5.8	1.6	2.2	1.3
Secondary	1.6	0.2	0.1	0.02
Tertiary	0.7	0	0	0

Figure 4-29: Maps showing the a) frequency of combined wet season water types (primary, secondary and tertiary), b) the frequency of primary, secondary and tertiary wet season water types and c) the exposure maps for the Mackay-Whitsunday region in the long-term (bottom) and 2017–18 wet season (top).

Table 4-6: Areas (km^2) and percentages (%) of the Mackay-Whitsunday region affected by different categories of exposure during the 2017–187 wet season (*and long-term values in brackets*).

NRM		Total	Potential Risk category Lowest ------------------------ Highest				Total exposed	Total non-exposed
			I	II	III	IV		
Surface area	area	48,957	11,344	420	154	*nil*	11,918	37,039
			(40,797)	(517)	(235)	(290)	(41,838)	(7118)
	%	*100%*	23%	1%	0.3%	*nil*	24%	76%
			(83%)	(1%)	(0.5%)	(1%)	(85%)	(15%)
Coral reefs	area	3,216	240	7	1	*nil*	247	2,969
			(3129)	(18)	(3)	(1)	(3,151)	(65)

	%	*100%*	7%	0.2%	0.02%	*nil*	8%	92%
			(97%)	(1%)	(0.1%)	(0.04%)	(98%)	(2%)
Surveyed seagrass	area	307	200	75	19	*nil*	293	14
			(174)	(33)	(42)	(46)	(294)	(13)
	%	*100%*	65%	24%	6%	*nil*	96%	4%
			(57%)	(11%)	(14%)	(15%)	(96%)	(4%)

Figure 4-30 and Figure 4-31 illustrate the changes in water quality and environmental conditions in the Mackay-Whitsunday region and focus on surface data collected by JCU and AIMS between December 2017 and April 2018. The 2017–18 wet season was characterised by below average rainfall in the Mackay-Whitsunday region and consequent river discharge, resulting in river plumes that were for most of the wet season not well developed and therefore the sampling sites received a moderate riverine influence. Weekly river discharges during the 2017–18 sampling period were below the long-term mean weekly discharge value, except for week 18 (98,269 ML) that was above the long-term mean weekly discharge value (38,814 ML).

Sampling of the Mackay-Whitsunday region was limited to weeks 7, 12, and 21. No week had *in-situ* samples collected across all colour classes (1 to 6), and no water quality samples were collected in colour classes 1, 2, 3 or 4. Therefore, a full description of water quality changes across colour gradients was not possible.

Maximum TSS and DIN concentrations (25 April 2018; 4.0 mg L^{-1} and 0.7 µg L^{-1}, respectively) and minimum Secchi depth were measured during week 21 in colour class 5 (no Chl-*a* was measured during this week). The concentrations were similar across weeks in colour classes 5 and 6. The highest weekly mean TSS concentrations were measured during weeks 7 and 12 and were in colour class 5 (2.6 mg L^{-1}). The highest weekly mean Chl-*a* concentrations and minimum Secchi depth were measured during week 12 in colour class 5 (1.0 µg L^{-1} and 2.7 m, respectively) and the highest weekly mean DIN concentration was measured during week 21 in colour class 5 (0.4 µg L^{-1}). This is approximately 1.1 and 1.6 times that of the wet season TSS and Chl-*a* GVs, respectively, for the open coastal and mid-shelf waters. The GVs, however, are seasonal means and the ecological effect of the acute concentration peak is not known.

The mean seasonal TSS concentrations measured across the secondary water type was 2.4 mg L^{-1}, i.e. equal to the wet season TSS GV of 2.4 mg L^{-1} (Table E-9). The mean seasonal Chl-*a* concentrations in the secondary and tertiary water types were 0.9 and 0.7 µg L^{-1}, respectively, i.e. approximately 1.4 and 1.1 times that of the the wet season Chl-*a* GV of 0.63 µg L^{-1}.

Finally, the mean seasonal TSS concentration in the tertiary waters, and PP and PN concentrations in the secondary and tertiary water types were all below their respective wet season GVs (Table E-9). No data were available in the primary water type.

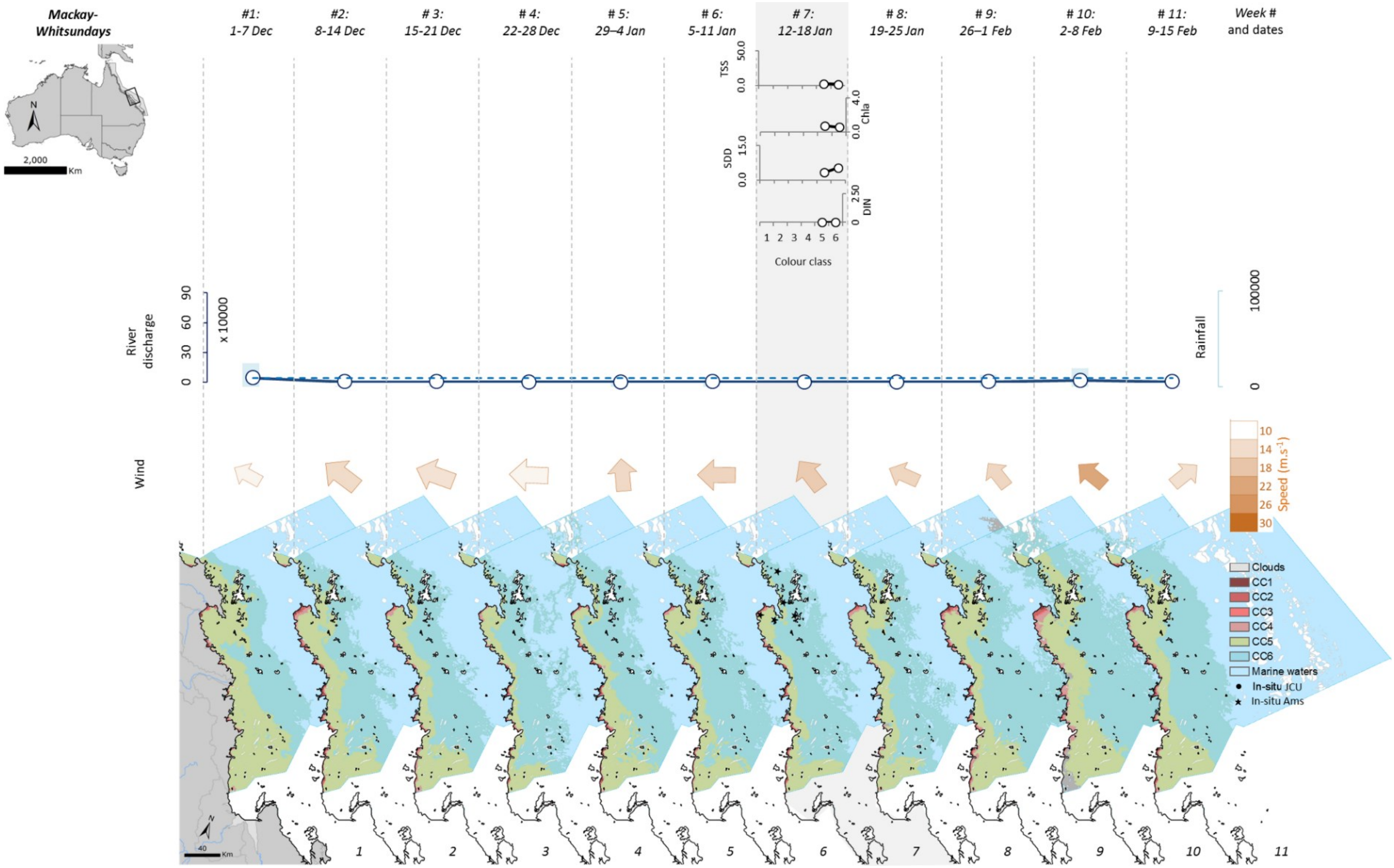


Figure 4-30: Panel of water quality and environmental characteristics in the Mackay-Whitsunday region throughout the 2017–18 wet season period: weeks 1 to 11. Details included in the panels: mean TSS (mg L^{-1}), Secchi depth (SDD) (m), Chl-*a* (µg L^{-1}) and DIN (µg L^{-1}) within each colour class; weekly river discharge (ML/day) and rainfall (mm) (note different scales between regions); wind speed ($m.s^{-1}$) and direction; and the wet season water type maps showing the six wet season colour classes as well as the location of the *in-situ* data collected by JCU and AIMS. The long-term mean weekly river discharge is indicated by a dotted blue line.

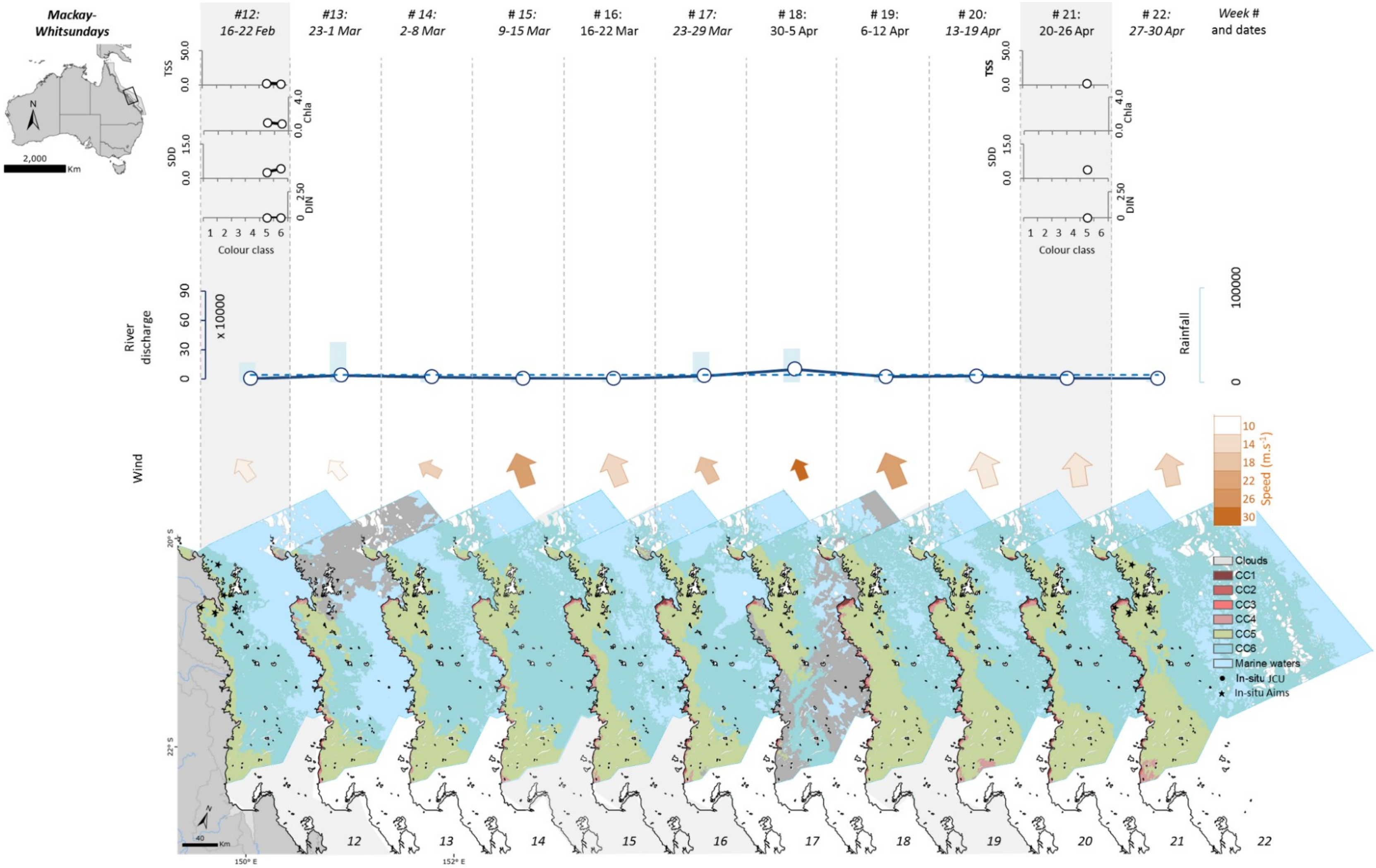


Figure 4-31: Panel of water quality and environmental characteristics in the Mackay-Whitsunday region throughout the 2017–18 wet season period: weeks 12 to 22. Details included in the panels: mean TSS (mg L^{-1}), Secchi depth (SDD) (m), Chl-*a* (µg L^{-1}) and DIN (µg L^{-1}) within each colour class; weekly river discharge (ML/day) and rainfall (mm) (note different scales between regions); wind speed ($m.s^{-1}$) and direction; and the wet season water type maps showing the six wet season colour classes as well as the location of the *in-situ* data collected by JCU and AIMS. The long-term mean weekly river discharge is indicated by a dotted blue line.

4.8 Modelling and mapping summary

Modelling and mapping products were developed to report on wet season marine conditions, map the estimated influence of river discharge and resuspension events, and identify which Reef regions may be the most at risk from exposure to land-sourced pollutants.

Main results:

- Tracer simulations (eReefs hydrodynamic model):

Tracer simulations showed that sites in enclosed coastal waters had many days of exposure to river discharge, especially for the Normanby, Russell-Mulgrave, Tully, and Burdekin Rivers. Open coastal and mid-shelf waters were also exposed to river plumes, especially in the Wet Tropics. In the Cape York region (Normanby River), plume exposure reached offshore waters for short periods.

River discharge predominantly travelled north along the coastline; however, plumes were sometimes transported in a southerly and easterly direction, which was observed in the Wet Tropics and Burdekin regions. River discharge could extend far from the source for short periods, as was observed for the Russell-Mulgrave River, where discharge reached >200 km north of the river mouth.

- Water type frequency maps (MODIS data)

Maps showed a well-documented inshore-to-offshore spatial pattern, with the highest frequency of the primary water type (typically enriched in sediment and dissolved organic matter, brownish turbid waters) in the coastal areas and mid-shelf to offshore areas most frequently exposed only to the tertiary water type (typically detectable water quality concentations but with a low risk of any detrimental ecological effect). The extent and frequency of the water types were variable across regions and across the shelf, reflecting the constituent concentrations, river discharge volumes and resuspension events.

- Exposure maps (MODIS and field water quality data)

Tertiary water type concentrations were under the available wet season GVs, only TSS concentrations were above the wet season GVs in the secondary water type, and TSS, Chl-*a*, PP and PN concentrations were above the wet season GVs in the primary water type.

Exposure maps showed that approximately 20% of the total area of the Reef was exposed to a potential risk in 2017–18, which was much lower than the long-term average area for all regions. Regional exposure results were as follow:

- Cape York: 25% of the total area of the Cape York region, 40% of the Cape York coral reefs and 94% of the Cape York seagrasses were exposed to a potential risk. The region and reefs areas were lower than the long-term average areas.
- Wet Tropics: 37% of the total area of the Wet Tropics region, 43% of the Wet Tropics coral reefs and 98% of the Wet Tropics seagrasses were exposed to a potential risk. The region and reef areas were lower than the long-term average areas.
- Burdekin: 16% of the total area of the Burdekin region, 2% of the Burdekin coral reefs and 98% of the Burdekin seagrasses were exposed to a potential risk. The region and reef areas were much lower than the long-term average areas.
- Mackay Whitsunday: 24% of the total area of the Mackay-Whitsunday region, 8% of the Mackay-Whitsunday coral reefs and 96% of the Mackay-Whitsunday seagrasses were exposed to a potential risk. The region and reef areas were much lower than the long-term average areas.

Of the area exposed, the lowest exposure categories (categories I and II) were most prevalent, in agreement with long-term trends, but across smaller areas, more particularly for category I. This characteristic was related to the relatively low mean concentrations of many of the water quality parameters, which may be linked to the below long-term median discharge. There were no areas in the highest potential risk exposure category IV.

The panels showing the pressures combined with the wet season water types and frequency maps for each NRM region are an innovative way to visually assess the combined influence of several drivers on wet season conditions. They highlight the need to distinguish the influence of river discharge, as opposed to other processes such as resuspension, in driving water quality as well as the need to keep integrating spatial and temporal information obtained from the wet season water type maps with the *in-situ* water quality measurements. This method will be explored further to establish a metric specific to river plumes, distinct from overall wet season conditions.

- Load maps (MODIS, field water quality and load data)

The dispersion of DIN and TSS loads was modelled to examine potential distribution of the estimated end-of-catchment pollutant loadsacross the Reef lagoon. The 2017–18 outputs were similar to those for other near long-term median discharge years.

The incorporation of the river-derived DIN and TSS loading contribution maps, and the assessment of the relative contribution from each river to the NRM regions, provided insight to the extent of influence in relatively high and low discharge years. The outputs highlight many cross-regional influences in the large discharge events between adjoining NRM regions and the variation between years.

The cross-regional influences highlight the need to assess and define management priorities at a basin scale, and the importance of recognising these influences, outside of the administrative marine NRM boundaries.

Comparison to estimated pre-development end-of-catchment loading map identified the Wet Tropics as the dominant area of anthropogenic influence for DIN, and the Burdekin region as the dominant area of anthropogenic influence for TSS.

Caveats

It should be noted there are several caveats to the modelling and mapping products

- Exposure maps
    - The exposure categories are not validated against ecological health data and represent at this stage relative potential risk categories for seagrass and coral reef ecosystems. The lowest exposure categories (I and II) are characterised by low frequency of the primary and secondary water types, and the highest exposure categories (III and IV) are characterised by high frequency of primary and secondary water types. Category I whilst evident by colour on the exposure maps is interpreted to pose little risk to ecosystem health.
    - Only surface areas inside the Reef marine boundaries are reported. Surface exposure can affect ecosystem condition; however, plumes may not directly reach ecosystems that are at depth.
    - This assessment does not take into account the current condition of Reef ecosystems and long-term impacts on these communities. For example, it is recognised that inshore communities may be adapted to wet season water types and exposure history; therefore, the highest risk of an ecological response could be during large events when primary/secondary water types extend into otherwise low exposure (more offshore) areas.

- Reporting the areas of coral reefs and seagrass in the highest potential exposure categories cannot be assessed in terms of ecological relevance at this stage and is included as a comparative measure between regions and between years.
- One-week exposures are reported for which the ecological consequence is not known.

- Load maps

The dispersion function in the model for TSS results in some uncertainty in the offshore areas, as seen in the 2008, 2009, 2011 and 2012 assessments (Figure 4-14). There has been no validation of model results with empirical data at the outer boundary of the Reef, and it is therefore unknown whether river-derived TSS would generally be transported this far offshore. Recent research suggests that riverine flows (and associated TSS) could potentially influence certain parts of the outer Reef during high flow events (Fabricius et al., 2016), although it is unclear whether the influence is related to riverine-derived TSS or influenced by primary productivity (i.e. riverine nutrient influence causing phytoplankton blooms). The latest sediment modelling through the eReefs framework provides support that fine sediment particles have the capacity to influence the mid and outer-shelf of the Reef (Margvelashvili et al., 2018).

The modelled dispersion is driven by average wind conditions that are typically represented in a south-easterly direction. The variation between the observed results in 2017 and the modelled outcome in 2017 highlighted this limitation, which is intended to be addressed through incorporation of the eReefs model applications over the next two years.

5. Focus area water quality and Water Quality Index

The following sections provide detailed analysis of key water quality variables in focus areas in the context of local environmental drivers, specifically focused on identification and interpretation of year-to-year trends. For each of the four focus regions, the following information is included and discussed (with the exception of Cape York, where some data are presented differently as this is only the second year of monitoring this region):

- a map of monitoring locations
- time-series of the combined discharge from local rivers that influence the region
- regional trends in key water quality parameters from 2005 to 2018
- presentation of the long-term trend and annual condition of ambient water quality relative to GVs using the WQ Index.

Site-specific data and additional information tables are presented in Appendix E (referred to by Figure and Table numbers prefixed 'E') and may be referred to for detail. These appendices include:

- Figure E-1: Time-series of chlorophyll and turbidity measured by moored FLNTUSB instruments
- Figure E-2: Time-series of temperature and salinity measured by moored Sea-Bird Electronics instruments
- Table E-1: Summary of the relative annual discharge for the major catchment rivers
- Table E-2 Cape York: Summary statistics for each water quality variable from each monitoring location, June 2017 to June 2018
- Table E-3 Wet Tropics, Burdekin and Mackay Whitsunday: Summary statistics for each water quality variable from each monitoring location, June 2017 to June 2018
- Table E-4: Annual summaries of moored FLNTUSB turbidity measurements for each monitoring location, including percentage exceedances of GVs
- Table E-5 to Table E-9: Summary of water quality data (collected as part of the JCU event-based sampling) across the wet season colour classes and water types for Reef-wide results and each focus area.

5.1 Cape York region

The Cape York region is divided into four sub-regions: Endeavour Basin, Normanby Basin, Stewart River and Pascoe River. The monitoring results are presented separately for each.

Regional water quality monitoring by the MMP commenced in the Cape York region in January 2017 and continued during the 2017–18 water year. Twenty-nine primary sites throughout four sub-regions (Figure 5-1) are sampled four to six times per year during ambient conditions. Up to 20 additional flood samples may be collected each year. The timing of ambient sampling is influenced by seasonal winds. Wind strength from May to October regularly exceeds 25 km/hour, restricting safe access to sampling locations (BOM, 2011). Sampling for the 2017–18 monitoring period began in October 2017 and ended in June 2018.

As the 2017–18 water year is only the second year of sampling for the Cape York region, long-term trends have not been analysed. Water quality results within each sub-region have been assessed relative to distance from river mouths (ambient conditions) and salinity (event) and compared against the draft Eastern Cape York Water Quality Guidelines for the enclosed coastal, open coastal, mid-shelf and offshore zones (Honchin et al., 2017).

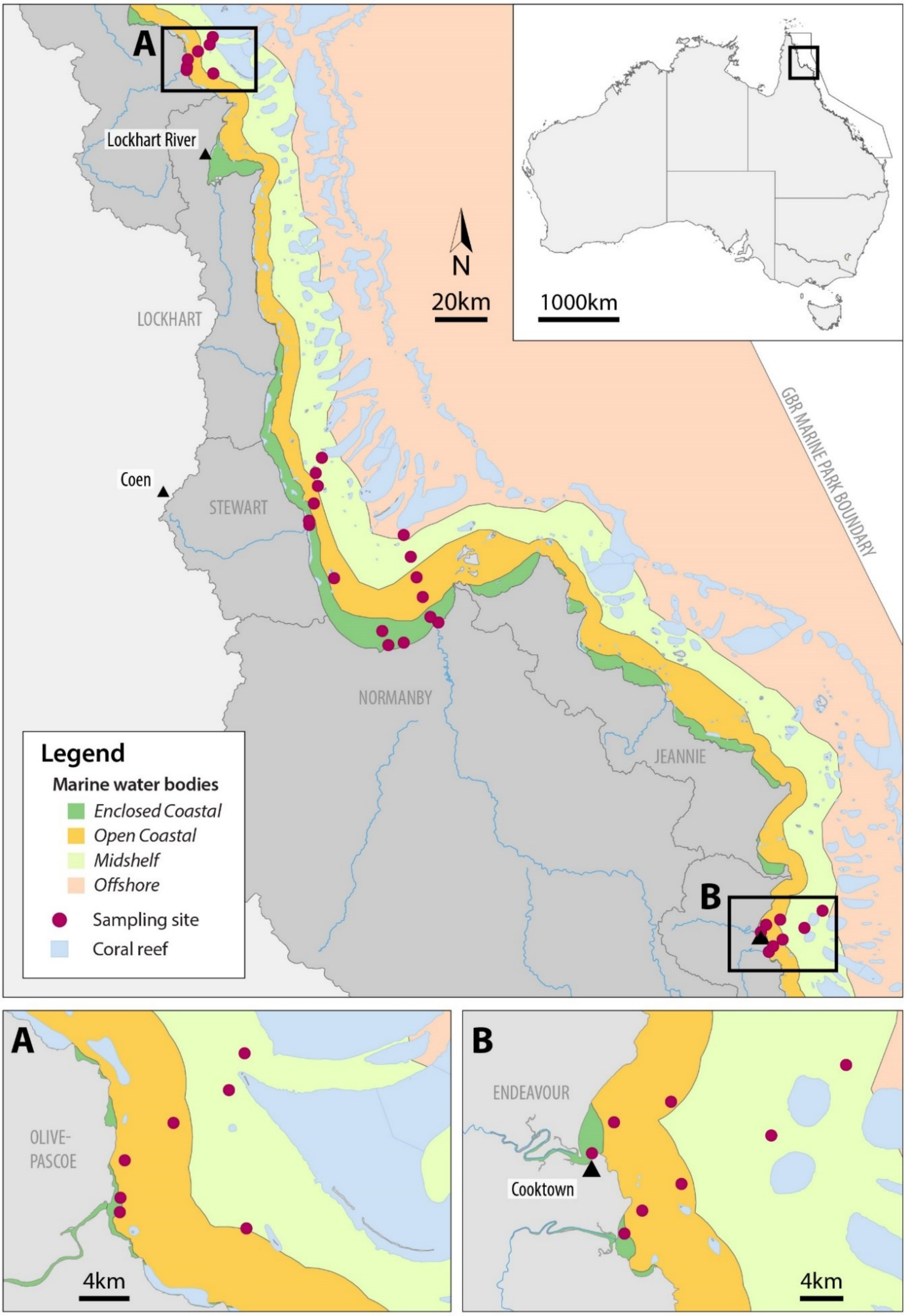


Figure 5-1: Water quality sampling sites in the Cape York region shown with water body boundaries.

The distinction between flood and ambient conditions during the wet season (for reporting purposes and comparison with baseflow annual guidelines) is complicated by the fact that minor floods noticeably affect water quality at the enclosed coastal zone sites while other sites further along the same transect remain unaffected. For this report, water quality results have been categorised as ambient wet, dry or event, based on an evaluation of the river hydrograph at the time of sampling, antecedent rainfall, salinity measurements at sample locations and field observations; however, there remains some grey area between these categories as discussed in the following sections.

Multiple events of different magnitude influenced Cape York marine waters during the 2017–18 wet season. In particular, the Pascoe River and Annan-Endeavour transects were regularly influenced by floodwater, resulting in a higher number of 'event' samples and less 'ambient' samples than planned.

5.1.1 Cape York region–Endeavour Basin

The Endeavour Basin coastal region is influenced by discharge from the Endeavour and Annan Rivers. Seven sampling stations for the Endeavour and Annan Rivers are located along a transect from the river mouths to open coastal waters, representing a gradient in water quality (Figure 5-2). During the 2017–18 wet season, a total of 28 surface and subsurface samples were collected from the Annan and Endeavour transect over 3 days during ambient conditions (November and December 2017 and June 2018). An additional 34 samples were collected over 7 days in January and March 2018 under conditions that were influenced by freshwater flood events at one or both rivers (Figure 5-3).

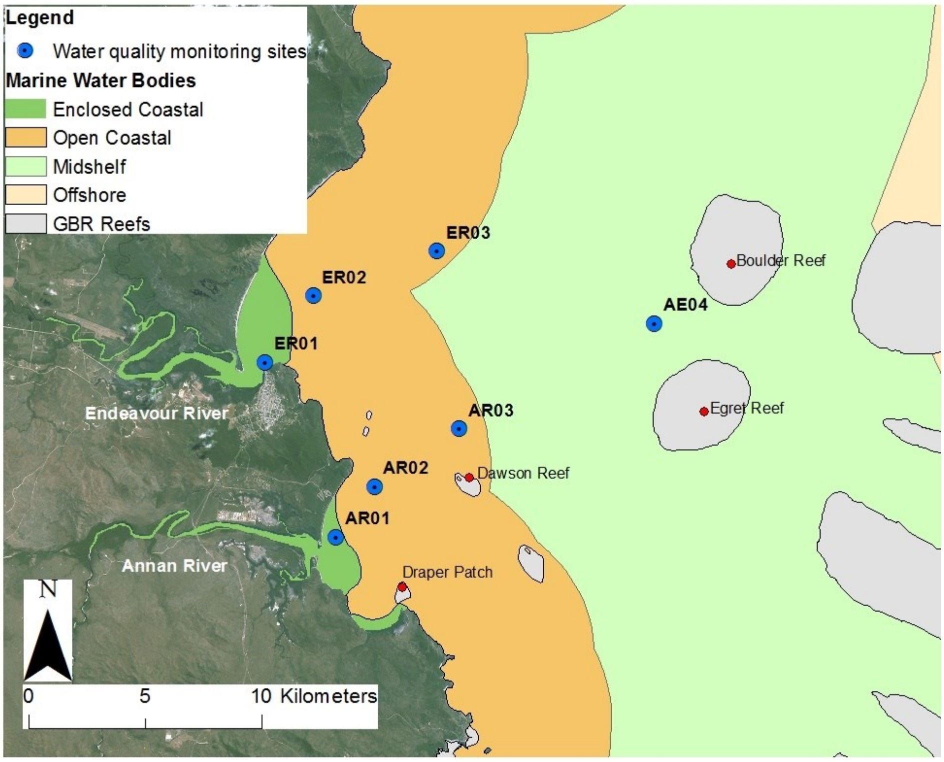


Figure 5-2: Water sampling sites in the Endeavour Basin focus area with water body boundaries.

The total discharge from the Endeavour Basin for the 2017–18 water year was slightly above the long-term median discharge (Table 3-1, Figure 5-4 and Figure 5-5). Total discharge measured at the Annan River Beesbike gauge 107003A was 314 GL for the water year, while 172 GL was recorded at the Endeavour River Flaggy gauge (107001B) (https://watermonitoring.information.qld.gov.au/host.htm). Estimated total Endeavour Basin discharge corrected for the catchment area is 1119 GL for the water year (Table 3-1).

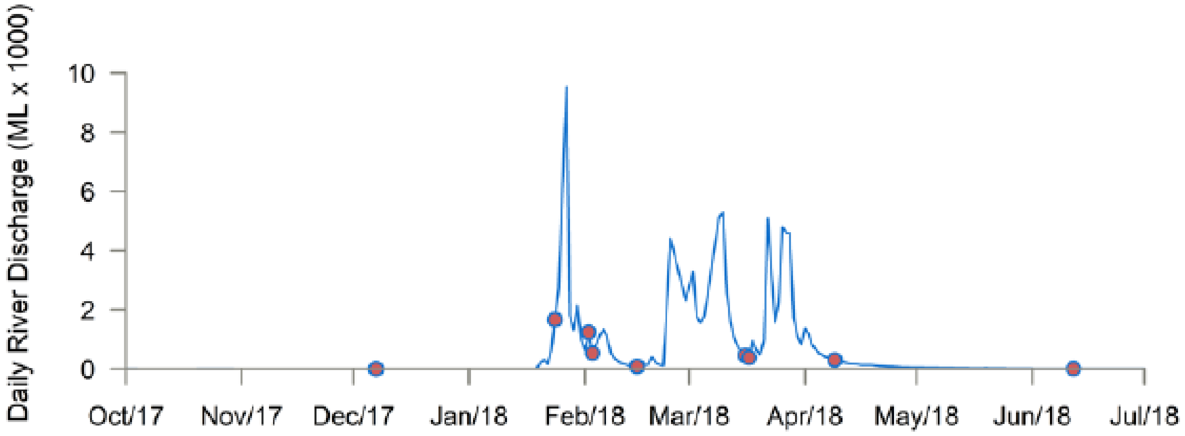


Figure 5-3: Daily discharge for the Annan River (gauge 107003A) for the 2017–18 wet season. Red dots represent sampling dates.

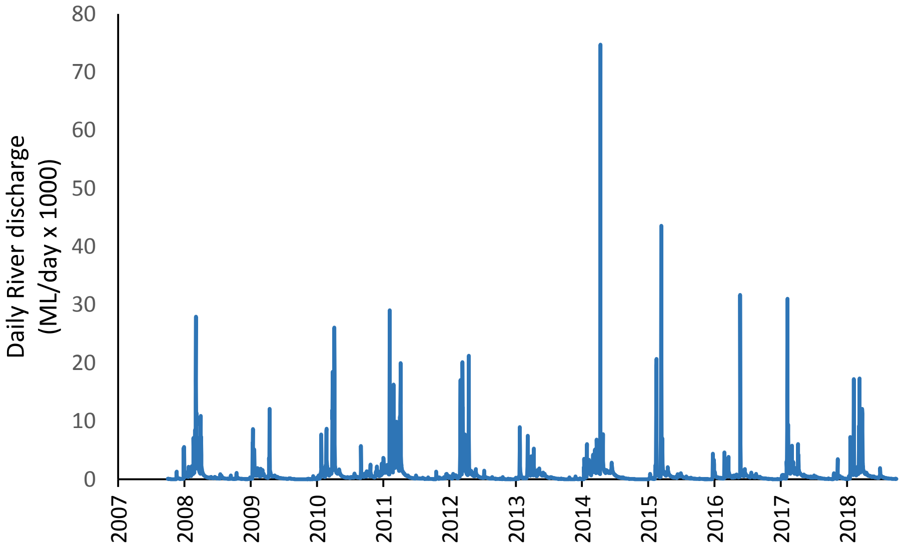


Figure 5-4: Long-term daily discharge for the Annan River (gauge 107003A).

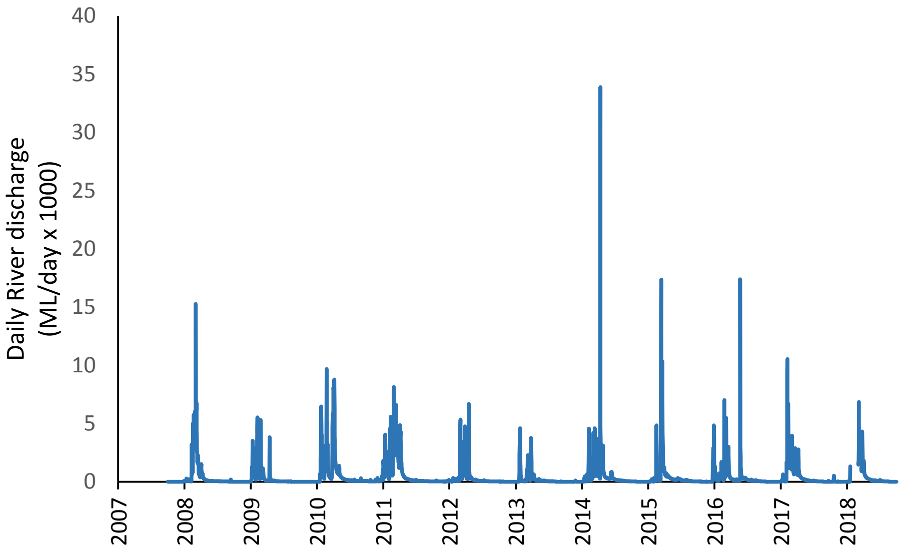


Figure 5-5: Long-term daily discharge for the Endeavour River (gauge 107001B). Note there were large gaps in discharge data for the 2017–18 wet season.

The combined discharge and loads estimated for the 2017–18 water year from the Endeavour Basin are shown in Figure 5-6 and were in the average range recorded over the previous 10 years (Table 3-1, Figure 5-4). Over the 12-year period from 2006:

- discharge has varied from 452 GL (2012–13) to 1836 GL (2010–11)
- TSS loads have ranged from 23 kt (2012–13) to 92 kt (2010–11)
- DIN loads from 23 t (2012–13) to 92 t (2010–11)
- PN loads from 36 t (2012–13) to 147 t (2010–11).

These load calculations, derived from the Source Catchments model, may underestimate total Endeavour Basin loads when compared with empirical load calculations because the model does not accurately incorporate loads from Oaky Creek, which is a significant anthropogenic sediment source to the Annan River and coastal zone (Howley, 2016; J. Shellberg unpublished data).

The estimated area of influence for the Endeavour Basin has not been mapped using the hydrodynamic model.

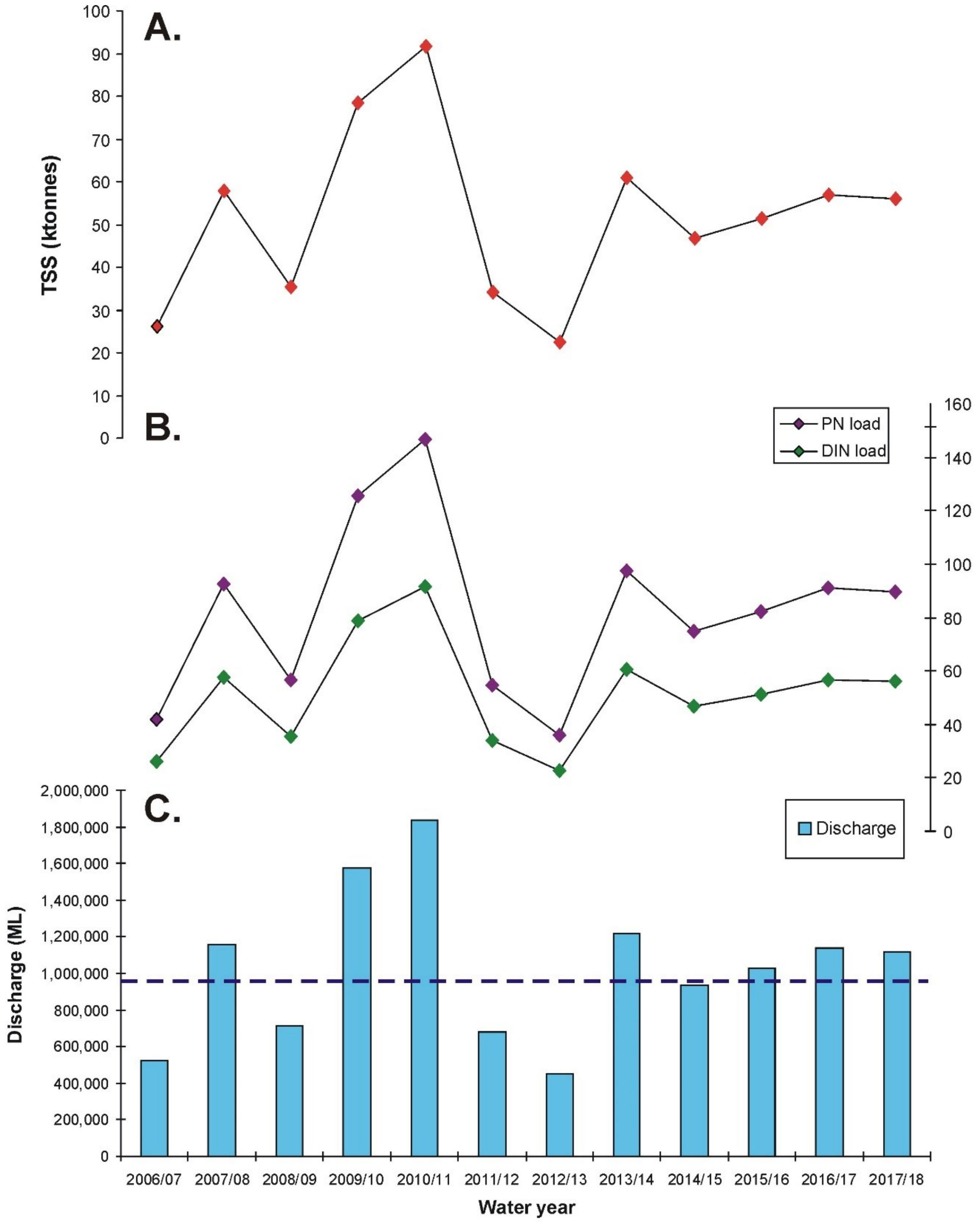


Figure 5-6. Loads of (A) total suspended solids (TSS), (B) dissolved inorganic (DIN) and particulate nitrogen (PN), and (C) discharge for the Endeavour Basin from 2006 to 2018. The loads reported here are based on the annual mean concentration reported in the Source Catchments modelling data and applied to each water year. Dotted line represents the long-term median for basin discharge.

The loading maps presented in Section 4 assessed the relative contribution of loads from each river to the Cape York NRM region. Figure 4-7 and Figure 4-11 show the estimated DIN and TSS contributions for the Cape York region. The largest contributions to the DIN and TSS loadings in 2017–18 were from the Normanby River (33% and 49%, respectively). The Pascoe River contributed ~20% to the regional DIN loading and the Pascoe and Endeavour Rivers also contributed ~12% each to the regional TSS loading. The Wet Tropics rivers contributions from the Daintree, Mossman and Russell-Mulgrave Rivers were small (~8% in total) but still evident in the comparably low discharge year of 2017–18.

Event water quality

Moderate-sized flood events occurred in January, February and March (Figure 5-3). An additional 34 flood event samples were collected from select sites over 8 days (Figure 5-3) including 4 days during the peak and falling limb of the first event of the wet season (19, 23, 24 and 30 January), and during 2 larger events on 9 and 27 March. Samples were also collected from the Endeavour transect sites (ER01, ER02, ER03 and AE04) on the 17th March while the Endeavour River was in flood.

A maximum 2017–18 TSS concentration of 370 mg L^{-1} was measured at ER01 (near the mouth of the Endeavour River) at the peak of the 'first flush' event on 19 January. This corresponded with PP (50 mg L^{-1}) and PN (450 mg L^{-1}) concentrations at ER-01 approximately 50- and 90-times above concentrations measured outside the plume. The NOx concentration at ER01 (69 µg L^{-1}) was approximately 18 times that of ambient concentrations. DON and NH_3 in the plume sample were over 1.5 times that of ambient concentrations, while PO_4 and DOP did not change. At the time of sampling, ER-02 and other transect sites to the east were not inundated by floodwaters due to strong south easterly winds pushing the plume north along the coast (Figure 5-7).

Figure 5-7: Endeavour river flood plume heading north along the coast on 19 January 2018. TSS 320 mg L^{-1} was recorded at site ER01 on this date.

On the receding limb of this first flush event, TSS concentrations at ER01 dropped to 35 mg L^{-1} (23 January 2018) and 7 mg L^{-1} (24 January 2018) and then rose to 77 mg L^{-1} on 30 January 2018 after another minor flood pulse. Figure 5-8 shows the visible extent of the plume reaching mid-shelf reefs on 31 January 2018. Flood water from rivers such as the Bloomfield and Daintree are also likely to have contributed to this plume. Dispersal models estimate that Wet Tropics rivers contributed 8% of the total Cape York TSS and DIN loads during the 2017–18 wet season.

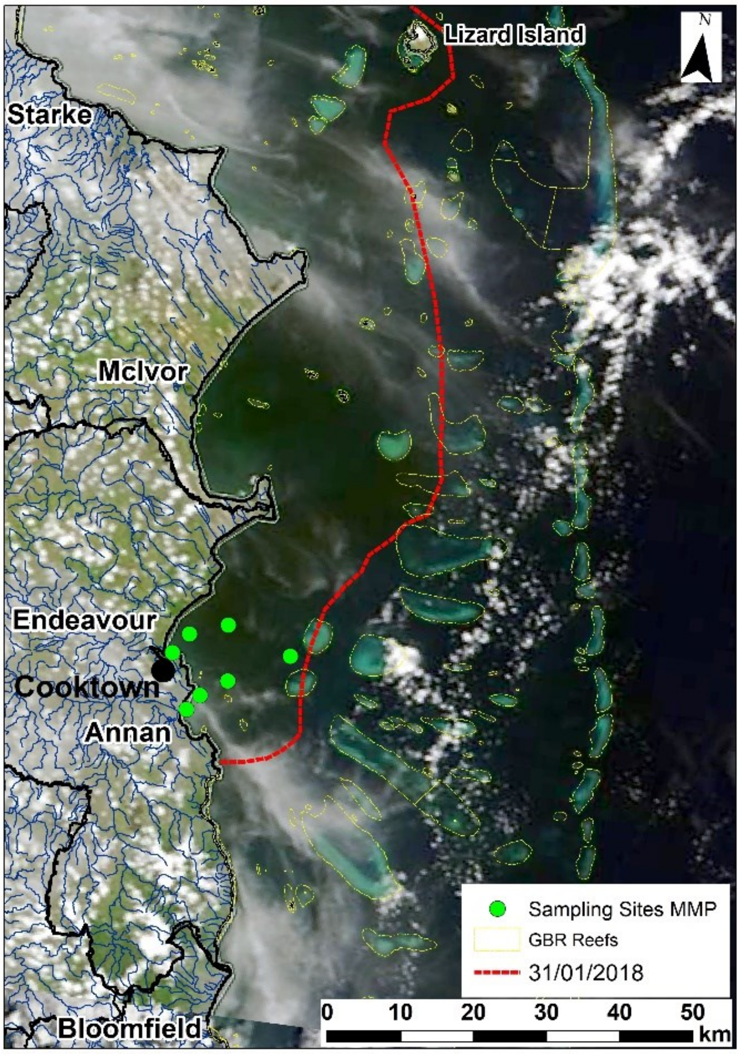


Figure 5-8: Annan and Endeavour River flood plumes extending out to mid-shelf reefs on 31 January 2018. Red line depicts approximate visible plume extent, not differentiating between primary, secondary or tertiary waters (Source: NASA MODIS image)

During March 2018 both the Endeavour and Annan River were frequently turbid with regular rainfall and rapidly rising and falling floodwaters. Samples collected on the 9, 17 and 27 March 2018 contained TSS concentrations ranging from 13 to 24 mg L^{-1} at AR01 and 29 to 88 mg L^{-1} at ER01. Plume waters containing TSS concentrations as high as 57 mg L^{-1} inundated coral and seagrass meadows around Draper Patch reef located 3 km southeast from the Annan River mouth (salinity 16.7 PSU; 27 March 2018). The freshwater influence did not reach beyond the open coastal zone and surface samples collected outside the visible plume boundary ranged from 2 to 4.7 mg L^{-1}.

Similar to TSS, elevated nutrient concentrations were measured in the enclosed coastal zone and into the open coastal zone during the March flood events, with concentrations around half of that measured at the peak of the first flush event in January. However, the maximum 2017–18 event Chl-*a* concentration (1.47 µg L^{-1}) was detected at ER01 on 17 March 2018 (salinity 29.1 PSU) following the largest magnitude flood of the wet season. On the same day, Chl-*a* concentrations were 0.52 and 0.56 µg L^{-1} in the open coastal zone (ER02 and ER03, respectively) and <0.2 µg L^{-1} at AE-04 near the reefs in the mid-shelf zone.

Event TSS concentrations generally decreased along the salinity gradient; with the exception of a concentration of 77 mg L^{-1} at the Endeavour River boat ramp (approx. 0.5 km upstream from ER01) on 17 March 2018 (salinity 30 PSU) and a subsurface ER02 sample on 24 January 2018 (TSS 120 mg L^{-1}, salinity 32 PSU).

Ambient water quality

Ambient water quality results were plotted against distance from the mouths of the Annan or Endeavour Rivers (Figure 5-9) and salinity gradients (Figure 5-10). There were no clear trends in TSS concentrations with distance, but Secchi depth increased with distance from the mouth. Concentrations of DON, DOP, PN and PP stayed relatively constant across the sites. Note that:

- Maximum ambient concentrations of NO_x (19.5 µg L^{-1}), NH_3 (12.0 µg L^{-1}), PO_4 (3.9 µg L^{-1}) and Chl-*a* (1.4 µg L^{-1}) were recorded in the open coastal zone (sites AR02, AR03, ER02 and ER03, respectively)
- Maximum concentrations of PN (72 and 70 µg L^{-1}) and PP (22 µg L^{-1}) were detected in the open coastal and midshelf zone on 27 October 2017 and may be related to wind resuspension of sediments
- Ambient concentrations of TSS for 2017–18 ranged from 1.7 to 29 mg L^{-1} with a mean of 4.4 mg L^{-1}. TN ranged from 81 to 157 µg L^{-1} (mean 100 µg L^{-1}) and was comprised on average of 82% DON and 11% PN.
- TP concentrations ranged from 4 to 31 µg L^{-1} (mean 8.1 µg L^{-1}) and was comprised of 51% PO_4, 34% DOP and 15% PP on average.

Analyses of ambient sampling results against the draft Eastern Cape York regional guidelines (Table E-2) show median concentrations of NO_x and PO_4 in enclosed coastal waters exceed the guidelines for base flow (annual) conditions. In the open coastal zone, ambient 20-50-80th percentile concentrations of NH_3 exceed the annual GVs and mean Secchi depth (8.4 m) is less than the annual mean GV (≥10 m). For the dry season sample results, median TDN, NO_x and PO_4, and mean TSS and PN for open coastal zone samples exceeded the relevant dry season GVs. For wet season open coastal samples, median TSS, TDN, NO_x and PO_4 also exceeded the GVs. In the mid-shelf region, median ambient (wet and dry season combined) concentrations of TSS, TDN, NH_3, NO_x and PO_4 exceeded the annual GVs. Exceedances in this zone (and others) are only indicative due to the small ambient sample dataset and draft status of GVs.

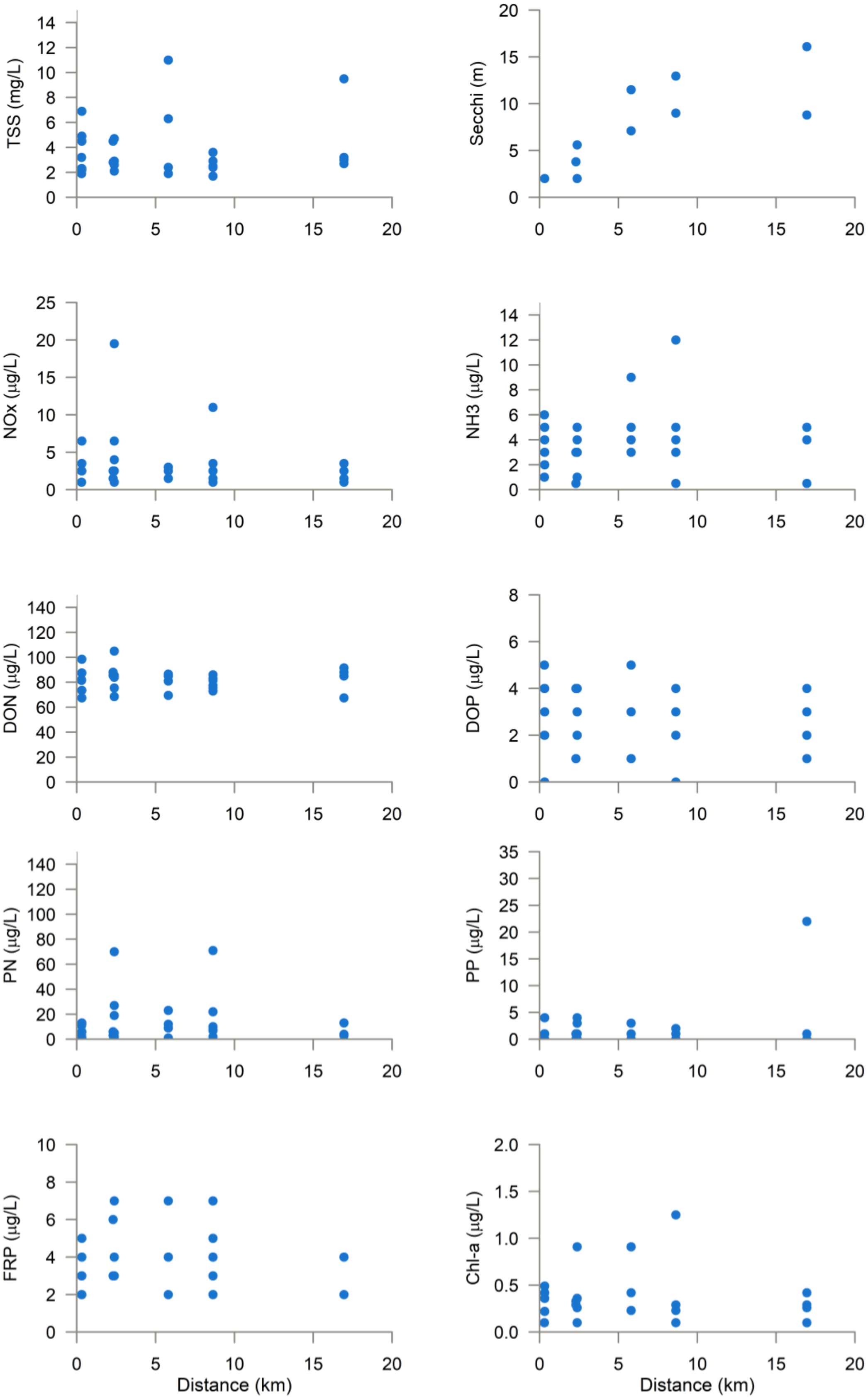


Figure 5-9: Water quality concentrations (surface and subsurface samples) and Secchi depth over distance from river mouth (km) for the Endeavour Basin sub-region during ambient conditions (2017–18 water year).

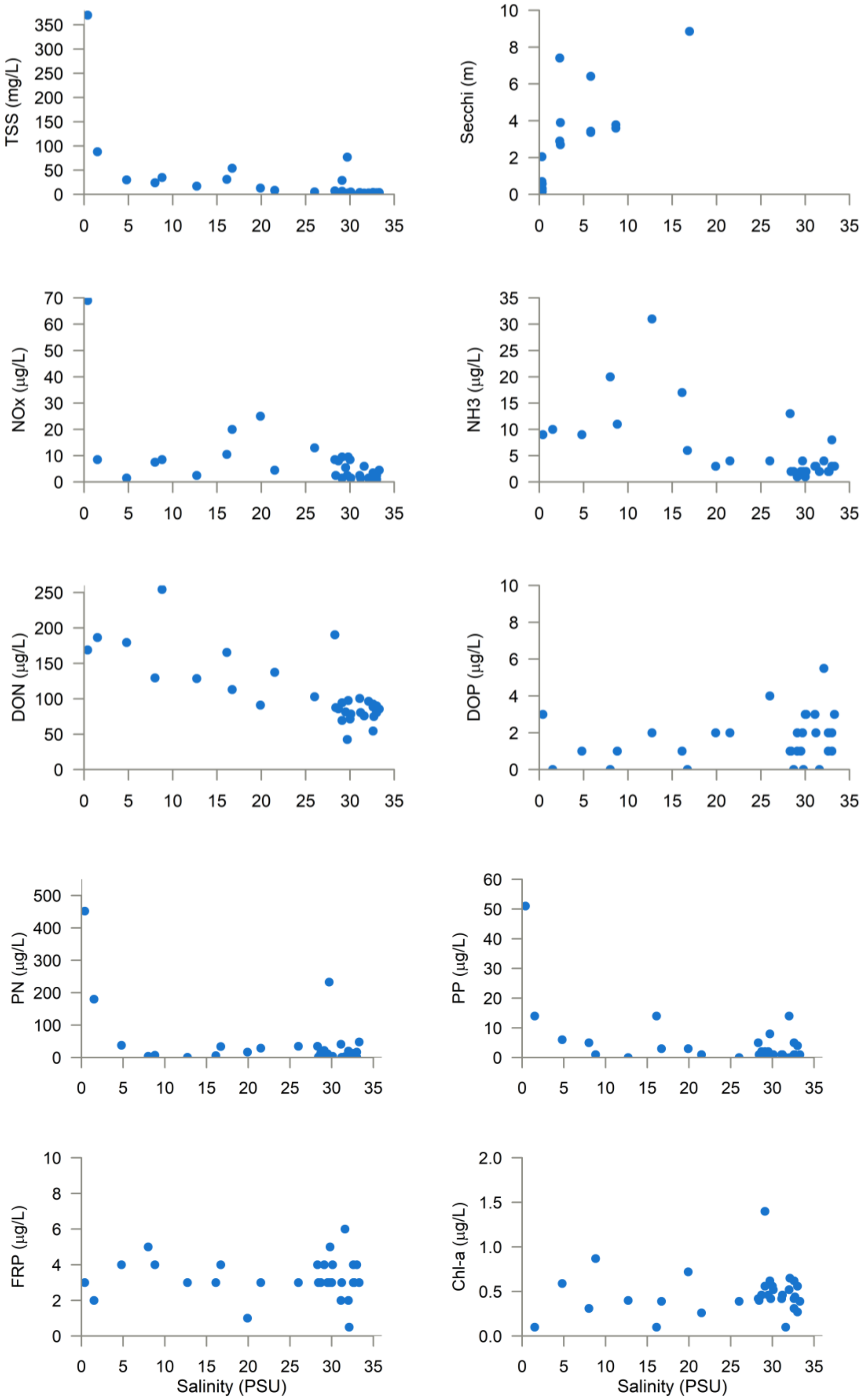


Figure 5-10: TSS, nutrient and Chl-*a* concentrations over the salinity gradient for the combined Annan-Endeavour flood events (19, 23 and 24 January, and 9, 17 and 27 March 2018).

5.1.2 Cape York Region–Normanby Basin

The Normanby Basin is influenced by discharge from the Normanby, Laura, Kennedy, Hann, Mossman, Morehead and Annie Rivers, plus three tributaries—the North Kennedy, Normanby and Bizant.

Six of ten sampling stations for the Normanby Basin are located along a transect from the Normanby River mouth to open coastal waters and Corbett Reef (Figure 5-11). Two additional sample sites are located near the Kennedy River and one near the Bizant River mouth in the enclosed coastal zone. An additional site (CI01) is located near the Cliff Isles ('Marrpa' in traditional Lama Lama language). Due to the distances covered by these sample locations, as well as tidal restrictions getting into and out of local rivers to access the sites, it is not possible to sample all sites in any one day. Therefore, some sites have been sampled more frequently than others.

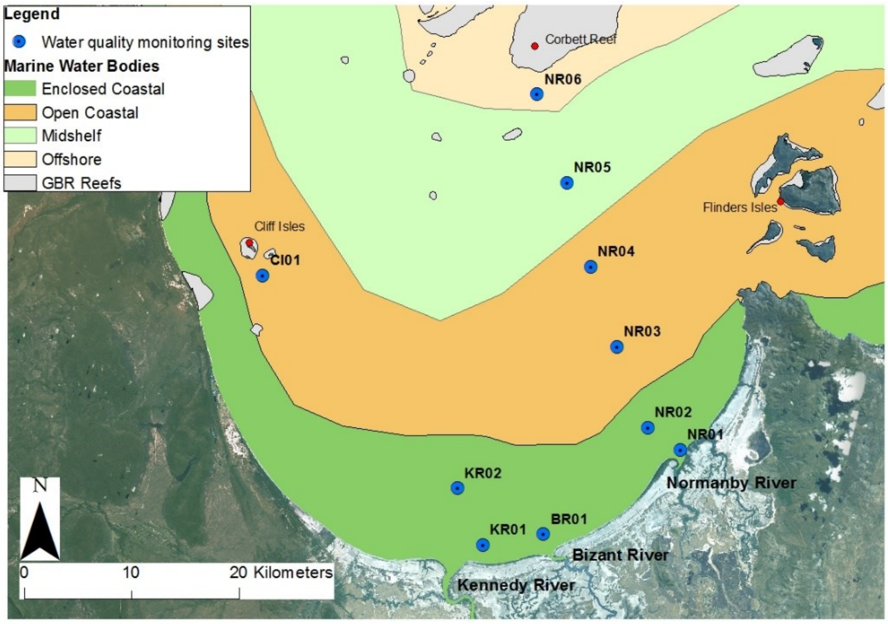


Figure 5-11: Water quality sampling sites in the Normanby Basin focus area with water body boundaries.

A total of 49 samples were collected over eight days (including consecutive days) from November 2017 to April 2018 (Figure 5-12). CL01 and NR01 were each sampled four times, NR-06 and KR-02 were sampled twice, and all other sites were sampled three times. Both surface and subsurface samples were collected at all sites except for the river mouths where water depth was less than 3 m.

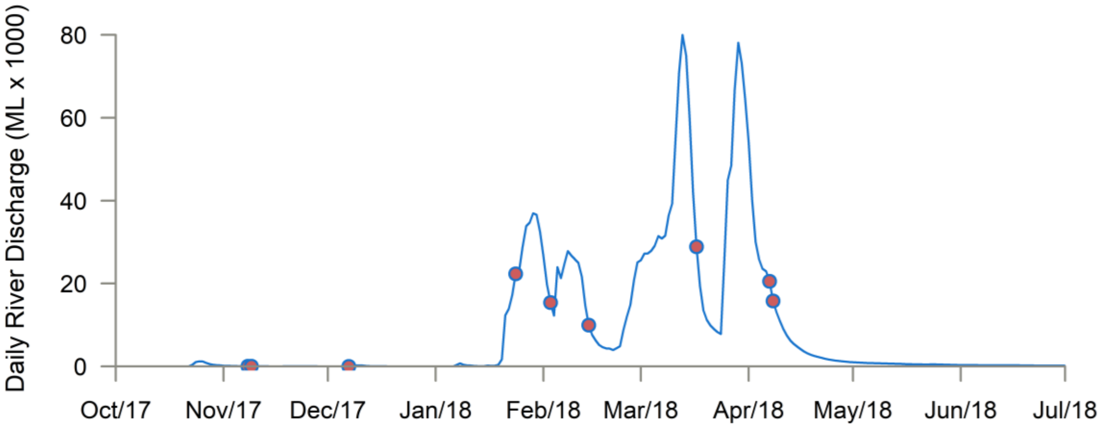


Figure 5-12: Daily discharge for the Normanby River (gauge 105107A) for the 2017–18 water year. Red dots represent sampling dates.

Discharge from the Normanby River for the 2017–18 water year (Figure 5-13) was slightly above the long-term median (Table 3-1). Total discharge measured at gauge 105107A (located approximately 70 km upstream from the Normanby River mouth at Kalpowar Crossing) was approximately 2281 GL with 98% of discharge between the months of January and April (Figure 5-12; DNRME Water Monitoring Information Portal, https://water-monitoring.information.qld.gov.au/host.htm). Total discharge for the whole of the Normanby Basin cannot be accurately calculated as there is no gauge on the Kennedy River or at the mouth of any of the three Normanby Basin distributaries. A 'whole of Basin' discharge volume of 4333 GL has been estimated for the 2017–18 water year based on discharge measured at the Kalpowar gauge upscaled to the entire basin area.

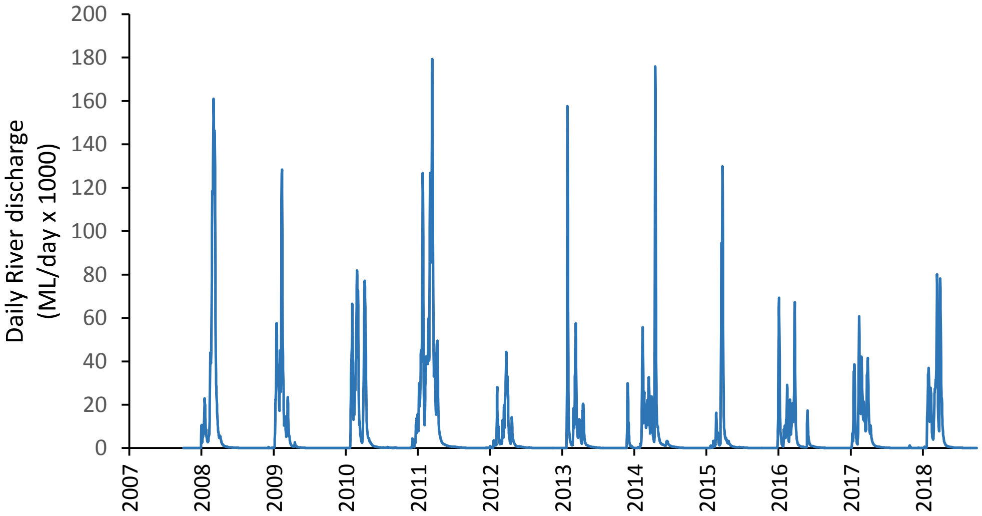


Figure 5-13: Daily discharge for the Normanby River (Kalpowar gauge 105107A).

The combined discharge and loads estimated for the 2017–18 water year from the Normanby Basin are shown in Figure 5-14. The combined discharge and loads estimates for the 2017–18 water year from the Normanby Basin were around the average recorded over the past 10 years. Over the 12-year period from 2006:

- discharge has varied from 2182 GL (2011–12) to 11,333 GL (2010–11)
- TSS loads are estimated to have ranged from 55 kt (2014–15) to 509 kt (2010–11)

- DIN loads ranged from 42 t (2011–12) to 270 t (2010–11)
- PN loads ranged from 124 t (2009–10) to 1184 t (2013–14).

Figure 4-8 and Figure 4-12 show that the Normanby River was the greatest contributor to the river-derived DIN and TSS loading in the Cape York region in 2017–18. This is the case in all years modelled and correlates with regional assessments of end-of-catchment river loads (e.g. Howley et al., 2016; Waterhouse et al., 2016).

Ambient water quality

The Normanby results represent one sampling event during the dry season and three surveys during the wet season. Freshwater discharge influenced samples close to the mouths of the Normanby and Kennedy Rivers during the wet season monitoring trips on 14 February 2018 (salinity of 9 PSU at NR01) and 7 and 8April (10–12 PSU at KR01 and NR01). Figure 5-15 shows the decline of NH_3, DON, DOP, PN, PP and reactive silica concentrations and increasing Secchi depth over distance from the river mouths, reflecting the freshwater influence in the shallow enclosed coastal zone.

TSS concentrations also declined with distance from the river mouths (Figure 5-15). This was due to both freshwater discharge and sediment re-suspension. The maximum 2017–18 TSS concentration (24 mg L^{-1}) was measured during the dry season (9 November 2017) at KR01, most likely due to the wind-driven re-suspension of shallow Princess Charlotte Bay sediments. Tidally-forced resuspension also has a major influence on estuary turbidity and the creation of in-shore turbid plumes at Princess Charlotte Bay. Turbidity dataloggers installed in the Normanby, Bizant, and Kennedy estuaries have recorded turbidity values between 300 to 500 NTU on outgoing spring tides during ambient conditions (Howley and Shellberg, unpublished data).

The mean TSS concentration for the 2017–18 Normanby transect was 4.9 mg L^{-1}. Under ambient conditions (salinity >30 PSU), the mean TN concentration was 117 µg L^{-1} comprised on average of 82% DON and 10% PN. TP (mean 7.5 µg L^{-1}) was comprised of 49% DOP, 17% PP and 33% PO_4 on average.

Chl-*a* concentrations for 2017–18 ranged from <0.2 to 2.0 µg L^{-1} with the maximum concentration detected during the dry season at NR03. The mean dry season concentration was 0.50 µg L^{-1} compared to a mean wet season concentration of 0.62 µg L^{-1} across all sites.

In the enclosed coastal zone, median PO_4 concentrations (ambient wet and dry season results combined) exceeded the annual 50th percentile guideline for the Normanby Basin enclosed coastal zone. This may be partially due to the receding flood influence in the enclosed coastal zone on two occasions. The Normanby Basin enclosed coastal guidelines are based on targets for a 10% reduction of current conditions. There are no guidelines for Secchi depth or TSS in the enclosed coastal zone.

In the open coastal zone, mean Secchi depth (5.3 m) was less than the annual guideline (≥10 m) and the 20-50-80th percentiles for NH_3 exceeded the relevant GVs. In the analysis of open coastal wet season results alone, TSS, TN, TDN and NO_x, PO_4 and PP all exceeded the 20-50-80th percentile wet season GVs. The relatively small number of wet season samples may not be representative of ambient wet season conditions, or the open coastal GVs for Cape York may not be applicable in Princess Charlotte Bay. For the dry season open coastal zone samples (November 2017) median concentrations of TDN, NO_x and Chl-*a* exceeded the 50th percentile water quality objectives.

For the mid-shelf water body samples, median values of TSS, TDN, NH_3, NO_x, and PO_4 exceeded the annual water quality GVs. In the offshore water body, site NR06 was only sampled twice in the wet season (surface and subsurface). Not surprisingly, the comparison of these wet season results against the annual GVs show multiple exceedances (Table E-2).

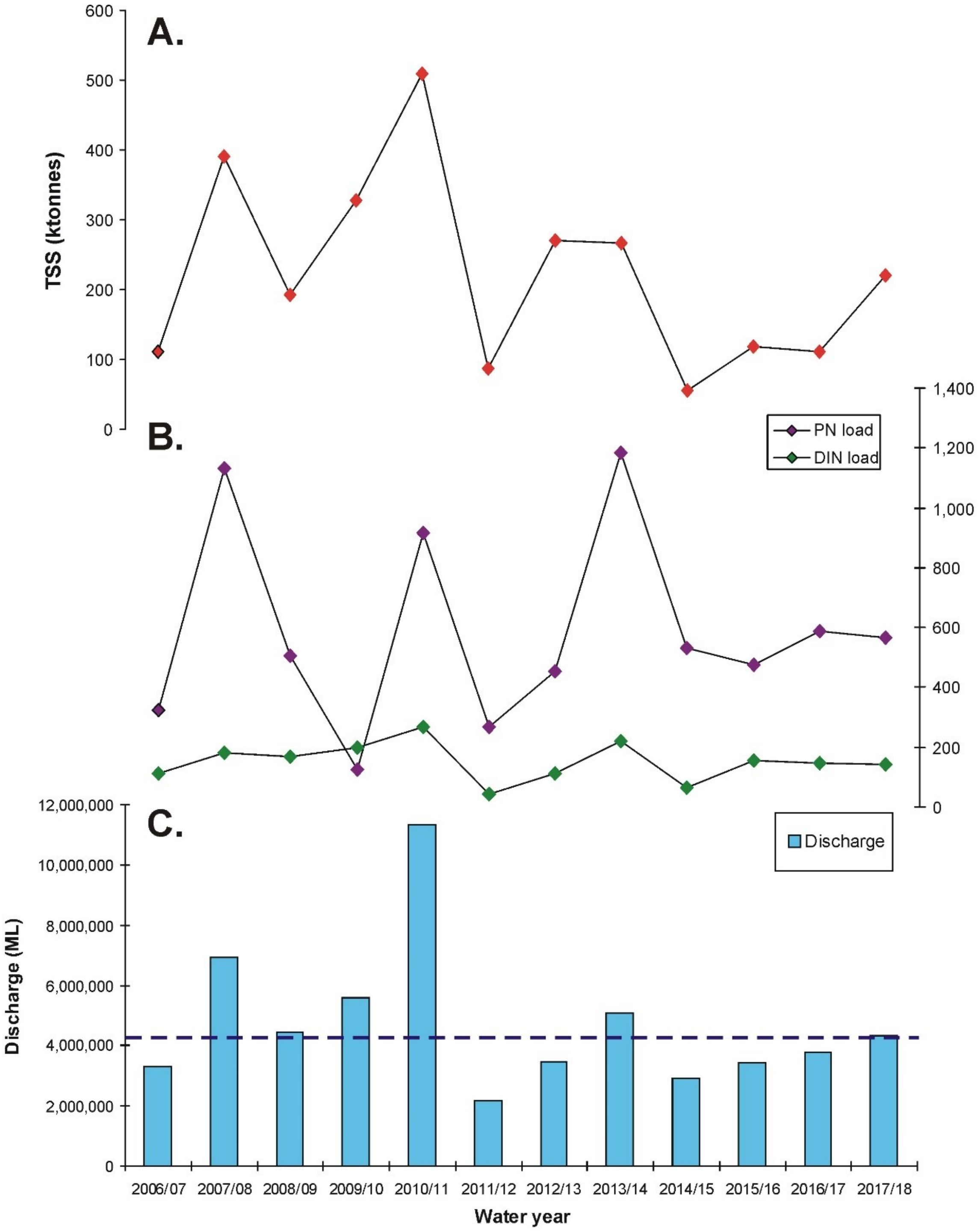


Figure 5-14: (A) TSS loads, (B) DIN and PN loads and (C) discharge for the Normanby Basin from 2006 to 18. The loads reported here are a combination of 'best estimates' based on 'up-scaled' discharge and monitoring data from the Normanby River at Kalpower gauging station (covers ~50% of the basin area). The dotted line represents the long-term median for basin discharge.

Event water quality

As discussed above, relatively small events (approximately 577 GL and 634 GL total event discharge—below average for a Normanby flood event) preceded sampling on 14 February 2018 and 7 and 8 April 2018. In April, the freshwater plume reached as far as NR03 (salinity

25.4 PSU) and CI01 (salinity 19 PSU). This freshwater discharge contained elevated (above ambient) concentrations of nutrients, particularly for:

- NH_3 (2.3 times higher than ambient means)
- PN (3.9 times higher than ambient)
- PP (2.3 times higher than ambient)
- DON (1.6 times higher than ambient)
- reactive silica (3.6 times higher than ambient)
- Chl-*a* (1.8 times higher than ambient).

However, concentrations remained low compared to samples collected during peak stages of larger magnitude flood events sampled previously. For example, a maximum 2018 event TSS concentration of 13 mg L^{-1} was measured at NR01 (14 Feb 2018) compared to 84 mg L^{-1} at NR01 during an April 2014 event (Howley et al., 2018). A maximum 2018 event Chl-*a* concentration of 1.56 µg L^{-1} was measured at BR01 (8 Apr 2018) compared to 8.82 µg L^{-1} in the January 2013 Normanby flood plume (Howley et al., 2018). This may be related to the timing of the plume sampling (falling limb versus peak river discharge) and/or the relatively small magnitude of the events sampled. Either way, the samples collected in 2018 are not representative of average or above-average magnitude Normanby Basin event conditions.

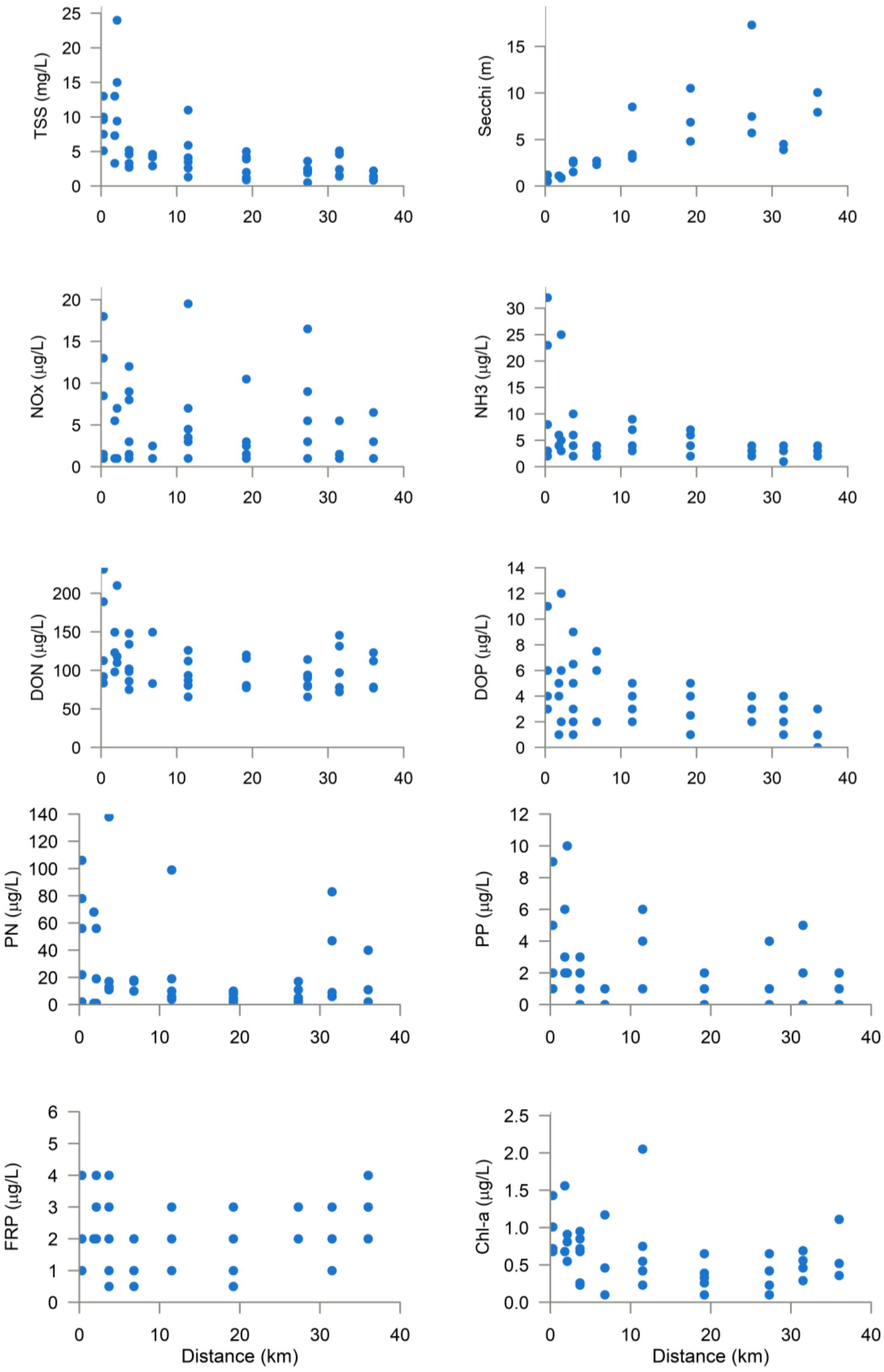


Figure 5-15: Water quality concentrations (surface and subsurface) and Secchi depth over distance (km) from river mouth for the Normanby Basin sub-region, all 2017—18 sampling dates.

5.1.3 Cape York Region–Stewart River

The Stewart River transect is influenced primarily by discharge from the Stewart River, although during flood conditions it can also be influenced by floodwater from the Normanby and Kennedy Rivers.

Five sampling stations for the Stewart River are located in a transect from the river mouth to mid-shelf waters, representing a gradient in water quality (Figure 5-16). The transect (surface and subsurface) was sampled six times (over 8 days) during the 2017–18 sampling season, including twice during dry season conditions (December 2017 and June 2018) and four times during the wet season (

Figure 5-17). Similar to the Normanby transect, there was some freshwater influence during wet season ambient sampling dates, particularly at sites in the enclosed coastal zone (SR-01 and SR-02). An additional sample was collected outside of a visible plume line located between SR01 and SR02 on 3 February 2018. Another additional sample was collected opportunistically at SR01 on 24 January during the rising stage of the first event of the wet season. However, no focused event sampling occurred due to the challenge of accessing the remote area during peak event conditions when roads to Port Stewart are flooded.

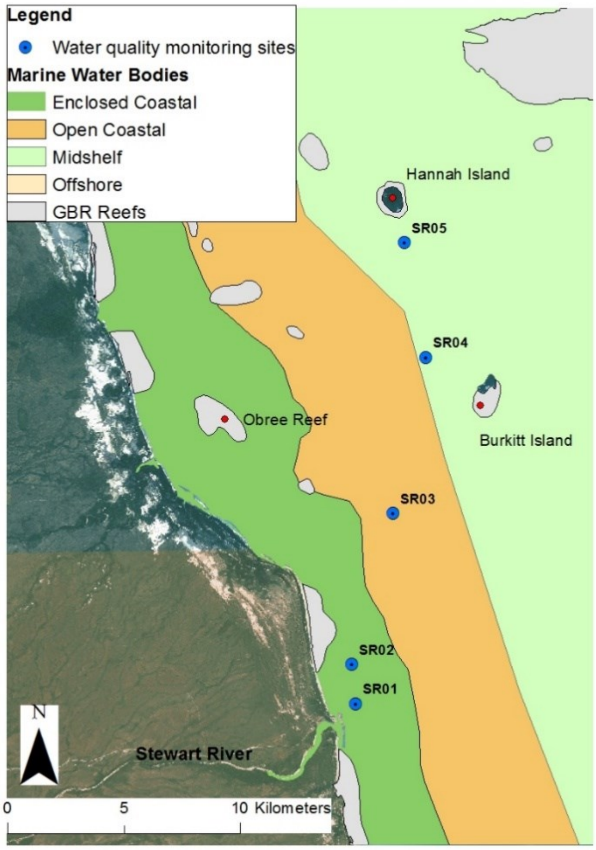


Figure 5-16: Water quality sampling sites in the Stewart River transect with water body boundaries.

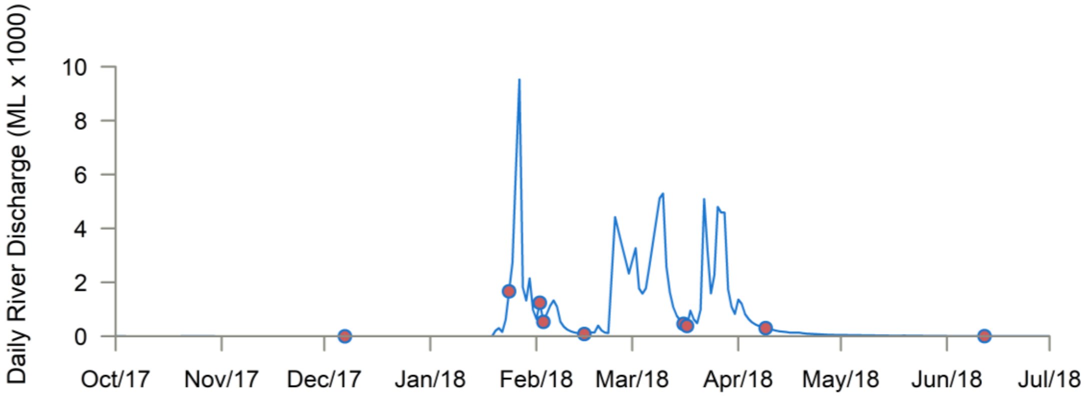


Figure 5-17: Daily discharge for the Stewart River (gauge 104001A) for the 2017–18 water year (missing daily discharge during event on 26 January 2018). Red dots represent sampling dates.

The total annual discharge for 2017–18 water year is estimated at 826 GL based on the measurements from the Stewart River gauge 104001A corrected for catchment area. This is greater than the long-term median annual discharge, although the maximum peak daily event discharge (9530 ML, 27 January 2018) was approximately half the peak daily discharge measured over previous years flood events (Table 3-1, Figure 5-18) (note that gauge 104001A did not record discharge volume on 26 January).

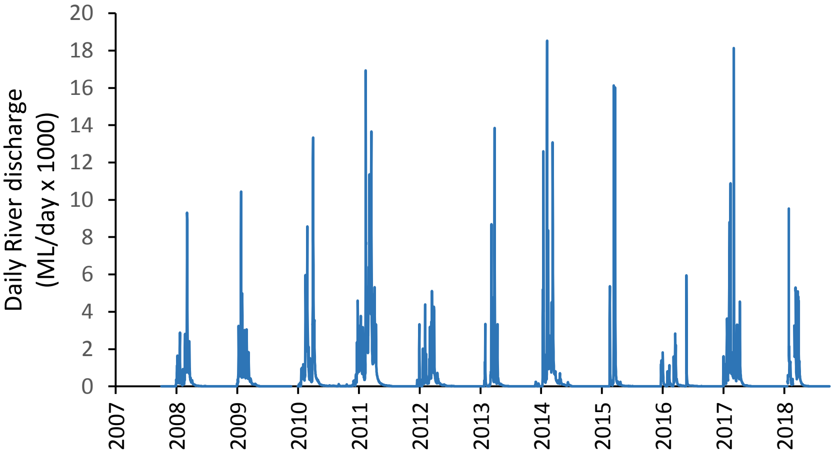


Figure 5-18: Daily discharge for the Stewart River (gauge 104001A).

The combined discharge and loads estimated for the 2017–18 water year from the Stewart Basin are shown in Figure 5-19. The discharge and loads calculated for the 2017–18 water year from the Stewart Basin were in the average range estimated over the previous 10 years. Over the 12-year period from 2006:

- discharge has varied from 299 GL (2014–15) to 2181 GL (2010–11)
- TSS loads are estimated to have ranged from 6 kt (2014–15) to 44 kt (2010–11)
- DIN loads ranged from 15 t (2014–15) to 109 t (2010–11)
- PN loads ranged from 18 t (2015–16) to 131 t (2010–11).

Figure 4-8 and Figure 4-12 show that the Stewart River contributed an estimated ~6% of the river-derived DIN and ~4% of TSS loading in the Cape York region in 2017–18.

The estimated area of influence for the Stewart River has not been mapped as it is not included in the eReefs hydrodynamic model.

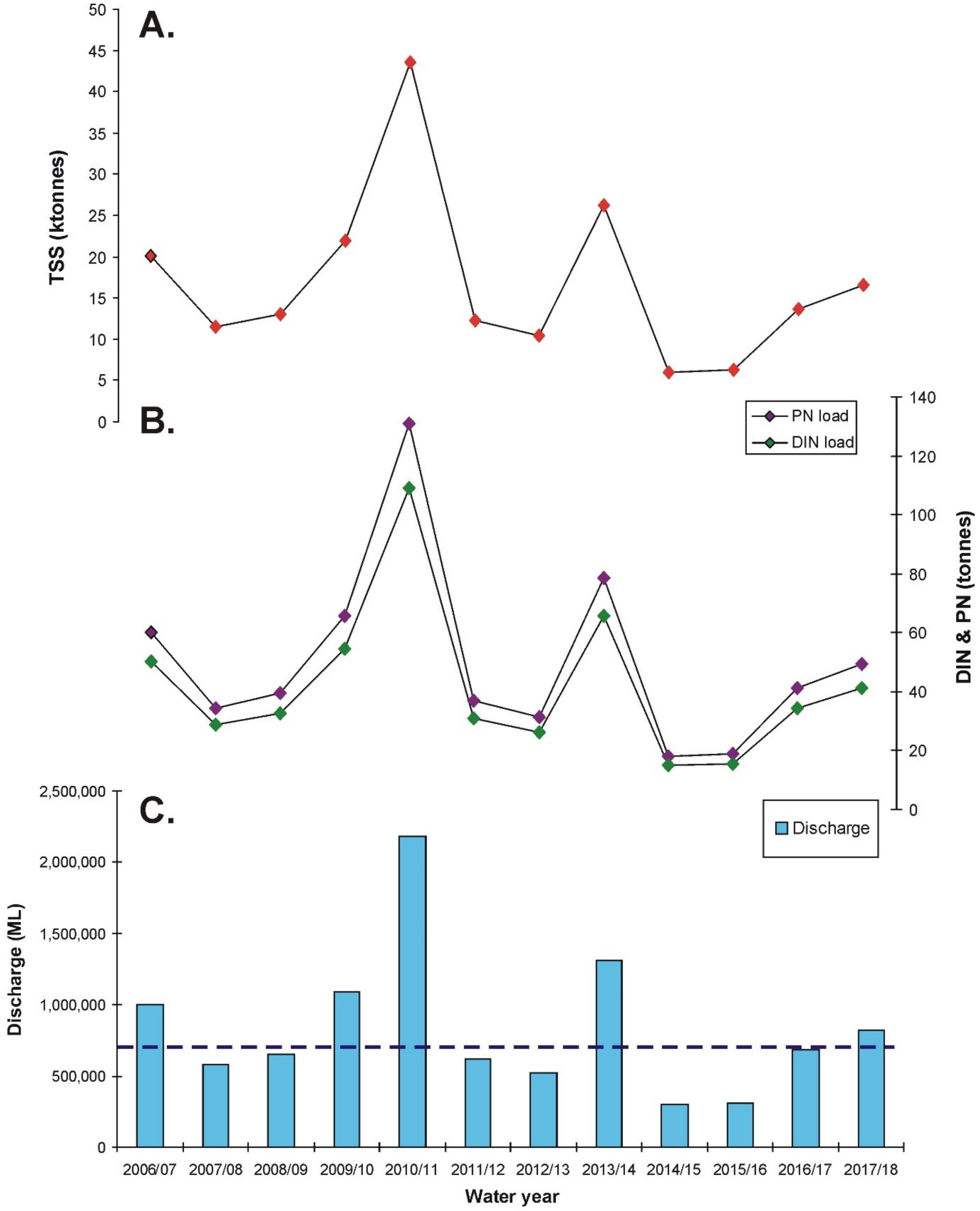


Figure 5-19. (A) TSS loads, (B) DIN and PN loads and (C) discharge for the Stewart Basin from 2006 to2018. The loads reported here are based on the annual mean concentration reported in the Source Catchments modelling data and applied to each water year. Dotted line represents the long-term median for basin discharge.

Ambient and event water quality

The 2017–18 Stewart River transect water quality results are plotted against distance from the river mouth in Figure 5-20. The plots show few clear trends.

Ambient TSS concentrations for the Stewart River transect (2017–18 water year) ranged from 0.2 to 25 mg L^{-1} with a mean concentration of 4.3 mg L^{-1}. Concentrations of Chl-*a* ranged from <0.2 to 1.3 µg L^{-1}, and mean ambient Chl-*a* was 0.4 µg L^{-1}.

Although there was no focused flood event monitoring during the 2017–18 wet season, samples were collected during the rising stage (24 January 2018) of the first event of the wet season near the mouth of the Stewart River (SR01). A TSS concentration of 56 mg L^{-1} was measured during this first flush event, compared to a mean ambient concentration of 4 mg L^{-1} for SR01 for the 2017–18 water year. Concentrations of NO_x (47.5 µg L^{-1}), DON (330.5 µg L^{-1}) and DOP (9 µg L^{-1}) at SR01 were 4 to 5 times higher than the ambient means. Only 2 µg L^{-1} PN (based on calculations of TN-TDN) were present in the event sample.

Elevated TSS concentrations of 17 and 25 mg L^{-1} were measured at SR01 and SR03 on 2 February 2018 and 3 February 2018, respectively; however, both these measurements were from subsurface samples and respective surface concentrations were relatively low at 7 and 4 mg/L. Maximum PN concentrations were detected in enclosed coastal sites SR01 and SR02, also primarily in subsurface samples. The maximum PP concentration was detected at 16.5 m depth at open coastal site SR05, potentially due to wind-driven resuspension of sediments. PO_4, NH_3 and Chl-*a* remained relatively constant across the sites (Figure 5-20). Maximum and mean Chl-*a* concentrations were 1.3 and 0.40 µg L^{-1}, respectively.

When compared against the annual water quality GVs for the enclosed coastal zone, Stewart River results (wet and dry season combined) were generally within the GVs with the exception of PO_4, which exceeded the 20-50-80th percentile guidelines. In the open coastal zone, mean Secchi depth (5.6 m) was less than the annual GV (≥10 m) and NH_3 concentrations exceeded the annual GV for all percentiles. In both cases, this may be because most samples were collected during the wet season. However, median TSS, TDN, PO_4 and NO_x concentrations for the open coastal zone wet season samples also exceeded the wet season GVs. Mean dry season TSS (4.0 mg L^{-1}) exceeded the 1.6 mg L^{-1} GV and median TDN, NO_x, PO_4 and Chl-*a* also exceeded the dry season open coastal GVs. In the mid-shelf zone, median TN, TDN, NH_3, NO_x, PO_4 and Chl-*a* concentrations (wet and dry season combined) exceeded the annual GVs.

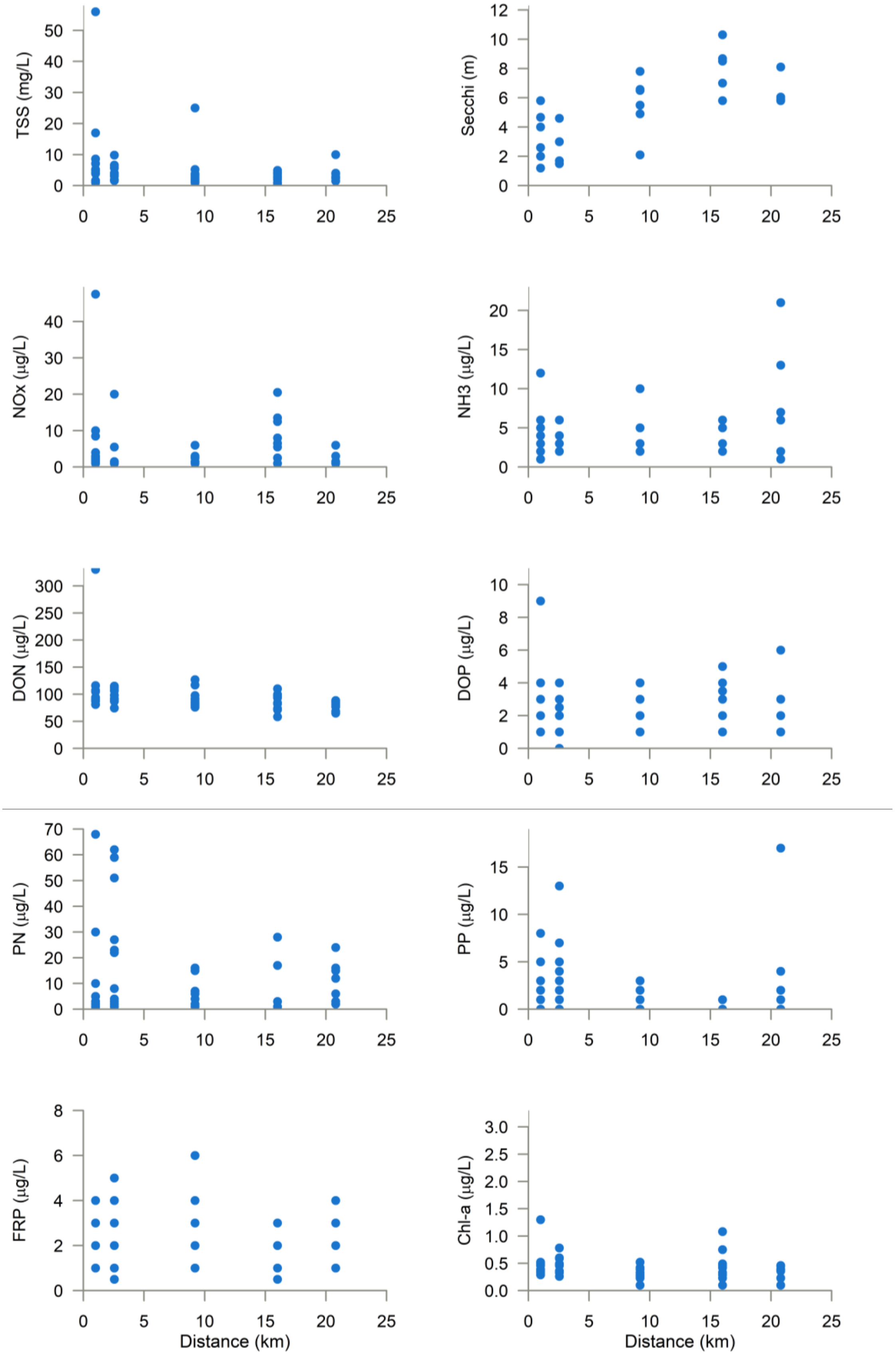


Figure 5-20: Water quality concentrations (surface and subsurface) and Secchi depth over distance (km) from river mouth for the Stewart River sub-region, all 2017–18 sampling dates.

5.1.4 Cape York Region–Pascoe River

The Olive-Pascoe Basin is comprised of the Pascoe River and the Olive River. During the first year of sampling (2016–17), five sampling stations (PRN01 to PRN05) were located along a transect from the mouth of the Pascoe River north to open coastal waters, and two additional sites were located to the south; PRS01 (south of the river mouth) and PRBB located at Middle Reef (locally known as Blue Bells). Due to the observance of floodwaters flowing to the southeast during the 2017–18 wet season, additional sites were added along the southern transect at the end of the sampling season (PRS02, PRS03 and PRS05, Figure 5-21.

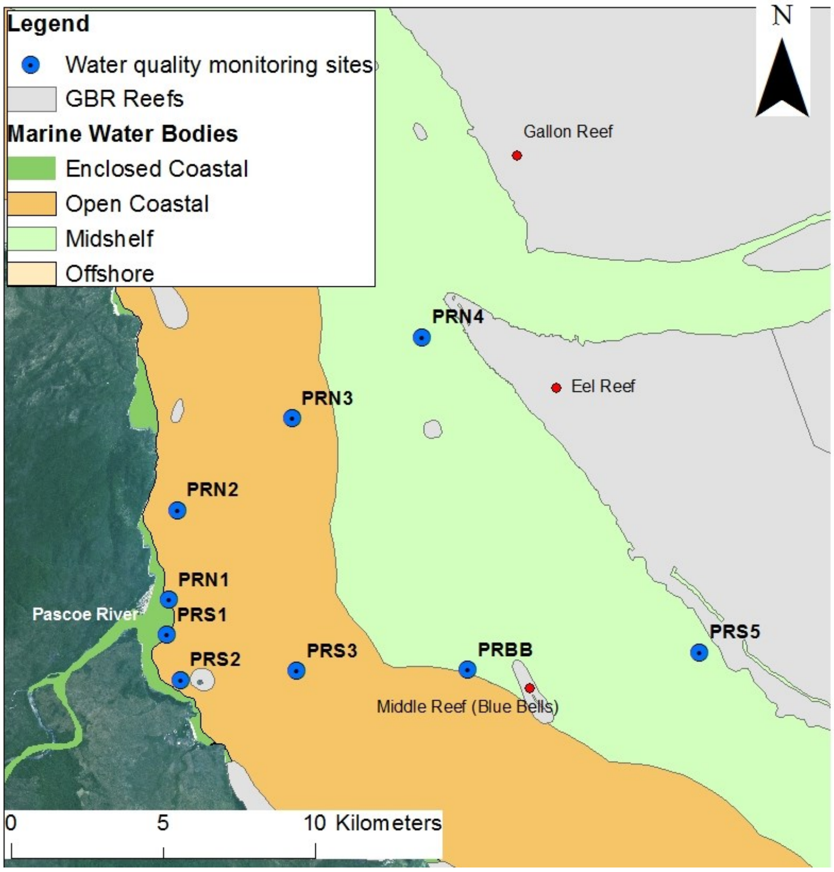


Figure 5-21: Water quality sampling sites in the Pascoe River transect with water body boundaries.

The Pascoe transect was sampled over 8 days between February and April 2018, and a total of 48 ambient samples (subsurface and surface) were collected on the 16 February, 12 March, 18 March and 6 April. An additional 21 event samples were collected at select sites along the northern and southern transects (depending on plume direction) and inside and outside of plume lines on 2 and 4 February following minor flooding, and on 27 March and 1 April close to the peak of the largest event of the year. There was some turbid freshwater influence at enclosed coastal water body sites even on regular 'ambient' sampling days.

Annual discharge for the Pascoe River at the Garraway gauge (102102A) was 1142 GL for the 2017–18 water year. Total discharge for the Olive-Pascoe Basin over the 2017–18 water year was estimated as 3425 GL, which is above the long-term median (2740 GL) (Table 3-1). Peak daily discharge (129 GL) at the Garraway gauge (located 42 km upstream from the mouth) occurred on 25 March 2018 (

Figure 5-22), with daily discharge shown in

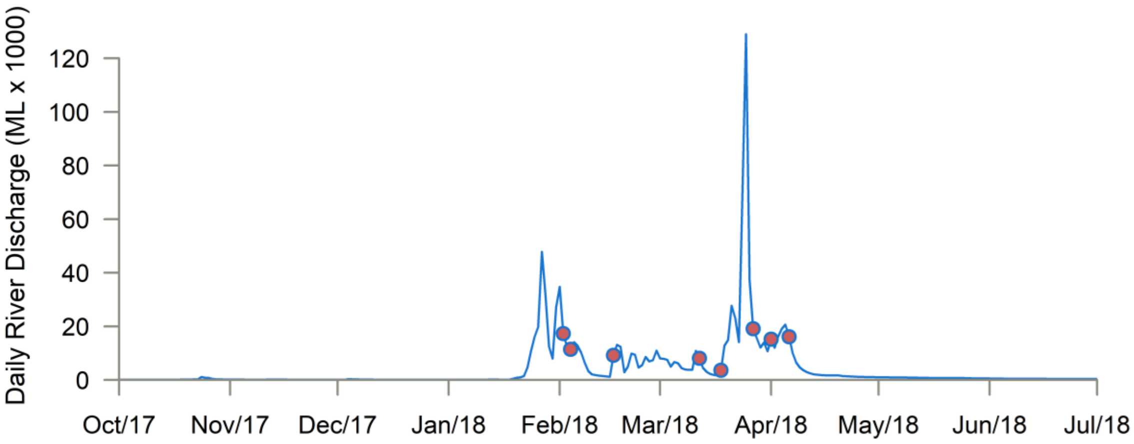


Figure 5-23.

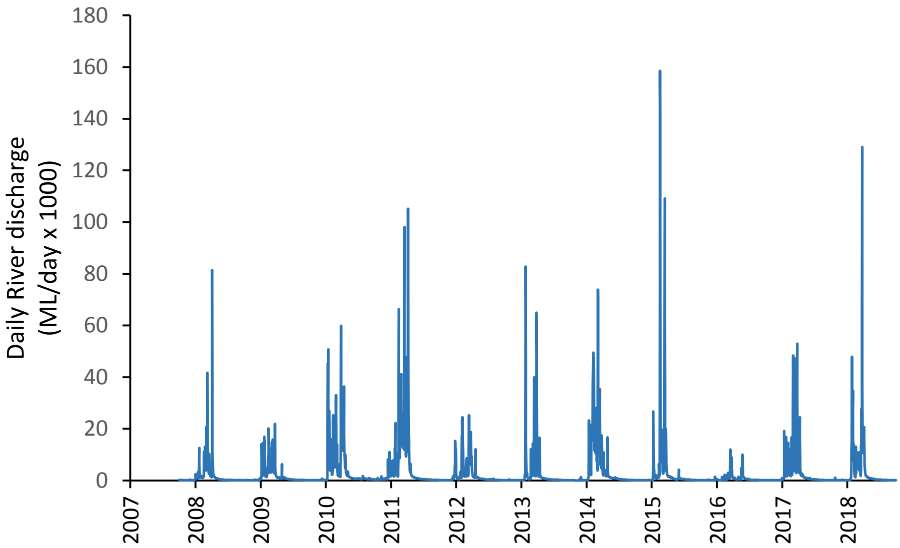


Figure 5-22: Long-term daily discharge for the Pascoe River (gauge 102102A).

The combined discharge and loads estimated for the 2017–18 water year from the Pascoe Basin are shown in Figure 5-24. The loads calculated for the 2017–18 water year from the Pascoe catchment (does not include the Olive catchment) were in the upper range estimated over the past 10 years. Over the 12-year period from 2006:

- discharge has varied from 425 GL (2015–16) to 3191 GL (2010–11)
- modelled TSS loads have ranged from 20 kt (2015–16) to 147 kt (2010–11)
- DIN loads ranged from 30 t (2014–15) to 229 t (2010–11)
- PN loads ranged from 55 t (2015–16) to 414 t (2010–11).

Figure 4-8 and Figure 4-12 show that the Pascoe River had the second largest contributions to the regional river-derived DIN (~20%) and TSS (~12%) loading in the Cape York region in 2017–18.

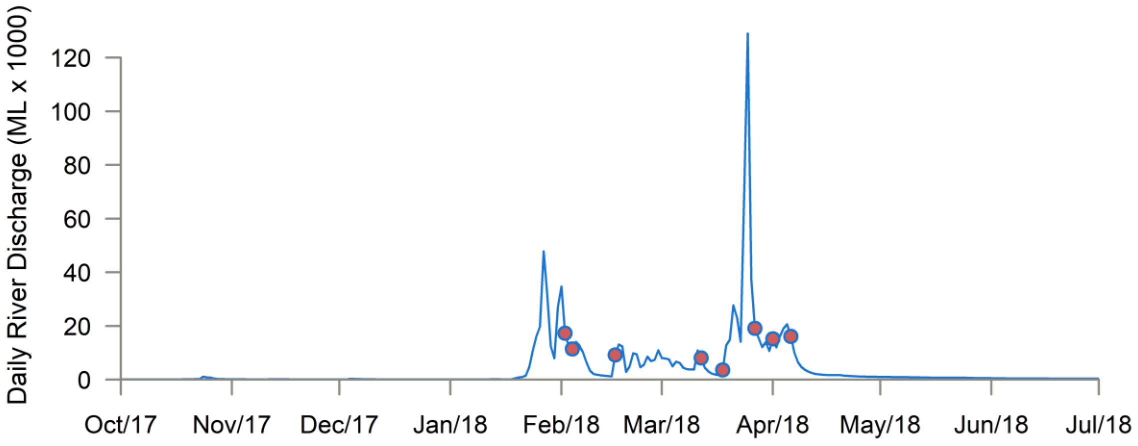


Figure 5-23: Daily discharge for the Pascoe River (gauge 102102A) for the 2016–17 water year. Red dots represent sampling dates.

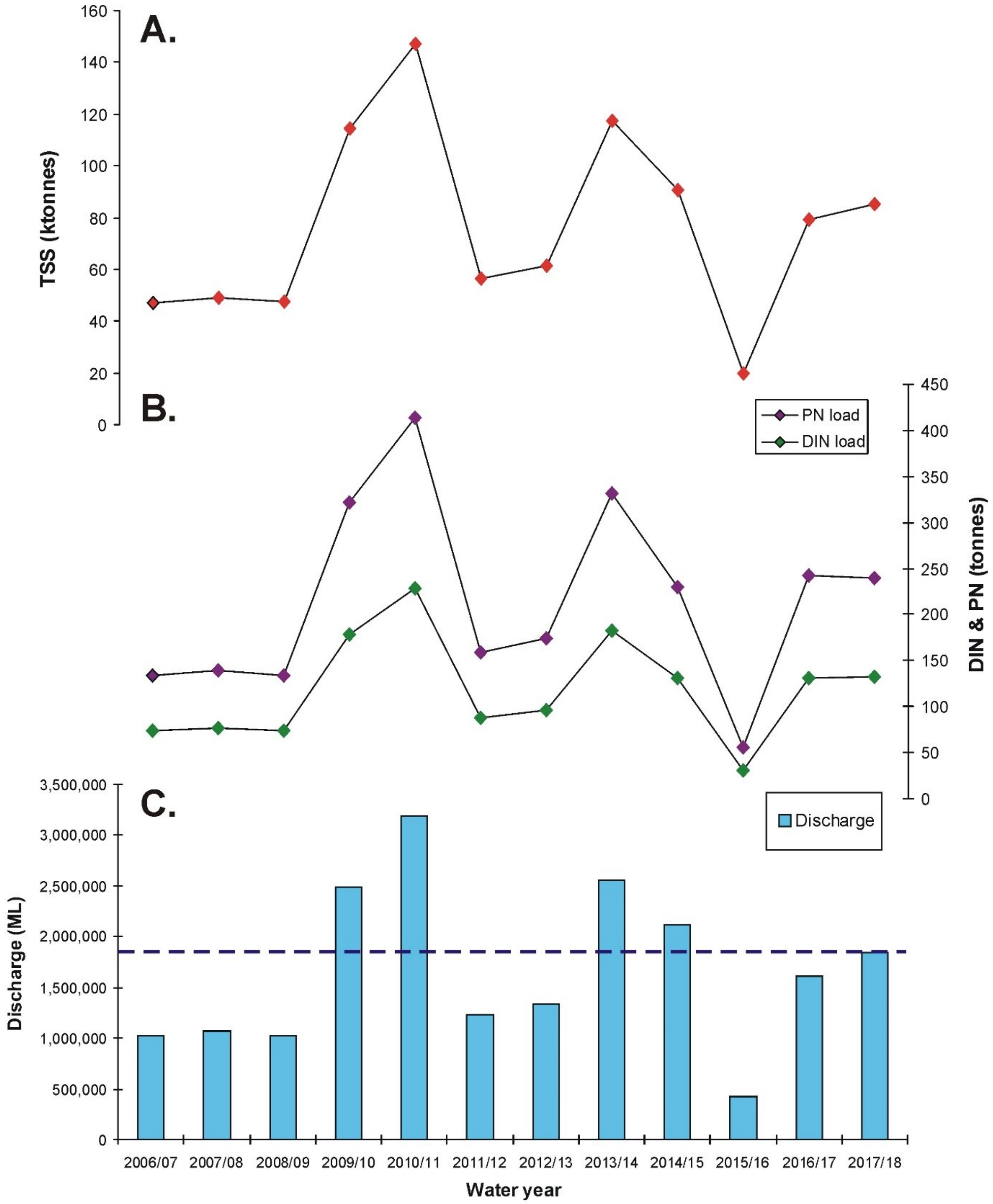


Figure 5-24: (A) TSS loads, (B) DIN and PN loads and (C) discharge for the Pascoe catchment (note Pascoe catchment only, does not include Olive catchment) from 2006 to 2018. The loads reported here are a combination of 'best estimates' based on 'up-scaled' discharge data from gauging stations and monitoring data for 2014–15 and 2016–17) and an average of the annual mean concentrations for these two water years applied to the remaining dataset. Dotted line represents the long-term median for basin discharge.

Event water quality

Samples collected on 2 and 4 February 2018 coincided with the falling limb of the first event of the 2017–18 wet season, resulting in reduced salinity and increased TSS at PRS1. Both tidal and freshwater flood influences on water quality were also observed near the river mouth. On the incoming tide on 2 February 2018, a salinity of 32.5 PSU and TSS 4.5 mg L^{-1} were recorded at PRS1. On the outgoing tide later the same day, PRS1 had a salinity of 15 PSU and TSS of 13 mg L^{-1}. Samples collected along the northern transect sites (PRN1–PRN5) on the incoming tide had little freshwater influence (salinity >30 PSU) and low TSS (<4 mg L^{-1}).

Peak daily discharge for the water year occurred on 25 March 2018 at the Garraway gauge (located 42 km upstream from the Pascoe River mouth). Two days later (27 March 2018), event samples were collected at sites PRN1, PRN2, PRS1, PRBB, and at two additional sites along a south eastern transect within the plume. The plume boundary at the time of sampling was approximately 4.8 km to the east, near PRS3. A maximum TSS concentration of 31 mg L^{-1} was measured at PRS1, and TSS decreased conservatively along the salinity gradient (Figure 5-25). Chl-*a* concentrations doubled when TSS dropped below 10 mg L^{-1}, as is common in the Reef lagoon and river plumes worldwide (Dagg et al., 2004; Howley et al., 2018).

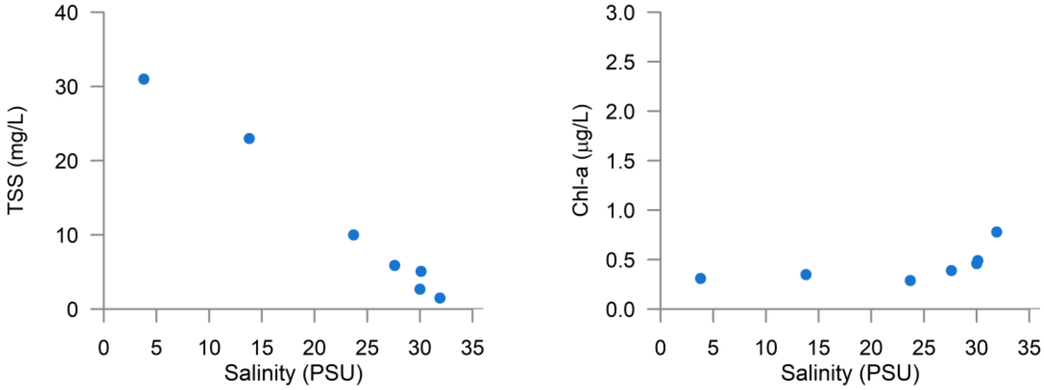


Figure 5-25: Event samples collected at Pascoe transect sites on 27 March 2018

Four event samples were collected during a minor flood on 1 April 2018. Two samples were collected inside the plume and two outside the visible plume line. NO_x, PP and reactive silica concentrations were significantly higher inside the plume (NO_x: mean 7.3 µg L^{-1} compared to 1.3 µg L^{-1} outside the plume, SiO_4 plume mean 7.4 µg L^{-1} compared to 0.4 µg L^{-1} outside the plume). PN concentrations were higher outside the plume (average 9.5 µg L^{-1}) than within (1.0 µg L^{-1}). The plume boundary was approximately 3 km to the southeast near SR02 and just beyond Pigeon Island.

Freshwater discharge was also evident in the enclosed coastal zone on 18 March 2018 (PRS01 salinity 21 PSU and TSS 7 mg L^{-1}) and on 6 April when salinity was <1 and TSS concentrations of 22 and 11 mg L^{-1} were measured at PRN1 and PRS1, respectively. TSS, NO_x and PN concentrations decreased along the salinity gradient (Figure 5-26), while Secchi depth increased. Chlorophyll-*a* concentrations increase above a salinity of 20 PSU, coinciding with the decrease (uptake) of NO_x and NH_3 and increased light availability (TSS <10 mg L^{-1}).

Flood event samples collected during the 2017–18 water year may be the first samples collected from a Pascoe River flood plume. These samples were not collected on the rising flood stage; therefore, they may not represent maximum event concentrations. However, they provide an initial indication of the range of concentrations to be expected in average magnitude flood plumes from this river.

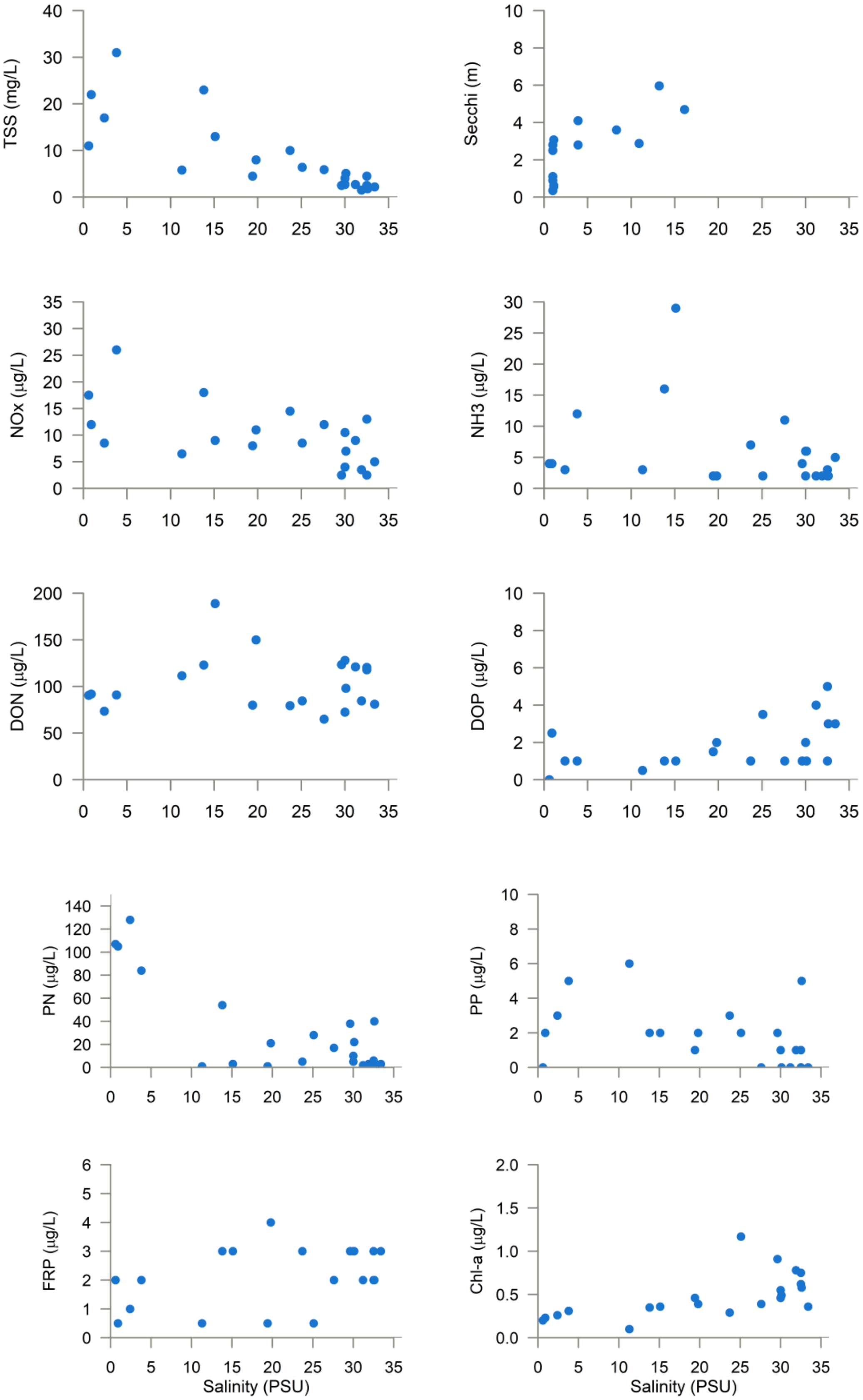


Figure 5-26: Event water quality concentrations (surface and subsurface samples) and Secchi depth over the salinity gradient for the Pascoe River sub-region 2017–18 water year.

TSS concentrations in Pascoe River plumes remained relatively low compared to other Cape York flood plumes, with a maximum TSS value of 31.0 mg/L and mean of 7.4 mg L^{-1}, compared to plumes from the Annan-Endeavour (max 370 mg L^{-1}, mean 31.1 mg L^{-1} for 2017–18 event samples) or Normanby Rivers (max 125 mg L^{-1}, mean 14 mg L^{-1} over three flood events; Howley et al., 2018). Phytoplankton production also remained relatively low, with a max 1.2 µg L^{-1} and mean 0.5 µg L^{-1} Chl-*a* concentration, similar to concentrations from Annan-Endeavour plumes (max 1.5 µg L^{-1}, mean 0.5 µg L^{-1}). These Chl-*a* values are also in a similar range to those measured previously in two Normanby River plumes (2012 and 2014) but are low compared to a 2013 Normanby River first flush event (max 8.8 µg L^{-1}, mean 1.7 µg L^{-1}; Howley et al., 2018).

Ambient water quality

During the 2017–18 water year, no samples were collected along the Pascoe transect during the dry season.

As with the other Cape York transects, wet season sampling was regularly influenced by minor freshwater flooding, with samples in enclosed coastal waters having reduced salinity and elevated TSS compared to non-event conditions. Due in part to this freshwater influence, concentrations of PN, PP and TSS in the Pascoe River transect decreased over distance from the river mouth while Secchi depth increased (Figure 5-27). Maximum DOP, DON and Chl-*a* concentrations were also detected in the enclosed coastal zone near the mouth of the river (sites PRN1 and PRN2). NH_3 and PO_4 show little variation across the sites.

Ambient TSS concentrations for the Pascoe transect ranged from 0.8 to 32 mg L^{-1}, with an average of 3.8 mg L^{-1}. TN had a mean of 110 µg L^{-1} (max 221 µg L^{-1}), which was comprised primarily of DON (86%) and PN (9%). Mean TP was 6.7 µg L^{-1} (max 15 µg L^{-1}) comprised of 41% DON, 26% PP and 33% PO_4 on average. Chl-*a* ranged from 0.2 to 1.8 µg L^{-1}, with a mean ambient concentration of 0.6 µg L^{-1}.

In the enclosed coastal zone, median DOP concentrations exceeded the annual water quality guideline for Eastern Cape York (Table E-2); however, the Pascoe River transect was only sampled during the wet season therefore is not representative of annual conditions. There are no wet season specific GVs for Pascoe River enclosed coastal waters. In the open coastal zone, median wet season concentrations of TSS, NO_x and NH3 all exceeded the wet season GVs. In the mid-shelf zone, median TSS, TDN, NO_x, NH_3, PO_4 and Chl-*a* concentrations exceeded the annual baseflow GVs and mean Secchi depth (8.0 m) was less than the GV (≥10 m). As with the enclosed coastal zone, samples were collected only during the wet season; however, there are no wet season specific GVs for this zone.

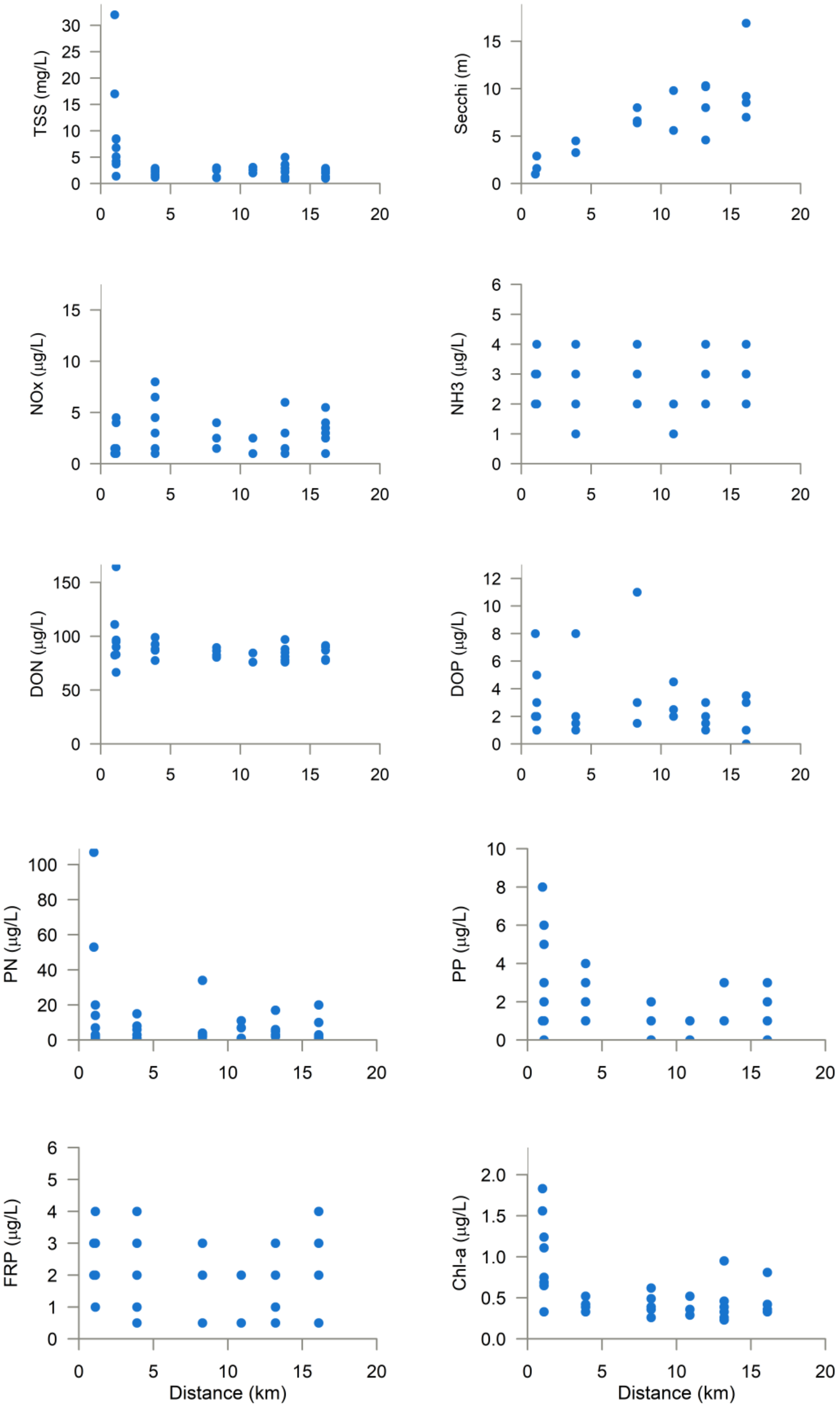


Figure 5-27: Water quality concentrations (surface and subsurface samples) and Secchi depth over distance (km) from river mouth for the Pascoe River sub-region (all 2017–18 samples).

5.2 Wet Tropics region

The Wet Tropics region is divided into three sub-regions and results on the pressures and monitoring results are presented separately for each.

5.2.1 Barron Daintree

Under the revised MMP sampling design implemented in 2015, this sub-region contains the six sites of the 'Cairns Transect', which are sampled three times a year (Figure 5-28).

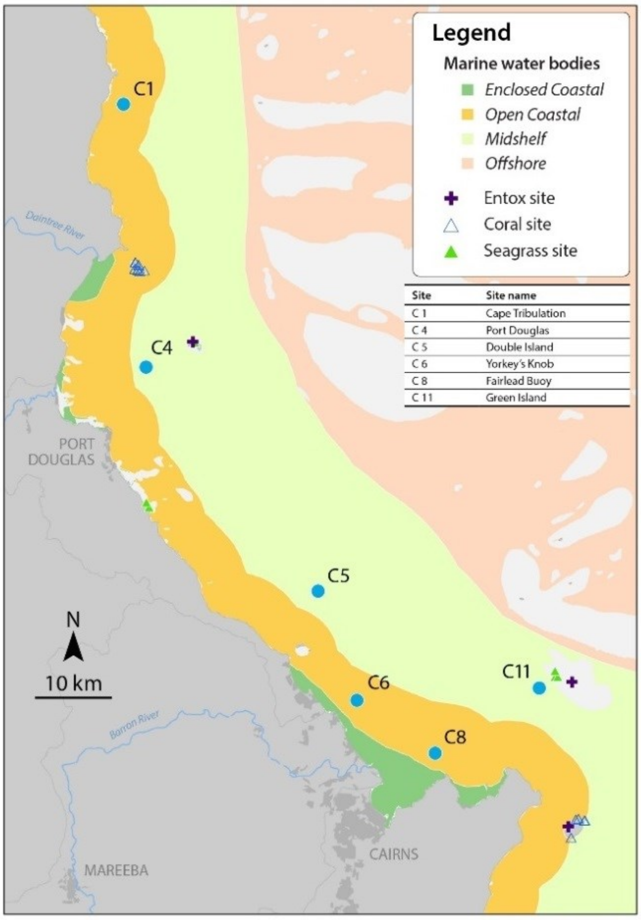


Figure 5-28: Sampling sites in the Barron Daintree sub-region shown with water body boundaries.

The total discharge during the 2017–18 water year was very close to the long-term median discharge (Figure 5-29), similar to the 2016–17 water year.

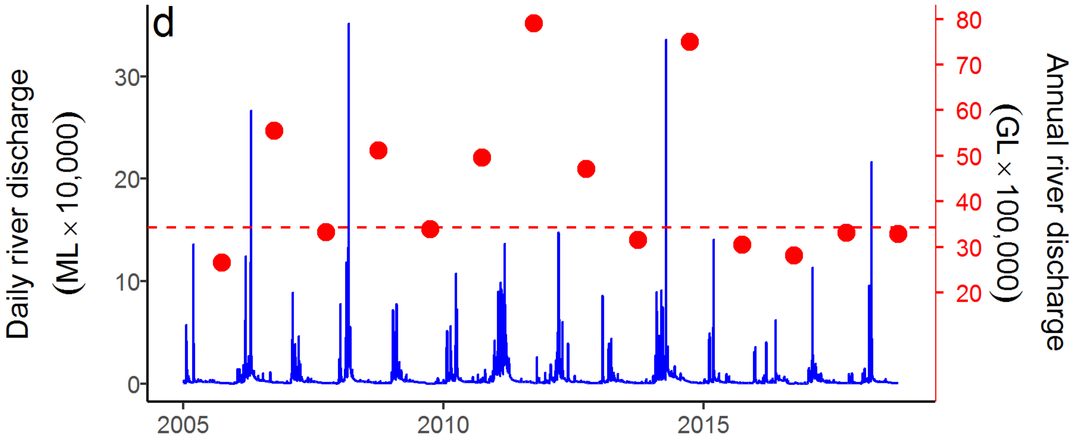


Figure 5-29: Combined discharge for the Barron (Myola gauge) and Daintree (Bairds gauge) Rivers. Daily (blue) and water year (October to September, red symbols) discharge volumes shown. Red dashed line represents long-term median of the combined annual discharge.

The combined discharge and loads calculated for the 2017–18 water year from the Barron, Daintree and Mossman Basins were around the median (Figure 5-30). While discharge from the Daintree and Mossman Basins were near the long-term median, the discharge from the Barron Basin in 2017–18 was 1.6 times above the long-term median (Table 3-1).

Of the three sub-regions within the Wet Tropics NRM region, the Barron, Daintree and Mossman Basins collectively contribute the lowest discharge and consistent loads compared to the two sub-regions to the south (i.e. Russell-Mulgrave and Johnstone Basins and the Tully-Murray and Herbert Basins).

The loading maps presented in Section 4 can also be assessed to determine the relative contribution of loads from each river to the marine NRM region. This is relevant to all transects for the Wet Tropics region. Figure 4-7 and Figure 4-12 show the estimated DIN and TSS contributions for the Wet Tropics region in 2017–18 and 2010–11.

In 2017–18, the greatest DIN contributions to the Wet Tropics marine NRM region were from the Herbert (37%), Johnstone (21%), Tully (17%) and Russell-Mulgrave (14%) Rivers. TSS contributions were dominated by the Johnstone (32%) and Herbert (26%) Rivers. These results are comparable with the results of the relative risk assessment of DIN and TSS on coral reefs and seagrass recently completed as part of the 2017 Scientific Consensus Statement (Waterhouse et al., 2017c). The Daintree, Mossman, and Barron Rivers had minimal contributions to the Wet Tropics DIN loading (all <2%), although the Barron was estimated to contribute ~9% to the TSS loading. As noted above the Daintree and Mossman Rivers are predicted to contribute to the southern areas of the Cape York region with the northward movement of the plume.

The panels show the important influence of the Burdekin River and northward movement of the river plume into the Wet Tropics region in the flood events of 2010–211, accounting for approximately 40% of the TSS loading and approximately 10% of the DIN loading. Figure 4-7 also shows that all of the Wet Tropics rivers can influence the Cape York region, and the Daintree, Mossman and Russell-Mulgrave Rivers still had a small contribution (~8%) to the DIN loading during 2017–18. The Herbert River also influences the DIN and TSS loading for the Burdekin region in most of the years modelled.

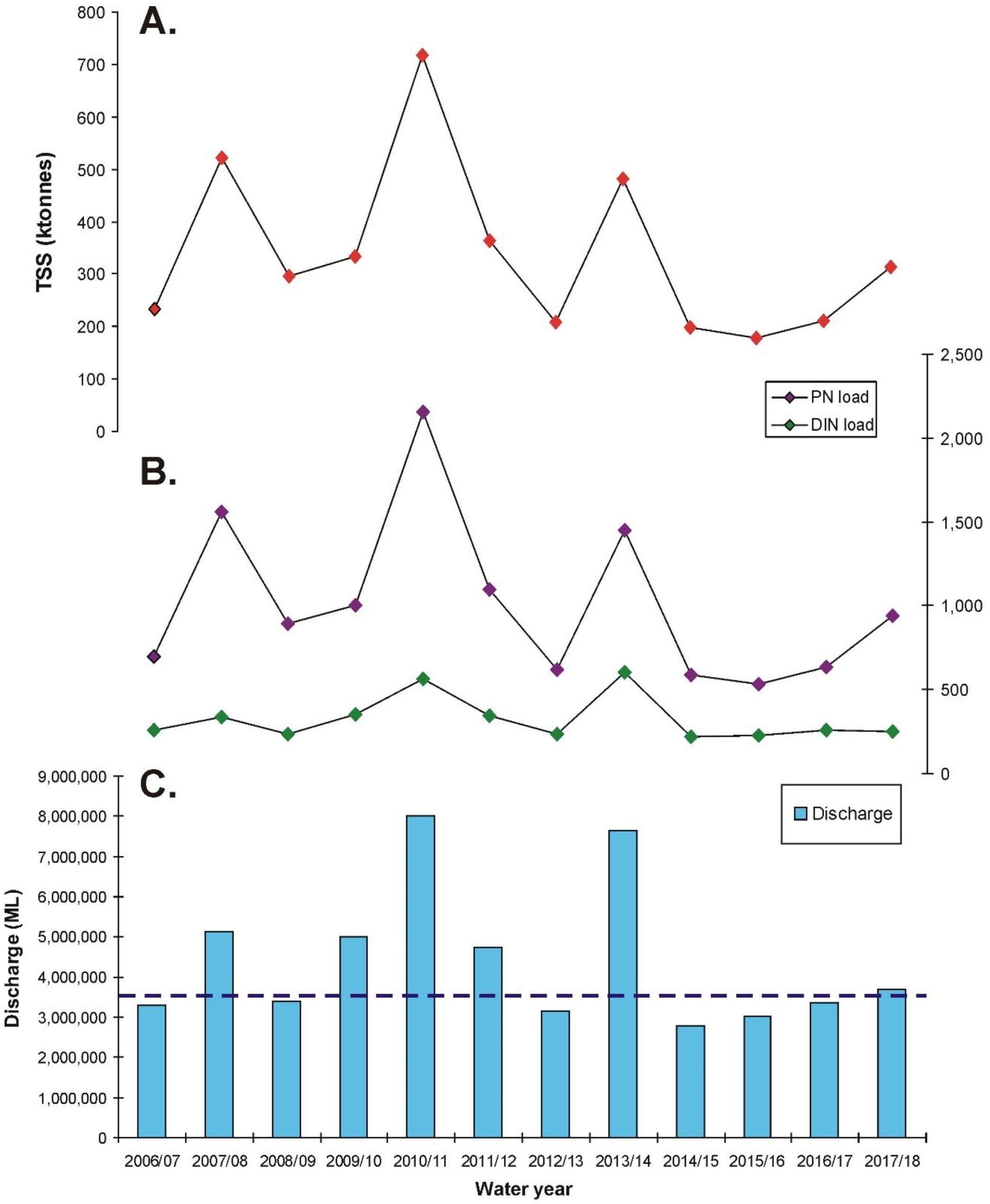


Figure 5-30. (A) TSS loads, (B) DIN and PN loads and (C) discharge for the Barron, Daintree and Mossman Basins from 2006 to 2018. The loads reported here are a combination of 'best estimates' for each basin based on 'up-scaled discharge data from gauging stations, monitoring data (Barron River), the DIN model developed in Lewis et al. (2014) and annual mean concentrations and discharge from monitoring data or Source Catchments modelling data. The dotted line represents the long-term median for basin discharge.

Ambient water quality and the in-situ Water Quality Index

Long-term trends in water quality variables measured during ambient periods (e.g. not during peak flood events) of the dry and wet seasons are presented in Figure 5-31. It is important to note that the trend analysis used removes variability associated with wind, waves and tides (see Methods). Thus, individual data points can have slightly different values compared to raw data. This analysis is designed to detect long-term and regional-scale trends in water quality by removing the effect of change in local weather and tides.

Distinct long-term trends (since 2005) were observed in some water quality variables, while others showed little change over time (Figure 5-31). Concentrations of Chl-*a* and TSS were relatively stable over time and mean values of these variables are currently at water quality GVs (Great Barrier Reef Marine Park Authority, 2010). Concentrations of PO_4 were relatively stable over time, whereas NO_x concentrations have generally increased since 2005 and are presently close to GVs. Concentrations of NO_x reached a maximum in 2014–15 and declined in the following years; however, 2017–18 monitoring shows that NO_x is presently increasing. Secchi depth showed a distinct decreasing trend (i.e. water clarity is worsening) since 2005 and current values are not meeting GVs. Concentrations of PN are stable and below GVs, whereas PP concentrations have increased and are now exceeding GVs. Mean concentrations of POC have been relatively constant over the monitoring period, whereas concentrations of DOC have increased dramatically since monitoring began (Figure 5-31).

The WQ Index is now calculated using two different formulations to communicate the long-term trend in water quality (based on the pre-2015 sampling design) as well as a metric for annual condition (based on the post-2015 sampling design, which increased the power to detect changes in water quality). The Methods section and Appendix D-3 contain details of the calculations for both indices.

The long-term WQ Index has shown water quality to be ‘very good’ and ‘good’, although this version of the Index shows a gradual decline in water quality since 2005 (Figure 5-31a, circles). The annual condition WQ Index currently shows water quality to be ‘moderate’ for the last two years (Figure 5-31a, squares). This version of the Index scores water quality parameters against GVs relevant to the season when samples are collected (wet versus dry GVs) and includes additional inshore sites to better characterise areas affected by river discharge.

It is important to note that the two versions of the WQ Index are designed to answer separate questions and therefore differences in scores between the versions are expected.

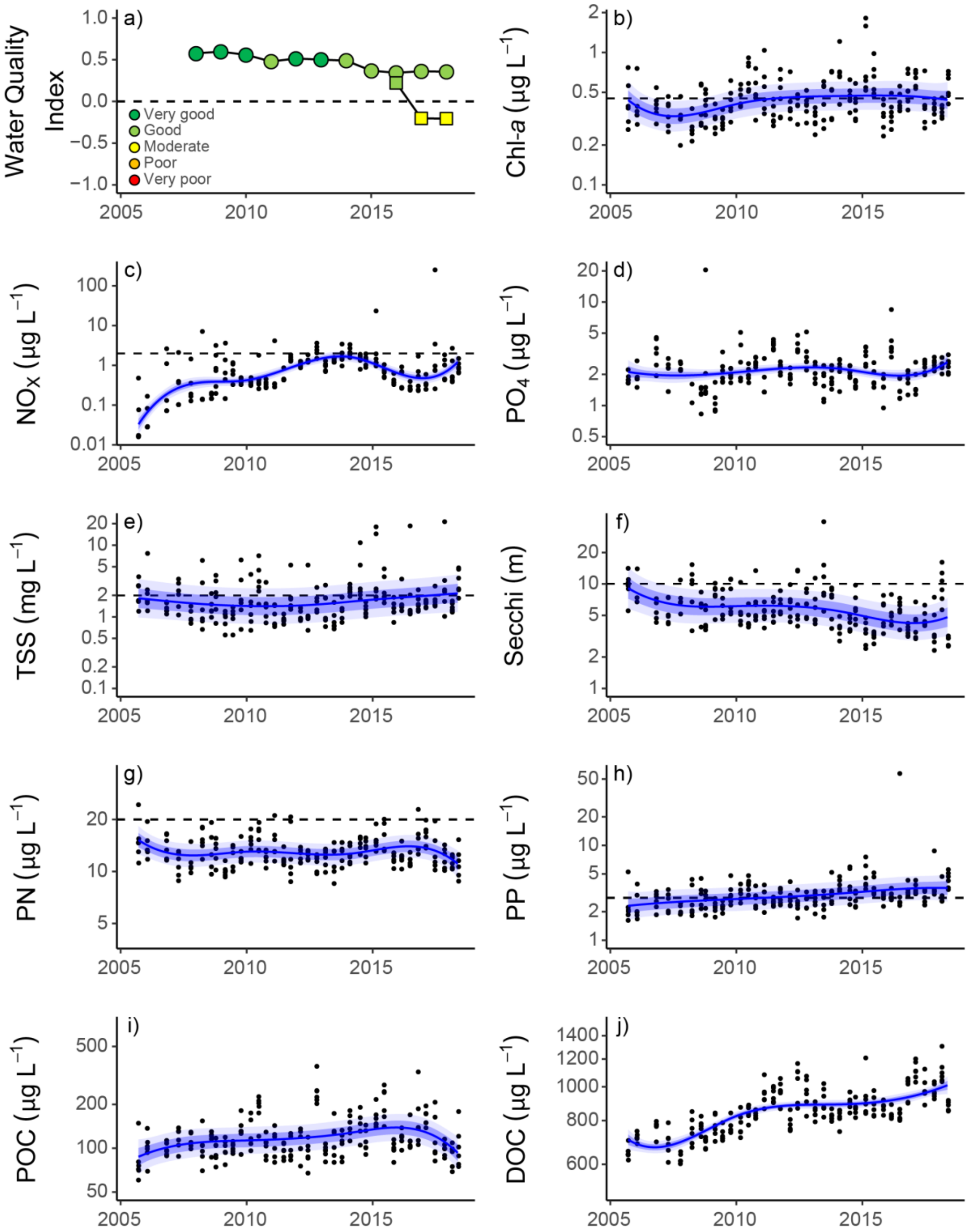


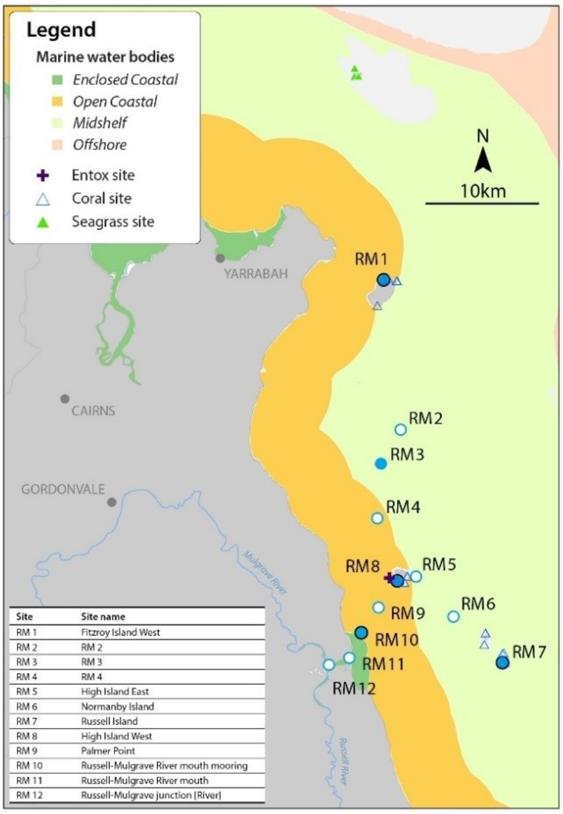
Figure 5-31: Temporal trends in water quality variables for the Barron Daintree sub-region. a) WQ Index, b) chlorophyll *a* (Chl-*a*), c) nitrate/nitrite (NO_x), d) phosphate (PO_4), e) total suspended solids (TSS), f) Secchi depth, g) particulate nitrogen (PN), h) particulate phosphorus (PP), i) particulate organic carbon (POC) and j) dissolved organic carbon (DOC). The long-term trend in the WQ Index is shown by circles, while the annual condition uses squares. Calculations are described in Appendix D-3. Trends in manually sampled water quality variables are represented by blue lines with blue shaded areas defining 95% confidence intervals of those trends accounting for the effects of wind, waves and tides after applying x-z detrending. Dashed horizontal reference lines indicate annual guideline values.

Event water quality

No event sampling was conducted in the Barron Daintree focus area in 2017–18.

5.2.2 Russell-Mulgrave

The Russell-Mulgrave focus area is primarily influenced by discharge from the Russell-Mulgrave and Johnstone Basins and, to a lesser extent, by other rivers south of the focus area, such as the Burdekin (Brodie et al., 2013; Waterhouse et al., 2017b). Three stations were sampled three times per year in this focus area until the end of 2014 to determine regional water quality. Following the implementation of the revised MMP water quality sampling design in 2015, 12 sampling stations are sampled in this sub-region up to 10 times per year, with six stations during both the dry and wet season and seven only during major floods (Appendix C, Table C-1). The sampling stations in this new design are located in a transect from the river mouth to open coastal waters, representing a gradient in water quality. Seven stations are located in the enclosed coastal or open coastal water body and five stations are located in the mid-shelf water body (Figure 5-32).



Site	Site name
RM 1	Fitzroy Island West
RM 2	RM 2
RM 3	RM 3
RM 4	RM 4
RM 5	High Island East
RM 6	Normanby Island
RM 7	Russell Island
RM 8	High Island West
RM 9	Palmer Point
RM 10	Russell-Mulgrave River mouth mooring
RM 11	Russell-Mulgrave River mouth
RM 12	Russell-Mulgrave junction [River]

Figure 5-32: Sampling sites in the Russell-Mulgrave focus area, shown with the water body boundaries.

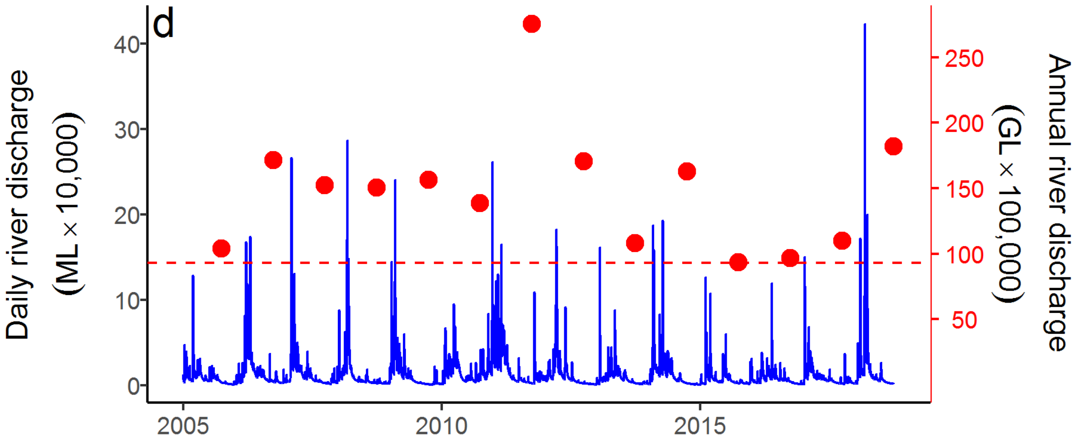


Figure 5-33: Combined discharge for the North and South Johnstone (Tung Oil and Central Mill gauges, respectively), Russell (Bucklands gauge) and Mulgrave (Peat's Bridge) Rivers. Daily (blue) and water year (October to September, red symbols) discharge is shown. Red dashed line represents the long-term median of the combined annual discharge. Please note as this is the combined discharge, high flows in one river will not necessarily be visible in the graph.

The combined discharge volume of the Russell-Mulgrave and Johnstone Rivers exceeded the long-term median over the 2017–18 water year (Figure 5-33).

Compared to the Barron Daintree Mossman sub-region, the combined discharge and loads calculated for the 2017–18 water year from the Russell-Mulgrave and Johnstone Basins were in the higher range to that recorded over the past decade (Figure 5-34).

Discharge, TSS, PN and DIN loads were amongst the highest measured since the large 2010–11 water year. Over the 12-year period:

- discharge has varied from 5100 GL (2015–16) to 16,900 GL (2010–11)
- TSS loads have ranged from 320 kt (2014–15) to 1200 kt (2010–11)
- DIN loads ranged from 981 t (2016–17) to 5000 t (2010–11)
- PN loads ranged from 1400 t (2014–15) to 4900 t (2010–11).

Of the three sub-regions within the Wet Tropics NRM region, the Russell-Mulgrave and Johnstone Basins collectively contribute similar discharge and loads to the Tully-Murray and Herbert Basins during low to average rainfall/discharge years, although the latter basins contribute higher values (particularly DIN) during the high discharge years such as in 2008–09 and 2010–11 water years.

Figure 4-7 and Figure 4-11 show the estimated DIN and TSS contributions for the Wet Tropics region in 2017–18 and 2010–11, highlighting the dominant influence of the Johnstone River to river-derived DIN (21%) and TSS (32%) loadings in the Wet Tropics region. The contribution to the Wet Tropics river-derived loading from the Russell-Mulgrave River was predicted to be around 14% for DIN and TSS.

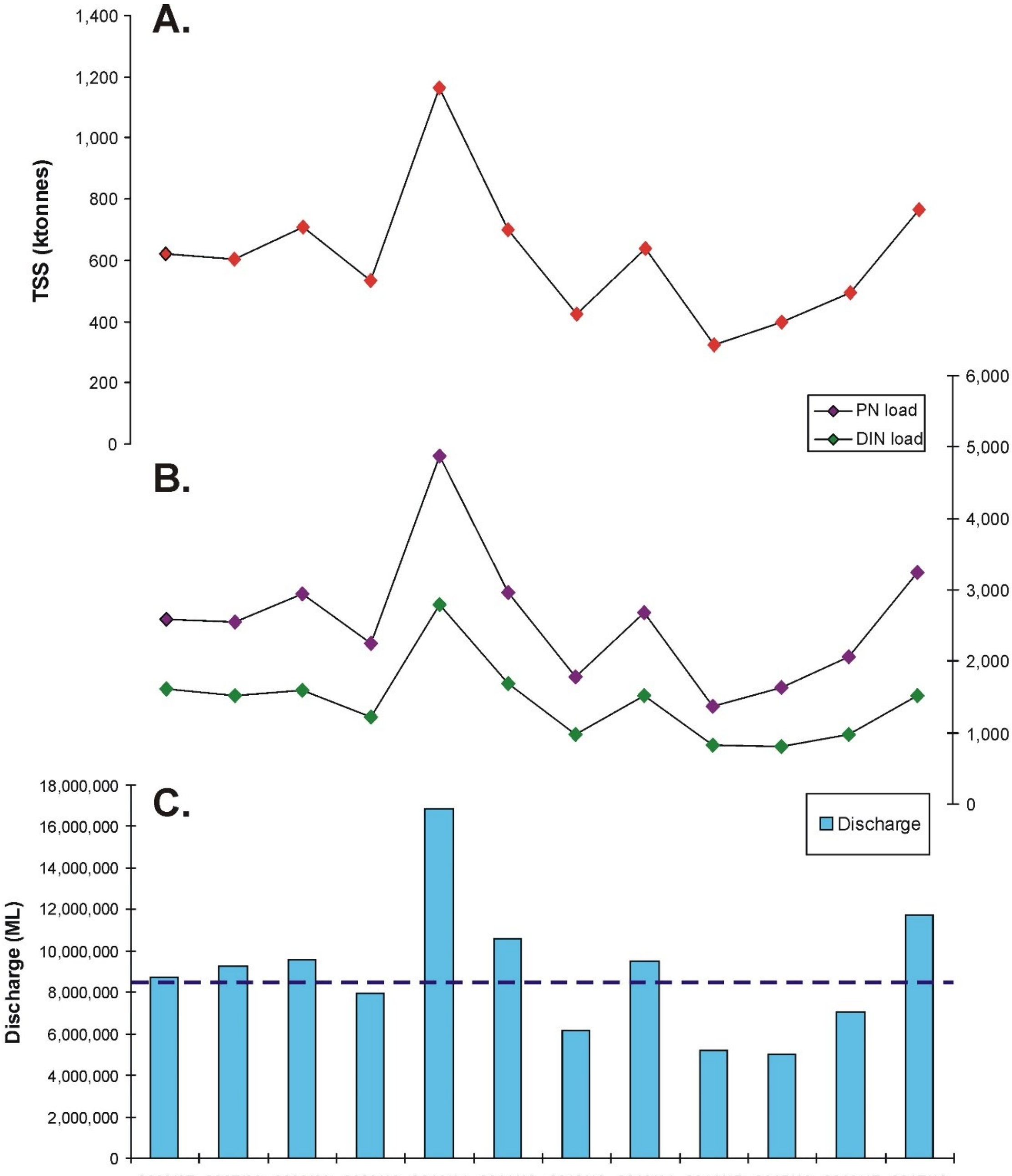


Figure 5-34: Loads of (A) total suspended solids (TSS), (B) dissolved inorganic (DIN) and particulate nitrogen (PN), and (C) discharge for the Russell, Mulgrave and Johnstone Basins from 2006 to 2018. The loads reported here are a combination of 'best estimates' for each basin based on 'up-scaled discharge data from gauging stations, monitoring data (Johnstone River), the DIN model developed in Lewis et al. (2014) and annual mean concentrations and discharge from monitoring data or Source Catchments modelling data. Dotted line represents the long-term median for basin discharge.

Ambient water quality and the in-situ Water Quality Index

When interpreting the long-term water quality trends in this region, it should be noted that the location of some of the loggers have changed and that the number of water sampling sites and frequency of sampling was increased during 2015. Some of these new sites were placed further inshore and they are therefore likely to be more often affected by primary and secondary plume-type waters.

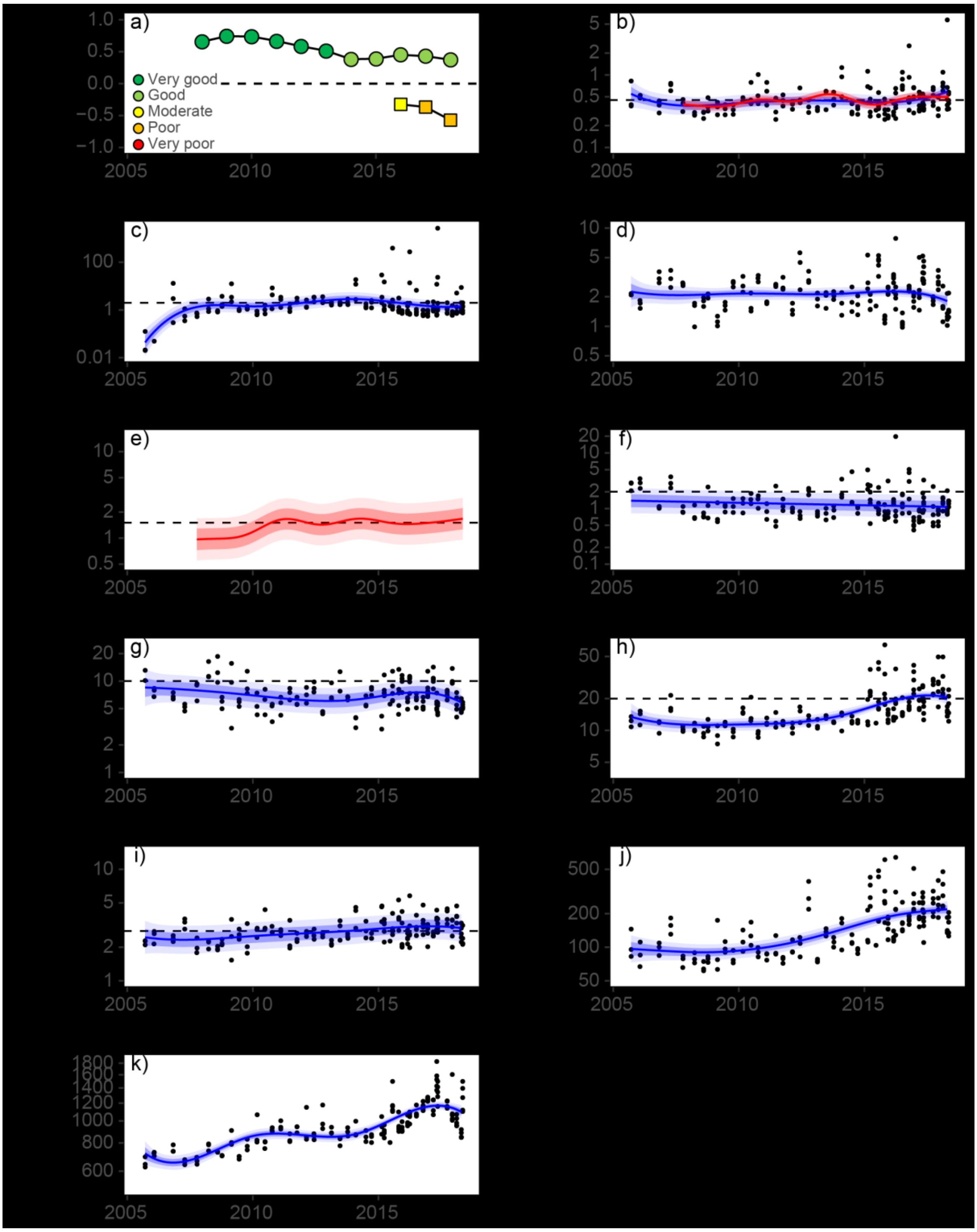


Figure 5-35: Temporal trends in water quality for the Russell-Mulgrave sub-region. a) WQ Index, b) chlorophyll a (Chl-a), c) nitrate/nitrite (NO_x), d) phosphate (PO4), e) turbidity, f) total suspended solids (TSS), g) Secchi depth, h) particulate nitrogen (PN), i) particulate phosphorus (PP), j) particulate organic carbon (POC) and k) dissolved organic carbon (DOC). The long-term trend in the WQ Index is depicted with circles, while the annual condition (implemented with sampling changes in 2015) is depited with squares in (a). Calculations are described in Appendix D-3. Trends in manually sampled water quality variables are represented by blue lines with blue shaded areas defining 95% confidence intervals accounting for the effects of wind, waves and tides after applying x-z detrending. Trends of records from ECO FLNTUSB instruments are represented in red, individual records are not displayed (see Figure E-1). Dashed horizontal reference lines indicate annual guideline values.

Distinct long-term trends (since 2005) were observed in some water quality variables, while others showed little change over time (Figure 5-35). Concentrations of Chl-*a* and TSS have been relatively stable over time; mean values of Chl-*a* derived from logger and water samples are presently at the water quality GV (Great Barrier Reef Marine Park Authority, 2010), whereas TSS concentrations are below the GV. Concentrations of PO_4 and NO_x have been relatively stable over time, and NO_x concentrations are presently at the GV. Secchi depth has generally decreased (i.e. water clarity is worsening) since 2005, and current values are not meeting the GV. Concentrations of PN and PP have increased since monitoring began and are now exceeding GVs; however, most of the increase in PN concentrations has occurred during the last 3 years, which may be related to changes in sampling regime post-2015. Mean concentrations of POC and DOC have increased dramatically since monitoring began, although DOC concentrations declined slightly during the 2017–18 monitoring year (Figure 5-35).

The WQ Index is now calculated using two different formulations to communicate the long-term trend in water quality (based on the pre-2015 sampling design) as well as an improved metric for annual condition (based on the post-2015 sampling design, which increased the power to detect changes in water quality). The Methods section and Appendix D-3 contain details of the calculations for both Index versions.

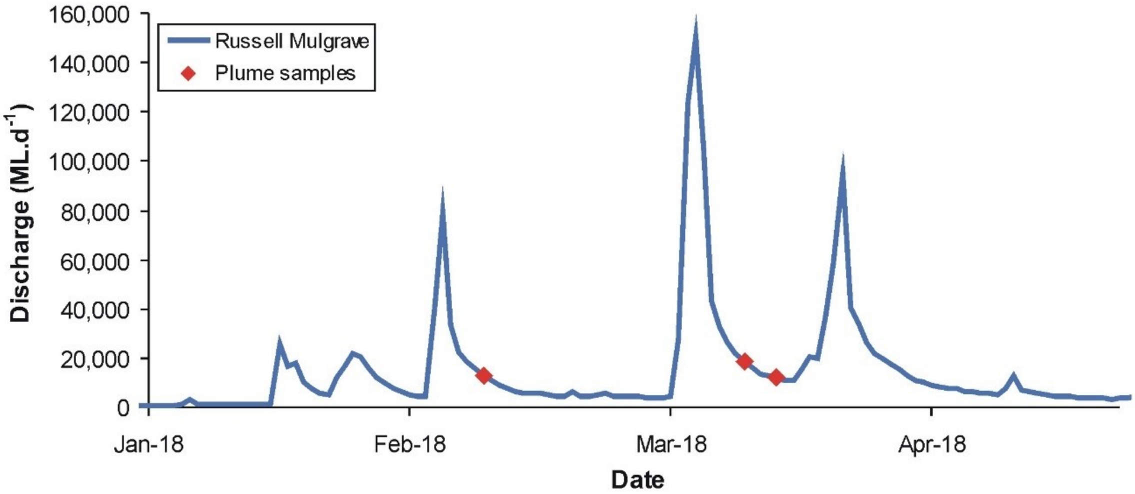
The long-term WQ Index has shown water quality to be ‘very good’ and ‘good’ relative to GVs, although this version of the Index shows a gradual decline in water quality since 2009 (Figure 5-35a). The annual condition WQ Index currently shows water quality to be ‘poor’ and declining for the last 2 years. This version of the Index scores water quality parameters against GVs relevant to the season when samples are collected (wet vs dry GVs) and includes additional inshore sites to better characterise areas affected by river discharge.

It is important to note that the two versions of the WQ Index are designed to answer separate questions and therefore differences in scores between the versions are expected.

Event water quality

Event sampling was conducted for the Russell-Mulgrave focus area following peak river discharge on three occasions: 11 February 2018, 15 March 2018 and 19 March 2018.

The Russell-Mulgrave River had one major flow event (peaked on 9 March 2018) and two moderate-sized flow events (peaked on 6 February 2018 and 27 March, respectively) (Figure 5-36). The total discharge for the 2018 water year (1 October 2017 to 30 September 2018) was 5760 GL, which is 1.3 times above the long-term median. The influence of the flood



waters from the Russell-Mulgrave River on the Reef is shown in

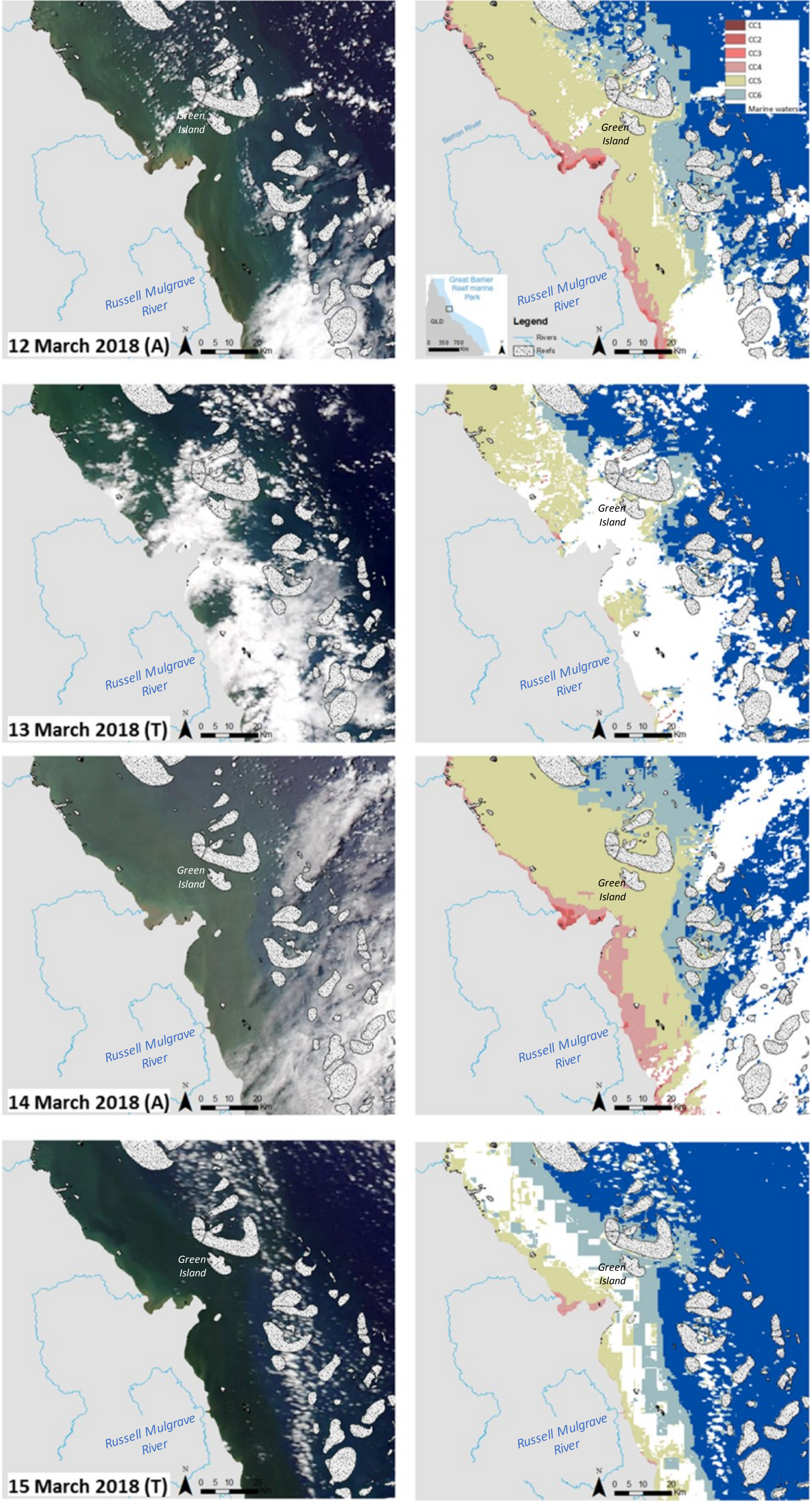


Figure 5-37. Figure 5-38 shows the daily discharge (ML) for the Russell-Mulgrave River, and the red diamonds show the three flood sampling campaigns conducted as part of the MMP. The timing of sampling of the Russell-Mulgrave flood plume in 2018 was restricted to shorter times on the water or until a few days after peak river flow due to poor weather.

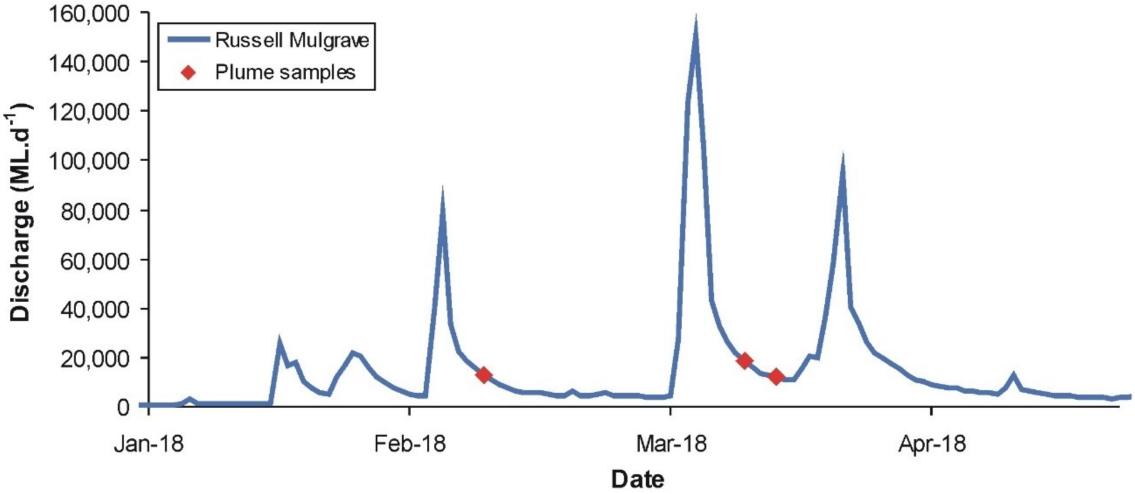


Figure 5-36: River discharge (in ML per day) from 1 January to 30 April 2018 for the Russell-Mulgrave River (Bucklands plus Peats Bridge gauges). Red diamonds show when plume sampling occurred offshore from the river mouth in the Russell-Mulgrave focus area.

A series of satellite images and the true colour analysis of wet season water types for 12 to 15 March 2018 is shown in

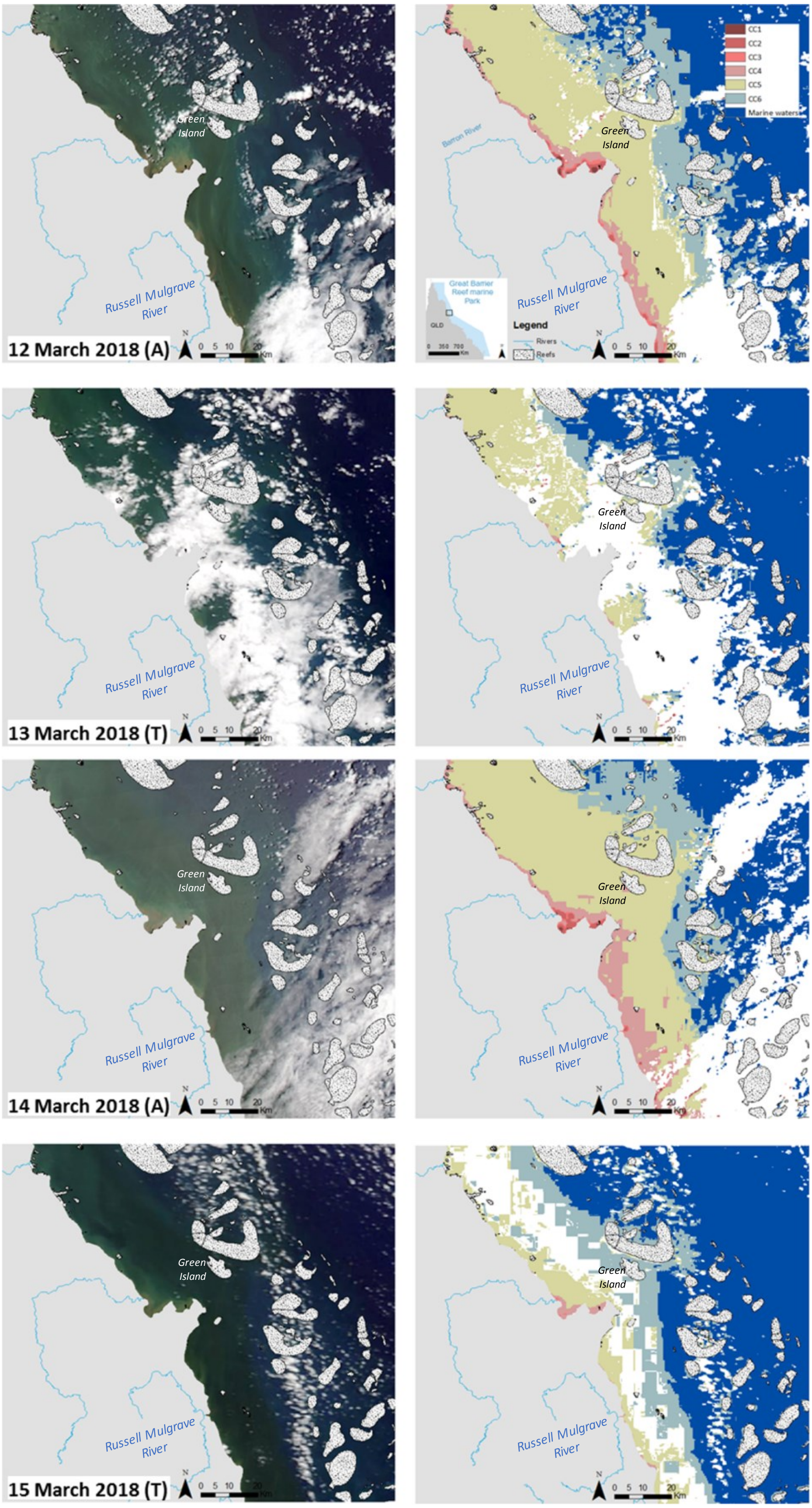


Figure 5-37. This illustrates the extensive areas of the secondary water type extending into mid-shelf areas in the region over this period, and the dissipation of these and the primary water type following the peak flow (see image for 15 March 2018).

Suspended sediment concentrations in the Russell-Mulgrave River plume were consistently below 10 mg L^{-1} over the salinity gradient, although the samples were collected during the wane of the hydrograph (peaks missed due to poor weather) where lower initial river concentrations would be expected. PN concentrations were highly variable over the estuarine mixing zone and likely related to the abundance of phytoplankton in the water and/or sediment resuspension (similar to results for Tully, see below). DIN concentrations gradually decreased from the 0 to 20 salinity zone before stabilising generally <20 µg L^{-1} by 25 PSU. Chl-*a* concentrations were mostly >0.5 µg L^{-1} and generally increased within the higher salinities as nutrients were utilised by algal communities. As sampling was conducted towards the tail end of the river flows, concentrations measured in these plumes tended to be lower compared to those sampled during peak flow conditions.

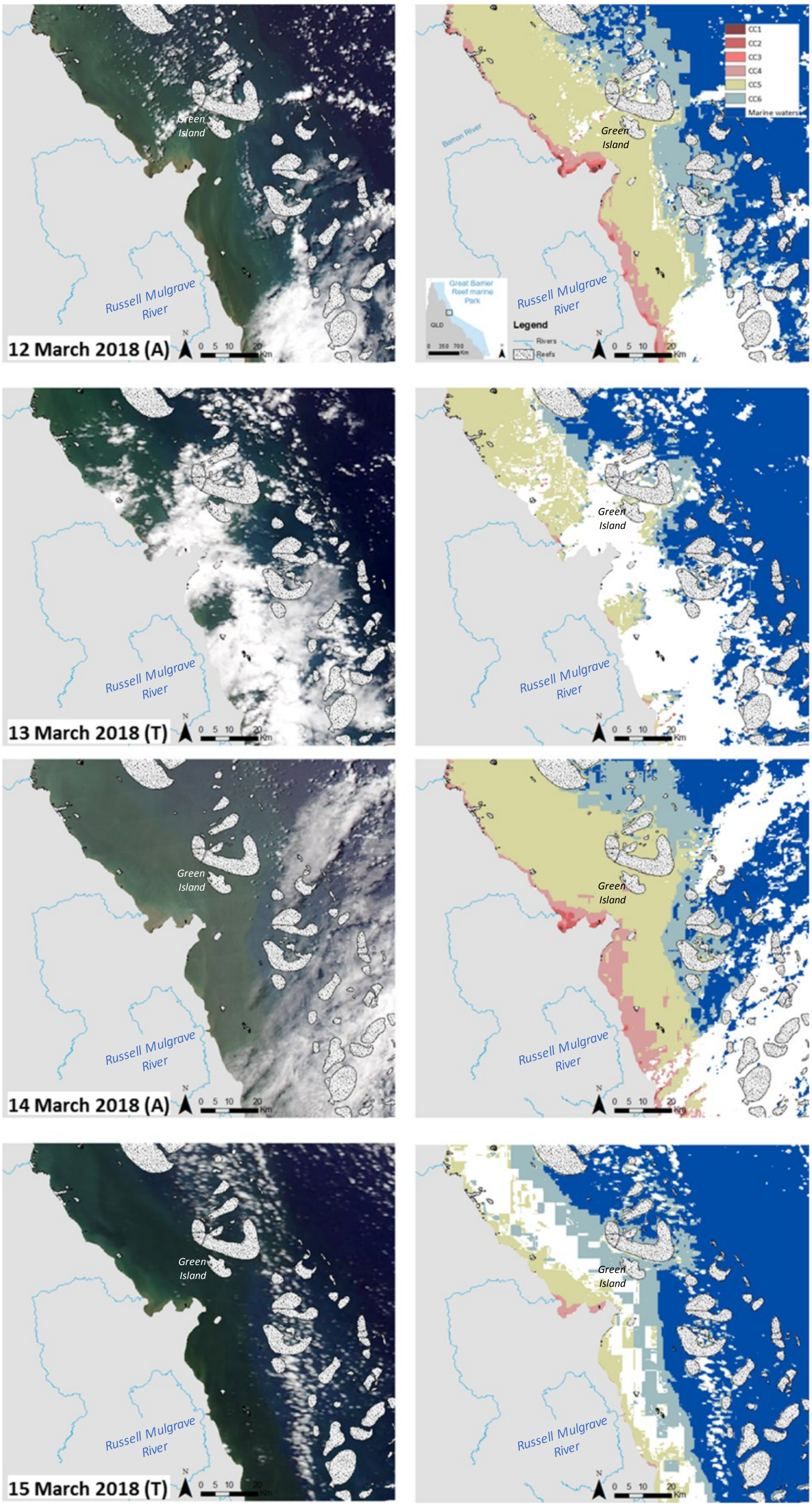


Figure 5-37: A collection of classified water type maps (right panels) showing the evolution of the Wet Tropics river plumes in the Cairns region from 12 to 15 March 2018: (A) MODIS-Aqua, (T) MODIS-Terra.

5.2.3 Tully

The Tully focus area is primarily influenced by discharge from the Tully-Murray and Herbert Rivers and, to a lesser extent, by the Burdekin River in large flow years (Brodie et al., 2013).

One station was sampled in this focus area three times per year until the end of 2014. After the implementation of the new MMP water quality sampling design in 2015, the Tully focus area includes 11 sampling stations, which are sampled up to 10 times per year, with six stations during both the dry and wet seasons and only five during the wet season (Table C-1). The sampling locations in this new design are located in a river mouth to open coastal water transect (Figure 5-38).

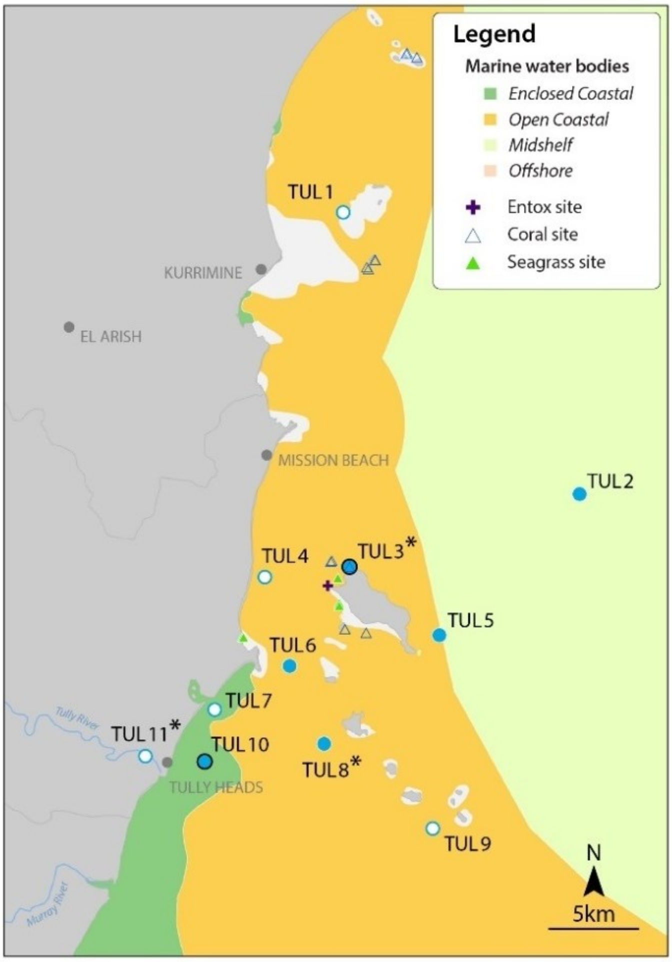


Figure 5-38: Sampling sites in the Tully focus area, shown with the water body boundaries.

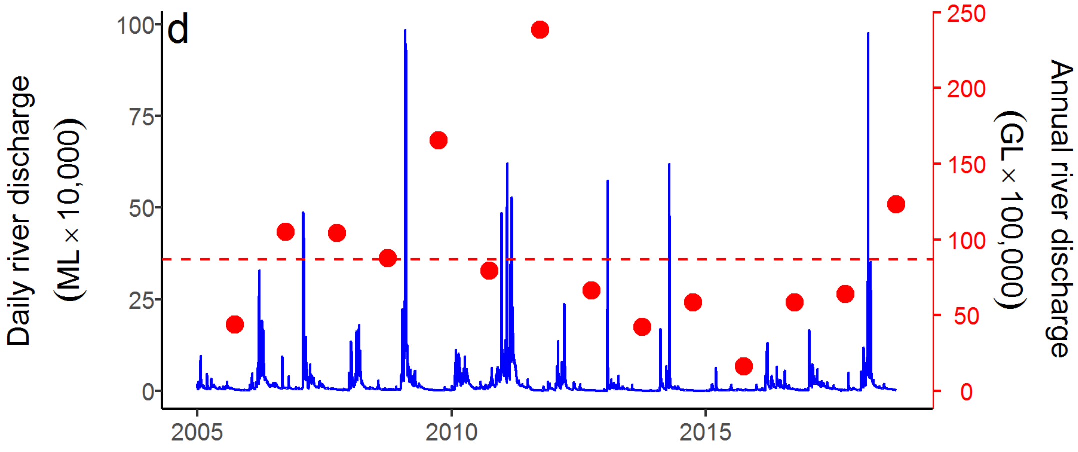


Figure 5-39: Combined discharge for Tully (Euramo gauge) and Herbert (Ingham gauge) Rivers. Daily (blue) and water year (October to September, red) discharge is shown. Red dashed line represents the long-term median of the combined annual discharge. Please note as this is the combined discharge, high flows in one river will not necessarily be visible in the graph.

The total discharge for the 2017–18 monitoring year was above than the long-term median (Figure 5-39), and the Herbert River annual discharge was 1.8 times higher than the long-term median (Table E-1).

The combined discharge and loads calculated for the 2017–18 water year from the Tully, Murray and Herbert Basins were in the higher range recorded over the past decade (Figure 5-40). Discharge, TSS, PN and DIN loads were the highest measured since the large 2010–11 water year. Over the 12-year period:

- discharge has varied from 4100 GL (2014–15) to 24,800 GL (2010–11)
- TSS loads have ranged from 210 kt (2014–15) to 1750 kt (2010–11)
- DIN loads ranged from 750 t (2014–15) to 5800 t (2010–11)
- PN loads ranged from 750 t (2014–15) to 5200 t (2010–11).

Of the three sub-regions within the Wet Tropics NRM region, the Tully, Murray and Herbert Basins collectively contribute similar discharge and TSS and PN loads to the Russell, Mulgrave and Johnstone Basins during low to moderate rainfall/discharge years, although the Tully, Murray and Herbert Basins contribute higher values during the high discharge years such as in 2008–09 and 2010–11 water years as well as generally higher DIN loads in the average to above average years.

Figure 4-7 and Figure 4-11 show the estimated DIN and TSS contributions for the Wet Tropics region in 2017–18 and 2010–11, highlighting the influence of the Tully River to river-derived DIN loadings in the Wet Tropics region (23%). The contribution to the Wet Tropics TSS loading from the Tully River was predicted to be around 10%.

Over the period 2006 to 2018, annual discharge for the Tully and Herbert Rivers (Figure 5-39) has varied around the long-term median with the exception of major floods of the Tully River in 2011 and of the Herbert River in 2009 and 2011 (Table E-1).

Ambient water quality and the in-situ Water Quality Index

When interpreting the long-term water quality trends in this region it should be noted that the location of some of the loggers have changed (TUL 3 and 6), and that the number of water sampling sites and frequency of sampling was increased in 2015. Some of these new sites were placed further inshore and they are therefore likely to be more often affected by primary and secondary plume-type waters.

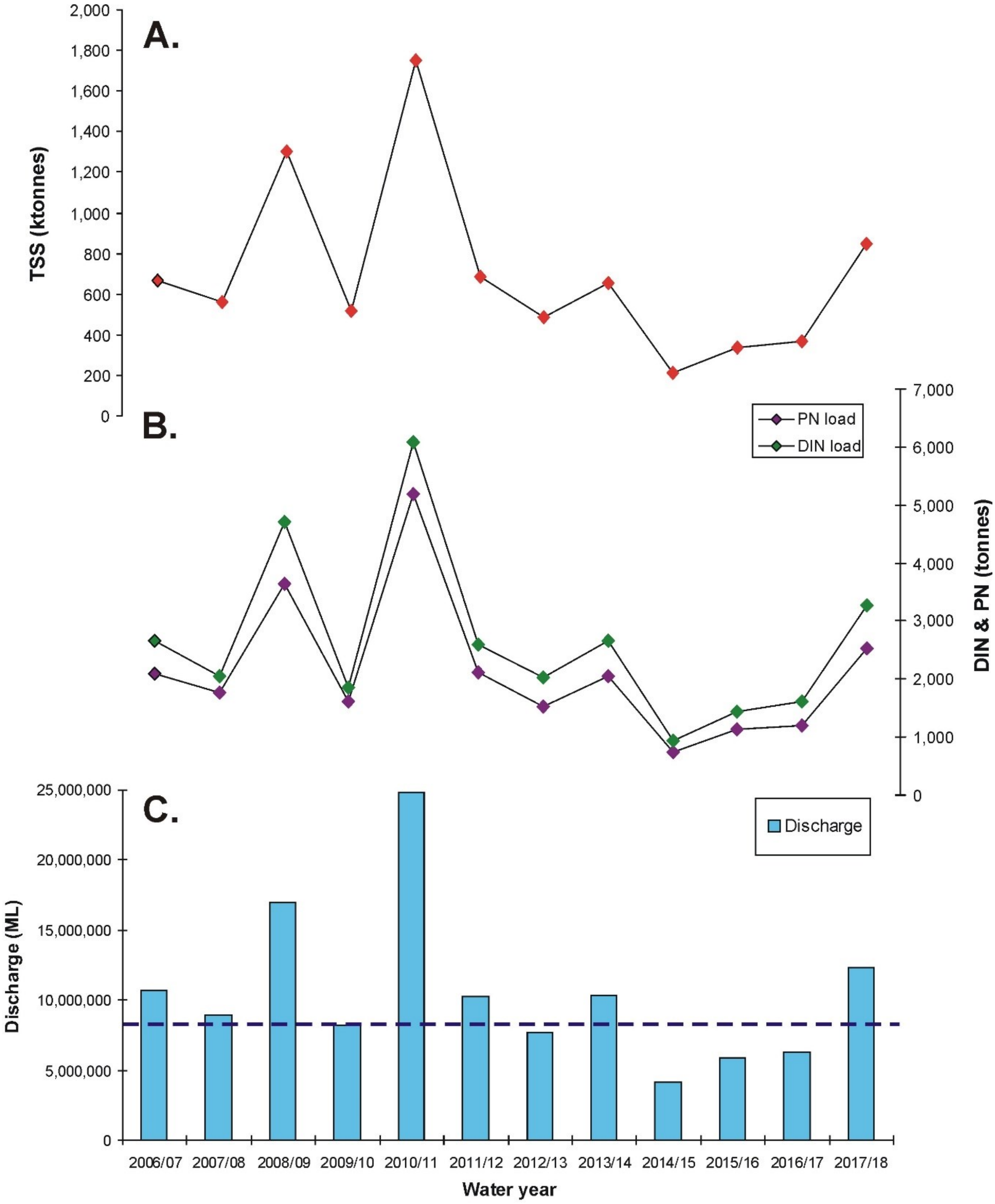


Figure 5-40: (A) TSS loads, (B) DIN and PN loads and (C) discharge or the Tully, Murray and Herbert Basins from 2006–07 to 2017–18. The loads reported here are a combination of 'best estimates' for each basin based on 'up-scaled discharge data from gauging stations, monitoring data (Tully and Herbert Rivers), the DIN model developed in Lewis et al. (2014) and annual mean concentrations and discharge from monitoring data or Source Catchments modelling data. The dotted line represents the long-term median for basin discharge.

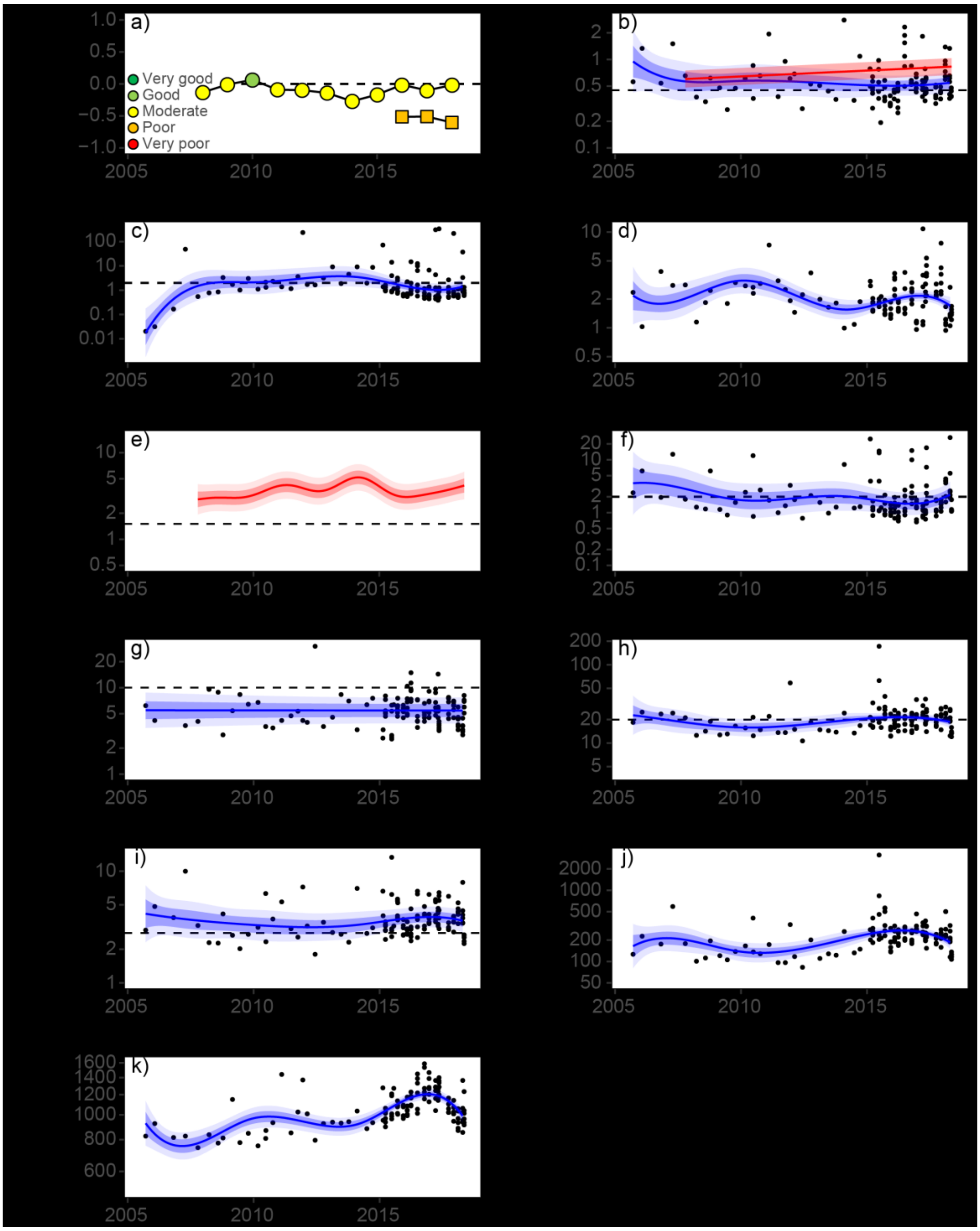


Figure 5-41: Temporal trends in water quality for the Tully sub-region. a) WQ Index, b) chlorophyll *a* (Chl-*a*), c) nitrate/nitrite (NO_x), d) phosphate (PO_4), e) turbidity, f) total suspended solids (TSS), g) Secchi depth, h) particulate nitrogen (PN), i) particulate phosphorus (PP), j) particulate organic carbon (POC) and k) dissolved organic carbon (DOC). The long-term trend in the WQ Index is depicted with circles, while the annual condition (implemented with sampling changes in 2015) is depited with squares in (a). Calculations are described in Appendix D-3. Trends in manually sampled water quality variables are represented by blue lines with blue shaded areas defining 95% confidence intervals of those trends accounting for the effects of wind, waves and tides after applying x-z detrending. Trends of records from ECO FLNTUSB instruments are represented in red, individual records are not displayed (see Figure E-1). Dashed horizontal reference lines indicate yearly guideline values.

Long-term trends in water quality variables measured during ambient periods (e.g. not during peak flood events) of the dry and wet seasons are presented in Figure 5-41. It is important to note that the trend analysis used removes variability associated with wind, waves and tides (see Methods). Thus, individual data points have slightly different magnitudes compared to raw data. This analysis helps elucidate long-term and regional-scale trends in water quality by removing the effect of changes in local weather and tides.

Distinct long-term trends (since 2005) were observed in some water quality variables, while others showed little change over time (Figure 5-41). Mean concentrations of Chl-*a* and TSS have been relatively stable over time, with mean values at or slightly exceeding the water quality GVs (Great Barrier Reef Marine Park Authority, 2010), although Chl-*a* concentrations derived from loggers show an increase since 2009. Concentrations of PO_4 and NO_x have varied over time, and NO_x concentrations are presently at the GV. Mean Secchi depth has not changed since monitoring began; however, current values are not meeting the GV. Mean concentrations of PN and PP have been relatively stable since monitoring began; PP values exceed the GV and PN values are close to the GV. Mean concentrations of DOC have increased dramatically since monitoring began (with a decline during the 2017–18 monitoring year), while POC has remained relatively stable (Figure 5-41).

The WQ Index is now calculated using two different formulations to communicate the long-term trend in water quality (based on the pre-2015 sampling design) as well as an improved metric for annual condition (based on the post-2015 sampling design, which increased the power to detect changes in water quality). The Methods section and Appendix D-3 contain details of the calculations for both Index versions.

The long-term WQ Index has shown water quality to be ‘moderate’ relative to GVs, with no long-term trend observed (Figure 5-41a). The annual condition WQ Index currently shows water quality to be ‘poor’ for the last three years. This version of the Index scores water quality parameters against GVs relevant to the season when samples are collected (wet vs dry GVs) and includes additional inshore sites to better characterise areas affected by river discharge.

It is important to note that the two versions of the WQ Index are designed to answer separate questions and therefore differences in scores between the versions are expected.

Event water quality

As described in Section 3.2.2, the Wet Tropics region experienced an above-average wet season with major flooding occurring in many rivers including the Herbert and Tully Rivers. The Tully River had two major flow events (peaked on 10 March and 28 March 2018, respectively), two moderate level flow events (peaked on 19 January and 7 February 2018, respectively) and one minor event (peaked on 2 January 2018). The Herbert River had a very large flow in March 2018 causing major flooding around the Ingham township, peaking on 9 March 2018 (Figure 5-42). The total discharge for the 2018 water year (1 October 2017 to 30 September 2018) was 4237 GL for the Tully River and 6386 GL for the Herbert River.

Figure 5-42 shows the daily discharge (ML) for the Tully and Herbert Rivers, and the red diamonds show the 11 flood sampling campaigns conducted as part of the MMP. On a number of occasions, sampling of the Tully flood plume in 2018 was restricted to shorter times on the water or until a few days after peak river flow due to poor weather.

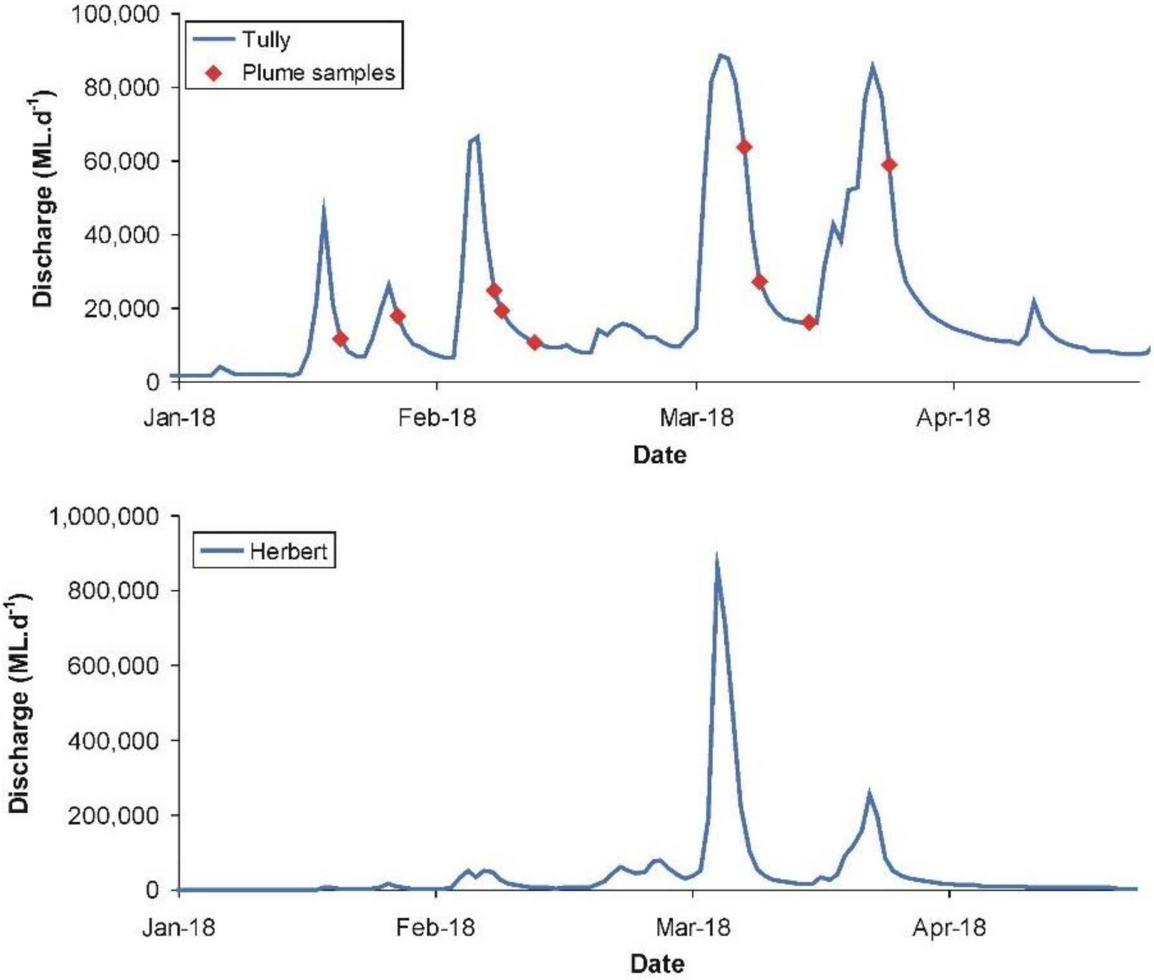


Figure 5-42: River discharge (in ML per day) from 1 January to 30 April 2018 for the Tully (top, Euramo gauge) and Herbert (bottom, Ingham gauge) Rivers. Red diamonds show when plume sampling occurred offshore from the river mouth in the Tully focus area.

Satellite images, when not obstructed by cloud cover, clearly distinguish the extent of the flood plumes from the Tully, Murray and Herbert Rivers over March 2018 (Figure 5-43A-D). The images show the plumes to be mainly confined to the inner shelf, but with evidence of some influence on parts of the mid-shelf. These images highlight the extended period of time that the region was influenced by these flood waters. The image from 29 March (Figure 5-43D) shows a particularly turbid area in the vicinity of Dunk Island sampling area.

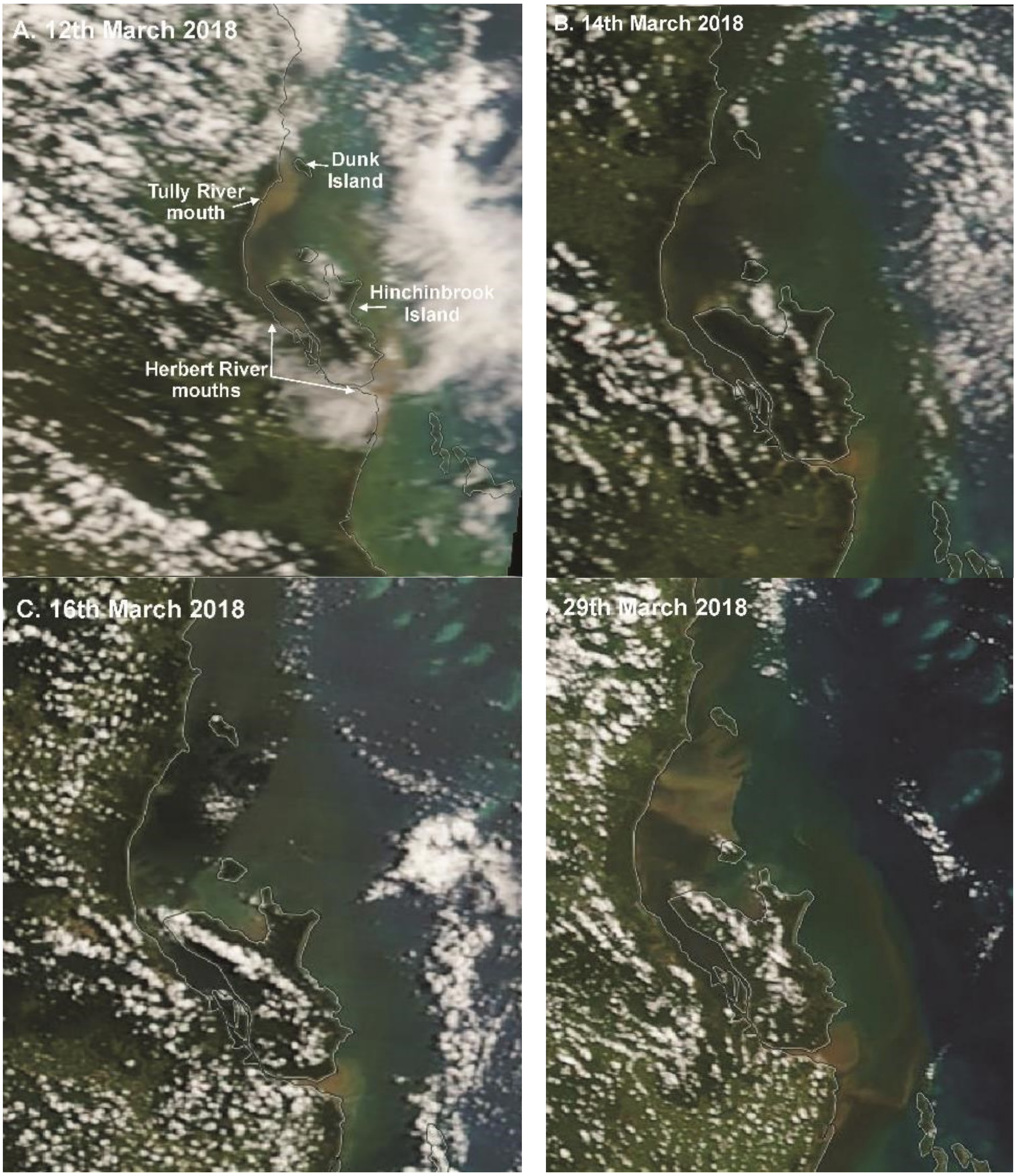


Figure 5-43: Satellite images of the flood plume from the Tully (+Murray) and Herbert Rivers on the 12 March 2018 (A), 14 March 2018 (B), 16 March 2018 (C) and 29 March 2018 (D).

Two series of satellite images and the true colour analysis of wet season water types for 12 March to 15 March and 29 March to 31 March 2018 are shown in

Figure 5-45 and Figure 5-46 respectively. The extended area of the secondary water type from 12 to 15 March 2018 referred to in

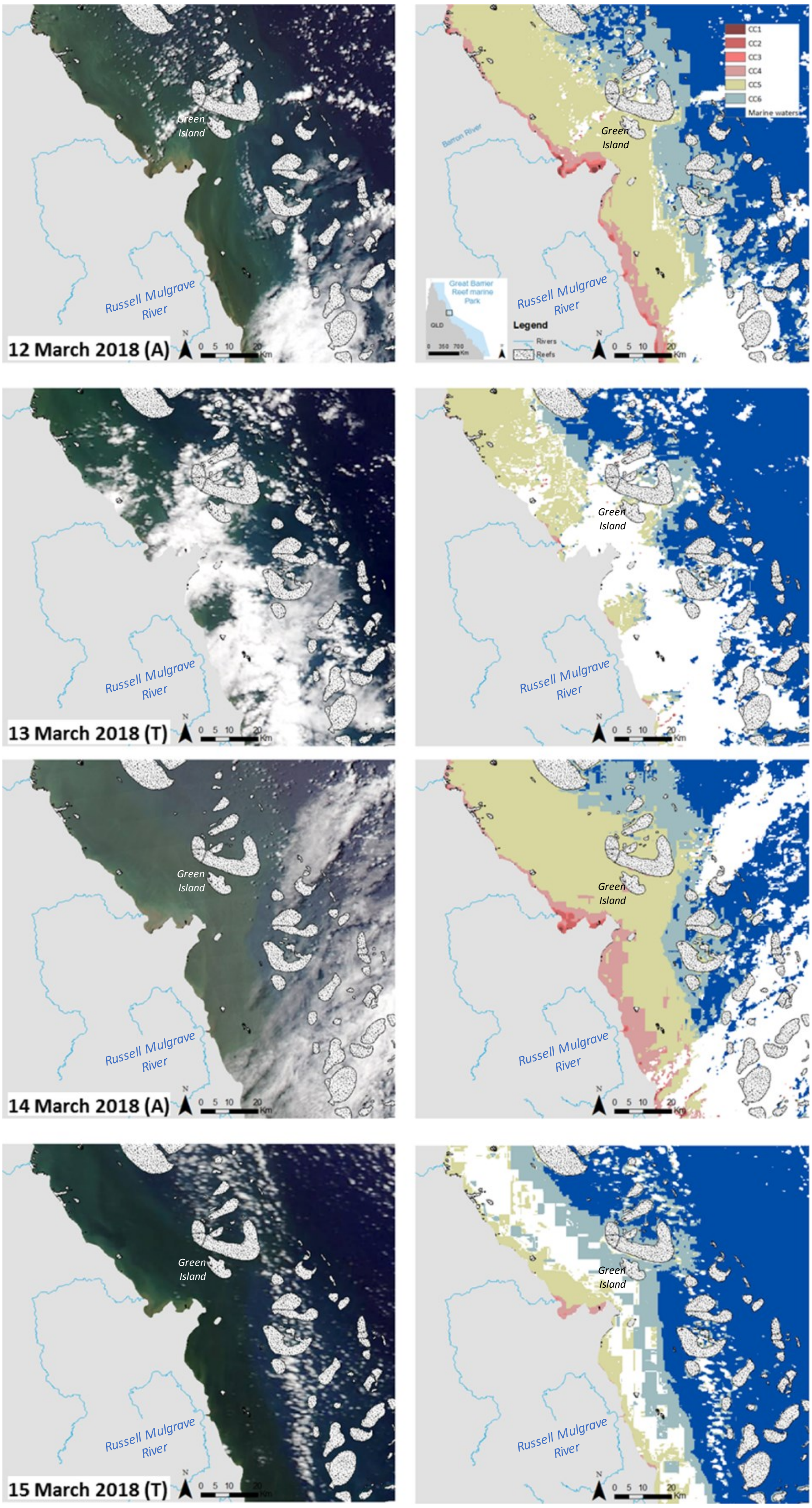


Figure 5-37 is also present across the broader Wet Tropics region. The analysis on 15 March 2018 shows large areas of the primary water type around the Herbert and Tully Rivers; cloud cover on the days prior to this prevents this analysis but it is likely that it was also present at that time following the peak discharge of the Herbert River on 9 March and Tully River on 10 March 2018.

The images for the 29 to 31 March 2018 period follow the second peak discharge in the Tully River on 28 March 2018. The extent of the primary and secondary water types shows similar patterns to those following the previous peak discharges, with turbid waters reaching the mid-shelf areas.

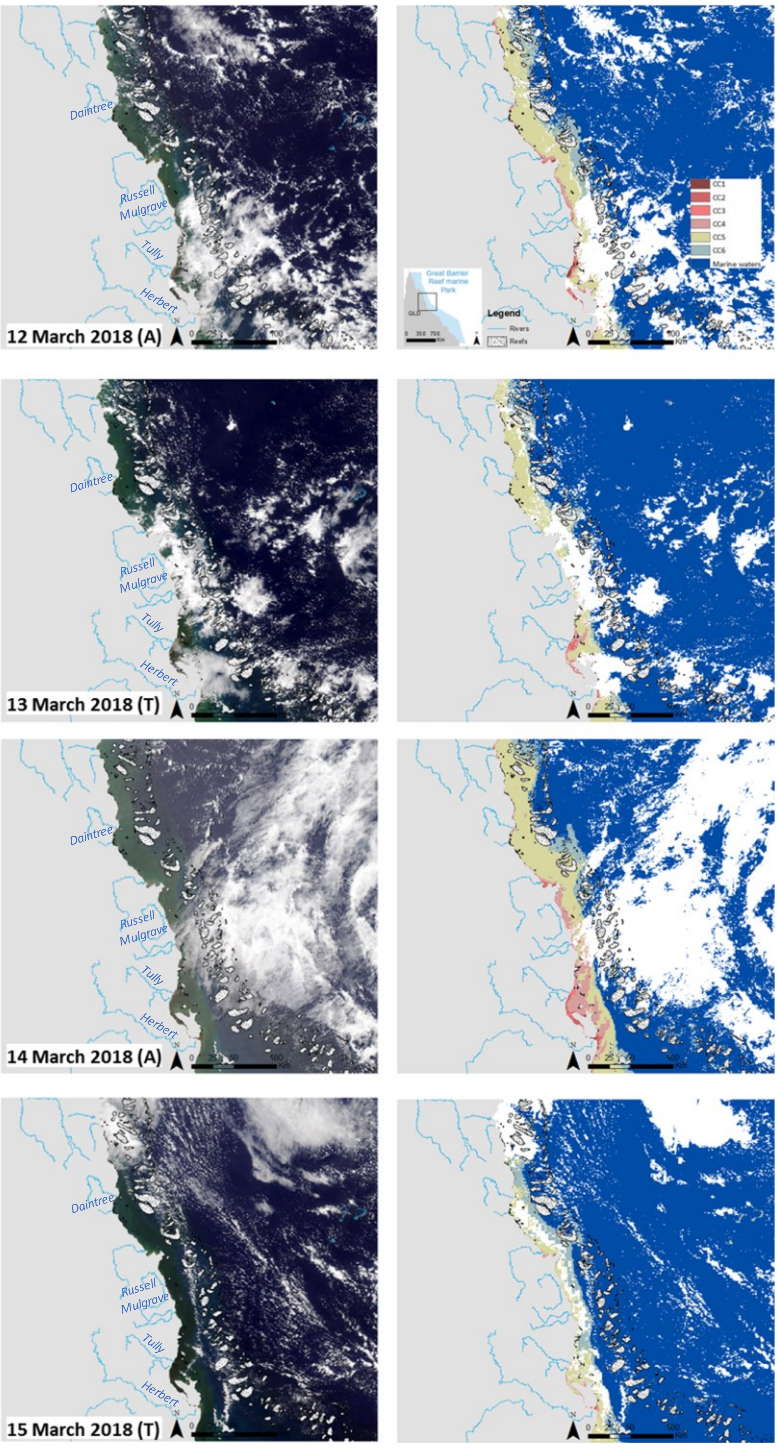


Figure 5-44: A collection of water type maps showing the evolution of the Wet Tropics River plumes from 12 to 15 March 2018: (A) MODIS-Aqua, (T) MODIS-Terra.

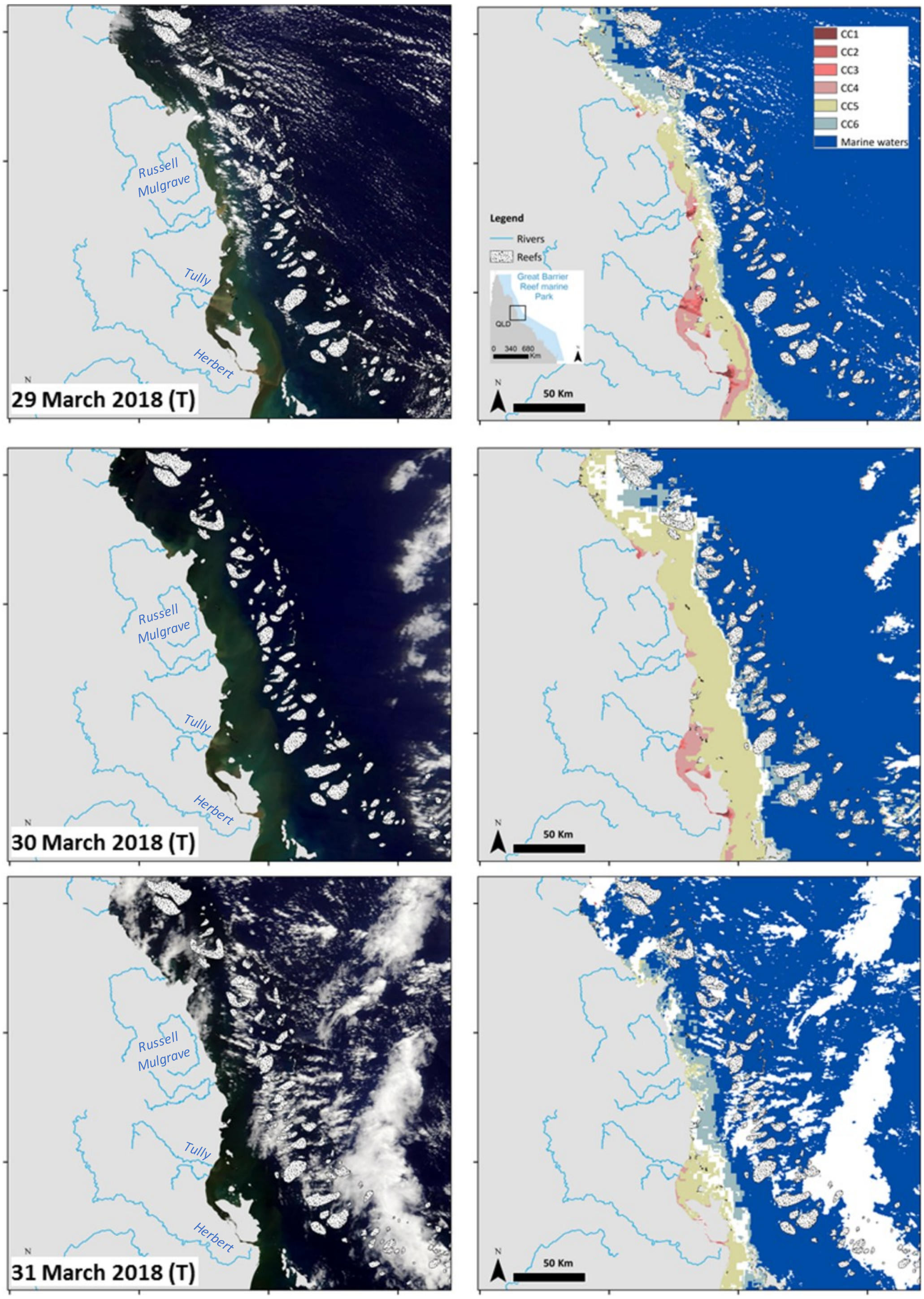


Figure 5-45: A collection of water type maps showing the evolution of the Wet Tropics River plumes from 29 to 31 March 2018: (A) MODIS-Aqua, (T) MODIS-Terra.

Suspended sediment concentrations in the Tully River gradually declined over the estuarine mixing zone (Figure 5-46A) with the exception of the odd outlier likely related to sediment resuspension. PN concentrations were highly variable over the estuarine mixing zone (Figure 5-46B) and likely related to the abundance of phytoplankton in the water. DIN concentrations gradually decreased from the 0 to 20 salinity zone before stabilising generally <20 µg L^{-1} (Figure 5-46C). Chl-*a* concentrations were also highly variable over the mixing zone but generally increased within the higher salinities as nutrients were utilised by algal communities (Figure 5-46D). The concentrations for all parameters were typical of those seen in moderate river discharge events in the Tully River in the past but were much lower than those measured in the Burdekin River.

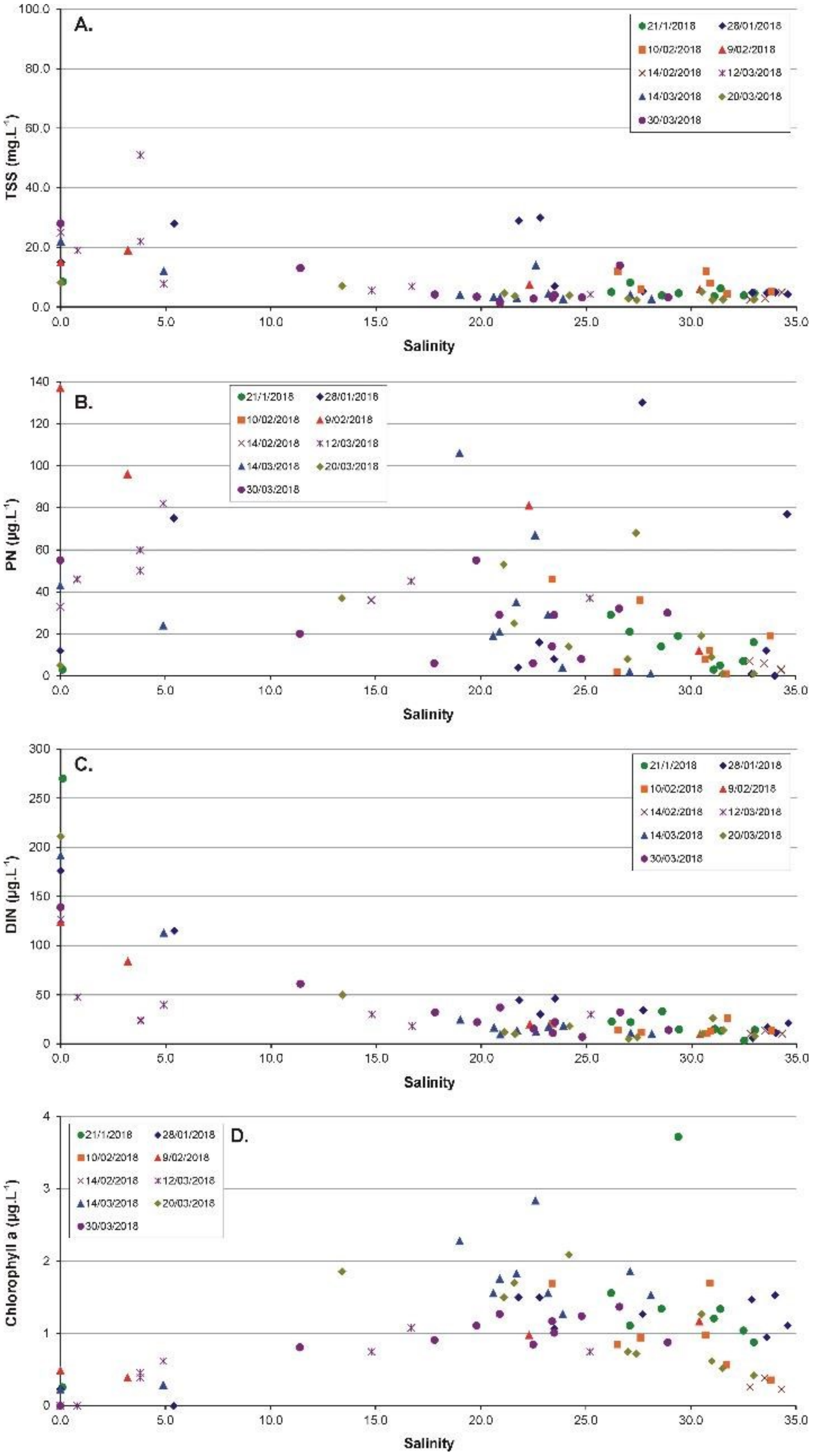


Figure 5-46: Water quality data from the Tully flood plume including total suspended solids (TSS: A), particulate nitrogen (PN: B), dissolved inorganic nitrogen (DIN: C) and chlorophyll a (D) highlighting the different days of sampling.

5.3 Burdekin region

Three stations were sampled in the Burdekin focus area three times per year until the end of 2014. The current sampling design includes 15 stations that are sampled up to nine times per year, with six stations sampled during both the dry and wet season, and nine stations during the wet season (Appendix C, Table C-1). The sampling locations in this new design are located in a river mouth to open coastal water transect (Figure 5-47).

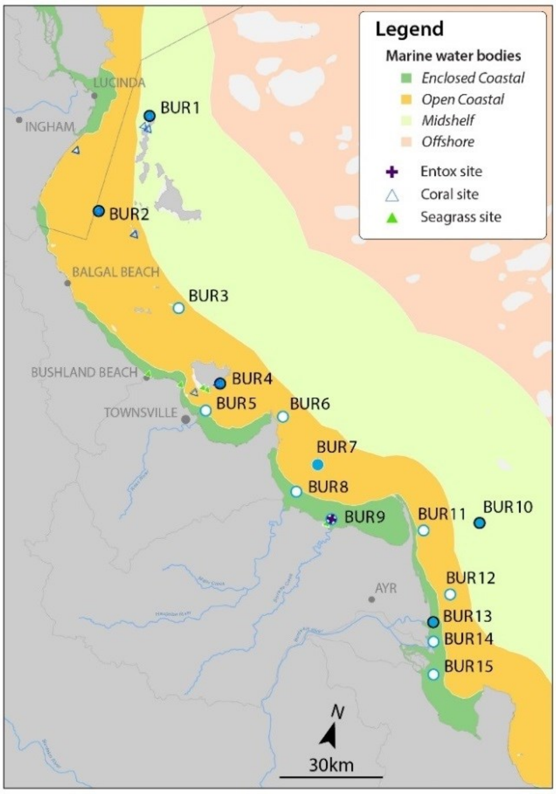


Figure 5-47: Sampling sites in the Burdekin focus area, shown with the water body boundaries.

Rainfall for the Burdekin Basin was generally low in 2017–18 in all catchments, which is reflected in annual discharge close to the long-term median (Figure 5-48). This contrasts substantively with the flow conditions between 2007 to 2012 (Table E-1) when annual discharge from the Burdekin River was well above median levels, followed by several drier-than-average years from 2013 to 2017 (Figure 5-48).

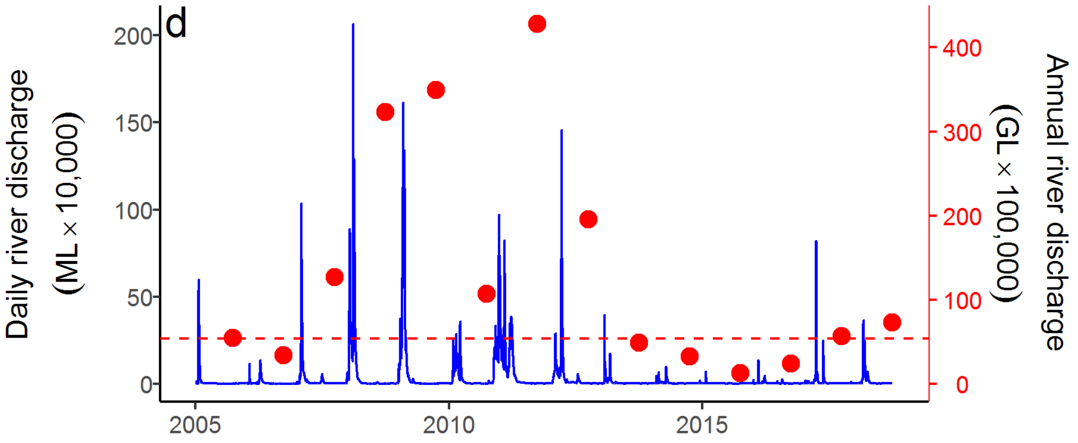


Figure 5-48: Discharge for the Burdekin River (Clare gauge). Daily (blue) and water year (October to September, red) discharge is shown. Red dashed line represents the long-term median annual discharge. Please note as this is the combined discharge, high flows in one river will not necessarily be visible in the graph.

The combined discharge and loads calculated for the 2017–18 water year from the Burdekin and Haughton Basins were around the long-term median and discharge was the highest since the 2011–12 water year reflecting a drier period in this region over the past 6 years (Figure 5-49). Indeed, the past 6 water years have had relatively low discharge as well as lower TSS, DIN and PN loads compared to the previous wetter period between the 2006–07 and 2011–12 water years. Over the 12-year period:

- discharge has varied from 930 GL (2014–15) to 37,300 GL (2010–11)
- TSS loads have ranged from 300 kt (2013–14) to 15,100 kt (2007–08)
- DIN loads ranged from 190 t (2014–15) to 3600 t (2010–11)
- PN loads ranged from 510 t (2013–14) to 21,900 t (2007–08).

During the very large discharge years (2007–08, 2008–09 and 2010–11), the Burdekin and Haughton Basins (dominated by the Burdekin Basin) produced by far the highest loads of TSS and PN compared to any of the other sub-regions. In contrast, the DIN loads are either similar to or lower than the Wet Tropics and Mackay-Whitsunday Basins during the high discharge years and much lower during the lower discharge years.

The loading maps presented in Section 4 can also be assessed to determine the relative contribution of loads from each river to the marine NRM region. Figure 4-7 and Figure 4-11 show the estimated DIN and TSS contributions for the Burdekin region in 2017–18. The panels show that the Mackay-Whitsunday rivers contributed to the Burdekin region in the large discharge event of 2010–11 and. to a lesser extent in 2017–18, with small DIN loading contributions from the Proserpine and O'Connell Rivers (~2% each), which are closest to the Burdekin NRM region boundary.

The Burdekin River had limited influence (<1% DIN and ~5% TSS) in the Wet Tropics region in 2017–18; however, the Herbert River influenced the Burdekin DIN loading (30%) in 2017–18; the Herbert River has influenced the Burdekin region in most of the years modelled. In 2017–18, the highest river-derived DIN loading contributions to the Burdekin region were from the Burdekin (42%), Herbert (30%) and Haughton (19%) Rivers, whereas the TSS contributions were dominated by the Burdekin River (69%) and to a much lesser extent, the Haughton River (22%).

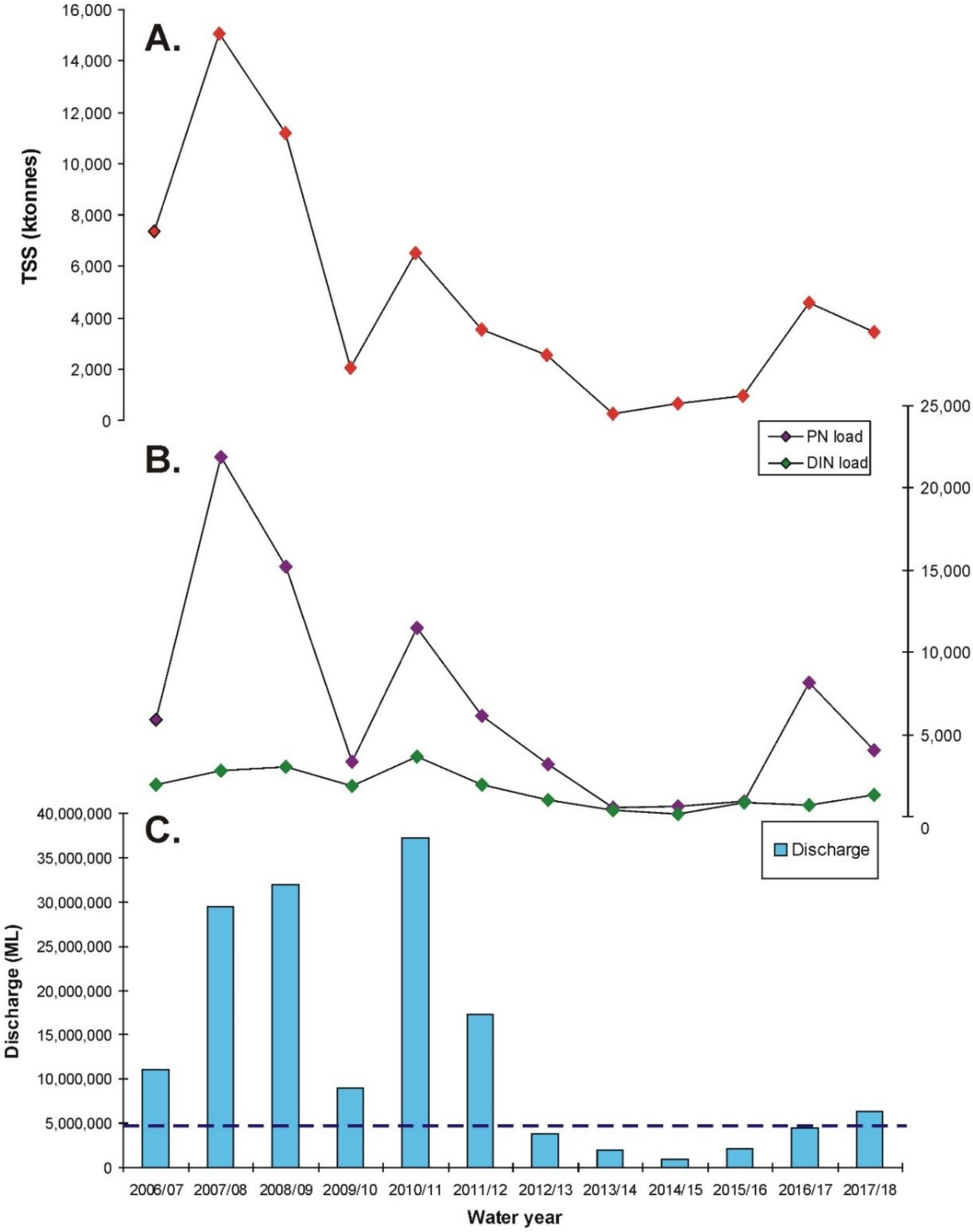


Figure 5-49: (A) TSS loads, (B) DIN and PN loads and (C) discharge for the Burdekin and Haughton Basins from 2006–07 to 2017–18. The loads reported here are a combination of 'best estimates' for each basin based on 'up-scaled discharge data from gauging stations, monitoring data (Burdekin River), the DIN model developed in Lewis et al. (2014) and annual mean concentrations and discharge from monitoring data or Source Catchments modelling data. Dotted line represents the long-term median for basin discharge.

Ambient water quality and the in-situ Water Quality Index

When interpreting the long-term water quality trends in this region it should be noted that the location of one of the loggers (BUR13) has changed, and that the number of water sampling sites and frequency of sampling was increased during 2015. Some of these new sites were placed further inshore and they are therefore likely to be more often affected by primary and secondary plume-type waters.

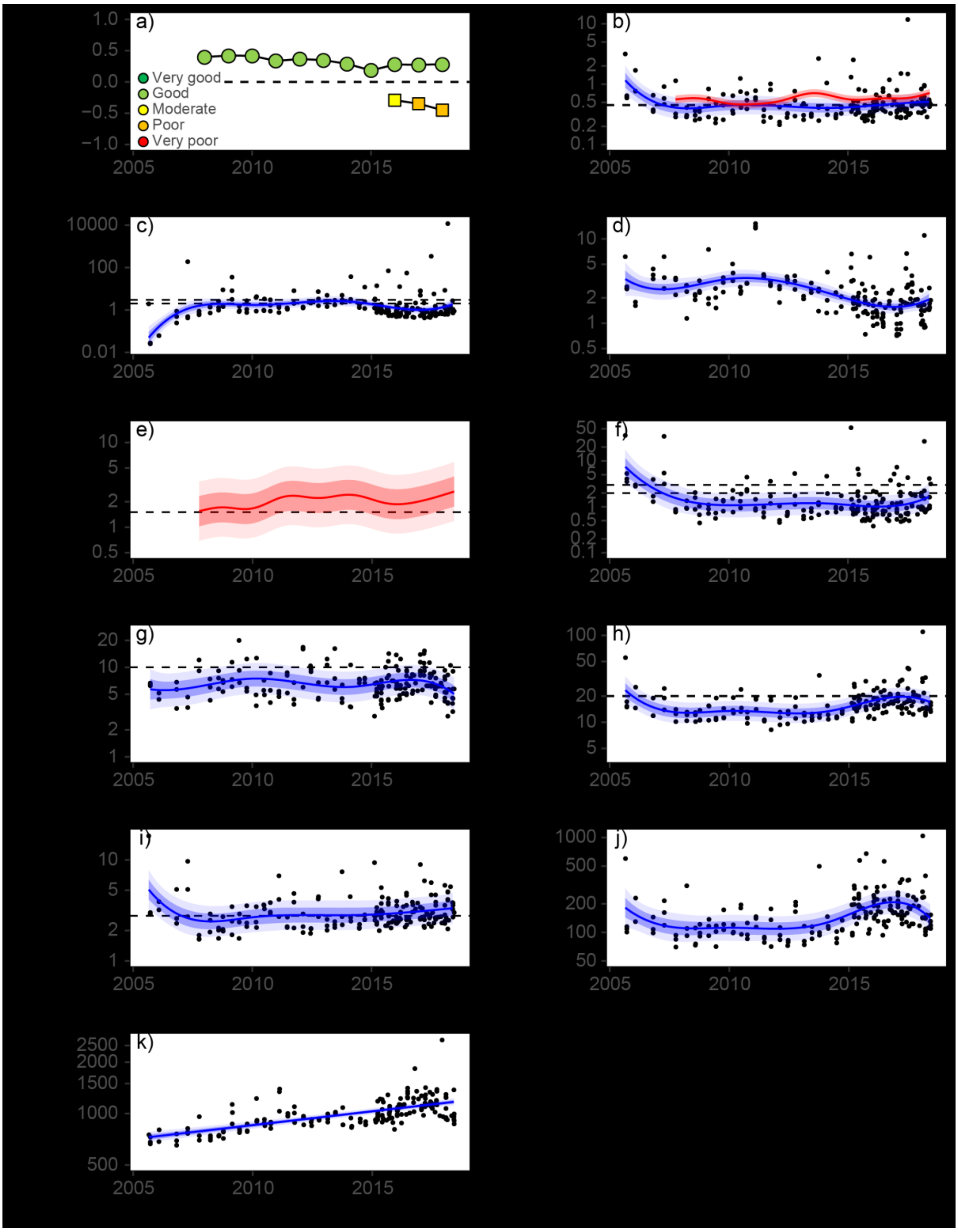


Figure 5-50: Temporal trends in water quality for the Burdekin focus area. a) WQ Index, b) chlorophyll *a* (Chl-*a*), c) nitrate/nitrite (NO_x), d) phosphate (PO_4), e) turbidity, f) total suspended solids (TSS), g) Secchi depth, h) particulate nitrogen (PN), i) particulate phosphorus (PP), j) particulate organic carbon (POC) and k) dissolved organic carbon (DOC). The long-term trend in the WQ Index is depicted with circles, while the annual condition (implemented with sampling changes in 2015) is depited with squares in (a). Trends in manually sampled water quality variables are represented by blue lines with blue shaded areas defining 95% confidence intervals of those trends accounting for the effects of wind, waves and tides after applying x-z detrending. Trends of records from ECO FLNTUSB instruments are represented in red, individual records are not displayed (see Figure E-1). Dashed horizontal reference lines indicate annual guideline values.

Long-term trends in water quality variables measured during ambient periods (e.g. not during peak flood events) of the dry and wet seasons are presented in Figure 5-50. It is important to note that the trend analysis used removes variability associated with wind, waves and tides (see Methods). Thus, individual data points have slightly different magnitudes compared to raw data. This analysis helps elucidate long-term and regional-scale trends in water quality by removing the effect of changes in local weather and tides.

Distinct long-term trends (since 2005) were observed in some water quality variables, while others showed little change over time (Figure 5-50). Mean concentrations of Chl-*a* and TSS have been relatively stable since 2009, with mean values of Chl-*a* slightly exceeding the water quality GVs and mean TSS below GVs (Great Barrier Reef Marine Park Authority, 2010). Concentrations of PO_4 have slowly declined over time, while NO_x concentrations have been relatively stable and are presently below the GV. These low concentrations relative to GVs may be related to the recent series of drier-than-average years that have occurred in the Burdekin region. Mean Secchi depth has not changed since monitoring began, but current values are not meeting the GV. Mean concentrations of PN and PP have increased slightly since monitoring began, and PP values presently exceed the GV while PN values are close to the GV. Mean concentrations of DOC have increased dramatically since monitoring began, while POC increased slightly in recent years (Figure 5-50).

The WQ Index is now calculated using two different formulations to communicate the long-term trend in water quality (based on the pre-2015 sampling design) as well as an improved metric for annual condition (based on the post-2015 sampling design, which increased the power to detect changes in water quality). The Methods section and Appendix D-3 contain details of the calculations for both Index versions.

The long-term WQ Index has shown water quality to be ‘good’ relative to GVs, with no long-term trend observed (Figure 5-50a). The annual condition WQ Index currently shows water quality to be ‘poor’ and declining for the last two years. This version of the Index scores water quality parameters against GVs relevant to the season when samples are collected (wet vs dry GVs) and includes additional inshore sites to better characterise areas affected by river discharge.

It is important to note that the two versions of the WQ Index are designed to answer separate questions and therefore differences in scores between the versions are expected.

Event water quality

Sampling of the Burdekin flood plume occurred in Upstart Bay on 5 and 6 March 2018, and off Magnetic Island on 13 March 2018 (Figure 5-51).

Heavy rainfall occurred in the upper Burdekin River catchment in late February/early March 2018, which triggered minor flood levels in the downstream river reaches to the Burdekin Falls Dam. While the end-of-catchment water level for the Burdekin River peaked just below the minor flood level on 5 March 2018, the flow event was the largest in the catchment area above the dam since 2012, and total Burdekin River discharge in the 2017–18 water year (1 October 2017 to 30 September 2018) (5,542,306 ML) was just above the long-term median (4,406,780 ML) (Figure 5-51). This was an important event to document given that the flow event was almost exclusively derived from the Upper Burdekin catchment, following on from the 2016–17 event, which was predominately sourced from the Bowen-Broken-Bogie sub-catchments; these two areas are the dominant contributors to sediment loads at the end of Burdekin Basin (see Bainbridge et al., 2014).

The available satellite image of the Burdekin plume on 6 March 2018 (i.e. 1 day after peak discharge) shows the extent of the plume largely confined within Upstart Bay and beginning to extend into Bowling Green Bay (Figure 5-52A). The next available image from 10 March shows the plume extending well northwards past Magnetic Island and into the Palm Island Group (Figure 5-52B). Images from 13 and 29 March (Figure 5-52C and Figure 5-52D, respectively) show the influence of the plume continuing in the region, evident around the Palm Island Group. Importantly, the images show the extent of the Burdekin plume was largely confined to the inner shelf of the Reef lagoon and did not impinge on the mid-shelf areas.

A series of satellite images and the true colour analysis of wet season water types for 2 to 15 March and 29 March

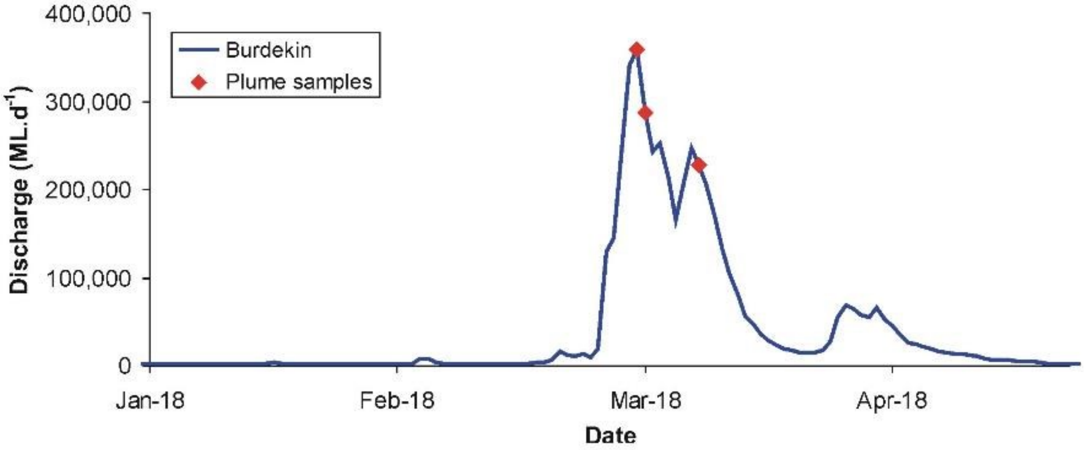
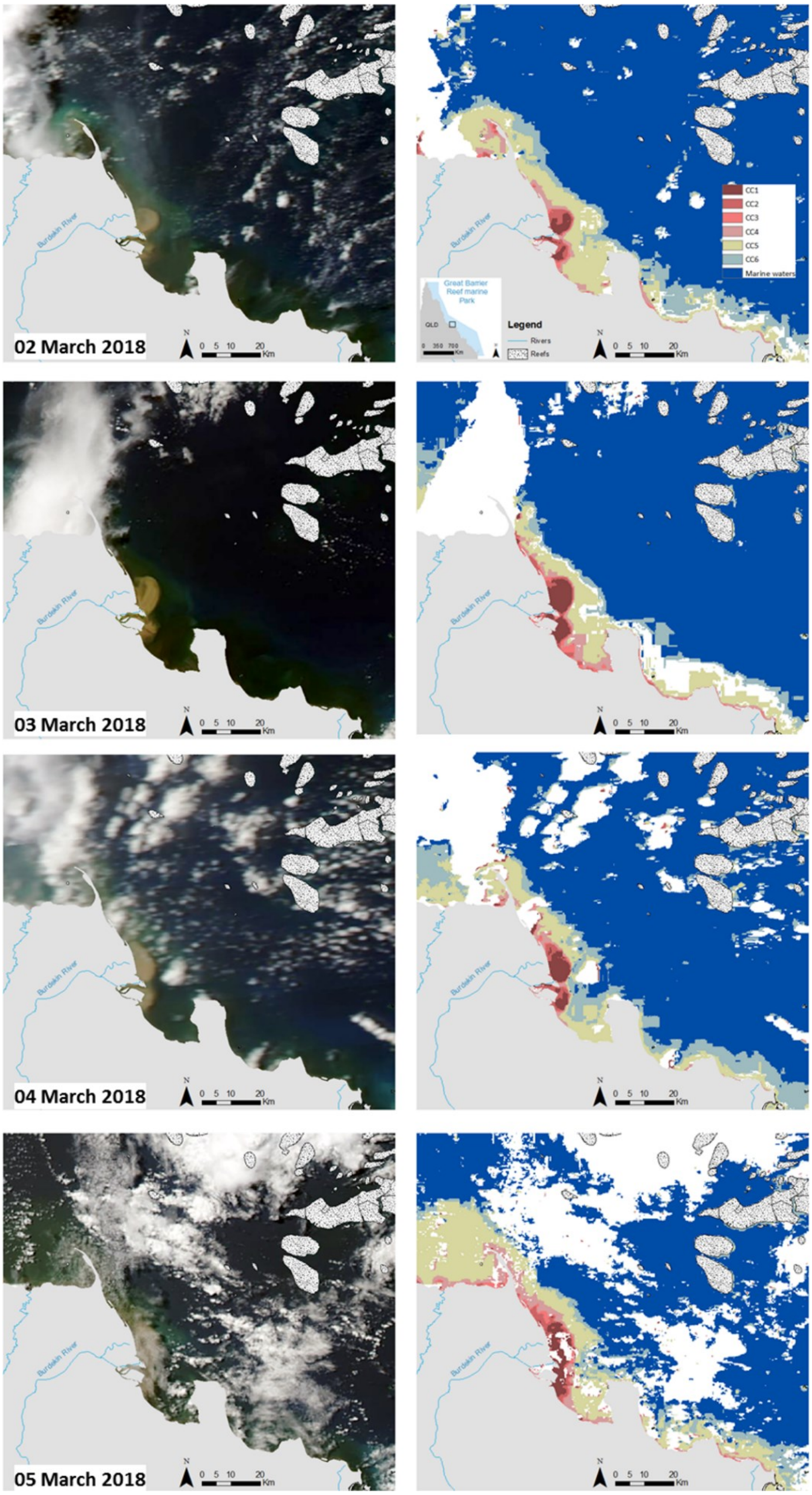


Figure 5-51: River discharge (in ML per day) from 1 January to 30 April 2018 for the Burdekin River (Clare gauge). Red diamonds show when plume sampling occurred offshore from the Burdekin river mouth.



to 31 March are shown in Figure 5-53 to Figure 5-56. The water type maps show the extension and intensification of the highly turbid primary water type following the peak of the discharge on 5 March 2018 (especially between 6 and 11 March 2018 (Figure

5-54); and through to 15 March 2018 (

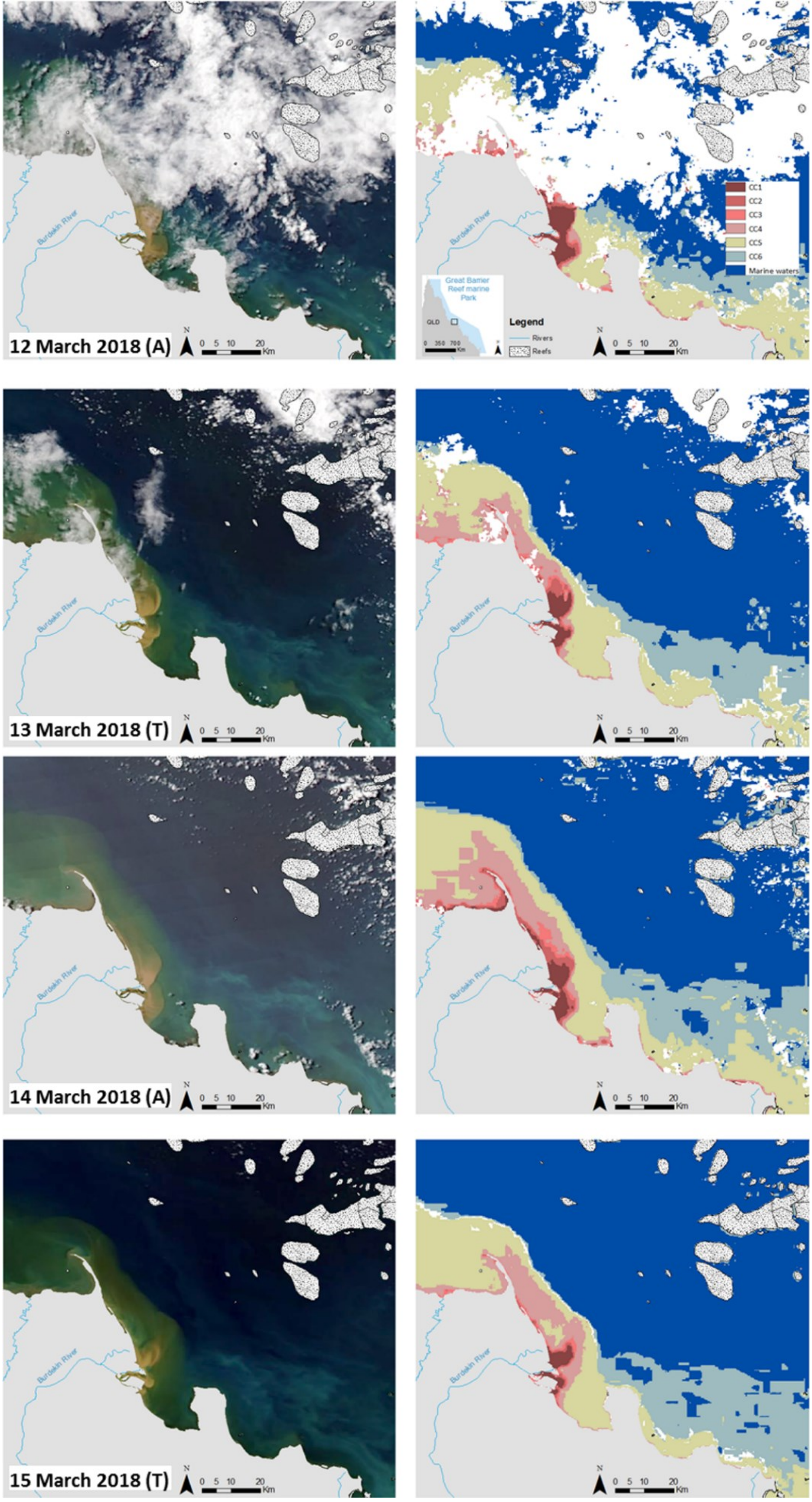


Figure 5-55). Throughout this period, the extent of the secondary water type also increased, but the extent of the tertiary water type was relatively constrained until the end of that period. The images and water type maps at the end of the month (29 to 31 March 2018) still show extended areas of the primary and secondary water types, even though the Burdekin River discharge reduced relatively quickly following the peak, and there was evidence of a greater extent of the tertiary water type to the south east.

Further discussion of these patterns and the variation between weeks is included with reference to Figure 4-27 and Figure 4-28 which show dissipation of the extent of the primary water type but persistence of the secondary water type through to the end of the wet season.

Sampling of the Burdekin flood plume included two trips in Upstart Bay on 5 and 6 March 2018 and off Magnetic Island on 13 March 2018. Further sampling was constrained by poor weather conditions. However, the limited sampling still captured the 0 to 10 salinity zone reasonably well, as well as some samples from the 25 to 30 salinity zone. The results of the water quality analysis are shown in Figure 5-57. The plots of TSS, PN, DIN and Chl-*a* over the estuarine salinity mixing zone show patterns consistent with previous sampling years, with the bulk of the suspended particulate matter (Figure 5-57A) and associated PN (Figure 5-57B) falling out by ~5 salinity (with the exception of the very high outlier PN concentration measured at 23 salinity). DIN was more variable and conservatively mixed, at least in the early plume stages while chlorophyll *a* showed no apparent pattern.

An example of the change of suspended sediment across the estuarine salinity mixing zone of the Burdekin River is shown in Figure 5-58 where TSS concentrations decreased quickly over the salinity gradient. However, pumping with the SediPump™ through NESP Project 2.1.5 (Lewis et al., 2018) shows the suspended particulate matter of similar colour can still be recovered in the higher salinity zones of the plume (e.g. 32 salinity). The SediPump™ samples allowed enough sample to be collected (for the first time) to characterise and trace the suspended particulate matter in these outer plume reaches.

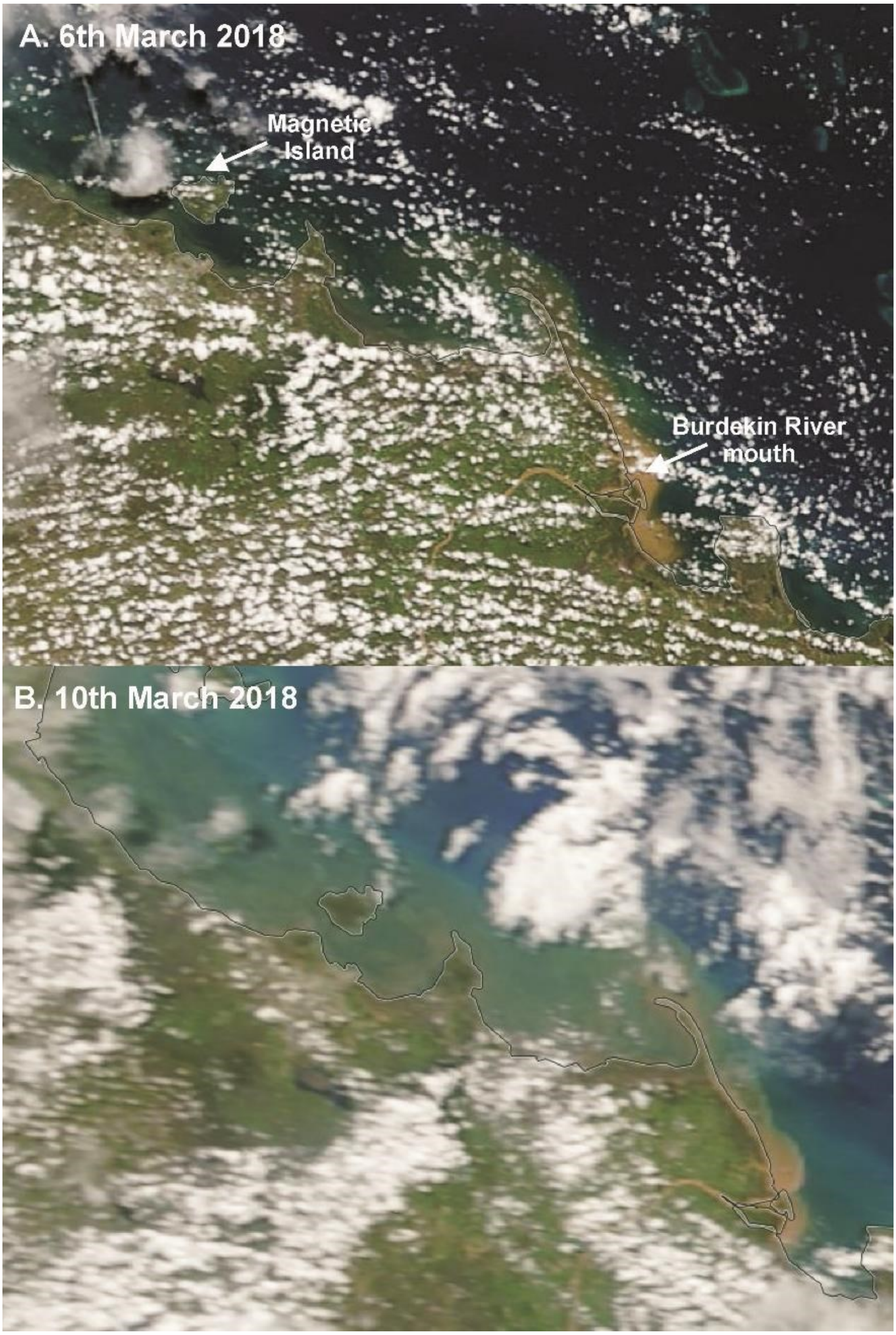


Figure 5-52: Satellite images of the flood plume from the Burdekin River on 6 March 2018 (A), 10 March 2018 (B) and (next page) 13 March 2018 (C) and 29 March 2018 (D).

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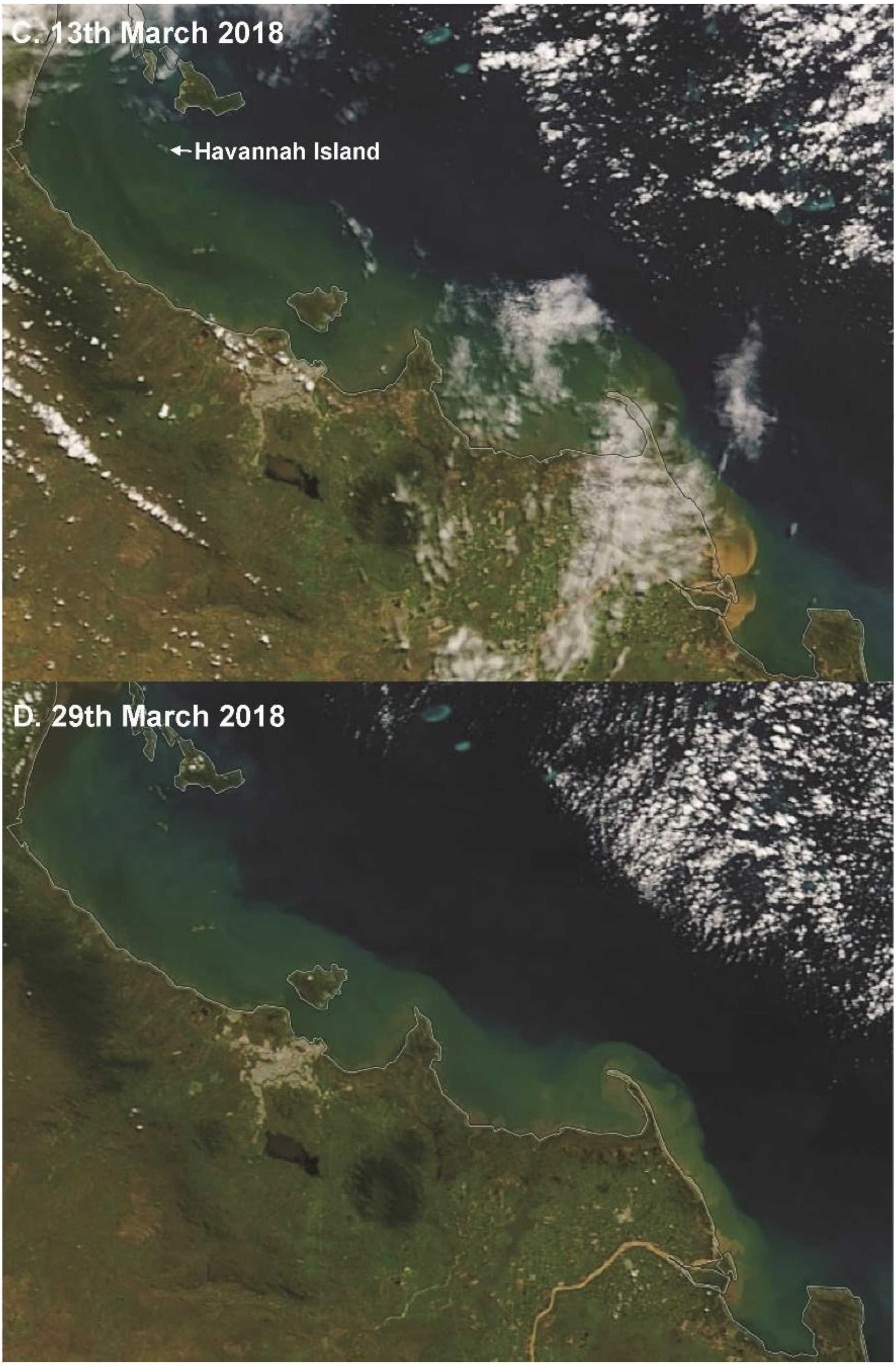


Figure 5-52: Satellite images of the flood plume from the Burdekin River on the 6 March 2018 (A), 10 March 2018 (B) (previous page), 13 March 2018 (C) and 29 March 2018 (D).

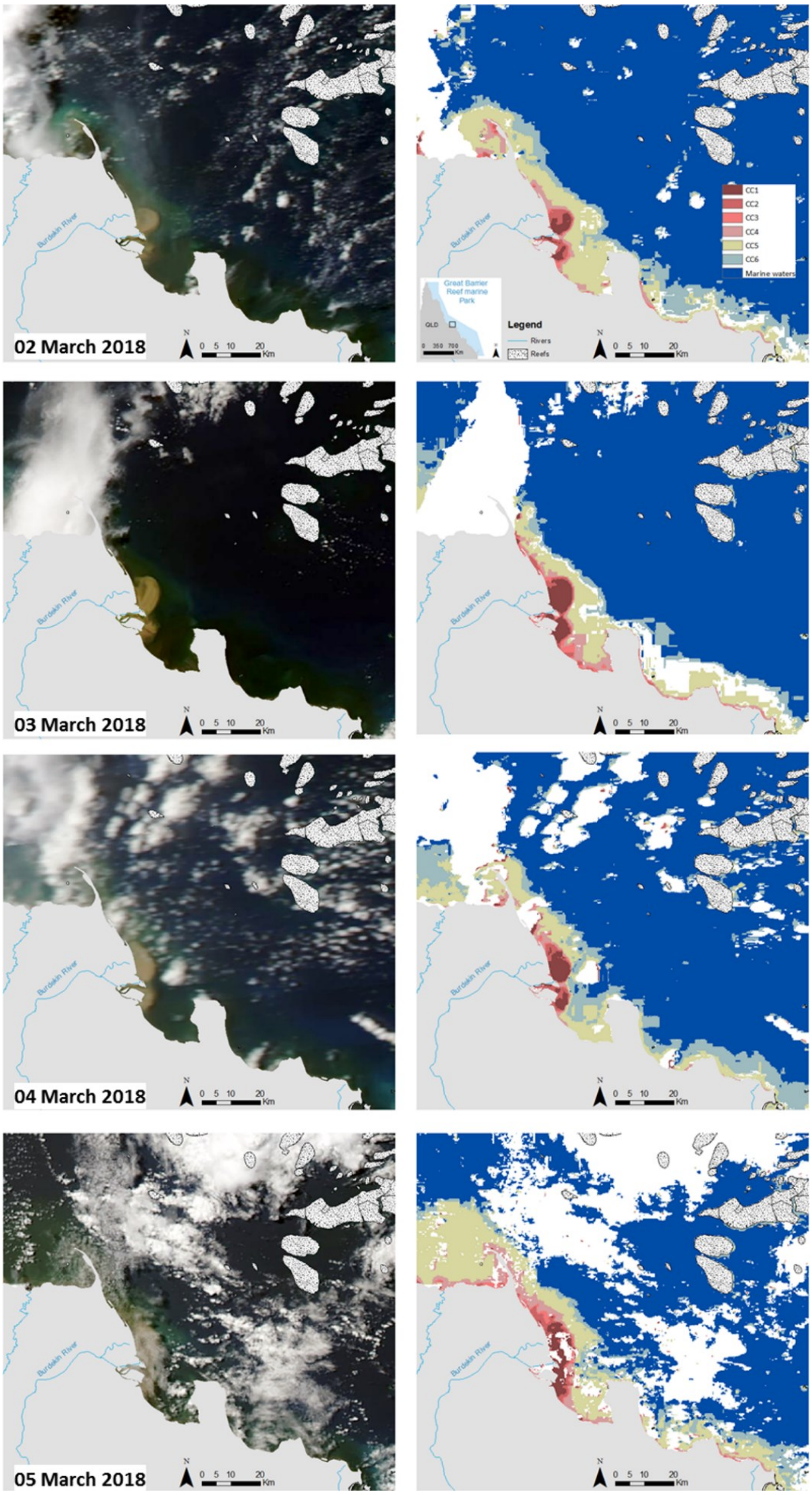


Figure 5-53: A collection of water type maps showing the evolution of the Burdekin River plumes from 2 to 5 March 2018: (A) MODIS-Aqua, (T) MODIS-Terra.

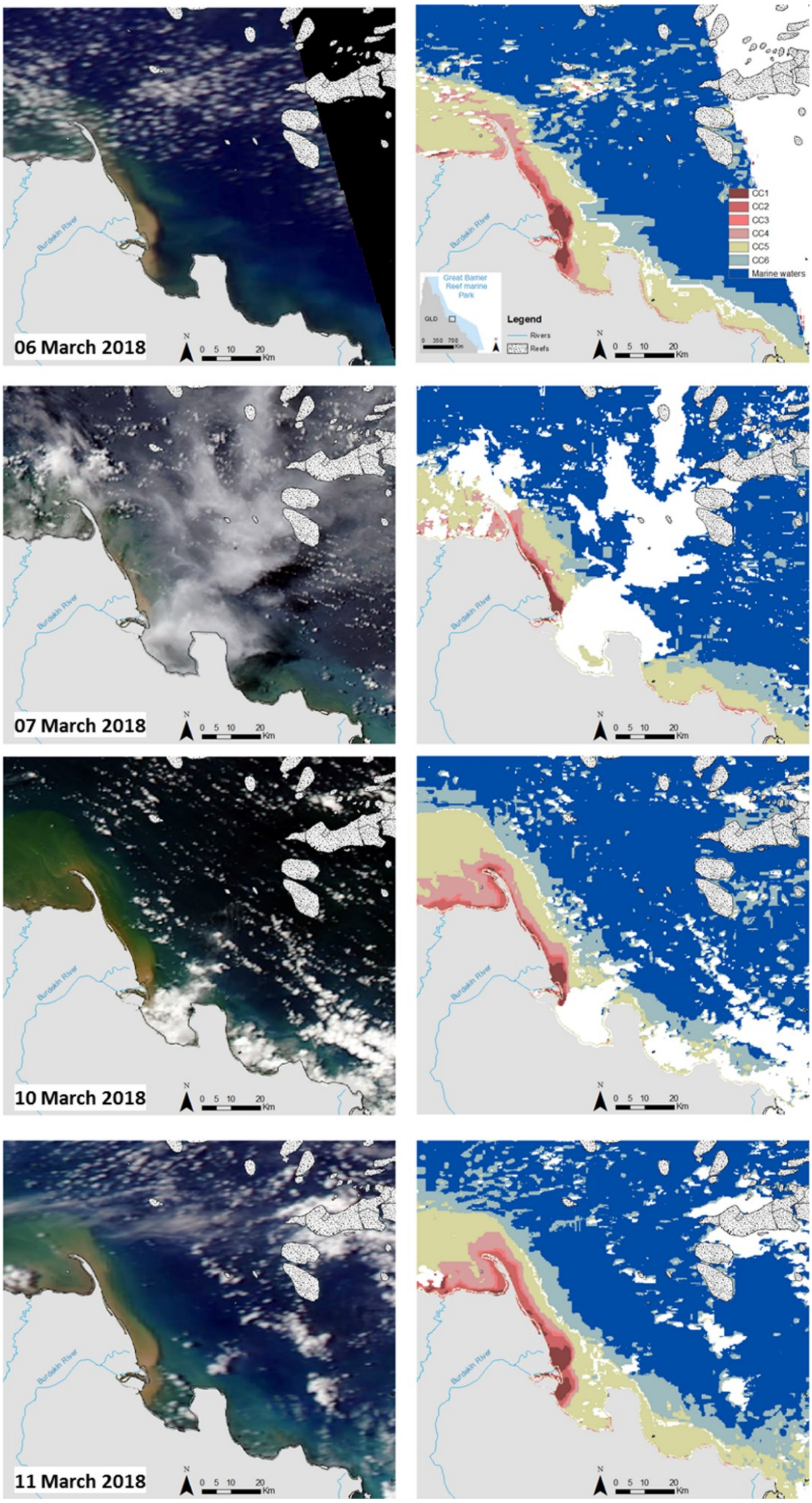


Figure 5-54: A collection of water type maps showing the evolution of the Burdekin River plumes from 6 to 11 March 2018: (A) MODIS-Aqua, (T) MODIS-Terra.

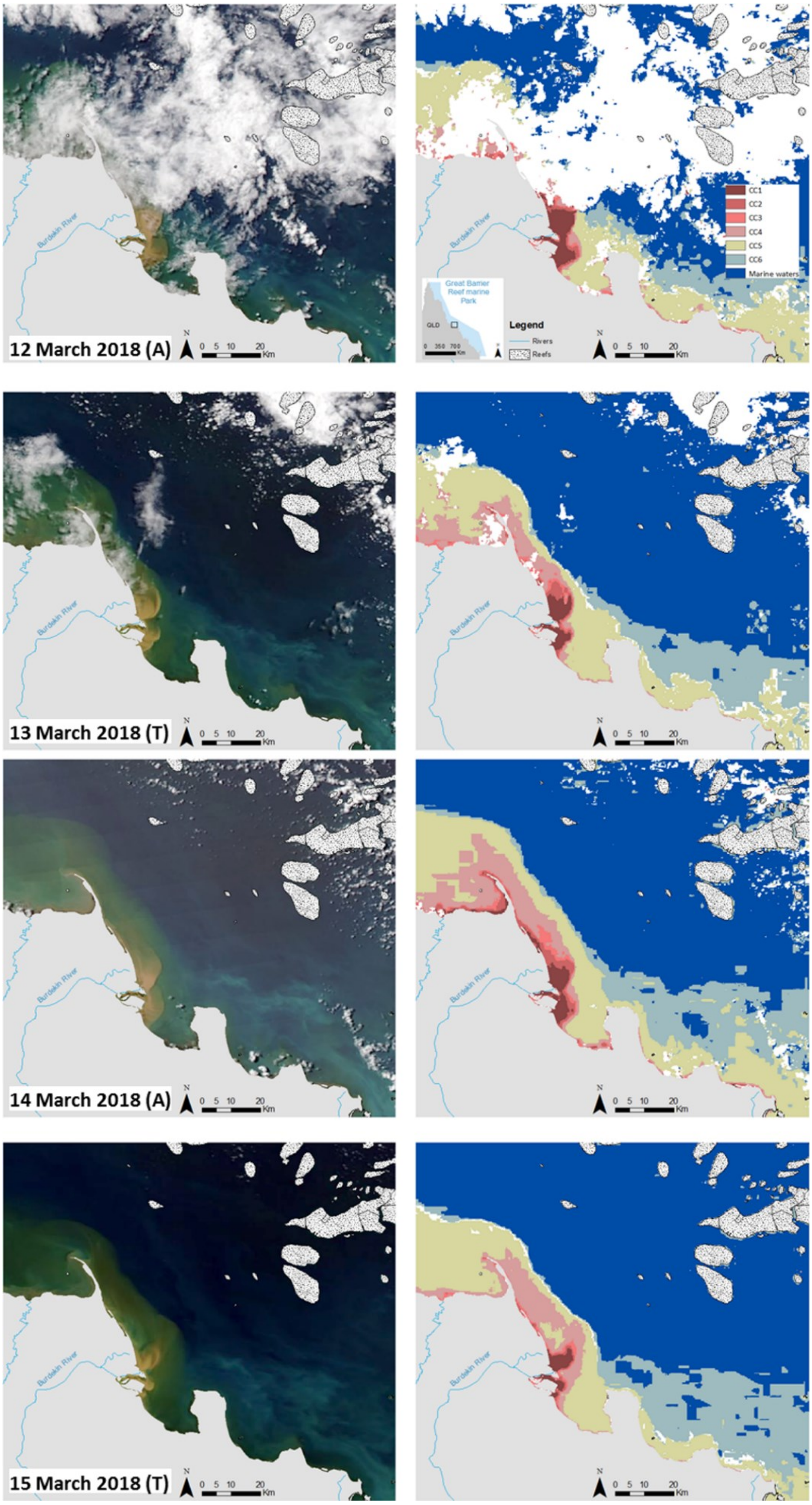


Figure 5-55: A collection of water type maps showing the evolution of the Burdekin River plumes from 12 to 15 March 2018: (A) MODIS-Aqua, (T) MODIS-Terra.

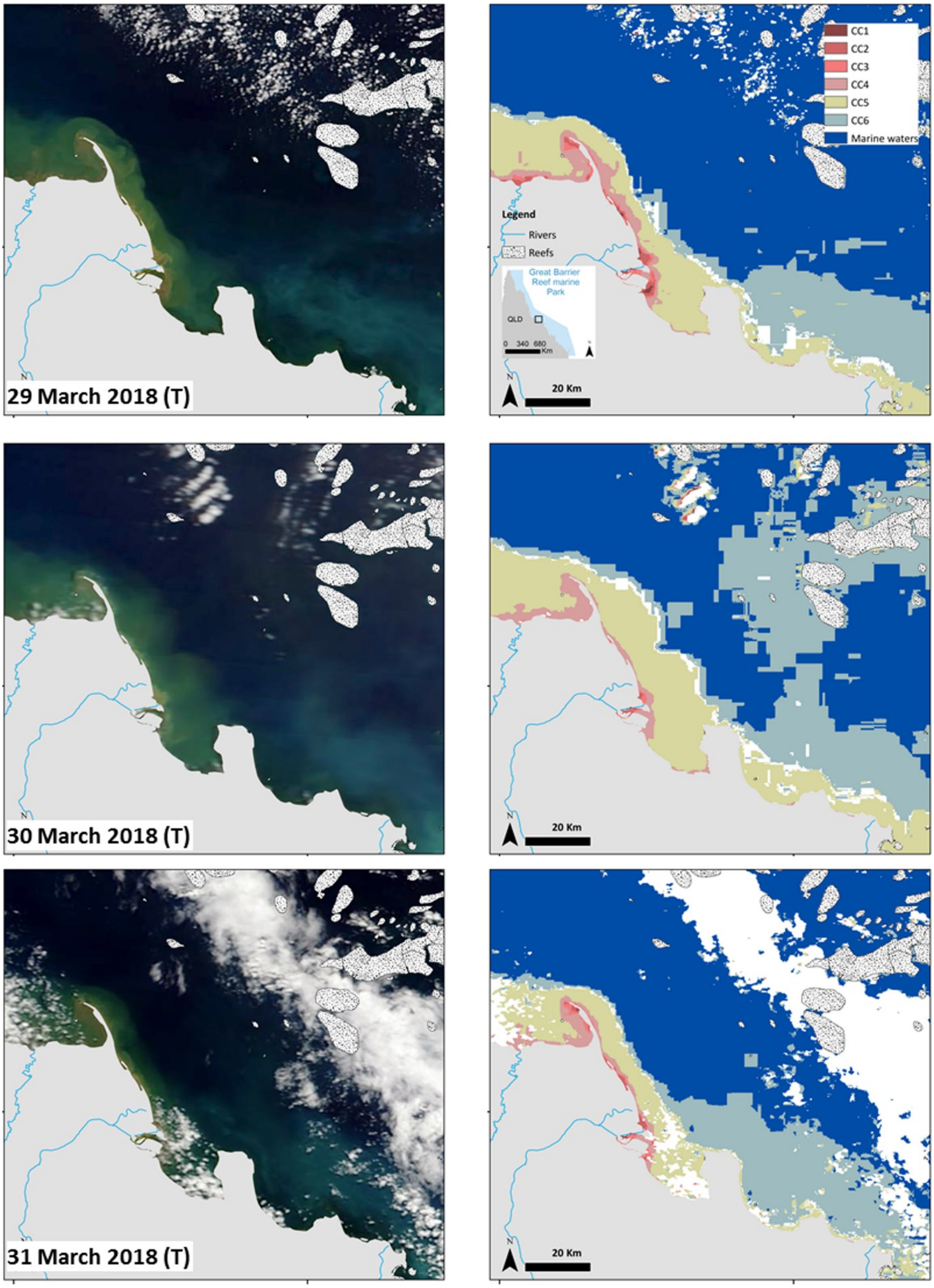


Figure 5-56: A collection of water type maps showing the evolution of the Burdekin River plumes from 29 to 31 March 2018: (A) MODIS-Aqua, (T) MODIS-Terra.

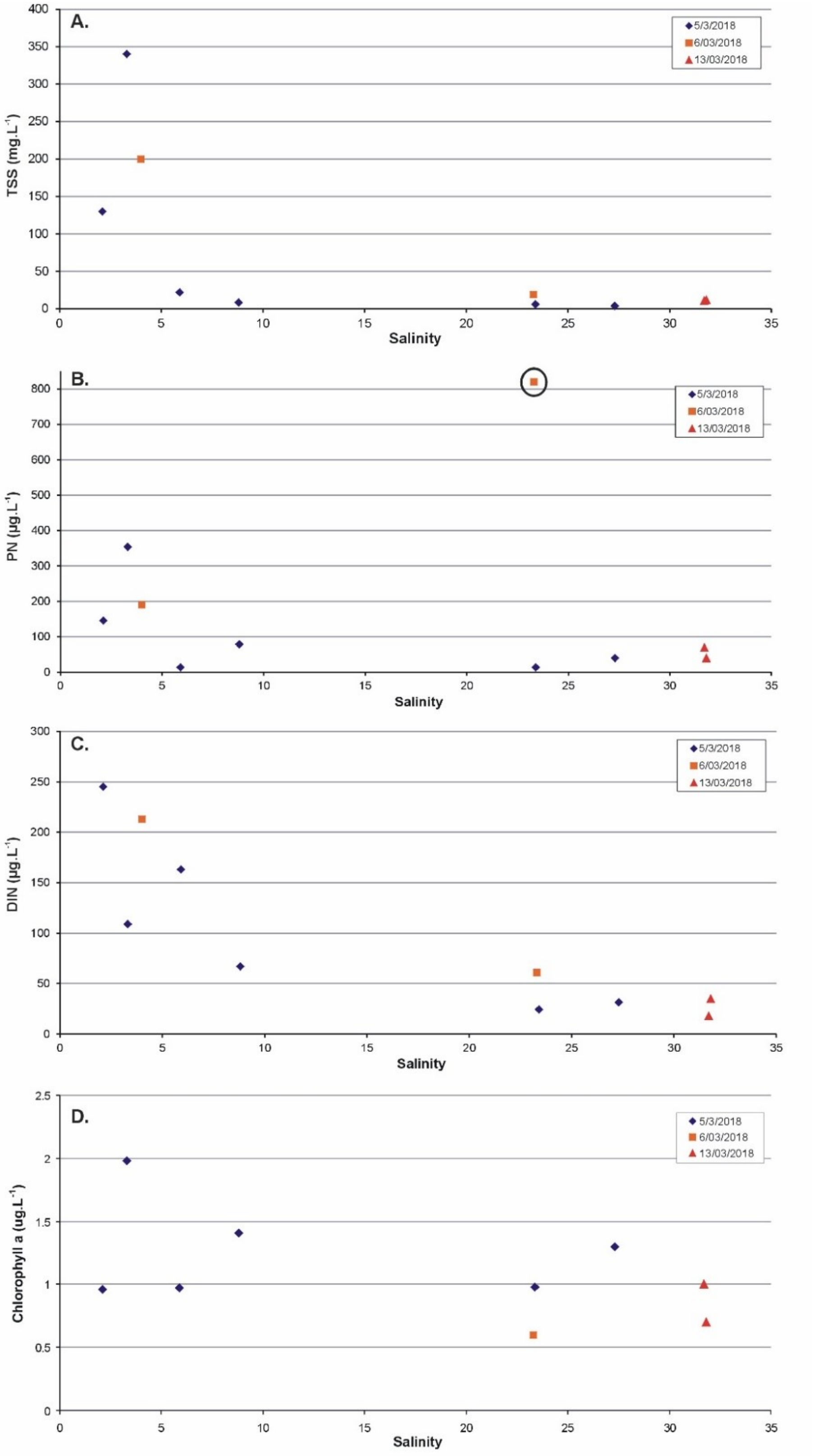
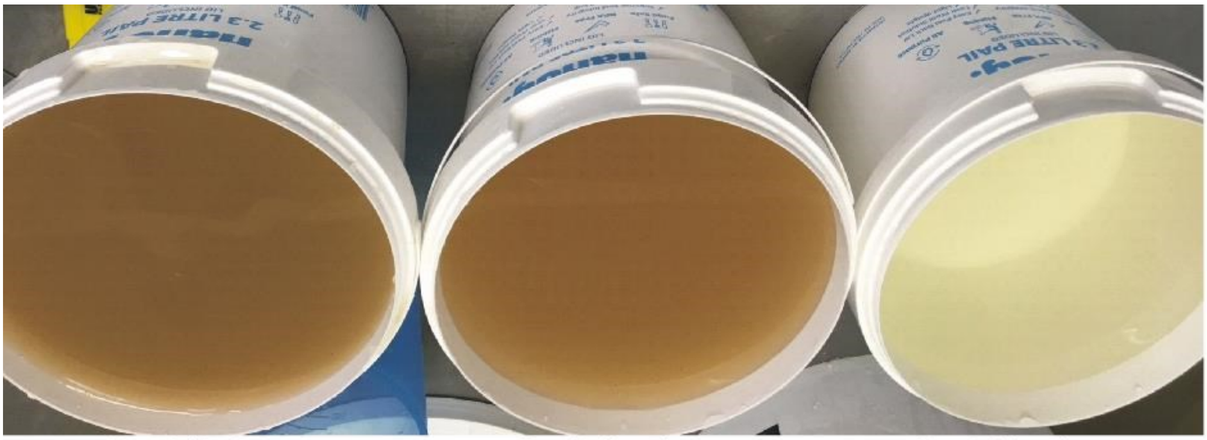


Figure 5-57: Water quality data from the Burdekin flood plume including total suspended solids (TSS: A), particulate nitrogen (PN: B), dissolved inorganic nitrogen (DIN: C) and chlorophyll *a* (D) highlighting the different days of sampling. Note the outlier in the PN data highlighted by a circle.



Burdekin River
Salinity = 0; TSS = 554 $mg.L^{-1}$

Burdekin plume
Salinity = 4; TSS = 200 $mg.L^{-1}$

Burdekin plume
Salinity = 23; TSS = 19 $mg.L^{-1}$

Burdekin plume
Salinity = 32; TSS = 12 $mg.L^{-1}$

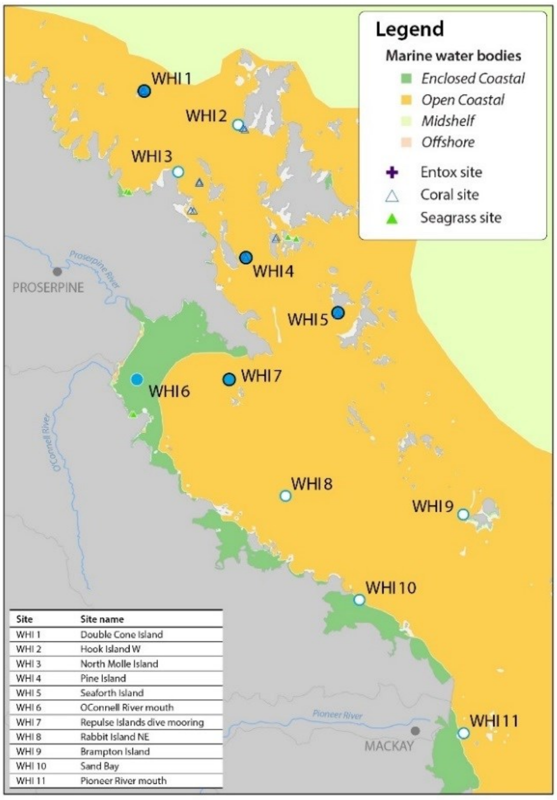
SediPump™ recovery
3 hours pumping

Figure 5-58: Photos showing changes in suspended sediment over the Burdekin estuarine mixing zone in March 2018. Top panel is samples from 6 March 2018 in Upstart Bay and bottom panel is the sample from Orchard Rocks off Magnetic Island on 13 March 2018 including the concentrated sediment using the SediPump™.

5.4 Mackay-Whitsunday region

The Mackay-Whitsunday region comprises four major river basins, the Proserpine, O'Connell, Pioneer and Plane Basins. The region is also potentially influenced by runoff from the Burdekin and Fitzroy Rivers during extreme events or through longer-term transport and mixing.

Eleven stations are sampled up to five times per year, with eight stations sampled during both the dry and wet season and only three during the wet season (Table 2-1). The sampling locations are located in a river mouth to open coastal water transect (Figure 5-59).



Site	Site name
WHI 1	Double Cone Island
WHI 2	Hook Island W
WHI 3	North Molle Island
WHI 4	Pine Island
WHI 5	Seaforth Island
WHI 6	OConnell River mouth
WHI 7	Repulse Islands dive mooring
WHI 8	Rabbit Island NE
WHI 9	Brampton Island
WHI 10	Sand Bay
WHI 11	Pioneer River mouth

Figure 5-59: Sampling sites in the Mackay Whitsunday focus area, shown with the water body boundaries.

Over the period 2007 to 2013, annual discharge from the O’Connell and Pioneer Rivers was above long-term median levels (Figure 5-60, Table E-1). Large floods (more than two times the long-term median) were recorded for the O’Connell River in 2011 and 2012, and the Pioneer River in 2008, 2010, 2011 and 2015 (Table E-1). In the 2016–17 water year, annual discharge for the region exceeded the long-term median, with flows almost twice the long-term median occurring the O’Connell and Pioneer Rivers. In the 2017–18 water year, however, flows were well below the long-term median (Figure 5-60).

The combined discharge and loads calculated for the 2017–18 water year from the Proserpine, O’Connell, Pioneer and Plane Basins were the second lowest since 2006–07 (the 2014–15 water year was the lowest). Over the 12-year period:

- discharge has varied from 730 GL (2014–15) to 17,400 GL (2010–11)
- TSS loads have ranged from 69 kt (2014–15) to 2500 kt (2010–11)
- DIN loads ranged from 190 t (2014–15) to 4500 t (2010–11)
- PN loads ranged from 280 t (2014–15) to 8600 t (2010–11).

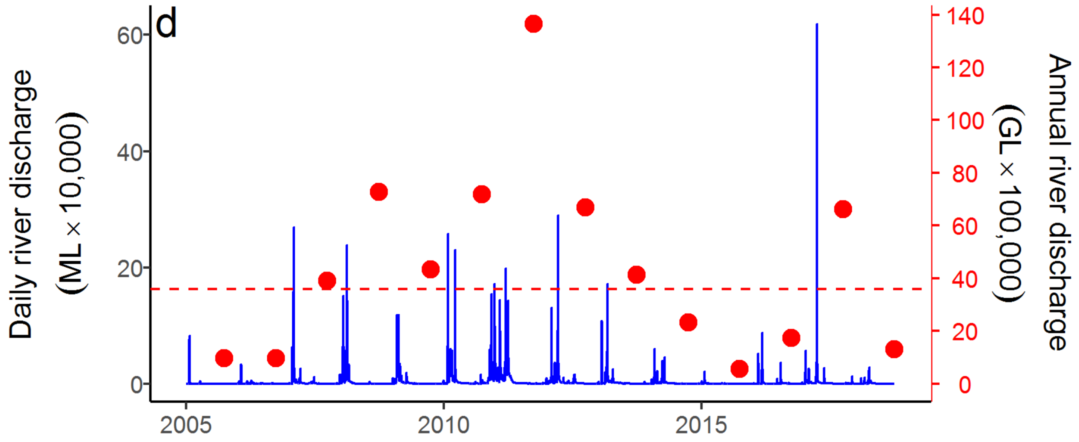


Figure 5-60: Combined discharge for the O'Connell (Stafford’s Crossing gauge) and Pioneer (Dumbleton TW gauge) Rivers. Daily (blue) and water year (October to September, red) discharge is shown. Red dashed line represents the long-term median of the combined annual discharges. Please note as this is the combined discharge, high flows in one river will not necessarily be visible in the graph.

The loading maps presented in Section 4 indicate the relative contribution of loads from each river to the marine NRM region. Figure 4-7 and Figure 4-11 show the estimated DIN and TSS contributions for the Mackay-Whitsunday region in 2017–18 and 2010–11. DIN loading in the Mackay-Whitsunday region was estimated to be almost all sourced from within the NRM region, with some minor influence of the Styx and Shoalwater basins. In contrast DIN loading was influenced by the Fitzroy River in the large event of 2010–11 (~26%) and contributed almost 65% of the TSS loading. In 2017–18, the Fitzroy River did not contribute to the Mackay-Whitsunday region river-derived DIN or TSS.

Figure 4-7 and Figure 4-11 also show that the Mackay-Whitsunday rivers can influence the Burdekin region. In 2017–18, the river-derived DIN loadings in the Mackay-Whitsunday region were around 25% each for Plane Creek, the Proserpine and O’Connell Rivers, with 20% from the Pioneer River. The O’Connell River had the highest contribution to the TSS loadings (38%) in the region, followed by the Pioneer River (25%) and Plane Creek (18%).

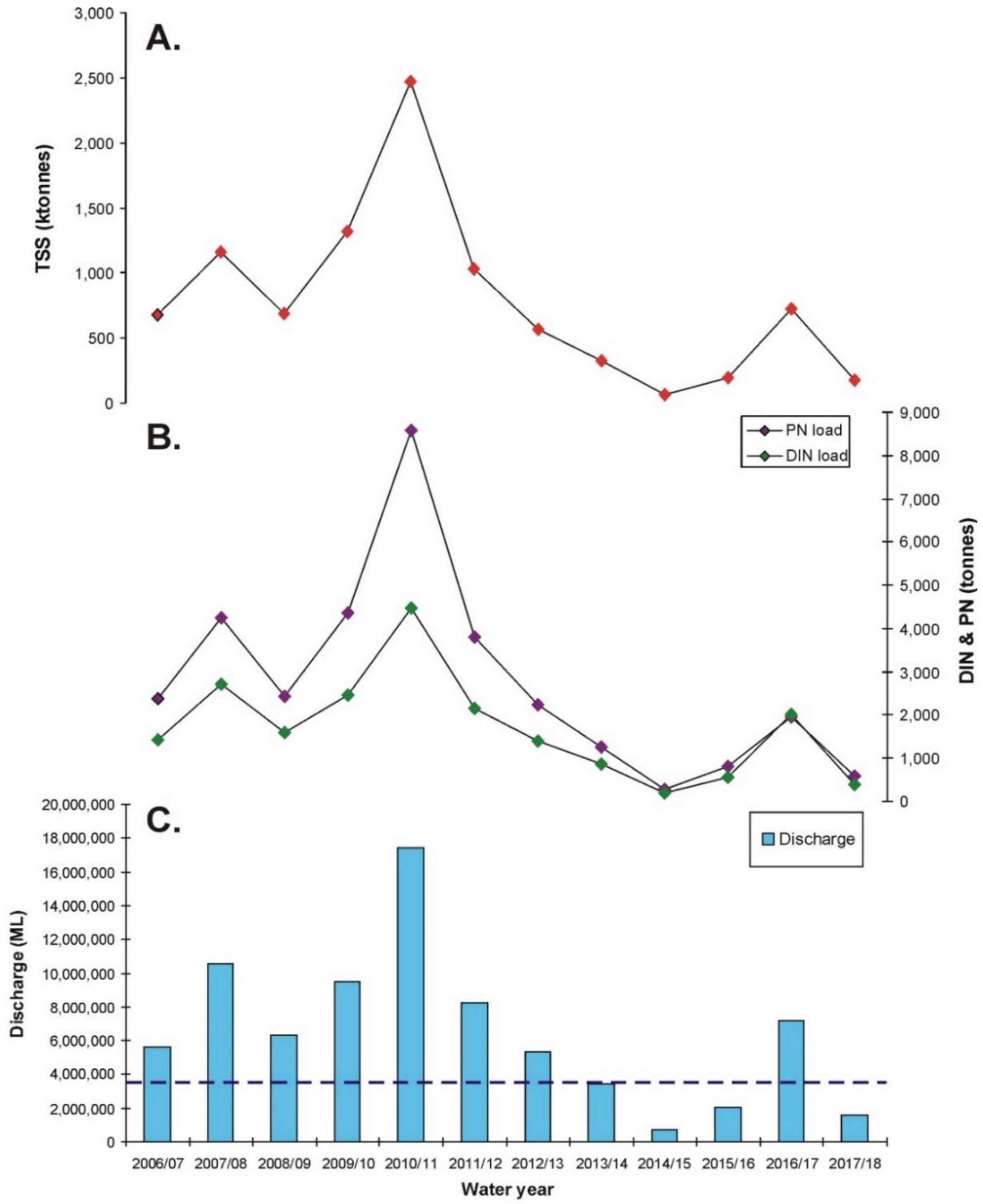


Figure 5-61: (A) TSS loads, (B) DIN and PN loads and (C) discharge for the Proserpine, O'Connell, Pioneer and Plane Basins from 2006–07 to 2017–18. The loads reported here are a combination of 'best estimates' for each basin based on 'up-scaled discharge data from gauging stations, monitoring data (O'Connell and Pioneer Rivers and Sandy Creek), the DIN model developed in Lewis et al. (2014) and annual mean concentrations and discharge from monitoring data or Source Catchments modelling data. Dotted line represents the long-term median for basin discharge.

Ambient water quality and the in-situ water quality index

When interpreting the long-term water quality trends in this region, it should be noted that the number of water sampling sites and frequency of sampling was increased during 2015. Some of these new sites were placed further inshore and they are therefore likely to be affected by primary and secondary plume-type waters.

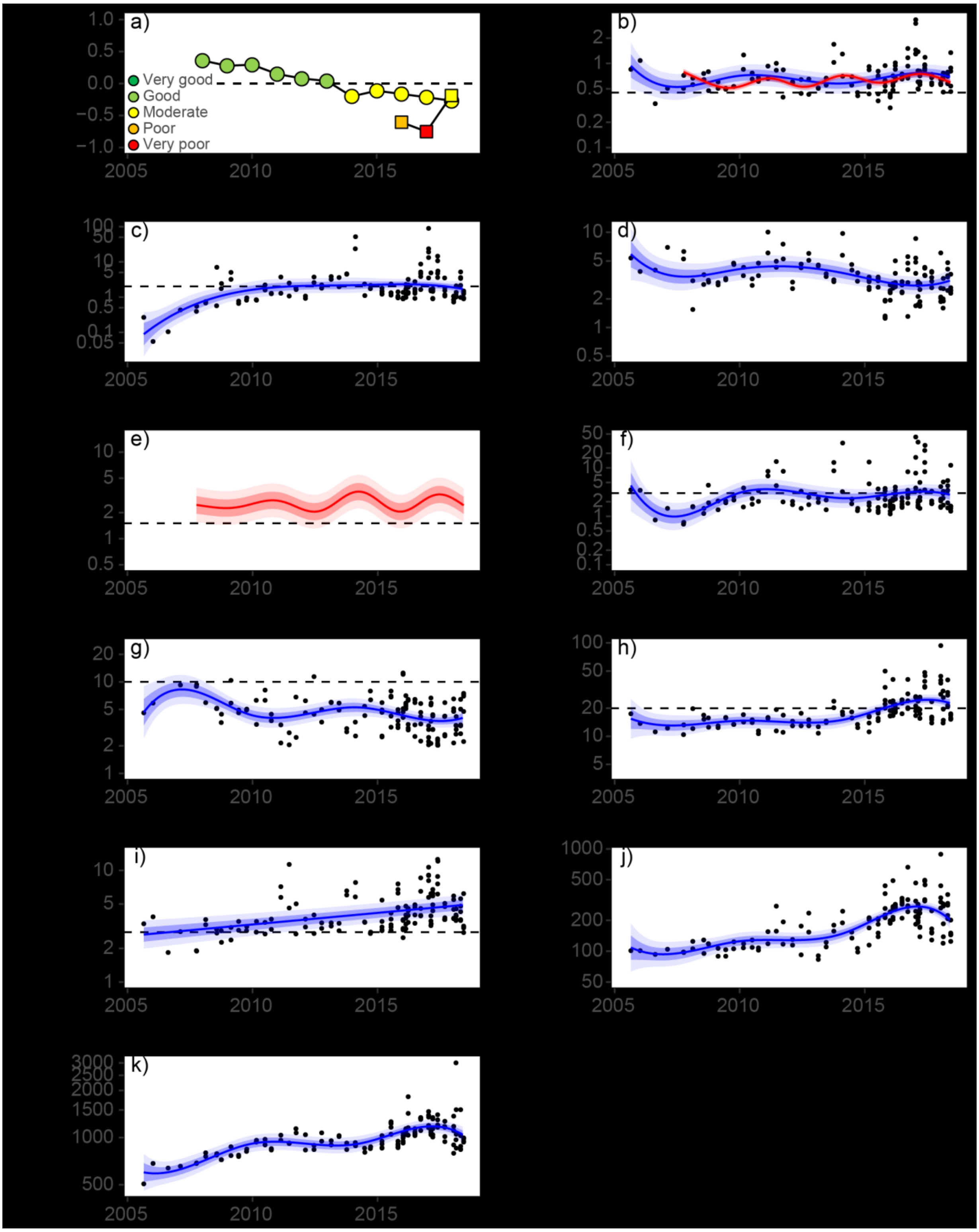


Figure 5-62: Temporal trends in water quality for the Mackay Whitsunday focus-region. a) WQ Index, b) chlorophyll *a* (Chl-*a*), c) nitrate/nitrite (NO_x), d) phosphate (PO_4), e) turbidity, f) total suspended solids (TSS), g) Secchi depth, h) particulate nitrogen (PN), i) particulate phosphorus (PP), j) particulate organic carbon (POC) and k) dissolved organic carbon (DOC). The long-term trend in the WQ Index is depicted with circles, while the annual condition (implemented with sampling changes in 2015) is depicted with squares in (a). Trends in manually sampled water quality variables are represented by blue lines with blue shaded areas defining 95% confidence intervals of those trends accounting for the effects of wind, waves and tides after applying x-z detrending. Trends of records from ECO FLNTUSB instruments are represented in red, individual records are not displayed (see Figure E-1). Dashed horizontal reference lines indicate annual guideline values.

Long-term trends in water quality variables measured during ambient periods (e.g., not during peak flood events) of the dry and wet seasons are presented in Figure 5-62. It is important to note that the trend analysis used removes variability associated with wind, waves and tides (see Methods).

Thus, individual data points have slightly different magnitudes compared to raw data. This analysis helps elucidate long-term and regional-scale trends in water quality by removing the effect of changes in local weather and tides.

Distinct long-term trends (since 2005) were observed in some water quality variables, while others showed little change over time (Figure 5-50). Mean concentrations of Chl-*a* and TSS have been relatively stable since 2009, with mean values of Chl-*a* exceeding the water quality GVs and mean TSS at GVs (Great Barrier Reef Marine Park Authority, 2010). Mean concentrations of PO_4 have slowly declined over time, while NO_x concentrations have been relatively stable since 2009 and are presently at the GV. Mean Secchi depth has declined since monitoring began (i.e. water clarity has become worse), and current values are not meeting the GV. Mean concentrations of PN and PP have increased since monitoring began and are presently exceeding the GVs. Mean concentrations of DOC and POC have increased dramatically since monitoring began, although both displayed a small decline during the 2017–18 monitoring year (Figure 5-50).

The WQ Index is now calculated using two different formulations to communicate the long-term trend in water quality (based on the pre-2015 sampling design) as well as an improved metric for annual condition (based on the post-2015 sampling design, which increased the power to detect changes in water quality). The Methods section and Appendix D-3 contain details of the calculations for both Index versions.

The long-term WQ Index has shown water quality to be ‘moderate’ relative to GVs for the last 5 years, and a long-term declining trend in water quality has been observed for the Mackay-Whitsunday region (Figure 5-62a). The annual condition WQ Index currently shows water quality to be ‘moderate’ and highly variable for the last three years, which is likely due to the higher-than-average discharge during the 2016–17 monitoring year. This version of the Index scores water quality parameters against GVs relevant to the season when samples are collected (wet vs dry GVs) and includes additional inshore sites to better characterise areas affected by river discharge.

It is important to note that the two versions of the WQ Index are designed to answer separate questions and therefore differences in scores between the versions are expected.

Event water quality

No event sampling was conducted in the Mackay-Whitsunday focus area during 2017–18.

6. Discussion

6.1 Long-term changes in water quality

Previous work has demonstrated that to detect trends in water quality and distinguish between long-term changes and natural variability, decadal time scales are required (Henson et al., 2016). After more than a decade of continuous sampling, there is evidence that some focus regions (e.g. Barron Daintree, Russell-Mulgrave, and Mackay Whitsunday) have experienced long-term declines in water quality, while other regions (e.g. Tully and Burdekin) do not appear to have experienced long-term decline or improvement in relation to water quality GVs.

In addition, year-to-year and seasonal differences in water quality are a key feature of this monitoring dataset. This is an important point, as it demonstrates that while overall multi-year water quality may be considered 'good' relative to GVs, inshore ecological communities often experience short-term periods of 'very poor' water quality in relation to episodic events such as river discharge (McKenzie et al., 2017; Petus et al., 2014a, b, 2016; Thompson et al., 2017). Ecological community response to such disturbances is confounded by other factors such as organism sensitivity and resilience; this complexity results in difficulty in directly linking river inputs to ecological community change.

The results for 2017–18 followed typical patterns of water quality in the inshore Reef, which generally show minor gradients away from river mouths, with elevated levels of most parameters closest to the coast. These gradients are influenced over short time periods by flood events and sediment resuspension, and over longer time periods by complex interactions between physical and biogeochemical processes (Schaffelke et al., 2017). Such dynamics are a part of the natural Reef ecosystem, albeit under lower levels of input of river-derived material than at present (Kroon et al., 2012).

A statistical analysis of 5 years of MMP water quality data showed significant variability between years and locations (Schaffelke et al., 2012). Most variation was explained by temporal factors (e.g. seasons, years, and river flow), highlighting the variable nature of the ecosystem, with regional aspects (such as latitude, land use on adjacent catchments, proximity to rivers, and resuspension) explaining a smaller amount of the variation.

Our analyses of long-term monitoring data from coastal waters of the Reef suggest that some variables showed no long-term net increases or decreases in concentration, whereas other variables have increased in concentration over time.

In most focus regions, TSS and Chl-*a* concentrations have not shown major long-term changes since 2005 and are generally close to GVs. Concentrations of NO_x have shown variability over time but are currently at GVs in most focus regions. Concentrations of PP have increased in most focus regions since 2005 and are now generally exceeding GVs. Secchi depths have declined in most focus regions since 2005 and are currently not meeting GVs. The most dramatic long-term changes have been for DOC and POC concentrations, which have increased substantially in most focus regions since 2005.

Increases in DOC over time are the result of many complex biotic and abiotic processes that occur in the coastal ocean. Our results suggest that the inputs of DOC and/or the transformation rates of DOC have changed since 2005. Most of the DOC pool in the Reef lagoon is derived from phytoplankton production, and therefore increases in plankton community production would result in elevated DOC concentrations. Plankton communities have been shown to increase their DOC production in response to environmental stress (e.g. changing light, temperature, and nutrient conditions) and changes in the plankton community structure (e.g. Church et al., 2002; Thornton, 2014).

Although productivity experiments have been episodically conducted in the Reef lagoon, no long-term monitoring of productivity has occurred to test this hypothesis. Increases in the coastal DOC pool could be related to catchment loading from changing land use (and time-lags associated with this, see Darnell et al., 2012), although there are no monitoring data available on the DOC loads from rivers since 2005.

Measured increases in DOC are nonetheless concerning as they could impact benthic ecological communities. DOC constitutes the major carbon source for heterotrophic microbial growth in marine pelagic systems and increases in DOC have previously been shown to promote microbial activity and coral diseases (Kline et al., 2006; Kuntz et al., 2005).

Without further information on the form of the DOC (i.e. what it is made of), the source of the DOC (i.e. where it is generated) and the transformation rates of the DOC (i.e. how fast it is produced and consumed), it is difficult to understand these changes and their ramifications for ecological communities. Future monitoring efforts of the Reef lagoon should include some process-based monitoring (e.g. rates of productivity or nutrient transformation) to better determine the sources of changes in water quality and the ability of land use practices to affect coastal water quality.

These complications highlight the importance of maintaining and further developing a range of monitoring, processing and modelling tools, supporting the integrated design of the MMP Inshore Water Quality Program. The results examining flood plume and ambient (non-flood plume) conditions coupled with other research programs within the Reef lagoon provide important insights on water quality in the Reef. For example, remote sensing research highlights the spatial and temporal influence of river plumes during the wet season within the Reef lagoon and helps to identify where coastal ecosystems may be at risk from exposure to elevated levels of pollutants (Devlin et al., 2015; Petus et al., 2014a, b, 2016) or chronic reduced light levels (Petus et al., in press).

In contrast, the ambient water quality monitoring during relatively calm weather shows that the influence of previous plumes is not evident (i.e. calm weather monitoring does not show correlations with the previous wet season loads) (Fabricius et al., 2016). Furthermore, recent studies highlight the influence of river discharge and associated constituents on water clarity in the inshore and mid-shelf Reef waters in the months following flood events using satellite photic depth data (Fabricius et al., 2014, 2016) or a combination of *in-situ* and satellite-derived data (Petus et al., in press).

We can greatly improve our ability to predict and manage the linkages between land management and marine water quality by addressing several key knowledge needs. Further research is required on key biogeochemical processes, including the production and consumption rates of carbon, nitrogen and phosphorus species.

One recent study has shown that the Reef lagoon organic nutrient pools contain approximately 94% and 75% of the bioavailable nitrogen and phosphorus, respectively, which deliver enough nutrients to sustain phytoplankton productivity in the Reef (Lønborg et al., 2017). Other recent work has highlighted that particulate nitrogen derived from river discharge is more bioavailable than previously thought and has potential to impact Reef water quality (Waterhouse et al., 2018); further work on the bioavailability of particulate nutrients is needed to increase the ecological relevance of current water quality guideline values.

This work suggests that NO_x concentration may not be a sufficiently sensitive indicator for nitrogen availability in the Reef. Addressing these knowledge needs will support policy development and provide greater confidence that management action has delivered improvement in coastal water quality.

6.2 Water quality and effects on marine communities

‘Water quality’ comprises the sediment, nutrient and contaminant concentrations present in a water body, and has an effect on certain physico-chemical properties such as water clarity (light attenuation). Aspects of water quality, such as nutrient concentrations, also influence key ecological processes including rates of primary productivity (especially in phytoplankton) and nutrient cycling. In addition to anthropogenic stressors, the Reef lagoon is influenced by many natural factors that affect suspended nutrient and sediment concentrations including: the upwelling of deeper Coral Sea waters onto the continental shelf (Benthuysen et al., 2016; Furnas and Mitchell 1996,), resuspension of bottom sediments by wind and waves (Orpin et al., 1999, extreme weather conditions such as cyclones (Dufois et al., 2017) and nitrogen fixation by cyanobacteria (Messer et al., 2017).

Overall, land-derived run-off is considered to be the largest source of ‘new’ nutrients to the inshore Reef (Bartley et al., 2017; Furnas et al., 2011). Water quality parameters in the Reef vary along cross-shelf and latitudinal gradients, with inshore reefs experiencing year-round elevated suspended sediment concentrations and (with the exception of the Cape York region) elevated Chl-*a* concentrations compared to offshore reefs (Furnas et al., 2005; Schaffelke et al., 2012). Reefs in the central and southern regions also experience elevated concentrations of dissolved inorganic nutrients compared to northern reefs (Furnas et al., 2005), although nutrient concentrations can show considerable year-to-year and seasonal variability (Schaffelke et al., 2012). Water quality variables in the inshore Reef are dynamic and reflect differences in inputs, transport, and many simultaneous biological and chemical processes.

Thirty-five major rivers drain into the Reef lagoon, and the average annual export of sediments, nutrients, and herbicides from these catchments to the coastal zone has increased more than 5-fold since European settlement (Kroon et al., 2012). River loading has large spatial and temporal variation, with the contribution of individual rivers differing substantially along the coast (Wolff et al., 2018) and during periods of high rainfall and monsoonal flood events (Devlin and Schaffelke 2009; Schroeder et al., 2012).

Local environmental conditions, such as water quality, influence the benthic communities including seagrasses and corals found in coastal and inshore waters of the Reef. Collectively, inshore coral reefs differ markedly from those found in clearer, offshore waters (e.g. Done, 1982; Wismer et al., 2009). The premise underpinning the Reef 2050 Plan is that loads of nutrients, sediments and pesticides delivered by rivers suppress ecological resilience. A review of the effects of water quality on seagrass and coral communities can be found in the MMP reports specific to ecological monitoring (McKenzie et al., 2017; Thompson et al., 2017).

The *2017 Scientific Consensus Statement: A synthesis of the science of land-based water quality impacts on the Great Barrier Re*ef concluded that: ‘Key Great Barrier Reef ecosystems continue to be in poor condition. This is largely due to the collective impact of land runoff associated with past and ongoing catchment development, coastal development activities, extreme weather events and climate change impacts such as the 2016 and 2017 coral bleaching events...’. Furthermore, ‘the decline of marine water quality associated with land-based run-off from the adjacent catchments is a major cause of the current poor state of many of the coastal and marine ecosystems of the Great Barrier Reef. Water quality improvement has an important role in ecosystem resilience’ (Waterhouse et al., 2017c).

6.3 Management response

Concern about the effects of land-based run-off first triggered the Australian and Queensland governments to formulate the Reef Water Quality Protection Plan for catchments adjacent to the Reef in 2003 (Anon, 2003). In 2015, the Australian and Queensland governments released the *Reef 2050 Long-Term Sustainability Plan* (Reef 2050 Plan) (Commonwealth of Australia, 2015). The Reef 2050 Plan identifies seven themes (ecosystem health, biodiversity, heritage, water quality, community benefits, economic benefits and governance) for managing the Great Barrier Reef World Heritage Area. The *Reef 2050 Water Quality Improvement Plan 2017-2022* (Reef 2050 WQIP) (Queensland and Australian government, 2018) delivers the water quality theme within the Reef 2050 Plan. The plan is a joint commitment of the Australian and Queensland governments and identifies actions that will help minimise the risk to the Reef from a decline in the quality of water entering the Reef lagoon from its adjacent catchments. It builds on three previous iterations of the Reef Water Quality Protection Plan (2003, 2009 and 2013). The long-term (2050) outcome for the plan is that '*Good water quality sustains the outstanding universal value of the Great Barrier Reef, builds resilience, improves ecosystem health and benefits communities*'.

The actions in the Reef 2050 WQIP support the implementation of improved land management practices in Reef catchments that are expected to result in measurable improvements in the downstream water quality of creeks and rivers. These actions should, with time, also lead to improved water quality in the inshore Reef, although system-scale changes may occur on decadal time-scales (Lefcheck et al., 2018). Recent assessments question whether these actions will be sufficient to ensure the resilience of the Reef ecosystems into the future (Bartley et al., 2014; Kroon et al., 2014; Kroon et al., 2016) and suggest that additional options involving system restoration may be required (Waterhouse et al., 2017c).

The *Paddock to Reef Integrated Monitoring, Modelling and Reporting Program* (Paddock to Reef program) serves as a framework to evaluate and report progress on Reef 2050 WQIP targets. The MMP is an integral part of this overarching program, and provides physico-chemical and ecological data to measure the condition and trend of Reef inshore water quality and ecosystems. The Paddock to Reef program was reviewed and updated in 2018 with the design extended to 2022. The revised scope of the program aligns with the expanded scope of the Reef 2050 WQIP and is complementary to and supportive of the Reef 2050 Plan, regional water quality improvement plans and the associated monitoring and reporting programs i.e. the Reef 2050 Integrated Monitoring and Reporting Program (RIMReP) and Regional Report Cards.

Sustained improvements in the marine water quality of the inshore Reef have not yet been observed in the MMP water quality program. The complexity of the relationship between land-based runoff and water quality, the influence of interannual variability, the progress of changed management practice adoption and the expected slow response timeframes between land-based changes and marine water quality all contribute to this lack of observed change.

Continued water quality monitoring and modelling of the Reef lagoon will be fundamental to detecting and tracking changes in response to management actions and interventions. It is still desirable to resume monitoring in the Fitzroy region and commence Burnett-Mary region monitoring to provide greater data coverage across the Reef lagoon

7. Conclusions

In this report, spatial and temporal trends of water quality indicators in the Reef have been provided for four focus areas. Changes to the MMP sampling design post-2015 (more sites, more sampling during the west season and new site locations further inshore) allow improved characterisation of wet season conditions and water quality in the inshore Reef. However, these changes make direct comparisons between current and historical (pre-2015) monitoring results difficult for all focus regions except the Barron Daintree (where sampling was not changed).

Results in focus areas showed variable responses to the relatively average river discharges and end-of-catchment pollutant loads in 2017–18. The river flow across all basins of the Reef during the 2017–18 wet season was close to the long-term median. A number of the Cape York, Wet Tropics and Burdekin region rivers had annual discharge up to 1.5 times above their long-term median flow. These influences are reflected in regional variability in the wet season conditions. More unusually, the Burnett-Mary region rivers had significant discharges in October 2017, which were up to three times the long-term median. These events were outside the assessment period for the wet season mapping products.

Monitoring showed that long-term water quality has:

- declined in parts of the Wet Tropics region but remains ‘good’ overall
- remained stable in the Burdekin region and is currently considered ‘good’
- declined for the Mackay-Whitsunday region over time and is currently considered ‘moderate’.

The annual condition version of the WQ Index can now be calculated to communicate inshore water quality conditions each year. This annual Index is more responsive to the effect of local pressures such as river discharge on water quality. This Index showed that inshore water quality was:

- generally ‘poor’ this year in the Wet Tropics and Burdekin regions, which was likely related to river discharge above or close to the long-term median in these regions
- ‘moderate’ in the Mackay-Whitsunday region having increased from a ‘very poor’ condition in 2016–17, which was likely related to this year’s drier-than-average wet season following last year’s wetter-than-average wet season.

Overall trends in some water quality variables have been detected in most regions, including:

- increasing concentrations of PP, DOC and POC
- mean concentrations of Chl-*a*, TSS and NO_x close to GVs
- declining Secchi depth (i.e. water clarity is decreasing) across the inshore Reef, which is not meeting water quality GVs.

The main findings for each focus region are highlighted below.

7.1 Cape York

As this was only the second year of sampling in the Cape York region under the MMP, no long-term trends could be evaluated. Samples from the Endeavour Basin, Normanby Basin, Pascoe River and Stewart River sub-regions were collected between November 2017 and June 2018.

During the 2017–18 wet season, discharge from the Cape York sub-regions was slightly above the long-term median discharge. Peak discharge from flood events was generally below average for each sub-region; however, regular rainfall and freshwater flooding impacted water quality at sites close to the river mouths on most wet season sampling dates.

- TSS concentrations were highest in the enclosed coastal zone for all subregions. Secchi depth increased with distance from river mouths both under ambient and event sampling regimes.
- For the Normanby transect, clear reductions were observed in NH_3, DON, DOP, PN, and PP concentrations over distance from the river mouths, also reflecting the freshwater influence in enclosed coastal waters.
- Cape York ambient TSS concentrations ranged from 1 to 32 mg L^{-1} (mean 4.3 mg L^{-1}). Ambient Secchi depth ranged from 0.5 to 17.3 m, with a mean of 5.8 m. The lowest mean Secchi depth was along the Normanby River transect (4.5 m) and the highest at the Annan-Endeavour River (8.5 m).
- Ambient Cape York Chl-*a* concentrations ranged from <0.2 to 2.1 µg L^{-1}, with a mean of 0.5 µg L^{-1}. The maximum concentration was detected along the Normanby transect in November 2017.
- There were numerous exceedances of the draft Eastern Cape York Water Quality Guidelines:
  - In enclosed coastal waters, PO_4 exceeded the annual guidelines in all subregions
  - In open coastal waters, NH_3 exceeded the annual guidelines and mean Secchi depth was <10 m for all sub-regions
  - Wet season TSS, NO_x and PO_4 concentrations exceeded the wet season guidelines for all regions. In the mid-shelf zone, TSS, TDN, NH_3, NO_x and PO_4 exceeded the annual guidelines for most regions. Exceedances of annual guidelines are likely to be at least partially due to the majority of samples being collected during the wet season.

There were no exceedances in the offshore water body.

Wet season and event water quality

- The 2017–18 wet season was characterised by below average river discharges for the first quarter of the wet season (until early February–week 9), then most weeks were characterised by above average weekly river discharges except for the 9 to 22 February (weeks 11–12) and 6 to 30 April periods (weeks 19 to 22).

- The largest contributions to the DIN and TSS loadings in 2017–18 were from the Normanby River (33% and 49%, respectively). The Pascoe River contributed ~20% to the regional DIN loading, and the Pascoe and Endeavour Rivers contributed ~12% each to the regional TSS loading.

- A maximum TSS of 370 mg L^{-1} was measured near the mouth of the Endeavour River during the first event of the wet season in January 2018. In contrast, the maximum Pascoe River event TSS concentration was 31 mg L^{-1} near the mouth of the Pascoe River.

- Most of the 2017–18 Annan-Endeavour flood plumes followed the coast and flowed north. However, on at least one occasion (31 January 2018) MODIS satellite images showed plume waters reaching mid-shelf reefs.

- Cumulative exposure mapping based on eReefs hydrodynamic output showed that Normanby River discharge heavily affected enclosed coastal waters in Princess Charlotte Bay, and also affected open coastal, mid-shelf, and even some offshore waters (for brief periods).

- During a March 2018 flood event, Annan-Endeavour plume water inundated corals and seagrass meadows at Draper Patch, 3 km southeast of the Annan River mouth, with TSS concentrations as high as 54 mg L^{-1}.
- Nutrient concentrations in event samples were highly elevated above background concentrations. During the January 2018 Annan-Endeavour event, PN and PP near the Endeavour River mouth were approximately 50 and 90 times greater than ambient concentrations. NO_x was approximately 18 times higher than ambient concentrations, and DON and NH_3 were over 1.5 times that of ambient concentrations. PO_4 and DOP did not change.
- Chl-*a* concentrations generally increased with declining TSS over the salinity gradient. This was most evident in the Pascoe transect during event samples, where Chl-*a* concentrations increased above a salinity of 15 PSU when TSS <10 mg L^{-1}.
- The mean seasonal TSS concentrations measured across the primary and secondary water types exceeded the wet season TSS GVs.
- The mean seasonal Chl-*a* and PP concentrations in the primary water type were just above their respective GVs.
- PN concentration exceeded the wet season PN GVs by 1.5 times in the primary water type.
- In 2017–18, the Cape York region was most affected by the lowest exposure category (categories I and II), in agreement with long-term trends. Approximately 25% of the total area of the Cape York region was exposed to a potential risk. This area was smaller than the long-term area. Only 0.1% of the Cape York region was exposed to the higher risk exposure category III and no area was exposed to the risk exposure category IV, which is slightly smaller than long-term exposure areas.

7.2 Wet Tropics

Ambient water quality

- Several water quality parameters did not meet GVs during the 2017–18 monitoring year. Mean concentrations of PP and Secchi depth did not meet GVs in the Barron Daintree and Tully regions. Mean concentrations of PN, PP, and Secchi depth did not meet GVs in the Russell-Mulgrave region.
- Several water quality parameters were at GVs in the 2017–18 monitoring year. Concentrations of Chl-*a* and NO_x have been relatively stable over time and mean values are currently at GVs for the Barron Daintree, Russell-Mulgrave, and Tully regions. Concentrations of TSS have been relatively stable over time and mean values are currently at GVs for the Barron Daintree and Tully regions.
- Dramatic increases in DOC concentrations have occurred since 2005 in the Barron Daintree, Russell-Mulgrave, and Tully regions. Increases in POC concentrations have also been detected in the Russell-Mulgrave region.
- Results from the long-term version of the WQ Index showed that water quality has declined since 2005 in the Barron Daintree and Russell-Mulgrave regions, but is still in ‘good’ condition. Water quality has not declined or improved in the long-term for the Tully region, with conditions presently rated ‘moderate’. These results indicate that Wet Tropics water quality has slowly declined since 2005, which is unrelated to the size of the wet season in a particular year.

- Results from the annual condition version of the WQ Index showed that water quality was 'moderate' in the Barron Daintree region for the 2017–18 monitoring year. Water quality was 'poor' in the Russell-Mulgrave and Tully regions. These results indicate that Wet Tropics water quality has been generally 'poor' for the last two years as a result of some large wet season discharge events in the sub-regions.

Wet season and event water quality

- The 2017–18 discharge from the Wet Tropics region was just above the long-term median, although major flooding developed in the Herbert, Tully and Russell-Mulgrave basins. Plume exposure over the 2017–18 wet season was generally consistent with a below average to average season. The Wet Tropics region had two major flow events in March and two moderate level flow events in January and February.
- Cumulative exposure mapping based on the eReefs hydrodynamic model output showed that enclosed coastal waters were heavily affected by river discharge from the Tully and Russell-Mulgrave Rivers. River discharge was mainly transported in a northerly direction along the coast, with measurable discharge reaching >200 km north from the Russell-Mulgrave River mouth. Some discharge from the Tully and Russell-Mulgrave Rivers was also transported in a southerly direction, although plume extent was not as large as northerly-directed plumes. Open coastal and mid-shelf waters were also affected by river discharge. Spatial extent and exposure from Barron River discharge were much lower than other Wet Tropics rivers.
- An increase in water quality concentrations was observed following these flow events. The maximum TSS surface concentrations and minimum Secchi depth were measured on 13 March 2018(during week 15). Using only sites with a colour class category (i.e. no cloud), the mean weekly TSS concentrations reached 19.0 mg L^{-1} (week 9: 26 January–1 February) and 14.1 mg L^{-1} (week 15: 9–15 March) in colour class 2. The mean weekly Chl-*a* reached 2.9 µg $^{L-1}$ during week 7 (12–18 January) in colour class 1 and 1.3 µg L^{-1} during week 15 (9–15 March) in colour class 2. The lower mean weekly Secchi depth was measured in colour class 2 during week 9 (26 January–1 February). The highest mean weekly DIN was measured during weeks 9 and 11 (26 January–15 February) in colour class 2 and during week 15 (9–15 March) in colour class 1.
- The mean seasonal TSS concentrations measured across the primary and secondary water types exceeded the wet season TSS GVs by 3.4 and 1.3 times. respectively. The mean seasonal Chl-*a* concentrations measured across the primary, secondary and tertiary water types exceeded the wet season Chl-*a* guidelines by 11.7, 1.3 and 1.1 times, respectively. PP and PN concentrations in the primary water type exceeded their respective wet season PN guidelines by 1.8 and 1.3 times.
- In 2017–18, the greatest DIN contributions to the Wet Tropics were from the Herbert (37%), Johnstone (21%), Tully (17%) and Russell-Mulgrave (14%) Rivers, whereas the TSS contributions were dominated by the Johnstone (32%) and Herbert (26%) Rivers.
- The wet season exposure mapping showed that the Wet Tropics was most affected by the lowest exposure category (category I), in agreement with the long-term trends. Approximately 37% of the total area of the region was exposed to a potential risk. This area was smaller than the long-term areas (59%) and was caused by a smaller total area exposed to the lower exposure category I (34% in 2017–18 versus 59% in the long-term). Only 0.3% of the Wet Tropics region was exposed to exposure category III and no area was exposed to exposure category IV. These areas were slightly smaller than long-term areas.

7.3 Burdekin

Ambient water quality

- Several water quality parameters did not meet GVs during the 2017–18 monitoring year. Mean concentrations of Chl-*a*, PP and Secchi depth did not meet GVs in the Burdekin region.
- Concentrations of TSS and NO_x have been relatively stable over time and mean values are currently below GVs for the region. Concentrations of PN have increased over time but are currently at GVs.
- Dramatic increases in DOC concentrations have occurred since 2005 in the region.
- Results from the long-term version of the WQ Index showed that water quality has remained relatively stable since 2005 in the region, and is in 'good' condition. These results indicate that Burdekin water quality has remained stable since 2005, which is unrelated to the size of the wet season in a particular year.
- Results from the annual condition version of the WQ Index showed that water quality was 'poor' in the region for the 2017–18 monitoring year. These results indicate that inshore Burdekin water quality has been generally 'poor' for the last 2 years, possibly as a result of average wet season discharge following several drier-than-average years.

Wet season and event water quality

- The Burdekin region experienced an average wet season in 2017–18, with flooding occurring at the end of the Burdekin River in early March. The flow events were almost exclusively derived from the upper Burdekin tributary which is one of the dominant contributors to sediment loads at the end of river. In general, weekly river discharges during the 2017–18 sampling period were below the long-term mean weekly discharge value.
- Cumulative exposure mapping based on the eReefs hydrodynamic model output showed that enclosed coastal waters were heavily affected by river discharge from the Burdekin River. River discharge was mainly transported in a westerly direction along the coast, with measurable discharge reaching >150 km north from the river mouth. Some discharge from the Burdekin River was also transported in an easterly direction, though plume extent was not as large as northerly-directed plumes. Open coastal and mid-shelf waters were also affected by river discharge.
- The mean seasonal TSS concentrations measured across the primary and secondary water types exceeded the wet season TSS GVs by 18 times and 3.2 times, respectively, and were just above in the tertiary water type. The mean seasonal Chl-*a* concentrations measured across the primary water type exceeded the wet season Chl-*a* GVs by 2 and were just above the GV in the secondary water types. PP and PN concentrations in the primary water type exceeded their respective wet season GVs by 3.7 and 2.8 times.
- In 2017–18, the highest river-derived DIN loading contributions to the Burdekin region were from the Burdekin (42%), Herbert (30%) and Haughton (19%) Rivers, whereas the TSS contributions were dominated by the Burdekin River (69%) and, to a much lesser extent, the Haughton River (22%).
- In 2017–18, the Burdekin region was most affected by the lowest exposure category (category I), in agreement with the long-term trends. Approximately 16% of the total area of the Burdekin region was exposed to a potential risk. This area was smaller than

the long-term areas and due to a smaller total area exposed to the lower exposure category I. Only 0.6% of the Burdekin region was exposed to exposure category III and no area was exposed to exposure category IV. These areas were smaller than long-term areas.

7.4 Mackay Whitsunday

Ambient water quality

- Several water quality parameters did not meet GVs during the 2017–18 monitoring year. Mean concentrations of Chl-*a*, PN, PP and Secchi depth did not meet GVs in the Mackay-Whitsunday region.
- Concentrations of TSS and NO_x have been relatively stable over time and mean values are currently at GVs for the region.
- Dramatic increases in DOC and POC concentrations have occurred since 2005 in the region.
- Results from the long-term version of the WQ Index showed that water quality has shown a long-term decline since 2005 in the region, and is currently in 'moderate' condition. These results indicate that Mackay-Whitsunday water quality has declined since 2005, which is unrelated to the size of the wet season in a particular year.
- Results from the annual condition version of the WQ Index showed that water quality was 'moderate' in the region for the 2017–18 monitoring year. These results indicate that inshore Mackay-Whitsunday water quality has improved compared to last year's condition of 'very poor'. This is likely due to 2017–18 being a much drier-than-average year following a large wet season the previous year.

Wet season and event water quality

- The 2017–18 wet season was characterised by below average rainfall in the Mackay-Whitsunday region and consequent river discharge, resulting in river plumes that were for most of the wet season not well developed and therefore the sampling sites received a moderate riverine influence. In general, weekly river discharges in the 2017–18 sampling period were below the long-term mean weekly discharge value.
- Sampling of the Mackay-Whitsunday region was limited to weeks 7, 12 and 21. No week had *in-situ* samples collected across all colour classes (1 to 6) and no water quality samples were in colour classes 1, 2, 3 or 4. This did not allow describing water quality changes across colour gradients. Maximum TSS and DIN concentrations and minimum Secchi depth were measured on 25 April 2018 (during week 21) in colour class 5. The highest weekly mean TSS concentrations were measured during weeks 7 (12–18 January) and 12 (16–22 February) and were in colour class 5. The highest weekly mean Chl-*a* concentrations and minimum Secchi depth were measured during week 7 in colour class 5 and the highest weekly mean DIN concentration was measured during week 21 in colour class 5.
- The mean seasonal TSS concentrations measured across the secondary water type was 2.4 mg L^{-1}, i.e. equal to the wet season TSS guidelines of 2.4 mg L^{-1}. The mean seasonal Chl-*a* concentrations in the secondary and tertiary water types were approximately 1.4 and 1.1 times the wet season Chl-*a* guidelines, respectively (no data were available in the primary water type).
- In 2017–18, the river-derived DIN loadings in the Mackay-Whitsunday region were approximately 25% each for Plane Creek, the Proserpine and O'Connell Rivers, with

20% from the Pioneer River. The O’Connell River had the highest contribution to the TSS loadings (38%) in the region, followed by the Pioneer River (25%) and Plane Creek (18%).

- In 2017–18, the Mackay-Whitsunday region was most affected by the lowest exposure category (category I), in agreement with the long-term trends. Approximately 24% of the total area of the Mackay-Whitsunday region was exposed to a potential risk. This area was smaller than the long-term area (85%) and was due to a smaller total area exposed to the lower exposure category I. Only 0.3% of the Mackay-Whitsunday region was exposed to exposure category III and no area was exposed to exposure category IV. These areas were slightly smaller than long-term areas.

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Appendix A. Case study: Analysis of variability in chlorophyll and turbidity time-series

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A-1 Introduction

As sensor technology improves and computing power increases, large datasets are becoming increasingly common in research and monitoring programmes worldwide. Datasets can be considered spatially high-frequency (i.e. taking measurements in many places at one time), temporally high-frequency (i.e. taking many measurements in time at one place) or a mixture of the two. Satellite observations of ocean colour and temperature are commonly-used types of high-frequency spatial data in marine science. Satellite images can also be considered high-frequency temporal data depending on the imagery acquisition time (the number of days between satellite imaging of a specific place).

Mobile sensor packages such as floats and gliders traverse the ocean measuring temperature, salinity, and biogeochemical variables at high temporal frequency (Riser et al., 2016; Roemmich et al., 2009). Moored sensor packages are one of the most common approaches for collecting high-frequency datasets. National ocean observing systems such as the Integrated Marine Observing System (IMOS) in Australia include networks of moorings that continuously measure physico-chemical and biogeochemical variables. IMOS mooring data has had many important outputs including monitoring changes in the coastal ocean, measuring extreme events, adding value to cross-disciplinary research, and validating other datasets (Lynch et al., 2014).

High-frequency datasets are rich in information and can be used in a myriad of ways including: deriving descriptive statistics for a variable of interest (such as mean, median, mode, histograms, etc); monitoring the duration and timing of events such as marine heat waves, storms, or the exceedance of defined water quality thresholds; and calibrating and validating ecosystem models and remote sensing data (Glenn et al., 2000). Use of sensors that estimate the concentrations of algal and other suspended particles has become widespread due to interest in monitoring the impact of land run-off on ecosystems.

Fluorometers are commonly used in marine waters to estimate the concentration of chlorophyll *a* (Chl-*a*), which is a proxy for phytoplankton abundance, based on the strength of fluorescence following a pulse of light. Nephelometers estimate the level of turbidity, a proxy for suspended particle concentrations, based on the back-scattering of a light pulse.

Particulate material concentrations are naturally variable at a range of timescales (~minutes–seasonal), especially in dynamic systems such as the coastal ocean. Time-series from sensors often show several-fold changes in fluorescence and turbidity on short timescales (~minutes–hours), which are typically related to local physical processes such as tidal forcing (Chang et al., 2002). Large variability (~order of magnitude) occurs at longer time-scales (~seasons – years), which is typically driven by the supply of particles to the coastal system through changes in productivity, inputs from terrestrial/oceanic sources, and ecosystem regime shifts (Cloern and Jassby, 2010).

The combination of many types of variability that operate at different time-scales often results in fluorescence and turbidity time-series that appear overly ‘noisy’ and can be confusing to interpret. Approaches from the field of engineering can be used to analyse these signals in a similar manner as sound or voltage datasets are processed. Spectral analysis techniques such as Fourier analysis can be used to decompose a ‘noisy’ signal into a series of oscillating signals, each with its own frequency (Cazelles et al., 2008). As a simplified example, Fourier analysis is often used to decompose time-series of water levels to derive tidal constituents.

Tides around the world are composed of multiple constituents (different waves related to gravitational and other forces, especially of the moon and sun), and ~2–4 of these constituents typically dominate the tidal signal (Kowalik, 2004). Constituents all have different frequencies, which is why the tide we observe *in-situ* changes over time (such as the spring-neap cycle) rather than remaining a perfectly uniform wave.

To demonstrate how spectral analysis works, we will create an idealised time-series of tidal data from two constituents and then use Fourier analysis to identify the main sources of variability in this tidal signal. A time-series of two idealised constituents is shown below: one is semi-diurnal (two high tides per day) (Figure A-1a), while the other is diurnal (one high tide per day) (Figure A-1b). When added together an idealised version of an observed tide is produced (Figure A-1c), which has two high tides per day with different magnitudes.

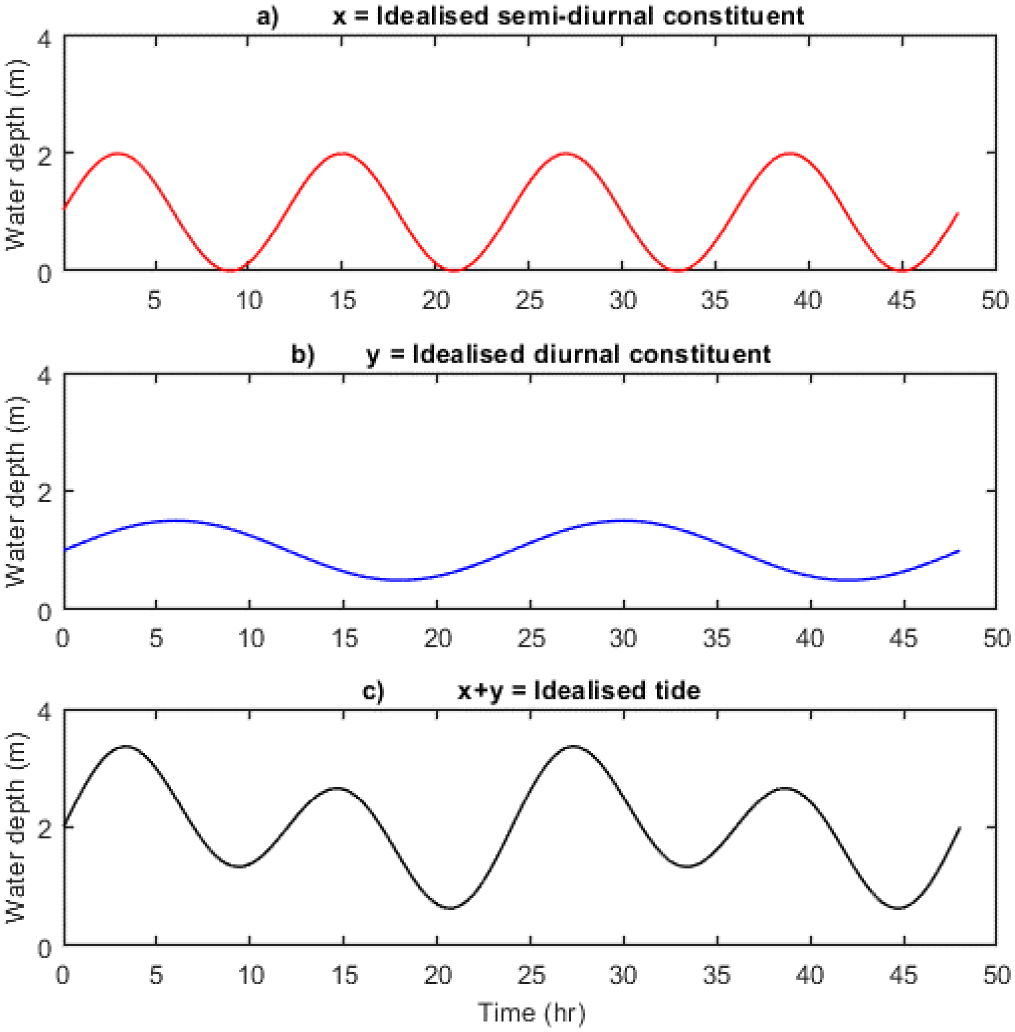

Figure A- 1: Idealised time-series of water depth for a) a semi-diurnal (twice daily) tidal constituent, b) a diurnal (once daily) tidal constituent, and c) the observed tide (sum of these two constituents).

This observed tidal signal can be decomposed with spectral analysis methods to identify key sources of variability in the time-series. Power spectral density (PSD) is a useful way to visualise the variability within a dataset (Figure A-2). Peaks at a particular frequency indicate that variability in the time-series is occurring at this frequency; in the case of our idealised tidal data, peaks occur at 24 and 12 hours, which correspond to the two constituents used to form this idealised tide.

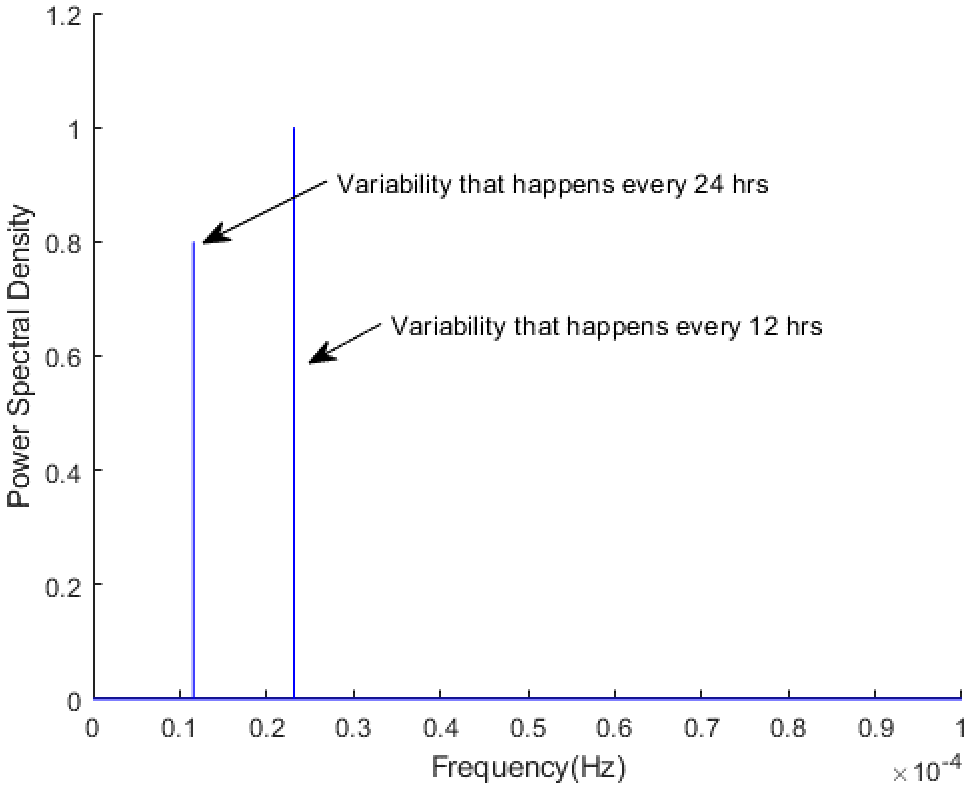

Figure A- 2: Power spectral density of idealised tidal data shown in Figure A-1. Note that frequency units are in Hz (s^{-1}), so variability that occurs every 12 hours occurs at 1/(12*3600) Hz.

Similar approaches have been used with satellite chlorophyll datasets to detect phytoplankton blooms (Blondeau-Patissier et al., 2014) and relate chlorophyll concentrations to large-scale ocean physics (Uz et al., 2001) or climatic conditions (Nezlin and Li, 2003). Time-series of irradiance have also been previously analysed with similar approaches to assess the amount of variability that can be related to turbidity (Anthony et al., 2004). However, spectral analysis is not commonly used in interpreting data from moored chlorophyll and turbidity sensors. This case study will assess the utility of this analysis applied to long-term records of chlorophyll and turbidity measured through the MMP.

A-2 Methods

Deployable data-logging instruments (WETLABS ECO FLNTUSB) were used to measure fluorescence and turbidity as part of the MMP at 15 locations in the Reef lagoon (see Section 2). Fluorescence measurements were converted to chlorophyll concentrations using factory calibrations and *in-situ* filtered samples. For this preliminary study, we used two years (1 August 2016–1 August 2018) of chlorophyll and turbidity data from one site (Tully River mouth mooring, TUL10) as a test dataset. Loggers record every 10 minutes (1/(10*60) Hz); therefore, the maximum resolvable frequency for this dataset is half the measurement frequency, or 20 minutes (1/(10*60*2) Hz). Fast Fourier transforms were performed using Tukey-Hanning windows on time-series after detrending (removal of the mean).

A-3 Results and Discussion

Chlorophyll and turbidity records measured at the Tully River mouth mooring showed variability at short (~hours–weeks) and longer (~weeks–months) time-scales (Figure A-3).

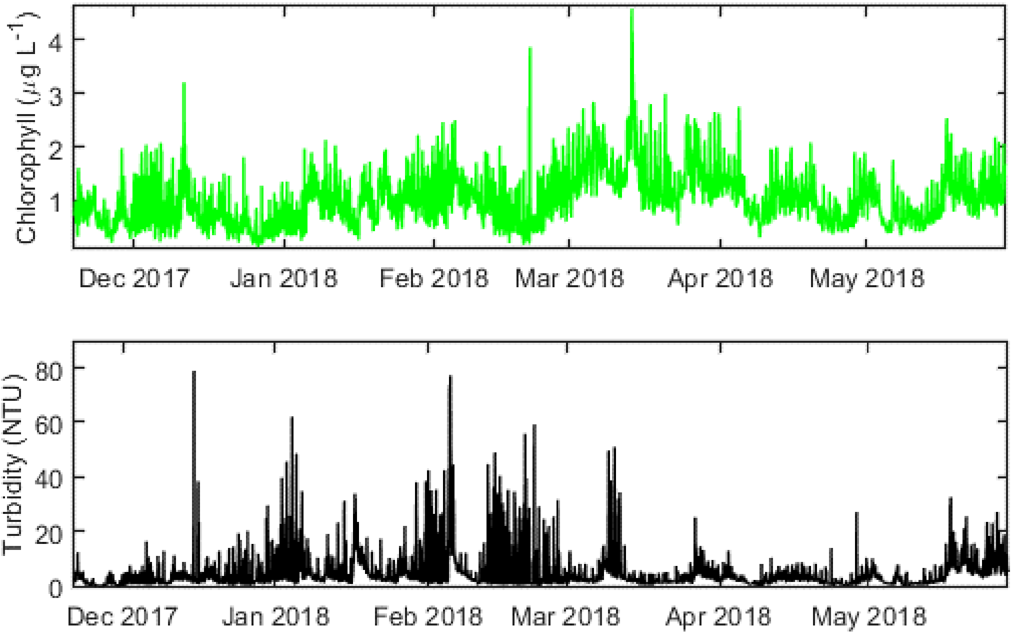

Figure A- 3: Time-series of chlorophyll and turbidity measured by moored Wetlabs FLNTUSB at Tully River mouth mooring (site TUL10) from 15 November 2017 to 1 June 2018, a subset of the full time-series to show variability on scales of ~days–weeks.

Spectral density analysis of these two years of data showed several interesting features. For both chlorophyll and turbidity datasets, peaks were observed at frequencies corresponding to 12 and 6 hour periods (Figure A-4). Variability associated with a 12 hour period is most likely due to semi-diurnal tides, which occur in the lagoon. Variability associated with a 6 hour period is likely related to overtides, a type of tidal constituent that can occur in inshore shallow water areas as a result of complex bathymetry and asymmetric tidal velocities (Ranasinghe and Pattiaratchi, 2000). Spectral analysis of chlorophyll and turbidity records outside of enclosed coastal waters would be less likely to show variability associated with overtides.

This analysis also suggests that a large amount of variability occurs at low frequencies (i.e. happens infrequently, such as monthly or annually). This can be seen by PSD values increasing as frequency decreases (Figure A-4). This is related to the length of the time-series analysed, which was two years for this preliminary study. With only a few years of data, it is difficult to resolve long-term processes; however, this limitation can be overcome by using some of the longer FLNTUSB time-series in future analyses (some of which are almost 10 years long).

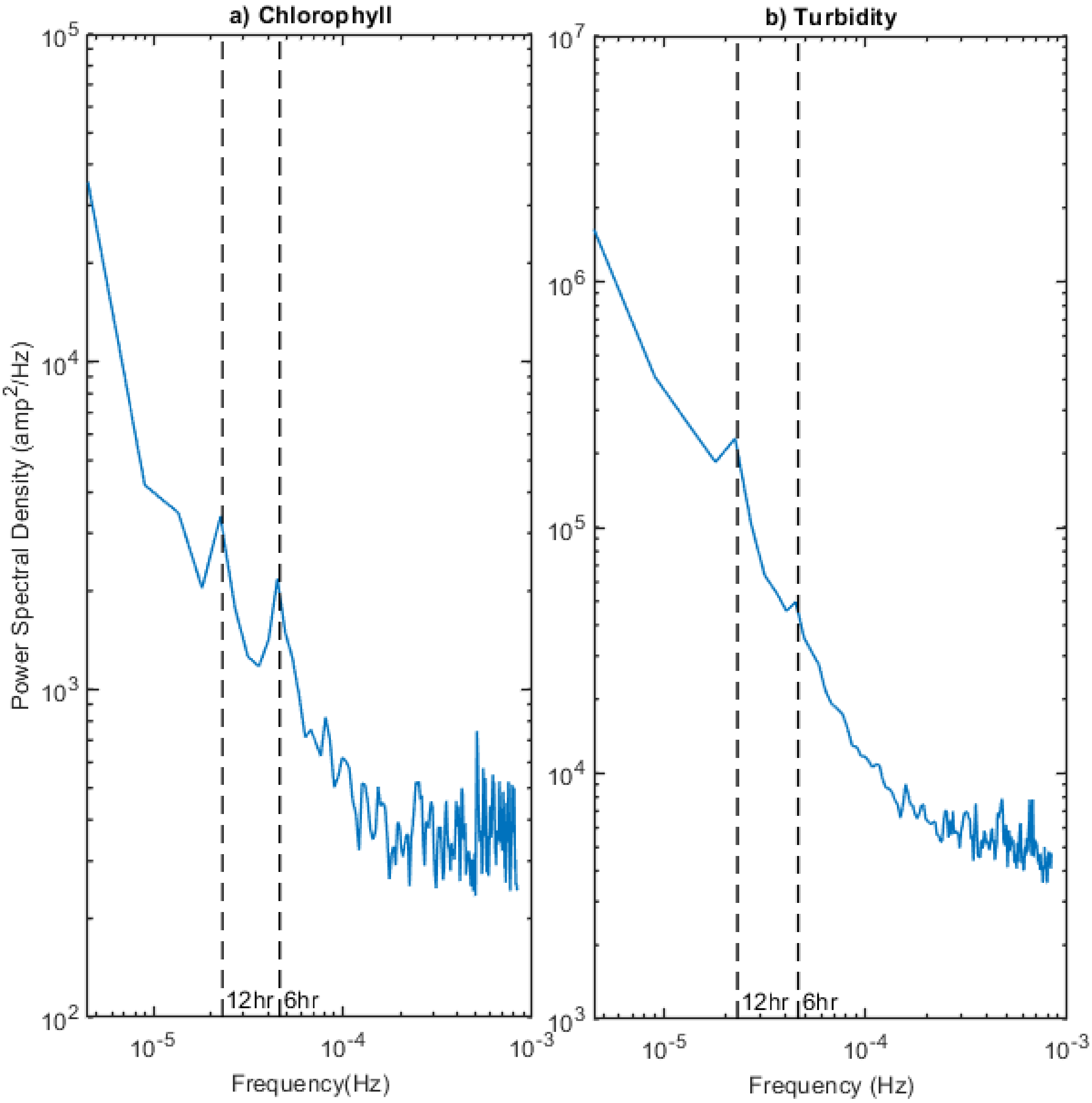

Figure A- 4: Power spectral density plots for a) chlorophyll and b) turbidity time-series measured at Tully River mouth mooring from 1 August 2016 to 1 August 2018. Dashed black lines indicate large amounts of variability occur at these frequencies (periods of 12 and 6 hours).

In conclusion, this case study has shown that spectral analysis can be a useful tool to understand time-series of chlorophyll and turbidity measurements collected from moored loggers. This work adds value and helps interpret some of the ‘noise’ present in this long-term dataset. Future analysis of the full suite of FLNTUSB records from 15 sites along gradients of latitude and river influence will greatly improve our understanding of drivers of chlorophyll and turbidity variability in the inshore Reef.

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Appendix B. Case study: Assessing continuity between satellite-derived water colour monitoring products

Caroline Petus and Dieter Tracey, TropWATER James Cook University

B-1 Introduction

An operational method has been developed that integrates satellite water colour data with field water quality and ecosystem monitoring data to assess trends in water composition and ecosystem health in the Reef. This method involves the classification of Moderate-Resolution Imaging Spectroradiometer (MODIS) coastal pixels into six distinct water bodies using a 'wet season' (WS) colour scale developed specifically for the Reef (this report: Section 2.7 and Supplementary material D-7). Several monitoring products are derived from this method and are operationally implemented into the MMP.

The quality of MODIS-Terra and MODIS-Aqua satellite imagery is declining due to their increasing age (launched in 1999 and 2002, respectively) and there is a substantial risk that MODIS satellites will be decommissioned in the near future. Hence, there is a need to test and transition the methods and products developed for the Reef to recent satellite platforms, such as the Sentinel-3 satellite launched in February 2016 by the European Space Agency (ESA).

The use of the Forel-Ule (FU) toolbox developed through the Citclops project is particularly attractive (http://www.citclops.eu/, Novoa et al., 2013; Van der Woerd and Wernand, 2015, 2018; Wernand et al., 2013). It includes an automated satellite toolbox to process satellite images (hereafter, FU satellite toolbox) as well as a smartphone application: Eye on Water application (hereafter, EOW App.). The FU satellite toolbox and EOW App. allow classifying coastal waters into 21 FU colour categories based on satellite imagery, including Sentinel-3 data, and field observations, respectively.

This study assessed the feasibility of using freely distributed Sentinel-3 Ocean Land Colour Instrument (OLCI) imagery and the FU satellite toolbox for the monitoring of flood waters in the Reef (defined as flood river plumes and associated resuspension events). It tested the feasibility to transition the methods from historical MODIS to the new Sentinel-3 satellites and from the WS colour scale to the historical Forel-Ule (FU) colour scale, so there are no gaps in ongoing MMP studies in the future.

This case study has also been submitted as a research paper in Journal of Environmental Management (Petus et al., in review).

B-2 Methods

The WS satellite toolbox

MODIS Level-0 imagery of the 2017–18 wet season (December 2017 to April 2018) was downloaded on the Ocean Colour Web (https://oceancolour.gsfc.nasa.gov/) and processed to true colour imagery by BOM using Seadas 7.4 (this report, Great Barrier Reef Marine Park Authority, 2018, Waterhouse et al., 2018). It was then processed with the WS satellite toolbox to produce MA-WS maps of the study area following the processes outlined in this report (Sections 2.7 and Supplementary material D-7). To complement cloudy MODIS-Aqua information, the MODIS-Terra true colour image of 29 March 2018 was downloaded from the NASA's EOSDIS worldview website and processed into MT-WS maps.

Sentinel-3A imagery of the study area was downloaded on the EUMETSAT Copernicus Online Data Access website (https://coda.eumetsat.int/#/home). They were processed with the FU satellite toolbox implemented in SNAP in order to produce S3-FU maps of the study area following processes outlined in Section 1.3. MA-WS and S3-FU maps showing marine conditions in the Burdekin and Wet Tropics NRM regions (Figure B-1) during the 2017–18 wet season were imported in ArcgMAP10.4.1 for post-processing (section below).

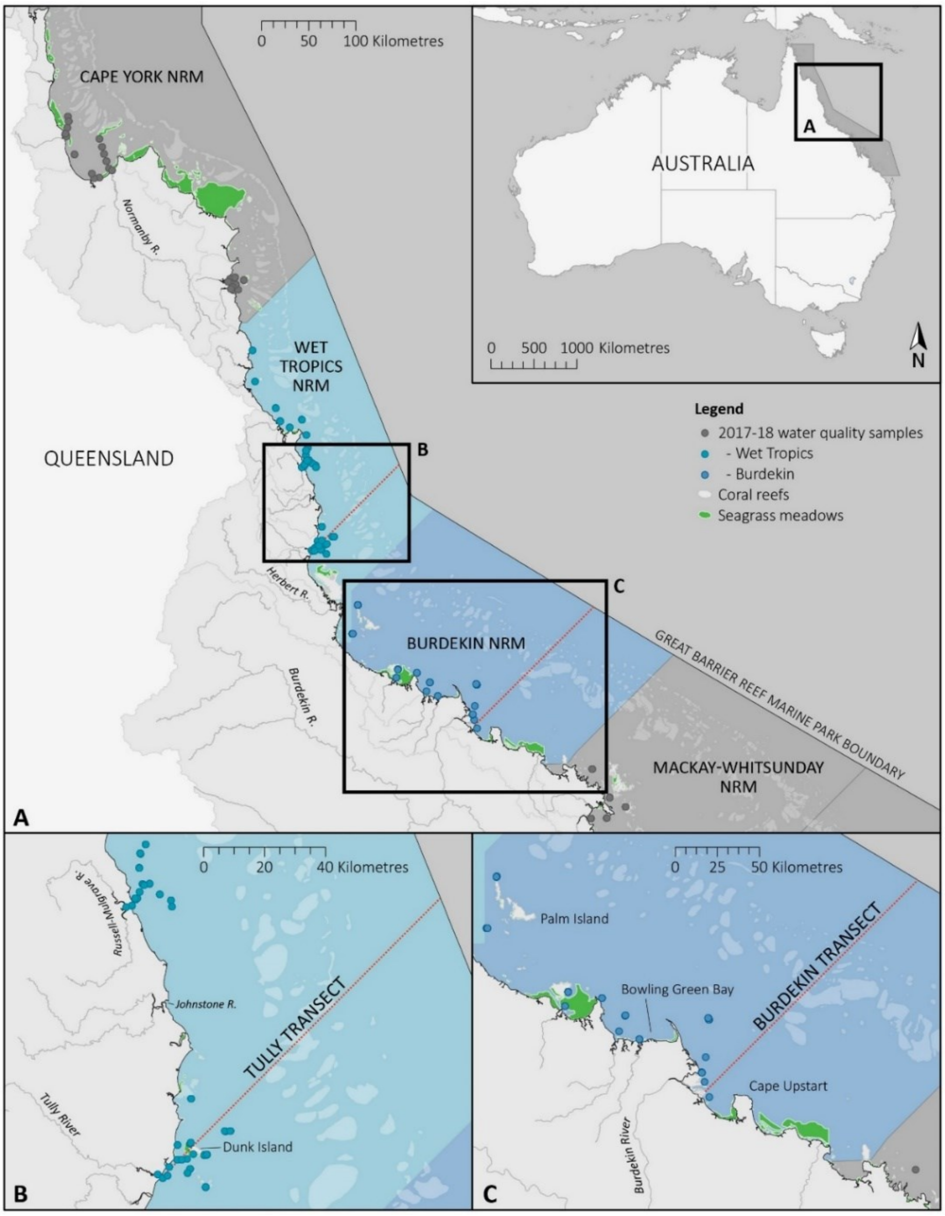

Figure B-1: Study area in the Marine Park: Tully, Herbert (Wet Tropics region) and Burdekin Rivers (Burdekin region) and field water quality measurements collected during the 2017–18 wet season.

The WS satellite toolbox is a semi-automated toolbox using a set of scripts (R and Python) that have been developed specifically for the Reef. The toolbox includes two main components: a spectral enhancement function to transform Red-Green-Blue (RGB) images into Intensity-Hue-Saturation (HIS) and a supervised classification method to cluster the enhanced pixels into ‘cloud’, ‘ambient water’ and six WS colour classes. The supervised classification uses typical apparent surface colour signatures (RGB and HIS values) of flood waters in the Reef (Alvarez-Romero et al., 2013). Discrimination of colour classes has been based on the Reef river flood plume typology as defined in Johnson et al. (2011) and in the

MMP (Devlin et al., 2012a and b, 2015; Waterhouse et al., 2017, 2018). It has been calibrated and validated with both satellite and historical *in-situ* water quality data, respectively (Alvarez-Romero et al., 2013; Devlin et al., 2015, Petus et al., 2016). Technical details about the WS colour scale classification can be found in this report (Section 2.7 and Supplementary material D-7).

The FU satellite toolbox

The FU colour scale comparator is a 21-level colour classification system based on human visual comparison with glass encased colour standards. It was developed in the late 19th century and can be used worldwide, with any natural water body (marine, coastal, estuarine, river and lake) (Figure B-2a).

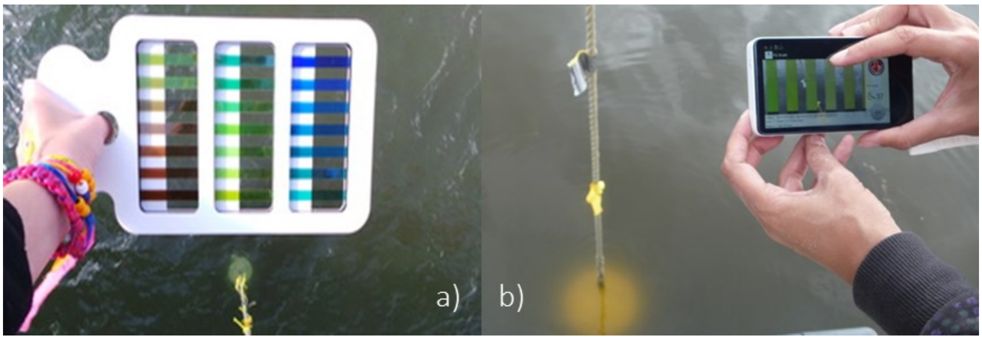

Figure B-2: FU scale measurements in the field using a Secchi disc and (a) the glass encased FU scale and (b) the FU-scale phone App. (source: CITCLOPS project: http://www.citclops.eu/)

An open access remote sensing toolbox has been recently developed to classify water bodies into FU categories from satellite ocean colour imagery through European EC-FP7 funding and the Citclops project. It has been recently implemented in the Sentinel-3 Toolbox, which is built on the Sentinel Application Platform (SNAP, http://step.esa.int/main/download/, Van der Woerd et al., 2016; Van der Woerd and Wernand, 2018).

The FU satellite algorithm converts satellite normalised multi-band reflectance information into a discrete set of FU numbers using uniform colourimetric functions (Wernand et al., 2012). The derivation of the colour of natural waters is based on the calculation of Tristimulus values of the three primaries (X, Y, Z) that specify the colour stimulus of the human eye. The algorithm is validated by a set of hyperspectral measurements from inland, coastal and marine waters (Van de Woerd et al., 2016; Van der Woerd and Wernand 2018).

Technical details about the FU scale algorithm, including detailed mathematical descriptions, are presented in Novoa et al. (2013), Van der Woerd and Wernand (2015, 2016), Van der Woerd and Wernand (2018) and Wernand et al. (2013). The FU scale is composed of 21 colours; going from indigo blue (high light penetration waters) to cola brown (turbid waters with an extremely high concentration of humic acids, Figure B-6a) (see http://www.citclops.eu/ for a full description of the FU colour classes).

Post processing

Weekly MODIS-A WSC and Sentinel-3 FU maps of the 2017–18 wet season were produced for the Burdekin and Wet Tropics marine regions. Weekly composites were chosen to minimise the amount of area without data per image due to masking of dense cloud cover very common during the wet season and flood events, as well as intense sun glint (Alvarez-Romero et al., 2013). The 'riskiest' colour-class (i.e. minimum WS or maximum FU value of each pixel/week) was used to map the colour class with the highest level of exposure to land-sourced pollutants for each wet season, week i.e. assuming that, in flood waters, the colour classes represent a gradient in exposure to land-sourced pollutants.

The colour class category corresponding to the location and week of acquisition of water quality sample collected during the 2017–18 wet season in the Burdekin and Wet Tropics regions (section 2.2, and Figure B-1) was then extracted using the raster with the bilinear method in R 3.1. The MA-WS and S3-FU weekly composite maps were then overlaid and the most frequently occurring (majority) FU value measured in each respective WS colour category across each wet season week (1 to 22 weeks) was extracted using the Zonal statistic tool in ArcGIS 10.4.1. This method was used to produce preliminary estimations of the FU scale categories corresponding to each WS colour class (1 to 6) and flood waters types (primary, secondary, and tertiary).

Heat maps were generated using WS and FU colour category data from two notional transects for each week of the wet season. Transects extended from the mouths of the Tully and Burdekin rivers to the offshore boundary of the Reef. Heat maps were used to illustrate the extent of river plumes and spatio-temporal dynamics of water bodies with distance from the coast across NRM regions and wet season weeks (22 weeks). Weekly composites were finally overlaid (i.e., presence/absence of each water type) and normalised (i.e., number of weeks divided by 22 wet season weeks) to compute MODIS-A and Sentinel-3 seasonal (2017–18) frequency maps of occurrence for each plume water type. Long-term MODIS seasonal frequency maps and water quality data (2003–18) were obtained from this report (section 3.3.2) and compared with the seasonal MODIS data.

B-3 Results

MA-WS and S3-FU maps

MA-WS weekly composite images (Figure B-3a and b) and heat maps (Figure B-4a and b), when not obstructed by cloud cover, clearly illustrated coastal water movements in the Wet Tropics and Burdekin regions, as well as the ‘greening’ of coastal waters during the 2017–18 wet season.

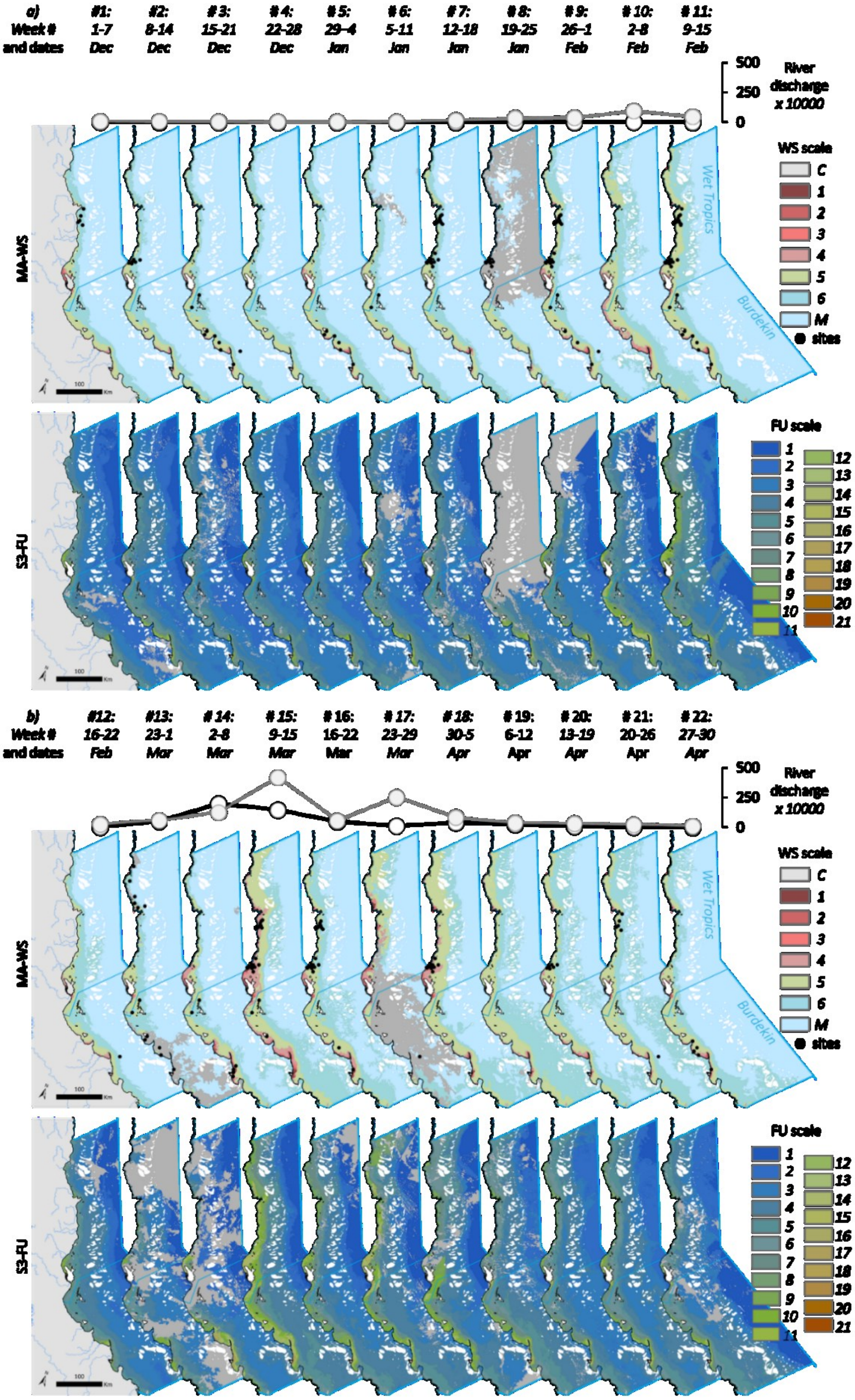

Figure B-3: Panel of weekly colour class composites showing movements of Wet Tropics waters bodies: comparison of S3-FU and MA-WA outputs for the 2017–18 wet season: a) weeks 1–11, b) weeks 12–22. M: Marine waters, C: Clouds. Week #: week number) and weekly river discharge (Mega Litres per week): black line: 2017-18 wet season, dotted line: historical (note the scale different from Figure B-8). Black dots: field sites sampled in 2017–18 (MMP).

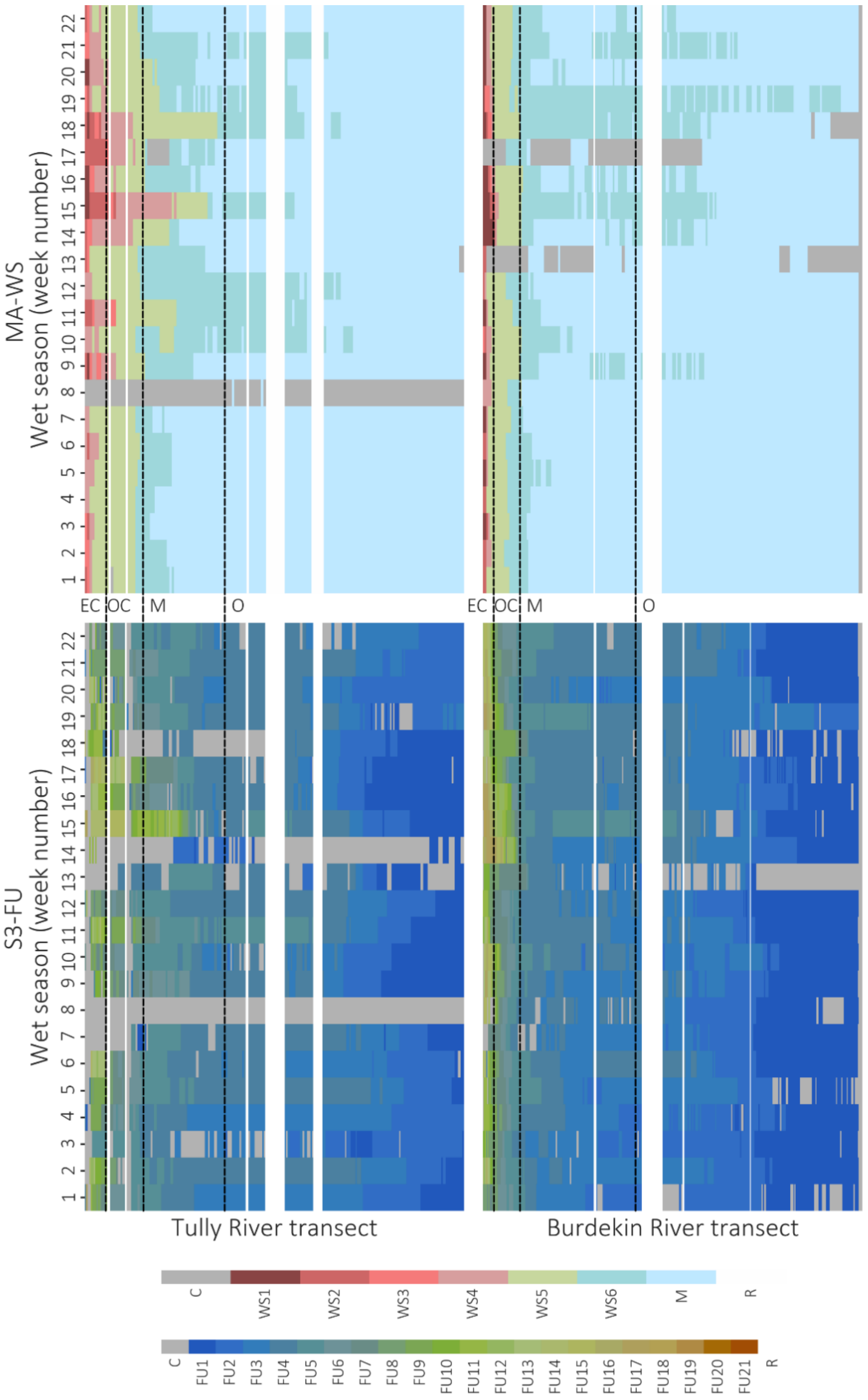

Figure B-4: Heat maps using (a, b) WS and (c, d) FU colour category data from two notional transects (x-axes) for each week of the wet season (y-axes, 22 weeks). Transects extend from the mouths of the (left) Tully and (right) Burdekin rivers to the offshore boundary of the Marine Park (see Figure B-1). The vertical dashed lines separate the different marine regions of the Marine Park. EC: enclosed coastal, OC: open coastal, M: mid-shelf, O: offshore, C: clouds or no data, R: coral reefs.

The MODIS composites allowed distinguishing the extent of the turbid, sediment dominated, flood waters off the Burdekin, Tully and Herbert Rivers in February and March 2018; measured as the primary water type in the WS scale (colour classes 1 to 4) as well as the spatial extent of the less turbid and more seaward secondary (colour class 5) and tertiary (colour class 6) water types.

The MA-WS primary waters from the Tully and Herbert rivers were largely confined to the enclosed coastal region of the Reef, but with evidence of some influence on parts of the open coastal and mid-shelf regions after the main flood events (weeks 14–15 and 17–18, Figure B-3a and Figure B-4a). They highlighted the influence of turbid flood waters surrounding Dunk Island, especially during weeks 14–15 and 18. The open coastal region off the Tully River was nearly always exposed to the secondary water type during the 2017–18 wet season and the tertiary water type extended as far as the offshore coral reefs in seven of the 22 weeks of the wet season (after week 10).

MA-WS weekly composites of the Burdekin region showed the extent of the turbid flood waters were mainly confined to the enclosed coastal region (Figure B-3a). primary waters were confined next to the estuary mouth (Upstart Bay) during weeks 1 to 12 and began to extend into Bowling Green Bay after the main peak discharge (week 13, Figure B-3b). The next weekly composite (week 16) showed the primary water type extending northwards past Magnetic Island. The secondary and tertiary water types were largely confined to the open coastal and mid-shelf regions, respectively, but the tertiary waters reached the offshore coral reefs after the main flood event (weeks 15, 18, 19 and 21).

The S3-FU weekly (Figure B-3) and heat maps (Figure B-4c and d) showed very similar patterns and MODIS primary water type corresponded to higher colour class categories in the FU scale (Figure B-3a and b).

The strong correlation between the MODIS WS and S3-FU maps was further illustrated by mapping river flood plumes off the Tully and Herbert rivers on 29 March 2018 (week 17, Figure B-5a) and off the Burdekin River on 14 March 2018 (week 15, Figure B-5b). In both images, existing large river flood plumes were well captured and showed the same northward orientation, shapes and spatial areas. Both images confirmed the influence of primary waters from the Tully and Burdekin rivers on Dunk Island and in the vicinity of Magnetic Island, respectively.

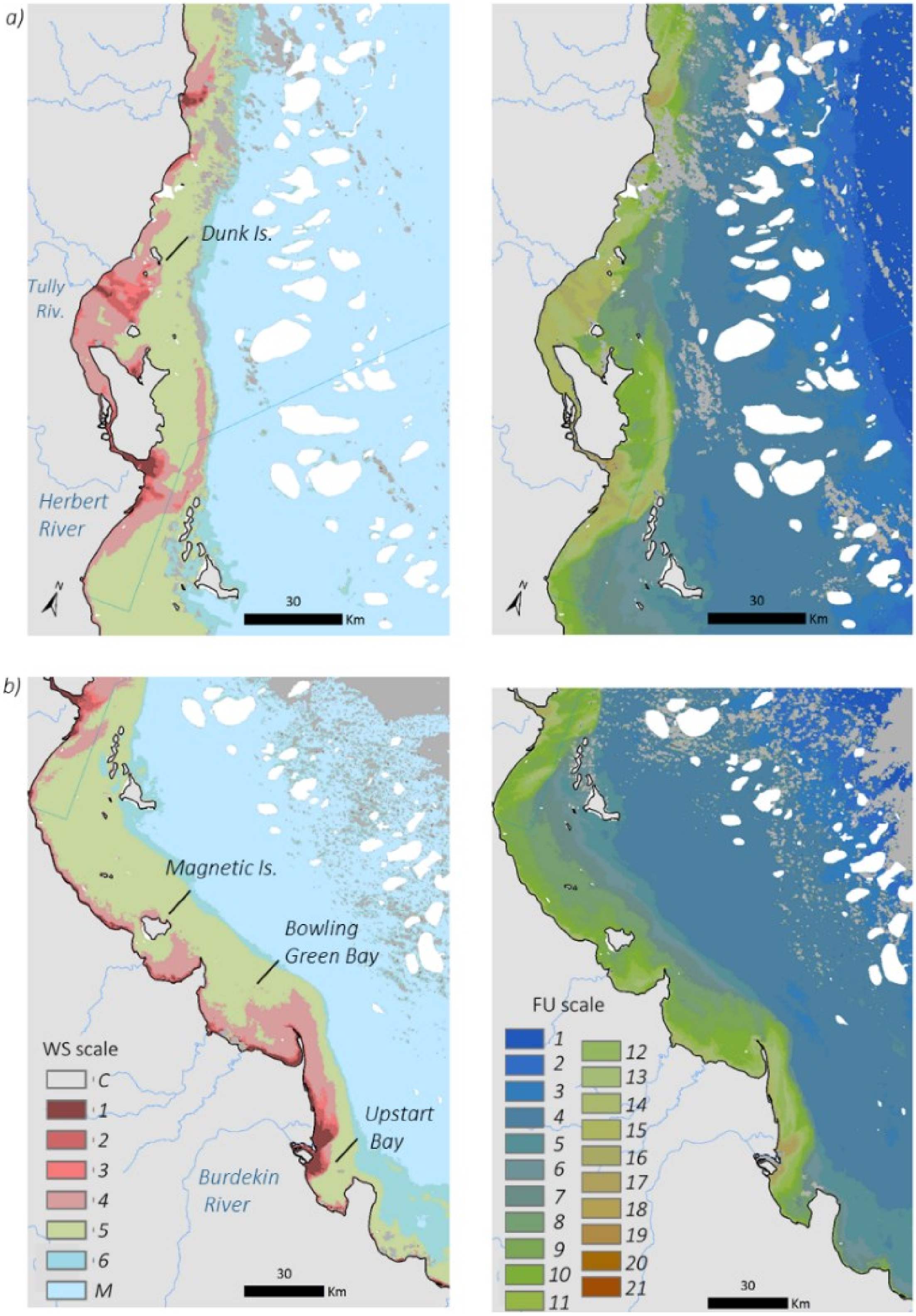

Figure B-5: MT-WS (left) and S3-FU (right) maps showing a) the Tully and Herbert river plumes of 29 March 2018 (the MODIS-A image was cloudy for this date) and b) the Burdekin river plume of 14 March 2018.

Water quality across colour gradients

TSS, Chl-*a*, CDOM and Secchi depth across the WS colour class gradient showed patterns consistent with previous sampling years (Figure B-6a, c). TSS concentrations in the Wet

Tropics region (average of 5.3 ± 6.7 mg L^{-1}) were much lower than the Burdekin region (average of 11.7 ± 44.4 mg L^{-1}) and mean TSS concentrations gradually decreased across the WS colour classes 3 to 6. CDOM was greater in the Wet Tropics (0.4 ± 0.5 m^{-1}) than the Burdekin (0.2 ± 0.4 m^{-1}) region, while Chl-*a* and Secchi depth levels were similar in both the Wet Tropics (0.9 ± 0.7 µg L^{-1}, 3.7 ± 3.3 m) and Burdekin regions (0.7 ± 0.5 µg L^{-1} and 4.3 ± 3.7 m), respectively. Chl-*a* was variable across the WS colour gradient, but generally increased (Wet Tropics) or was stable (Burdekin) within the colour classes 1 to 3, then decreased within colour classes 4 to 6. CDOM concentrations gradually decreased and, inversely, Secchi depth generally increased from colour classes 1 or 2 to 6.

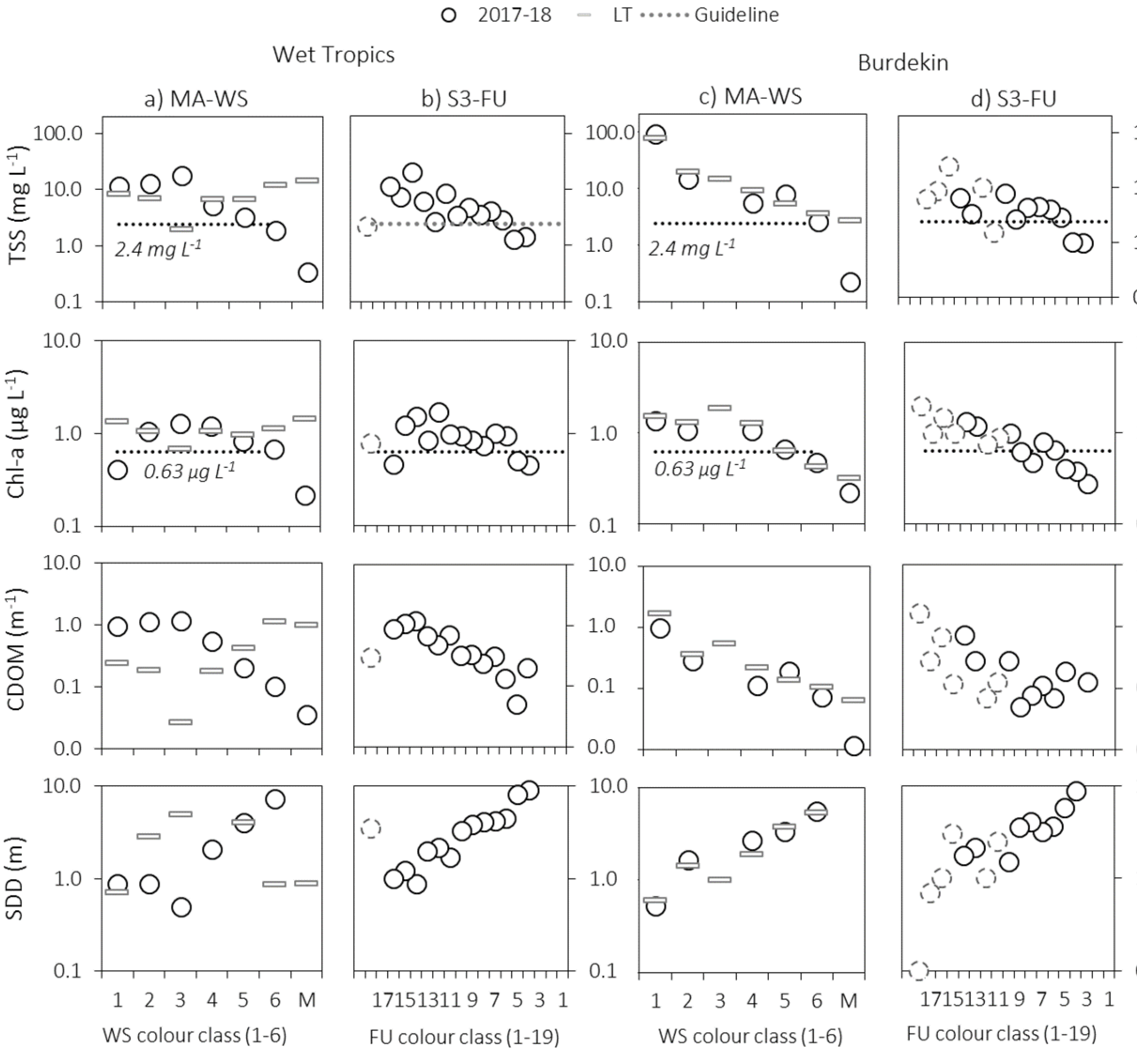

Figure B-6: Mean TSS, Chl-*a*, CDOM and Secchi depth (SDD) concentrations measured across (a, c) the WS and (b, d) the FU colour scales during the 2017–18 wet season in the (a, b) Wet Tropics and (c,d) Burdekin regions. The long-term (LT, 2002–18) values, from Gruber et al., in press) and wet season guideline values for the open coastal and mid-shelf waters of the Reef are also indicated on the MA-WS figures (a, c). Dotted circles indicate colour where ≤ 2 field samples have been collected.

Wet Tropics and Burdekin samples were collected across FU colour classes 1 to 18 (Figure B-6b, d) and very similar patterns were observed across the FU and WS colour classes for all water quality parameters. Especially, the increase in Chl-*a* concentration from WS colour classes 1 to 3 was mirrored by an increase in Chl-*a* concentration from FU colour classes 19 to 12. One noticeable exception was the water quality concentrations in the FU Wet Tropics colour class 18, but only 1 sample was collected in this FU colour class during the 2017–18 wet season (Figure B-7, dotted circles).

Most frequently occurring FU values (FU_{maj}) measured in the WS colour categories 1, 2, 3 and 4 (primary water type) ranged from 2 to 16, with median FU_{maj} of 13, 11, 11 and 9, respectively, in the Wet Tropics and 14, 11, 11 and 10 in the Burdekin region (Figure B-7). FU_{maj} ranged from 5 to 8 (Wet Tropics) or 10 (Burdekin) in the WS colour class 5 (secondary water type) with median values of 6. Finally, FU_{maj} ranged from 4 to 5 (Burdekin) or 6 (Wet Tropics) in the WS colour class 6 (tertiary water type) with median values of 4 in both regions.

Based on these results and the description of FU colour classes as given in the Citclops project website, the mean wet season water quality values across colour gradients were recalculated by grouping the FU colour classes 1–3 (equivalent to marine waters in the WS scale), FU colour classes 4–5 (equivalent to WS tertiary water type), FU colour classes 6–9 (equivalent to WS secondary water type) and FU ≥ 10 (equivalent to WS primary water type) Figure B-8).

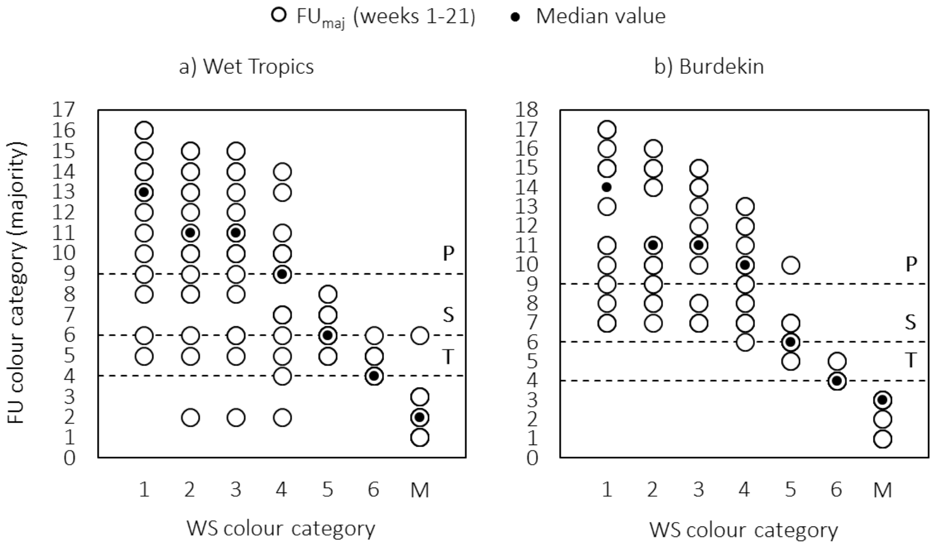

Figure B-7: Most frequently occurring FU value (FU_{maj}) measured in each respective WS colour category across each wet season week (22 weeks) in the a) Wet Tropics and b) Burdekin regions.

TSS, Chl-*a*, CDOM and Secchi depth across the WS and FU-equivalent water types showed similar patterns and mean water quality values, with TSS, Chl-*a* and CDOM concentrations decreasing and Secchi depth increasing from the primary to the tertiary water types. The greatest difference in concentration was measured for the TSS in the Burdekin primary waters (Figure B-8).

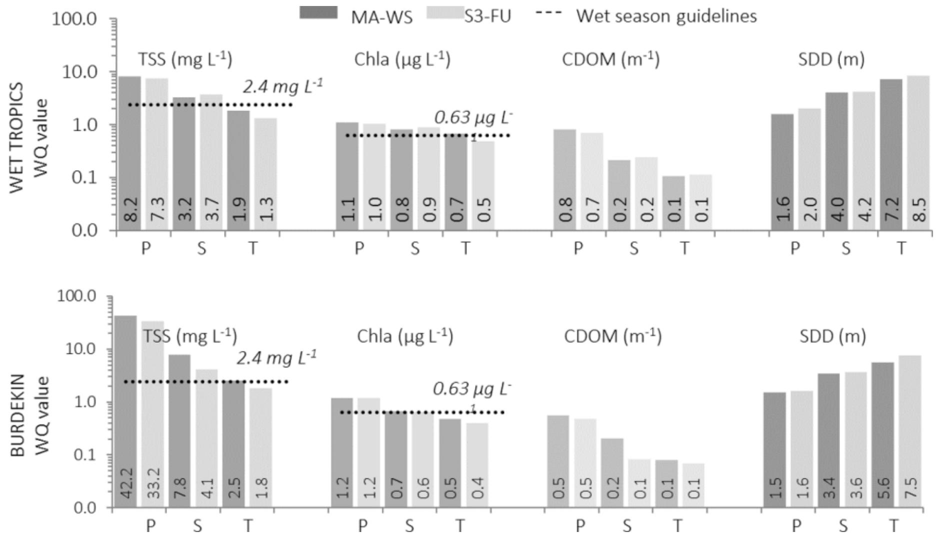

Figure B-8: Mean TSS, Chl-*a*, CDOM and Secchi depth (SDD) concentrations measured across the WS and FU-equivalent primary, secondary, tertiary water types during the 2017–18 wet season in the (top) Wet Tropics and (bottom) Burdekin regions. Wet season guideline values for the open coastal and mid-shelf waters of the Reef are indicated.

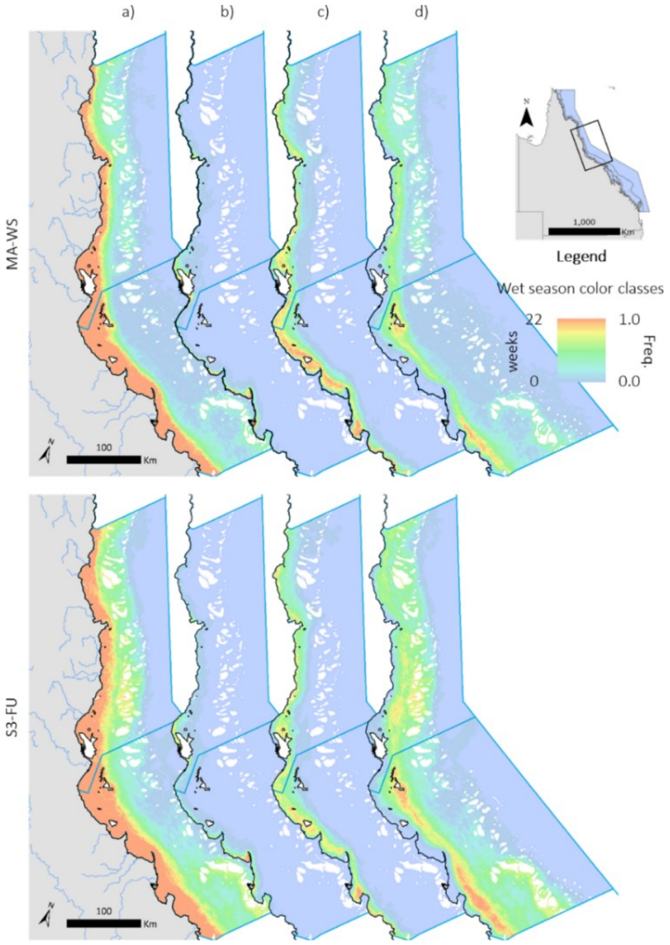

Figure B-9: Map showing the frequency of (top) MA-WS and (bottom) Fu-equivalent water types: a) combined, b) primary, c) secondary and d) tertiary in the 2017–18 wet season (22 weeks). The highest frequency is shown in orange and the lowest frequency is shown in blue.

The seasonal map showing the frequency of S3-FU 'equivalent' water types showed patterns similar to the MA-WS map (Figure B-9). These maps were in agreement with historical trends and showed highest frequency of the primary water type in the enclosed coastal areas, and the offshore areas and ecosystems most frequently exposed only to the tertiary water type. The main difference was for the tertiary water type, with S3-FU frequency maps showing more extended and frequent areas of tertiary-equivalent waters than the MA-WS frequency maps. However, Both the MA-WS and S3-FU tertiary water types were characterised by the lower TSS, Chl-*a* and CDOM concentrations of all water types (Figure B-9).

B-4 Discussion

This study confirmed the usefulness of the colour of the ocean retrieved from satellite imagery as an integral water quality indicator. It highlighted the potential of using Sentinel-3 OLCI imagery and the FU satellite toolbox for the mapping of flood water bodies in nearshore marine environments. The S3-FU maps support the monitoring of sediment transport and water clarity in the Reef and provide spatial datasets that can be used in conjunction with (or in the future rather than) the MA-WS maps to study the water quality of the Reef. Both the MA-WS and S3-FU maps provide simple and appealing water quality indicators for inclusion into water quality monitoring programs, as illustrated by the different monitoring outputs presented in this study.

Despite their technical and methodological differences (Table B-1), the MA-WS and S3-FU maps and derived monitoring products showed very similar patterns across the Wet Tropics and Burdekin regions of the Reef over the 2017–18 wet season (Figure B-3 to Figure B-9). This study covered a large range of water colours and proved the monitoring capability and similarity of these satellite ocean colour products by relating them to field water quality measurements (Figure B-6). More *in-situ* water quality data will need to be collected in the future to validate these preliminary results, and especially in the FU colour classes greater than 15 (estuarine to coastal turbid waters) where few or no water quality data were collected (Figure B-9).

As more field water quality data become available to calibrate the FU colour classes in the Reef, it will be possible to include S3-FU maps and derived monitoring products in studies aiming to assess drivers of the reduction in water clarity in the Reef. Because of the greater number of colour classes (21 colours versus 6 for the WS scale: Table B-1), the FU scale gives greater details than the WS scale on processes occurring within the very near-shore and river flood plume mixing fronts where the coarser sediments flocculate; but also in the greenish to blueish flood waters which are the more likely to reach the Reef mid-shelf and outer-shelf (Figure B-5).

Longer time series of water quality concentrations and FU colour classes will provide the data needed to re-cluster the S3-FU colour classes into more specific water types that capture phytoplankton production (for example, by subdividing the primary water type into different sub-water types).

In the future, it will also be possible to compare these water quality concentrations to ecologically-relevant water quality thresholds and to use these data in *magnitude x likelihood* risk frameworks to develop exposure maps and ecological risk-based assessments as already developed from the MA-WS data (e.g. Waterhouse et al., 2017 and Figure B-3e, f). This will help to further quantify the impact of floods and land-sourced pollutants on local ecosystems, including seagrasses and coral reefs (e.g. Petus et al., 2016).

Table B-1: Comparison of MA-WS and S3-FU characteristics.

Characteristics	***MA-WS***	***S3-FU***
Cost	Free	Free
Temporal coverage	Aqua since 2002 (Terra since 2000)	Since 2016 (Sentinel-3A) 2018 (Sentinel-3B)
Spatial resolution	500 m	300 m
Spatial Coverage	Whole Reef, regional	Whole Reef, regional
Repetitivity	1 per day (aqua only, 2 per day if using aqua and terra)	2 or 3 per week (sentinel-3A only), ~1 per day (Sentinel-3A + 3B, from 2018)
Classification scheme	Supervised classification using typical colour (HIS signatures) of flood plumes in the Reef (Alvarez-Romero et al., 2013)	Converts satellite normalized multi-band reflectance FU categories using uniform colourimetric functions (Wernand et al., 2012)
Atmospheric corrections	No	Yes
Number of colour classes	6	21
Applicability	Reef-specific Wet season flood waters only	Universal All surface water bodies
Phone App.	No	Yes: EOW App.

Dry season FU maps and monitoring products can be derived from Sentinel-3 data and the inclusion of dry season along with wet season monitoring products is another important step toward fully understanding the response of Reef ecosystems to flood waters, turbidity and land-sourced pollutant exposure.

Finally, FU colour scores could be calculated for each region of the Reef to study changes between colours at a range of time periods (weekly, seasonal, year-to-year) and geographical scales (sub-regional, catchment, regional). A preliminary example of such a metric is presented in Petus et al (in review).

We recommend inclusion of Sentinel-3 FU maps, but also of smartphone-derived FU measurements in future MMP reporting. The EOW App. available with the FU toolbox provides site measurements of the water colour that can be integrated with S3-FU data (Figure B-6b) and visualised on a map online (http://www.eyeonwater.org). Such field information will help ground-truth the Sentinel satellite information and can be used during cloudy conditions when satellite retrievals are impossible, which can be particularly useful in areas prone to persistent cloud cover, such as the Reef.

We recommend the collection of EOW App. measurements along with other water quality measurements routinely measured in the MMP. EOW App. data can be collected by citizen scientists and everyday visitors of the Reef and it is expected that the inclusion of citizen science would expand the outputs and reach of the MMP and other similar water quality-monitoring programs worldwide in the future.

B-5 Summary and conclusions

The colour of the ocean is one of the most simple and appealing indicators available to study the water composition of our ocean. Only few monitoring programs have focused on using the water colour retrieved from satellite imagery as an integral water quality indicator, but this simple optical parameter has been successfully implemented and operationalised over the last five years into the water quality component of the MMP using MODIS satellite imagery. However, the quality of MODIS satellite imagery is declining due to their increasing age, and this study tested and the possibility to transition the methods and products developed for the Reef to recent satellite platforms.

The study found that it is feasible to transition the methods from historical MODIS to the new Sentinel-3 satellites and from the WS colour scale to the freely available FU satellite and smartphone toolboxes for the future and continuous mapping of Reef waters. Preliminary results allowed clustering FU colour classes 1–5 (defined as waters with high light penetration,) into secondary (FU 4 -5) and tertiary (FU 1 - 3) equivalent water types and FU colour classes ≥ 10 (defined as coastal waters with high phytoplankton levels and increasing sediment and dissolved organic matter) as primary-equivalent water type. More *in-situ* water quality data will need to be collected in the future to validate these preliminary results.

The EOW App. available with the FU Satellite Toolbox is not yet trialled in the MMP but can provide site measurements of the water colour that can be integrated with the satellite S3-FU data. From 2019, EOW App. measurements will be collected along with other water quality measurements routinely measured in the MMP with a particular focus on periods of high river discharge and flood events. In conjunction with in-situ water quality measurements collected, this dataset will help further characterise Chl-*a*, CDOM, TSS, light typically associated with the respective FU colours across the Reef waters.

The colour of the ocean as retrieved by the MODIS or Sentinel satellites provides a lot of valuable water quality information and is expected in the future to help local authorities focus on areas with the highest risk of ecosystem impact, improve marine spatial planning for regional and governmental authorities, while also achieving engagement and educational goals.

B-6 References

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Appendix C: Water quality site locations and frequency of monitoring

Table C-1 lists all the stations included in the MMP, distinguishing the routine and reactive event sampling. The proposed number of visits to each station in the program design is shown in each column, with the number of actual visits shown in brackets in red text. The Cape York sampling program did not commence formally until April 2017 (due to delayed contracting arrangements with the Authority), although sampling commenced earlier where possible. Weather conditions also restricted access to the Normanby-Kennedy and Pascoe transects during the wet season.

Table C-1: Description of the water quality stations sampled by AIMS, JCU and CYWMP during 2017–18. Stations in bold font were part of the ambient monitoring design from 2005 to 2015. The proposed number of visits is shown in black text, while the actual number of visits is shown in brackets in red text.

Site Location	**Logger Deployment**		**Routine grab samples at fixed sites (proposed and actual)**		**Reactive event sampling**
NRM region	**Turbidity and chlorophyll**	**Salinity**	**Number of times site is visited/year by AIMS**	**Number of times site is visited/year by JCU/ CYWMP**	**Additional surface-sampling/year by JCU/ CYWMP**
Cape York					
Normanby-Kennedy transect					* (specific sites TBD)
Kennedy mouth				4 (Sampling 1 depth) (3)	
Kennedy inshore				4 (Sampling 2 depths) (2)	
Cliff Islands				4 (Sampling 2 depths) (4)	
Bizant River mouth				4 (Sampling 1 depth) (4)	
Normanby River mouth				4 (Sampling 2 depths) (4)	
Normanby inshore				4 (Sampling 2 depths) (3)	
NR-03				4 (Sampling 2 depths) (3)	
NR-04				4 (Sampling 2 depths) (3)	
NR-05				4 (Sampling 2 depths) (3)	
Corbett Reef				4 (Sampling 2 depths) (2)	
Pascoe transect					* (specific sites TBD)
Pascoe mouth north				6 (Sampling 2 depths) (3)	(3)
Pascoe mouth south				6 (Sampling 2 depths) (3)	(4)
PR-02				6 (Sampling 2 depths) (3)	(2)
PR-03				6 (Sampling 2 depths) (3)	(1)
PR-04				6 (Sampling 2 depths) (3)	(1)
PR-05				6 (Sampling 2 depths) (3)	(1)
Middle Reef				6 (Sampling 2 depths) (2)	(1)
Additional sites/ flood samples				(1)	(15)
Annan and Endeavour transect					* (specific sites TBD)
Annan mouth				6 (Sampling 2 depths) (3)	(3)
Walker Bay				6 (Sampling 2 depths) (2)	(3)
Dawson Reef				6 (Sampling 2 depths) (2)	(3)
Endeavour mouth				6 (Sampling 2 depths) (3)	(6)
Endeavour north shore				6 (Sampling 2 depths) (3)	(3)
Endeavour offshore				6 (Sampling 2 depths) (3)	(3)
Egret and Boulder Reef				6 (Sampling 2 depths) (3)	(2)
Big Unchartered Reef (no longer sampled)				6 (Sampling 2 depths) (0)	
Additional sites					(5)
Stewart transect					* (specific sites TBD)
Stewart mouth				6 (Sampling 2 depths) (6)	1

Site Location	**Logger Deployment**		**Routine grab samples at fixed sites (proposed and actual)**		**Reactive event sampling**
NRM region	**Turbidity and chlorophyll**	**Salinity**	**Number of times site is visited/year by AIMS**	**Number of times site is visited/year by JCU/ CYWMP**	**Additional surface-sampling/year by JCU/ CYWMP**
SR-02				6 (Sampling 2 depths) (6)	
SR-03				6 (Sampling 2 depths) (6)	
SR-04				6 (Sampling 2 depths) (6)	
Hannah Island				6 (Sampling 2 depths) (4)	
Additional site					1
Wet Tropics					
Cairns Long-term transect				0	
Cape Tribulation			3 (Sampling 2 depths) (3)		
Port Douglas			3 (Sampling 2 depths) (3)		
Double Island			3 (Sampling 2 depths) (3)		
Yorkey's Knob			3 (Sampling 2 depths) (3)		
Fairlead Buoy			3 (Sampling 2 depths) (3)		
Green Island			3 (Sampling 2 depths) (3)		
Russell-Mulgrave Focus Area					
Fitzroy Island West	√		6 (Sampling 2 depths) (5)		
RM2					** (Surface sampling only) (3)
RM3			6 (Sampling 2 depths) (5)	6 (Sampling 2 depths) (6)	
RM4					** (Surface sampling only) (3)
High Island East					** (Surface sampling only) (3)
Normanby Island					** (Surface sampling only) (3)
Frankland Group West (Russell Island)	√		6 (Sampling 2 depths) (5)	6 (Sampling 2 depths) (6)	
High Island West	√	√	6 (Sampling 2 depths) (5)	6 (Sampling 2 depths) (6)	
Palmer Point					** (Surface sampling only) (3)
Russell-Mulgrave River mouth mooring	√	√	6 (Sampling 2 depths) (5)	6 (Sampling 2 depths) (6)	
Russell-Mulgrave River mouth					** (Surface sampling only) (3)
Russell-Mulgrave junction [River]					** (Surface sampling only) (3)
Tully Focus Area					
King Reef				1	** (Surface sampling only) (10)
East Clump Point			6 (Sampling 2 depths) (5)	6 (Sampling 2 depths) (6)	
Dunk Island North	√	√	6 (Sampling 2 depths) (5)	6 (Sampling 2 depths) (6)	
South Mission Beach					** (Surface sampling only) (10)
Dunk Island South East			6 (Sampling 2 depths) (5)	6 (Sampling 2 depths) (6)	
Between Tam O'Shanter and Timana			6 (Sampling 2 depths) (5)	6 (Sampling 2 depths) (6)	
Hull River mouth					** (Surface sampling only) (10)
Bedarra Island			6 (Sampling 2 depths) (5)	6 (Sampling 2 depths) (6)	
Triplets					** (Surface sampling only) (10)
Tully River mouth mooring	√	√	6 (Sampling 2 depths) (5)	6 (Sampling 2 depths) (6)	
Tully River					** (Surface sampling only) (10)
Burdekin					
Burdekin Focus Area					
Pelorus and Orpheus Island West	√		4 (Sampling 2 depths) (4)	5 (Sampling 2 depths) (5)	
Pandora Reef	√		4 (Sampling 2 depths) (4)	5 (Sampling 2 depths) (5)	
Cordelia Rocks					** (Surface sampling only) (2)

Site Location	Logger Deployment		Routine grab samples at fixed sites (proposed and actual)		Reactive event sampling
NRM region	Turbidity and chlorophyll	Salinity	Number of times site is visited/year by AIMS	Number of times site is visited/year by JCU/ CYWMP	Additional surface-sampling/year by JCU/ CYWMP
Magnetic Island (Geoffrey Bay)	√		3 (Sampling 2 depths) (4)	5 (Sampling 2 depths) (5)	
Inner Cleveland Bay					** (Surface sampling only) (2)
Cape Cleveland					** (Surface sampling only) (2)
Haughton 2			2 (Sampling 2 depths) (4)	5 (Sampling 2 depths) (5)	
Haughton River mouth					** (Surface sampling only) (2)
Barratta Creek					** (Surface sampling only) (2)
Yongala IMOS NRS	√	√	11 (Sampling 2 depths) (12)		
Cape Bowling Green					** (Surface sampling only) (2)
Plantation Creek					** (Surface sampling only) (2)
Burdekin River mouth mooring	√	√	2 (Sampling 2 depths) (5)	5 (Sampling 2 depths) (5)	
Burdekin Mouth 2					** (Surface sampling only) (2)
Burdekin Mouth 3					** (Surface sampling only) (2)
Mackay Whitsunday					
Whitsunday focus area					
Double Cone Island	√		5 (Sampling 2 depths) (5)		
Hook Island W					** (Surface sampling only)
North Molle Island					** (Surface sampling only)
Pine Island	√		5 (Sampling 2 depths) (5)		
Seaforth Island	√		5 (Sampling 2 depths) (5)		
OConnell River mouth			5 (Sampling 2 depths) (5)		
Repulse Islands dive mooring	√	√	5 (Sampling 2 depths) (5)		
Rabbit Island NE					** (Surface sampling only)
Brampton Island					** (Surface sampling only)
Sand Bay					** (Surface sampling only)
Pioneer River mouth					** (Surface sampling only)

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Appendix D: Water quality monitoring methods

D-1 Comparison with Reef Water Quality Guideline values

The Water Quality Guidelines provide a useful framework to interpret the water quality measurements obtained through the MMP. Table D-1 gives a summary of the Guideline Values (GVs) for water quality variables in four cross-shelf water bodies (Great Barrier Reef Marine Park Authority, 2010). The MMP program design prior to 2015 included sites in the open coastal and midshelf water bodies. The MMP program design post-2015 now includes sites from all four water bodies.

At present, the Water Quality Guidelines do not define GVs for dissolved inorganic nutrients (nitrate and phosphate) in the Reef lagoon as these nutrients are rapidly cycled through uptake and release by biota and are variable on small spatial and temporal scales (Furnas et al., 2005, 2011). Due to this high variability, their concentrations did not show as clear spatial patterns or correlations with coral reef attributes as the other water quality parameters that were included in the Guidelines and are considered to be more representative of nutrient availability integrated over time (De'ath and Fabricius, 2010). However, the Queensland Water Quality Guidelines (Department of Environment and Resource Management [DERM], 2009) identify GVs for dissolved inorganic nutrients in marine water bodies. Guideline values for dissolved inorganic nutrients and turbidity (in enclosed coastal waters) were drawn from Queensland Water Quality Guidelines (Table D-1). Site-specific GVs for all water quality variables are shown in Table E-10.

Table D-1: Guidelines values for four cross-shelf water bodies from the Water Quality Guidelines for the Great Barrier Reef Marine Park (Great Barrier Reef Marine Park Authority, 2010). Guidelines for some values come from the Queensland Water Quality Guidelines, as indicated below.

		Enclosed coastal		Open coastal		Midshelf		Offshore	
Parameter	Unit	Wet Tropics	Central Coast	Wet Tropics	Central Coast	Wet Tropics	Central Coast	Wet Tropics	Central Coast
Chlorophyll *a*	µg L^{-1}	2.0	2.0	0.45	0.45	0.45	0.45	0.40	0.40
Particulate nitrogen	µg L^{-1}	n/a	n/a	20.0	20.0	20.0	20.0	17.0	17.0
Particulate phosphorus	µg L^{-1}	n/a	n/a	2.8	2.8	2.8	2.8	1.9	1.9
Suspended solids	mg L^{-1}	5.0	15.0	2.0	2.0	2.0	2.0	0.7	0.7
Turbidity	NTU	10.0^{QLD}	6.0^{QLD}	1.5*	1.5*	1.5*	1.5*	<1^{Qld}	<1^{Qld}
Secchi depth	m	1.0	1.5	10.0	10.0	10.0	10.0	17.0	17.0
NO$_x$	µg L^{-1}	10.0^{QLD}	3.0^{QLD}	2.0^{QLD}	3.0^{QLD}	2.0^{QLD}	2.0^{QLD}	2.0^{QLD}	2.0^{QLD}
PO$_4$	µg L^{-1}	5.0^{QLD}	6.0^{QLD}	4.0^{QLD}	6.0^{QLD}	4.0^{QLD}	6.0^{QLD}	4.0^{QLD}	5.0^{QLD}

^{QLD} This superscript indicates these values are Queensland Water Quality Guidelines (Department of Environment and Resource Management [DERM], 2009). Please note these are 80th percentile guidelines.

* The turbidity trigger value for open coastal and mid-shelf water bodies (1.5 NTU) was derived for the MMP reporting by transforming the suspended solids GVs (2 mg L^{-1}) using an equation based on a comparison between direct water samples and instrumental turbidity readings (see Appendix E and Schaffelke et al., 2009).

D-2 Summary statistics and time-series analysis

Values for water quality parameters at each monitoring location were calculated as depth-weighted means by trapezoidal integration of the data from discrete sampling depths. For sites where two samples were taken vertically in the water column (i.e., surface and bottom samples), this method averages these values to derive the depth-weighted mean. Summary statistics for all water quality variables are presented for all monitoring sites in Appendix E.

Concentrations were compared to GVs (Table E-10) for the following water quality constituents: Chl-*a*, PN, PP, TSS, Secchi depth, NO_x and PO_4.

Trends in key water quality variables (Chl-*a*, TSS, Secchi depth, turbidity, NO_x, PN and PP) over time are reported on a regional or sub-regional level. The Wet Tropics NRM region was divided into three sub-regions to reflect the different catchments influencing part of the region: Barron Daintree sub-region, Johnstone Russell-Mulgrave sub-region and Herbert Tully sub-region. The Burdekin and Mackay Whitsunday NRM regions were reported on regional levels using the marine boundaries of each NRM region, as provided by the Authority.

Generalised additive mixed effects models (GAMMs) were used to decompose each irregularly spaced time-series into its trend cycles (long-term) and periodic (seasonal) components (Wood, 2006). GAMMs are an extension of additive models (which allow flexible modelling of non-linear relationships by incorporating penalised regression spline types of smoothing functions into the estimation process), where the degree of smoothing of each smooth term (and by extension, the estimated degrees of freedom of each smoother) is treated as a random effect and thus estimable via its variance as with other effects in a mixed modelling structure (Wood, 2006). For each water quality variable within each region or sub-region, the variable was modelled against a thin-plate smoother for date and a cyclical cubic regression spline (maximum of 5 knots) for each month of the year. Spatial and temporal autocorrelation in the residuals was addressed by including sampling locations as a random effect and imposing a first order continuous-time auto-regressive correlation structure (Pinheiro and Bates, 2000).

Water quality measurements are likely to be influenced by the oceanographic conditions at the time of sampling. For variables that are sampled infrequently, variations in these physical conditions can add substantial noise to the data that can reduce detection and confidence in the underlying temporal signals.

All GAMMs were fitted using the mgcv (Wood 2006, 2011) package in R 3.0.1 (R Development Core Team, 2013).

D-3 Calculation of the Water Quality Index

In the Great Barrier Reef Report Cards published prior to 2016, water quality assessments were based on the MMP broad-scale monitoring using ocean colour remote sensing imagery that covers a larger area than the fixed sampling locations reported here (Brando et al., 2011). A recent project completed a proof-of-concept for an integrated assessment framework for the reporting of Reef water quality using a spatio-temporal statistical process model that combines all MMP water quality data and discussed reasons for differences between the different measurement approaches (manual sampling, *in-situ* data loggers, remote sensing; Brando et al., 2014). However, for this report, the focus is on interpreting trends in site-specific water quality, which is well described by the instrumental monitoring of turbidity and chlorophyll and by the parallel manual sampling of a suite of variables (e.g., nutrients, dissolved and suspended organic matter, suspended particulates) that influence the health, productivity and resilience of coral reefs.

The Water Quality Index (WQ Index) was developed by AIMS as a tool to interpret the status and trend in water quality variables measured by the MMP, and to compare monitored water quality to existing Water Quality GVs (Department of Environment and Resource Management, 2009; Great Barrier Reef Marine Park Authority, 2010). The WQ Index uses a set of five key indicators:

- Water clarity (TSS concentrations, Secchi depth, and turbidity measurements by FLNTUSB instruments, where available)
- Chl-*a* concentrations

- PN concentrations
- PP concentrations
- NO_x concentrations.

These five indicators are a subset of the comprehensive suite of water quality variables measured in the MMP inshore water quality program. They have been selected because GVs are available for these measures and they can be considered as relatively robust indicators that integrate a number of bio-physical processes in the coastal ocean.

TSS concentration, turbidity, and Secchi depth are indicators of the clarity of the water, which is influenced by a number of factors, including wind, waves, tides, and river inputs of particulate material. Chl-*a* concentration is widely used as a proxy for phytoplankton biomass as a measure of the productivity of a system or its eutrophication status and is used to indicate nutrient availability (Brodie et al., 2007). Particulate nutrients (PN, PP) are an indicator of nutrient stocks in the water column (predominantly bound in phytoplankton and other organic particles as well as adsorbed to fine sediment particles) but are less affected by small-scale variability in space and time than dissolved nutrients (Furnas et al., 2005, 2011). Nitrate is included as an indicator of dissolved nutrient concentrations in the coastal zone, which tend to be rapidly used by phytoplankton. Guideline values for NO_x from Queensland Water Quality Guidelines (Table D-1) are the 80th percentiles, which are considered to be high compared to the values normally found in the Reef lagoon. Therefore, compliance with the Queensland GVs does not properly reflect changes in the NO_x concentrations. Despite these limitations, we believe it is valuable to include NO_x concentrations in the WQ Index. A review of GVs for NO_x may be necessary to increase the reliability of the WQ Index.

The WQ Index is calculated using two different methods due to changes in the MMP design that occurred in 2015, as well as concerns that the Index was not responsive to changes in environmental pressures of each year. The changes in design included increased number of sites, increased sampling frequency and a higher sampling frequency during December to April to better represent wet season variability. Thus, statistical comparisons between MMP data from 2005–15 to 2015–onwards must account for these changes. The two versions of the WQ Index have different purposes.

`Long-term trend`: This version of the WQ Index is based on the pre-2015 MMP sampling design and uses only the original sites and three sampling dates per year. This sampling design had low temporal and spatial resolution and was aimed at detecting long-term trends in inshore water quality. To compensate for less frequent sampling, four-year running means are used to reduce the effect of sampling date on the Index. This version of the WQ Index is different to what was reported by Schaffelke et al. (2012) as we now include a scaling step that moves beyond a simple binary compliance vs non-compliance assessment. Steps in the calculation of this version of the WQ Index are:

1. Calculate four-year mean values for each of the seven indicators (i.e., all values from 2005–08, 2006–09, 2007–10, 2008–11, 2009–12, 2010–13 and 2011–14).

2. Calculate the proportional deviations (ratios) of these running mean values (V) from the associated GV (Table D-1) as the difference of binary logarithms (log_2 n) of values and guidelines:

   Ratio = log_2V - log_2 guideline

   Binary logarithm transformations are useful for exploring data on powers of 2 scales, and thus are ideal for generating ratios of two numbers in a manner that will be symmetrical around 0. Ratios of 1 and -1 signify a doubling and a halving, respectively, compared to the guideline. Hence, a ratio of 0 indicates a running mean that is the same as its GV, ratios <0 signify running means that exceeded the GV and ratios >0 signify running means that complied with the GV.

3. Ratios exceeding 1 or -1 (more than twice or half the GV) were capped at 1 to bind the WQ Index scales to the region -1 to 1.

4. A combined water clarity ratio was generated by averaging the ratios of Secchi depth, TSS and turbidity (where available).

5. The WQ Index for each site per four-year period was calculated by averaging the ratios of PP, PN, NO_x, Chl-*a* and the combined water clarity ratio.

6. In accordance with other Great Barrier Reef Report Card indicators, the WQ Index scores (ranging from -1 to 1) were converted to a 'traffic light' colour scheme for reporting whereby:

   a. < -0.66 to -1 equates to 'very poor' and is coloured red

   b. < -0.33 to -0.66 equates to 'poor' and is coloured orange

   c. < 0 to -0.33 equates to 'moderate' and is coloured yellow

   d. > 0 to 0.5 equates to 'good' and is coloured light green

   e. > 0.5 to 1 equates to 'very good' and is coloured dark green.

7. For the regional or sub-regional summaries, the Index scores of all sampling locations within a (sub-) region were averaged and converted into the colour scheme as above.

Annual condition: This version of the WQ Index is based on the post-2015 MMP sampling design and uses all sites and sampling dates per year. Due to high spatial and temporal sampling, a running mean is not used. Monitoring data are compared against site-specific GVs that include wet and dry season GVs (Table E-10). Steps in the calculation of this version of the WQ Index are:

1. For each of the seven indicators, the annual, wet and dry season (aggregations) means and medians (statistic) are calculated per year.

2. Guidelines from the Authority are consulted to select the appropriate aggregation (annual, wet, or dry season) and statistic (mean or median) for each site and indicator (Table E-10).

3. Calculate the proportional deviations (ratios) of these aggregation statistics from the associated GVs as the difference of base 2 logarithms (log_2 n) of values and GVs:

   Ratio = log_2V - log_2 guideline.

4. Ratios exceeding 1 or -1 (more than twice or half the GV) were capped at 1 to bind the WQ Index scales to the region -1 to 1.

5. A combined water clarity ratio was generated by averaging the ratios of Secchi depth, TSS concentration and turbidity (where available).

6. The WQ Index for each site was calculated by averaging the ratios of PP, PN, NO_x, Chl-*a* and the combined turbidity ratio.

7. In accordance with other Reef Report Card indicators (see Anon, 2011), the WQ Index scores (ranging from -1 to 1) were converted to a 'traffic light' colour scheme for reporting whereby:

   a. < -0.66 to -1 equates to 'very poor' and is coloured red

   b. < -0.33 to -0.66 equates to 'poor' and is coloured orange

   c. < 0 to -0.33 equates to 'moderate' and is coloured yellow

   d. > 0 to 0.5 equates to 'good' and is coloured light green
   e. > 0.5 to 1 equates to 'very good' and is coloured dark green.

8. For the regional or sub-regional summaries, the Index scores of all sampling locations within a region or sub-region, respectively, were averaged and converted into the colour scheme as above.

The annual condition version of the WQ Index has only been calculated since 2016 and is subject to future revision and refinement.

The WQ Guideline values used for each sampling site are shown in Appendix E, Table E-10.

D-4 Mapping of wet season water types

Remote sensing imagery is a useful assessment tool in the monitoring of turbidity and river flood plumes (hereafter river plumes) in the Reef lagoon. Combined with *in-situ* water quality sampling, the use of remote sensing is a valid and practical way to estimate wet season marine conditions as well as the extent and frequency of wet season water type (including river plumes) exposure on Reef ecosystems. Ocean colour imagery provides synoptic-scale information regarding the movement and composition of turbid waters. Thus, in the past nine years, remote sensing imagery combined with *in-situ* sampling of river plumes has provided an essential source of data related to the movement and composition of wet season water types, including river plumes, in Reef waters (e.g., Bainbridge et al., 2012; Devlin et al.; 2012a, b; Schroeder et al., 2012).

Following recommendations from the 2012–13 MMP report, marine areas exposed wet season water types are mapped using MODIS true colour (TC) images and the TC method extensively presented in Álvarez-Romero et al. (2013) and used in, for example, Devlin et al. (2013) and Petus et al. (2014b). The TC method is based on classification of spectrally enhanced quasi-true colour MODIS images (Álvarez-Romero et al., 2013). This method exploits the differences in colour existing between the turbid coastal waters (including river plumes) and the marine ambient water, and between respective wet season water types existing across coastal waters, including river plumes (Álvarez-Romero et al., 2013).

The wet season water types are produced using MODIS true colour imagery reclassified to six distinct colour classes defined by their colour properties (Figure D-1). The wet season colour classes are regrouped into three water types (primary, secondary and tertiary) characterised by different concentrations of optically active components (TSS, colour dissolved organic matter and Chl-*a*), which control the colour of the water and influence the light attenuation, and different pollutant concentrations.

The brownish to brownish-green turbid waters (colour classes 1 to 4 or primary water type) are typical for inshore regions experiencing river plumes or nearshore marine areas with high concentrations of resuspended sediments found during the wet season. These water bodies in flood waters typically contain high nutrient and phytoplankton concentrations but are also enriched in sediment and dissolved organic matter resulting in reduced light levels. The greenish-to-greenish-blue turbid waters (colour class 5 or secondary water type) is typical of coastal waters rich in algae (Chl-*a*) and contain dissolved matter and fine sediment. This water body is found in open coastal waters as well as in the mid-water plumes where relatively high nutrient availability and increased light levels due to sedimentation (Bainbridge et al., 2012) favour coastal productivity. Finally, the greenish-blue waters (colour class 6 or tertiary water type) correspond to waters with above ambient water quality concentrations. This water body is typical for areas towards the open sea or offshore regions of river flood plumes.

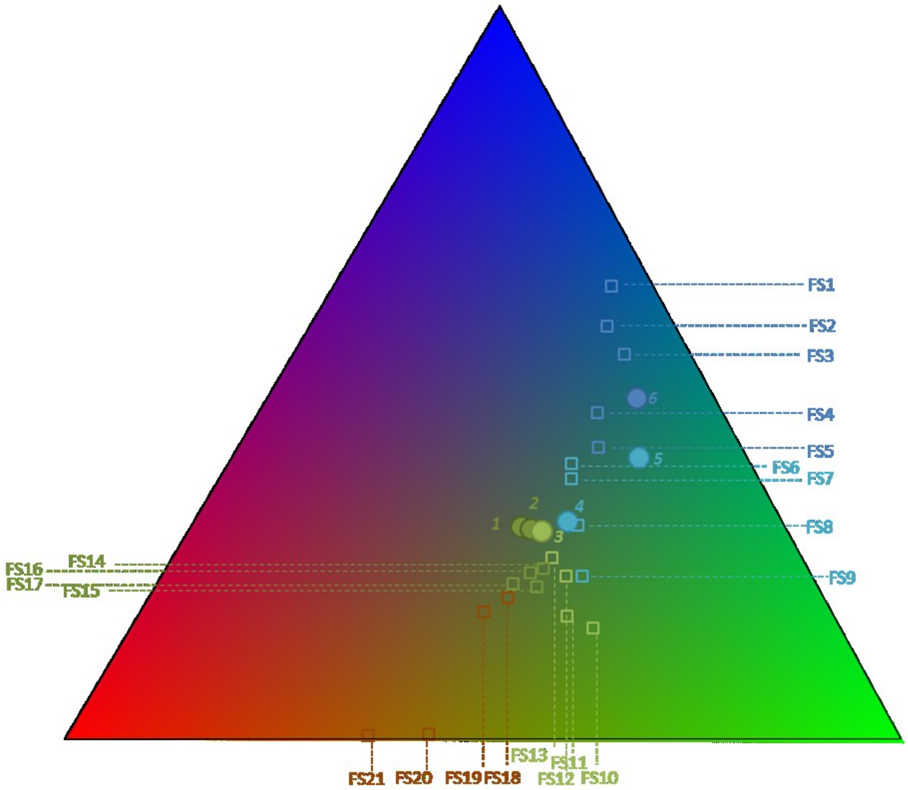

Figure D-1: Triangular colour plot showing the characteristic colour signatures of river plume waters (1 to 6) in the Red-Green-Blue (RGB or true colour) space, compared to approximate RGB colour of the Forel-Ule scale, a colour comparator used to estimate the colour of natural waters since the 19th century. FS1-5: Indigo blue to greenish blue waters with high light penetration. These waters have often low nutrient levels and low production of biomass and the colour is dominated by microscopic algae (phytoplankton). FS6-9: Greenish blue to bluish green waters. This water colour is still dominated by algae, but also increased dissolved matter and some sediment may be present and is typical for areas towards the open sea. FS10-13 scale: Greenish waters, often coastal, which usually display increased nutrient and phytoplankton levels, but also contain minerals and dissolved organic material. FS14-17 scale: Greenish brown to brownish green waters. Waters usually characterised by high nutrient and phytoplankton concentrations, but also increased sediment and dissolved organic matter. This water colour is typical for near-shore areas and tidal flats. FS18-21 scale: Brownish green to cola brown waters. Waters with an extremely high concentration of humic acids, which are typical for rivers and estuaries (source: http://www.citclops.eu/water-colour/measuring-water-colour; Novoa, 2014; Van der Woerd and Wernand, 2015; Wernand et al., 2013, 2014).

Supervised classification using spectral signatures

Daily MODIS Level-0 data are acquired from the NASA Ocean Colour website (http://oceancolour.gsfc.nasa.gov) and converted into true colour images with a spatial resolution of approximately 500 × 500 m using SeaWiFS Data Analysis System (SeaDAS; Baith et al., 2001). The true-colour images are then spectrally enhanced (from red-green-blue to hue-saturation-intensity colour system) and classified to six colour categories through a supervised classification using spectral signatures from plume water in the Reef lagoon. The six colour classes are further reclassified into three wet season water types (primary, secondary and tertiary) corresponding to the three wet season water types, as described above and defined originally by Devlin and Schaffelke (2009) and Devlin et al. (2012a).

Production of weekly wet season water type maps

This supervised classification is used to classify daily MODIS images (focused on the summer wet season, i.e., December to April inclusive). Weekly wet season water type composites are then created to minimise the image area contaminated by dense cloud cover and intense sun glint (Álvarez-Romero et al., 2013). The minimum colour-class value of each cell/week is used to map the colour class with the highest level of exposure to pollutants for each week (i.e., assuming the colour classes represented a gradient in exposure to pollutants i.e., CC1 > CC2 > CC3 > CC4 > CC5 > CC6).

Production of annual and multi-annual wet season water type maps

Weekly wet season water type composites are thus overlaid in ArcGIS (i.e., presence/absence of ’this’ wet season water type) and normalised, to compute annual normalised frequency maps of occurrence of wet season water type. Pixel (or cell) values of these maps range from 1 to 22; with a value of 22 meaning that ‘this’ pixel has been exposed 22 weeks out of 22 weeks of ‘this’ years’ wet season (December to April 2003 to 2015) to ‘this’ plume. Finally, annual frequency maps are normalised (0-1) overlayed in ArcGIS to create multi-annual (2003–17) normalised frequency composites of occurrence of wet season water types.

Water quality concentrations during the wet season

Additional information on wet season conditions can be reported by characterising the water quality concentrations across colour class and water types. Match-ups between sampled date and corresponding weekly wet season water type maps are performed at site location basis. using the *extract tool of* the raster package (Hijmans et al., 2015) with bilinear interpolation method in R 3.2.4. This tool interpolates from the values of the four nearest raster cells (R Development Core Team, 2015). Several land-sourced pollutants are investigated through match-ups between *in-situ* data and the six colour class maps, including DIN, PO_4, PP, PN, TSS, Chl-*a*, CDOM and K_D or Secchi depth and the mean, standard deviation, minimum, maximum values for each pollutant across colour classes and water types are calculated

D-5 Estimating the level of exposure of Reef ecosystems (coral reefs and seagrass meadows) to degraded (above guideline) water-quality conditions during the wet season

The satellite derived water quality maps (see Section 2.6) can be overlaid with information on the presence or distribution of ‘contamination receptors’, i.e., Reef ecosystems susceptible to the land-sourced pollutants. This method can help identify ecosystems which may experience acute or chronic high exposure to land-sourced pollutants. For example, Petus et al. (2014b) mapped the occurrence of very turbid water masses (primary water type) in Cleveland Bay (Burdekin marine region) in each wet season between 2007 and 2011 and compared the results to MMP seagrass health monitoring data. This analysis indicated that the decline in seagrass meadow area and biomass were positively linked to high occurrence of primary water type and confirmed the impact that decreased clarity can have on seagrass health in the Reef lagoon. Similarly, Petus et al. (2014a, 2016) proposed different frameworks to estimate the exposure and potential risk from exposure. The methods for estimating the level of exposure of Reef ecosystems (coral reefs and seagrass meadows) to over guideline water quality condition during the wet season are derived from these studies.

Mapping the exposure to degraded water quality conditions during the wet season

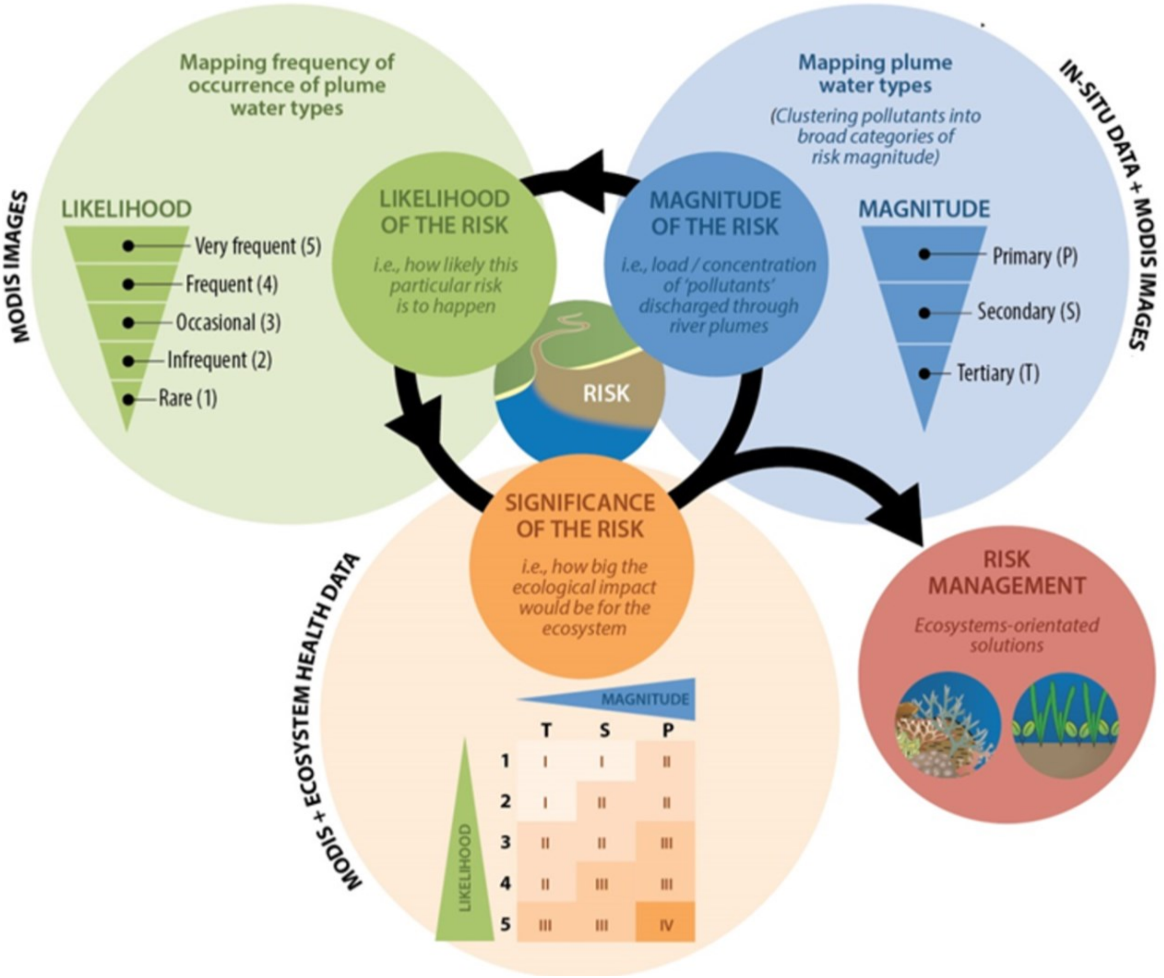

Figure D-2: Conceptual scheme of the risk framework proposed in Petus et al. (2014a).

In the MMP reports before 2015–16, the ‘potential risk’ was assessed as exposure to land-sourced pollutants concentrated in river plume waters (Figure D-2). ‘The magnitude of the risk’ corresponded to the concentration of pollutant discharged through the river plume and mapped through the primary, secondary and tertiary plume water types. The ‘likelihood of the risk’ was estimated by calculating the frequency of occurrence of each wet season water type. The potential risk from river plume exposure for Reef ecosystems was finally ranked (I to IV) assuming that ecological consequences increased linearly with the pollutant concentrations and frequency of exposure (Figure D-3). The potential risk categories were then a combination of the wet season water type (3 categories: primary, secondary and tertiary) and primary, secondary and tertiary frequency (five categories: 0–0.2, 0.2–0.4, 0.4–0.6, 0.6–0.8 and 0.8–1) and based on the risk matrix modified from Castillo et al. (2012) (Table D-2).

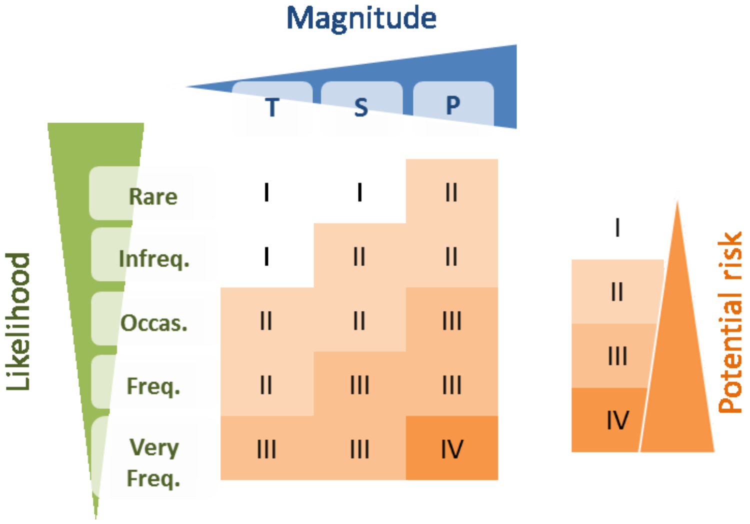

Figure D-3: Potential risk matrix in function of the magnitude and the likelihood of the river plume risk. Potential risk categories I, II, III, IV (modified from Petus et al., 2014b).

Table D-2: Frequency categories used to categorise the multi-annual maps of frequency of occurrence of plume water types (TC and L2 methods).

Likelihood	**Rare**	**Infrequent**	**Occasional**	**Frequent**	**Very frequent**
Frequency: number of weeks per wet season [normalised value]	1-4 [>0 – 0.2]	>4 – 8 [>0.2 – 0.4]	>8 – 13 [>0.4 – 0.6]	>13 – 17 [>0.6 – 0.8]	>17 – 22 [>0.8 – 1.0]

In a collaborative effort between the MMP monitoring providers (JCU water quality and seagrass teams and the AIMS coral monitoring team), an updated exposure assessment framework was developed in 2015–16 (modified from Petus et al., 2016), where the 'potential risk' corresponds to an exposure to above guideline concentrations of land-sourced pollutant during wet season conditions and focuses on the TSS, Chl-*a*, PP and PN concentrations. The *'magnitude of the exposure'* corresponds to the concentration of pollutants (proportional exceedance of the guideline) mapped through the primary, secondary and tertiary water types. The *'likelihood of the exposure'* is estimated by calculating the frequency of occurrence of each wet season water type. The exposure for each of the water quality parameters defined is as the proportional exceedance of the guideline multiplied by the likelihood of exposure in each of the wet season water type and calculated as below. For each cell (500 m x 500 m):

For each pollutant (Poll.) the exposure in each wet season water type (primary or secondary or tertiary, $Poll\_expo_{water\ type}$) is calculated:

$$Poll\_expo_{water\ type} = magnitude_{water\ type} \times\ likelihood_{water\ type}$$

$$magnitude_{water\ type} = ([Poll.]_{water\ type} - guideline)/guideline$$

$$likelihood_{water\ type} =\ frequency_{water\ type}$$

where $water\ type$ is the primary, secondary or tertiary wet season water types, $[Poll.]_{water\ type}$ is the wet season or long-term mean TSS, Chl-*a*, PN or PP concentration measured in each respective wet season water types and $guideline$ is the wet season Water

Quality Guidelines for TSS, Chl-*a*, PP and PN (2.4 mg L^{-1}, 0.63 µg L^{-1}, 3.3 µg $L^{-1}$and 25 µg L^{-1}, respectively).

For each pollutant, the total exposure ($Poll\_expo$) is calculated at the exposure for each of the wet season water types:

$$Poll\_expo = Poll\_expo_{Primary} + Poll\_expo_{Secondary} + Poll\_expo_{Tertiary}$$

The overall exposure score ($Score\_expo$) is calculated as the sum of the total exposure for each of the water quality parameters:

$$Score\_expo = TSS.\exp + Chla.exp + PP.\exp + PN.exp$$

Finally, the overall exposure score (ranging from 0 to 8) are categorised into four equal potential risk categories ([>0–3] = cat. I, [3–6] = cat. II, [6–9] = cat III and >9 = cat IV).

For example, using the long-term mean Chl-*a* values measured during high flow conditions in the primary, secondary and tertiary water type:

$$Chla\_exp_{Primary} = \frac{1.6-0.63}{0.63} \times frequency_{water\ type\ (0-1, cell-specific)}$$

$$Chla\_exp_{Secondary} = \frac{0.8-0.63}{0.63} \times frequency_{water\ type\ (0-1, cell-specific)}$$

$Chla\_exp_{Tertiary} = 0$ as chl levels are below the guideline for Chl-a;

The total exposure for Chl-*a*:

$$Chla\_expo = Chla\_expo_{Primary} + Chla\_expo_{Secondary} + Chla\_expo_{Tertiary}$$

Assessing the level of exposure of Reef ecosystems (coral reefs and seagrass meadows)

A risk does not exist unless (i) the stressor has the inherent ability to cause one or more adverse effects and (ii) it co-occurs or comes into contact with an ecological component (i.e., organisms, populations, communities, or ecosystems; US EPA, 1998) susceptible to the stressor. Ecological consequences of the risk will primarily be a function of the presence/absence of Reef ecosystems subjected to different occurrence and magnitude of risk (i.e., potential risk score).

Community characteristics such as the sensitivity and resilience of particular seagrass or coral communities, including the resilience associated with their natural levels of exposure to pollutants, are additional parameters that must be considered when scoring the risk from river plume exposure. However, the consequence of the exposure of species is complicated by the influence of the combined stressors and additional external influences including weather and climate conditions and the ecological significance of pollutant concentrations are mostly unknown at a regional or species level (Brodie et al., 2013).

In this report, the area (km^2) and percentage (%) of coral reefs and seagrass meadows affected by different categories of exposure are described. Areas and percentages of Reef waters and within the Wet Tropics, Burdekin and Mackay Whitsundays regions are also reported in recognition of other important habitats and populations that exist in these areas (Brodie et al., 2013). Figure D-4 presents the marine boundaries used for the Marine Park, each NRM region and the seagrass and coral reefs ecosystems. We assumed in this study that the shapefile can be used as a representation of the actual seagrass distribution. It is known, however, that absence on the composite map does not definitively equate to absence of seagrass and may also indicate unsurveyed areas.

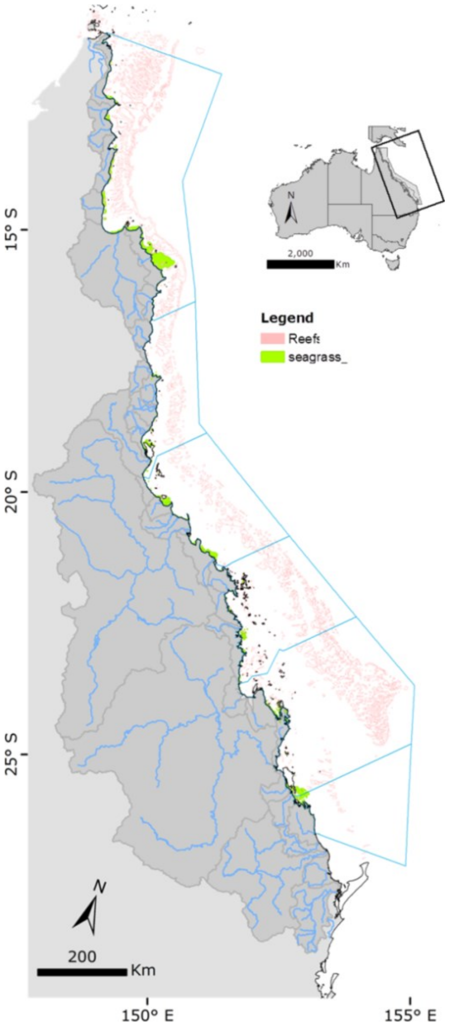

Figure D-4: Boundaries used for the Marine Park, each NRM region and the coral reefs and seagrass ecosystems. Coral reef and NRM layers derived from the Authority, supplied 2013. Seagrass layer is a composite of surveys conducted by Department of Agriculture and Fisheries, Qld.

D-6 Mapping the superficial dispersion of land-sourced nitrogen and sediment in the Great Barrier Reef: An Ocean Colour-based approach

An accurate quantification of DIN exposure in the Reef lagoon is highly desirable to identify the main areas under the highest exposure so that land-based management efforts can be targeted to specific regions. While previous studies have attempted to characterise the varying levels of DIN exposure within the Reef lagoon (e.g. Álvarez-Romero et al., 2013; Devlin et al., 2012a, 2012b), they have been limited by a lack of reliable annual catchment loading data and relative lower control of its dispersal mechanisms by not using *in-situ* measured data. For example, the studies of Devlin et al. (2012a, 2012b) do not account for differential patterns of diffusion and deposition of nitrogen in the coastal waters and the use of artificial boundaries (i.e., boundaries of marine NRM regions) results in some areas being associated/assigned with higher or lower exposure levels than those expected or reported. Álvarez-Romero et al. (2013) improved the nitrogen dispersion mechanism using satellite information, but this study provides the likelihood of nitrogen exposure and does not provide a distribution of mass throughout the Reef. Although the likelihood of nitrogen exposure helps to identify high risk exposure areas, it does not allow for the evaluation of potential reductions of nitrogen discharge based on land-based management actions.

An ocean colour based model has been developed to estimate the dispersion of dissolved inorganic nitrogen ($\mathrm{DIN} = NH_4^+ + NO_2^- + NO_3^-$) in river plume waters (da Silva et al., in prep.). This model, built on the model by Álvarez-Romero et al. (2013), combines *in-situ* data from the MMP, MODIS satellite imagery and modelled annual end-of-catchment DIN loads from the watersheds. In the model, loads provide the amount of DIN delivered along the Reef lagoon, the *in-situ* data provide the DIN mass in river plumes, and satellite imagery provides the direction and intensity of DIN mass dispersed across and along the Reef lagoon. This model produces annual maps of average DIN concentration in the Reef waters. Maps are in a raster format, which is a spatial data model that defines space as an array of equally sized cells arranged in rows and columns (ESRI, 2010).

The main modifications applied to the method presented in Álvarez-Romero et al. (2013) are the qualitative assessment of pollutant dispersion in river plumes is replaced by a relationship between *in-situ* DIN mass and the six colour classes in the river plume maps; the cost-distance function used in Álvarez-Romero et al. (2013) to reproduce the shape of each individual river plume is replaced by the path-distance function, which is also available in ArcMap Spatial Analyst (ESRI, 2010); and a DIN decay function is applied to DIN mass exported from the rivers to account for potential biological uptake.

Our model has four main components: (a) modelling of individual river plumes, (b) DIN dispersion function, (c) DIN decay function and (d) mapping of DIN concentration over the Reef lagoon. The conceptual model in Figure D-5 shows how each model component is set up and how they are combined to produce the DIN dispersion maps. The key output of the DIN dispersion maps is to produce river plume maps for each individual river in the model. Doing that, the end-of-catchment load of each river can be dispersed over its individual river plume. To control this dispersion, a relationship based on the mass proportion of DIN in each plume colour class is determined at the scale. To account for potential DIN uptake, the ratio between an *in-situ* DIN × salinity relationship and the theoretical DIN decay due to dilution (i.e., freshwater – marine water mixing) is used. This ratio defines a DIN decay coefficient, which is multiplied by the dispersed DIN load. After the load has been dispersed over each individual river plume, and corrected for DIN uptake, the resultant dispersed DIN from each river are summed together to represent the total annual DIN dispersion over the Reef lagoon discharged by the rivers. In the following these four major steps are presented, starting with the generation of individual river plumes.

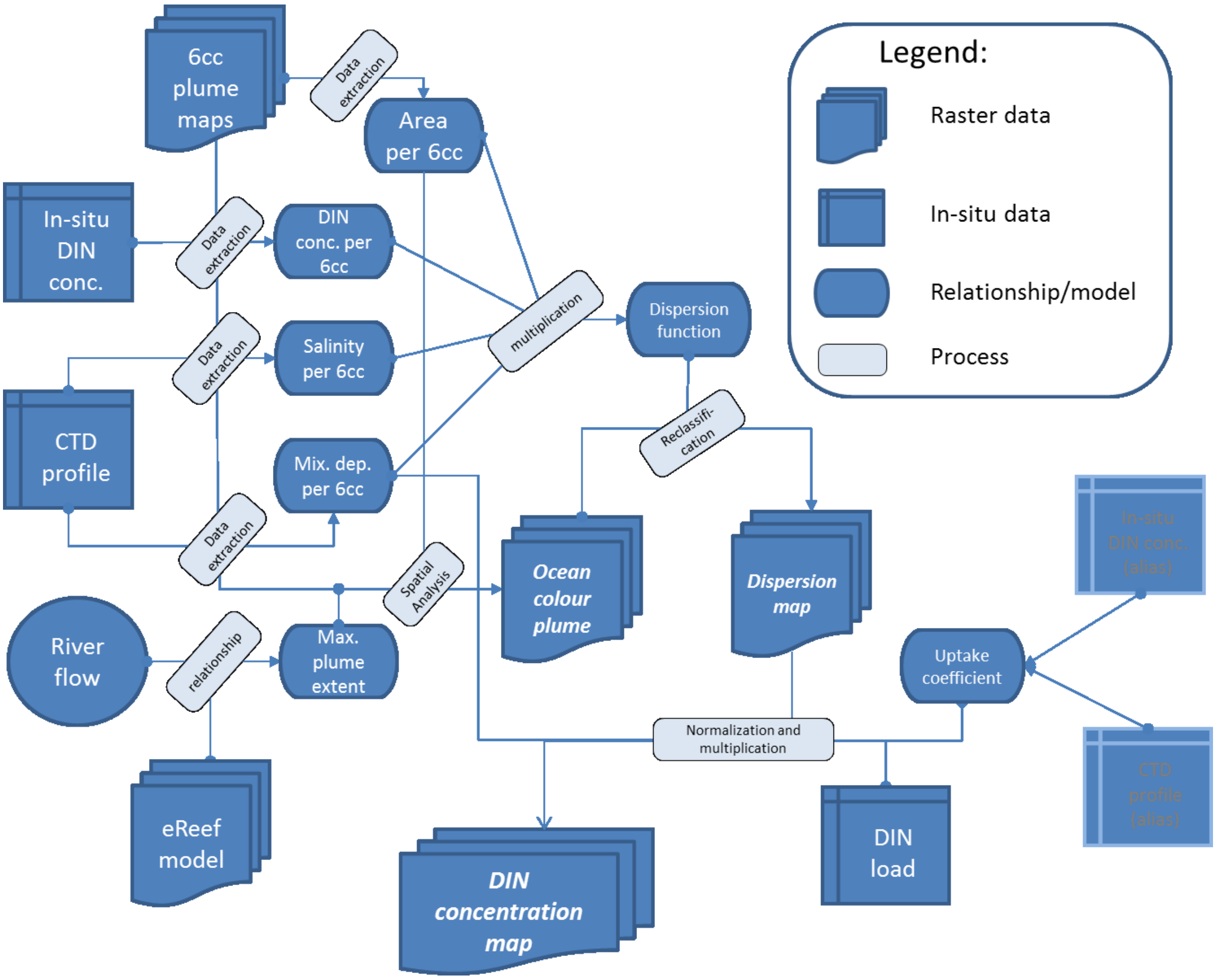

Figure D-5: Conceptual model for DIN concentration load mapping. See text for explanation.

(a) Modelling individual river plume (ocean colour plume)

The modelling of individual river plumes uses weekly wet season water type maps (i.e., raster files), the path-distance tool in ArcMap Spatial Analyst (ESRI, 2010) and a relationship between river discharge and plume extent obtained from a highly resolved hydrodynamic model for the Reef.

The path-distance tool determines the minimum accumulative travel cost from a source to each cell location in a raster (ESRI, 2010). For the path-distance tool, the point coordinates of the river mouths, a surface raster indicating the impedance for the plume movement, and a surface raster indicating the main direction of plume propagation are provided. For all rivers, a propagation direction of 315° Azimuth is selected to account for the prevailing wind (i.e., trade winds) and sea current direction in the wet season (Brinkman et al., 2014; Luick et al., 2007). Future development of this model, which can be produced in smaller time steps (it can be as short as a week, small temporal resolution of our plume maps), will allow to incorporate different directions of plume propagation as a function of the main wind direction on a weekly scale. The weekly wet season water type maps are used to provide the surface raster. This surface is calculated as the reciprocal (1/x) of the plume mode per wet season. In the plume calculation, the colour classes are inverted, so class 6 is placed close to the coast, class 5 is the second closest to the coast and so on. This inversion of the plume values is done so when calculating the reciprocal, it produces a higher travel cost close to the coast and a slower travel cost at the outer edge of the plume, aiming to reproduce the increasing size of wet season water types from the inner class to the outer classes.

Defining the edge of each river plume (i.e., its area of influence) is critical to calculate the dispersion of the DIN load. To do that, a discharge-plume distance relationship is derived from the dispersion of virtual tracers in a highly resolved hydrodynamic model (eReefs, Brinkman et al., 2014). In this approach, currently under development (Wolff et al., 2014), the river plume influence is defined as the area where the tracer concentration is equivalent to or below salinity 36, which corresponds to at least 5% hydrodynamic model simulation time (c.a., from December to April, inclusive). The maximum plume extent is set as a maximum distance between the river mouth and the outer edge of the plume influence area. Equation 1 (Figure D-6) presents the discharge-distance relationship, which is used to determine the maximum extent of the modelled individual river plume (*Dist*, km) as a function of its total wet season discharge (*Disch*, in megalitres, ML):

$$Dist = -2.720 \cdot 10^{-13} \cdot Disch^2 + 2.028 \cdot 10^{-5} \cdot Disch + 58.84 \qquad \text{(Eq. 1)}$$

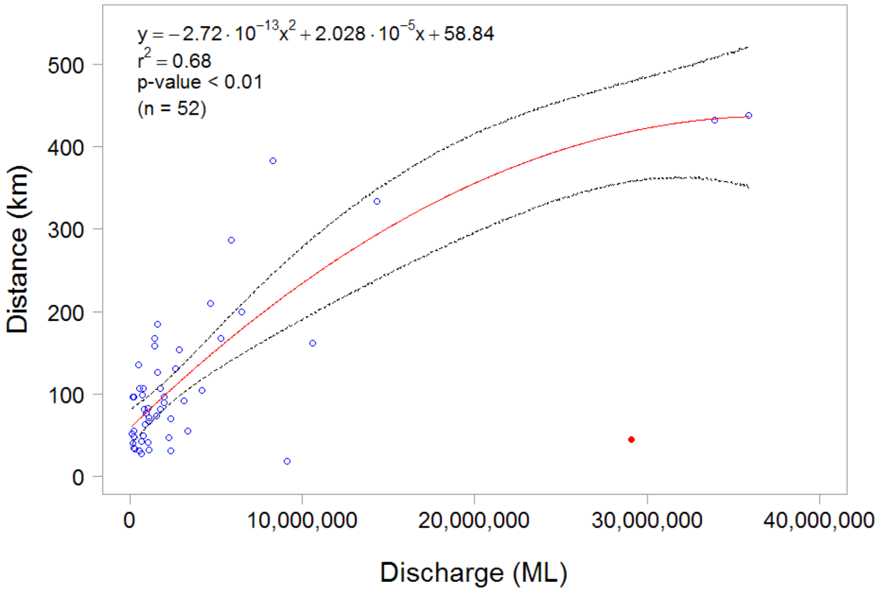

Figure D-6: Relationship between river discharge (million litres, ML) and distance (km) between river mouth and the outer edge of tracer plume as obtained from the eReefs hydrodynamic model for the Reef. Dashed lines stand for CI 95%. Red dot stands for point excluded from the regression model.

The edge of the plume influence area (i.e., Pd_{max}) is used to recalculate the modelled plume (*MP*), resulting in an ocean colour plume (*OCP*) as indicated below:

$$OCP = 1 + \frac{MP}{Pd_{max}/_5}. \qquad \text{(Eq. 2)}$$

In Equation 2, ‘1' changes the lowest value of the ocean colour plume at the river mouth from 0 to 1 (i.e., the first colour class), and '5' adjusts the quotient MP/Pd_{max} to result in an *OCP* equal to 6 at the outer edge of the plume (i.e., when $OCP = Pd_{max}$). Thus, ocean colour plume (*OCP*) has values varying from 1 at the river mouth to 6 at the edge of the plume, similar to the river plume maps.

Although the path distance captures the general shape of the river plumes when compared to those plumes produced by the hydrodynamic model (data not shown), it fails to distinguish each individual colour class. To correct that, the proportion between the median of the plume areas in the six-colour class maps is used to rescale the size of each six-colour class in the ocean colour plume (Table D-3).

Table D-3: Recalculation of the plume class interval for rescaling the size of each of the six colour classes.

Plume interval	Plume area median (2003-15)	Cumulative area	% in total	% increment	Recalculated plume interval
1 - 2	2149	2149	0.75	0.75	1.0000 - 1.0448
2 - 3	4253	6402	2.22	1.48	1.0449 - 1.1335
3 - 4	2218	8620	3.00	0.77	1.1336 - 1.1797
4 - 5	15526	24146	8.39	5.39	1.1798 - 1.5034
5 - 6	106585	130731	45.42	37.03	1.5035 - 3.7255
6 - 7	157065	287796	100.00	54.58	3.7256 - 7.0000

(b) DIN dispersion function

The DIN dispersion function is a raster surface that represents how much of the land-sourced DIN ends up in each colour class over the ocean colour plumes. The DIN dispersion function is based on the proportion of DIN mass among each colour class and uses three sources of data: (i) the river plume maps with six-colour class, (ii) *in-situ* DIN concentration and (iii) CTD vertical profiles. The latter two datasets have been opportunistically collected in river plume waters over the Reef lagoon as part of the water quality flood plume program under the Reef Rescue MMP (Figure D-7).

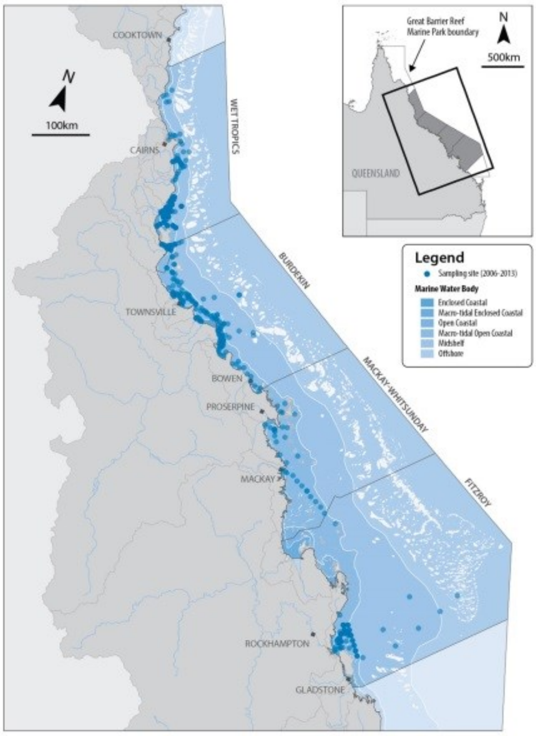

Figure D-7: The Marine Park (Queensland, Australia), boundaries of the NRM regions, and the sampling sites (colour density indicates recurrent sampling) included for validation.

The CTD profiles are used to determine the depth of the mixing layer for each colour class and also the surface salinity. The depth of the mixing layer is determined based on the mixing between the marine water and the freshwater, which creates a gradient in concentration. It is assumed that freshwater is diluted with the marine water at the same rate as DIN; therefore, mixing depth can be used to estimate total DIN mass throughout the water column under plume water influence. Using salinity variation from CTD vertical profiles to estimate the conservative mixing between freshwater and marine water, the appropriate mixing depth (*D*, in metres) becomes:

$$D = \frac{1}{(SAL_{max} - SAL_{min})} \int_0^{Z_{max}} (SAL_{max} - SAL_z) d_Z, \qquad \text{(Eq. 3)}$$

where, SAL_{max} and SAL_{min} stand for the maximum and minimum salinity, respectively, in the mixing gradient from surface to the bottom. The integral is the sum of the salinity difference from the salinity at depth Z to the maximum depth. This represents the sum of the total mass of freshwater throughout the water column. Dividing this sum by the maximum salinity difference, it is as though the total mass of the freshwater in the entire water column was compressed into a layer D thick of freshwater.

The river plume maps are used to calculate the area of each colour class and also for the match-ups between *in-situ* data (DIN concentration and CTD profiles) and the colour classes. The match-ups are done on a weekly basis, which is the smallest temporal resolution of the river plume maps (Álvarez-Romero et al., 2013). Match-ups are performed using *extract* in the raster package (Hijmans et al., 2015) with the bilinear interpolation method in R 3.2.4, which interpolates from the values of the four nearest raster cells (R Development Core Team, 2015). Only data sampled during flood regimes (c.a., flow exceeding the 75th percentile of daily long-term wet season flow, from 1970 to 2000) are used in the match-ups, as these data better represent the biogeochemical and transport processes for DIN. Figure D-8presents the variation of DIN concentration, superficial salinity, mixing depth layer and plume area grouped by the six-colour classes. Due to the skewed nature of these four variables, the median value is used as a measurement of the central tendency rather than the mean.

Because there is insufficient *in-situ* DIN data to calibrate each river individually, the assumption was made that DIN behaviour (exponential decay) is consistent across plumes. Although DIN data sampled in the river flood plumes were not evenly distributed over the Reef lagoon, the data are representative of those areas that experience large rainfall and higher nitrogen loads (Figure D-7). Further work (and monitoring data) is needed to develop regionally specific pollutant dispersion models.

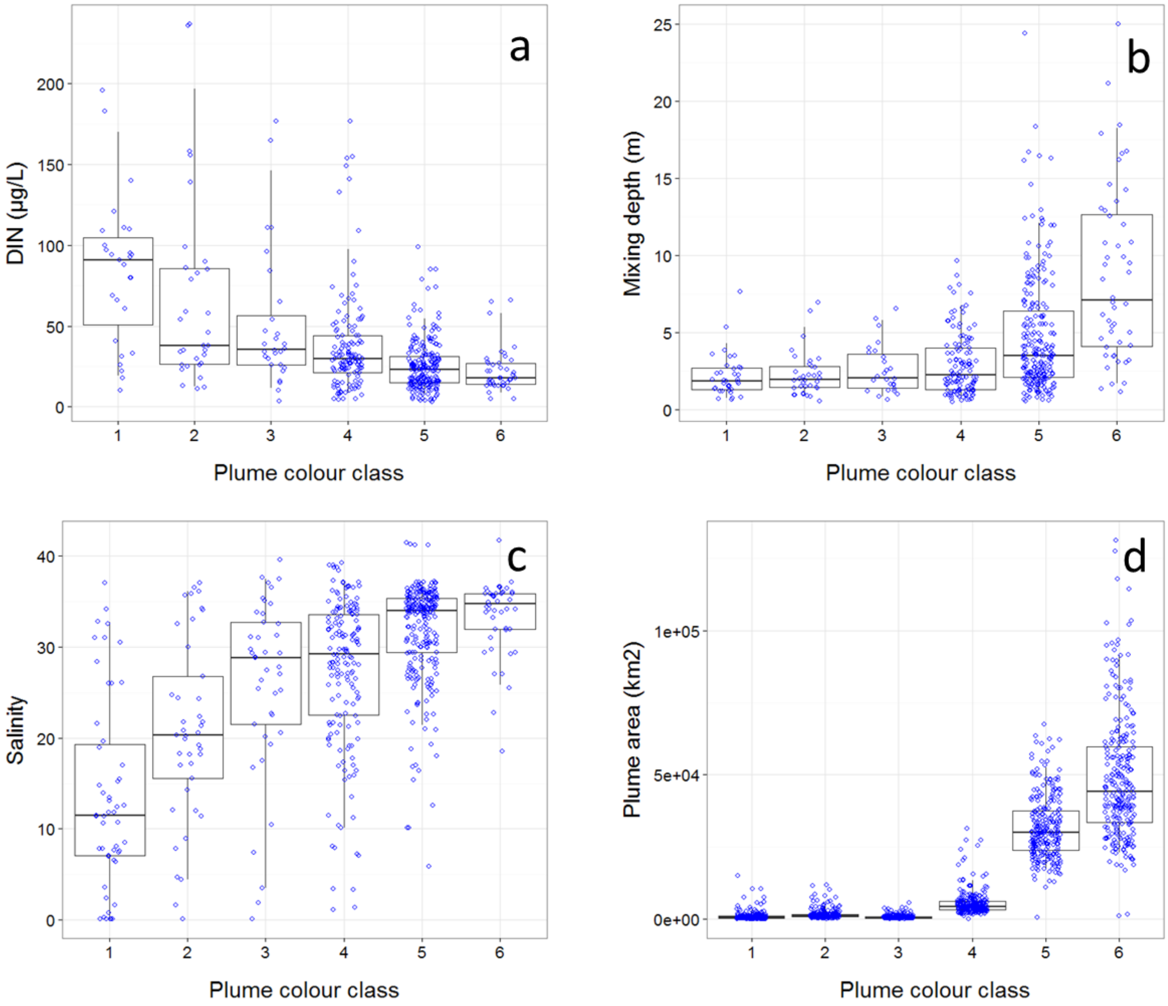

Figure D-8: *In-situ* DIN concentration (a), depth of the mixing layer (b), superficial salinity (c) and plume area (d) per colour class, measured over 13 wet seasons (December to April inclusive) from 2002-03 to 2014-15. Boxplot presents the median (dark black line), 25th and 75th percentile values (rectangle) and 5th and 95th percentile values (vertical lines). Nudge was applied to data on x-axis for better data visualisation.

The depth of the mixing layer, the *in-situ* DIN concentration and the area of each plume colour class are then used to estimate the DIN mass in each colour class by simple multiplication. The measured *in-situ* DIN concentration in plume waters is resultant of a mixing gradient between freshwater and marine water. To account for this mixing, a simple dilution model based on salinity is used. For example, under salinity half way between marine and freshwater, the total measured *in-situ* DIN concentration at the river mouth is also reduced by 50%. Figure D-9 shows the DIN mass variation over the six-colour class. To account for the error associated with each variable included in the DIN mass calculation, the 95% CI is calculated as two times the median absolute deviation (Harding et al., 2014) for each set of data and then transferred to the DIN mass per colour class by using basic rules for error propagation.

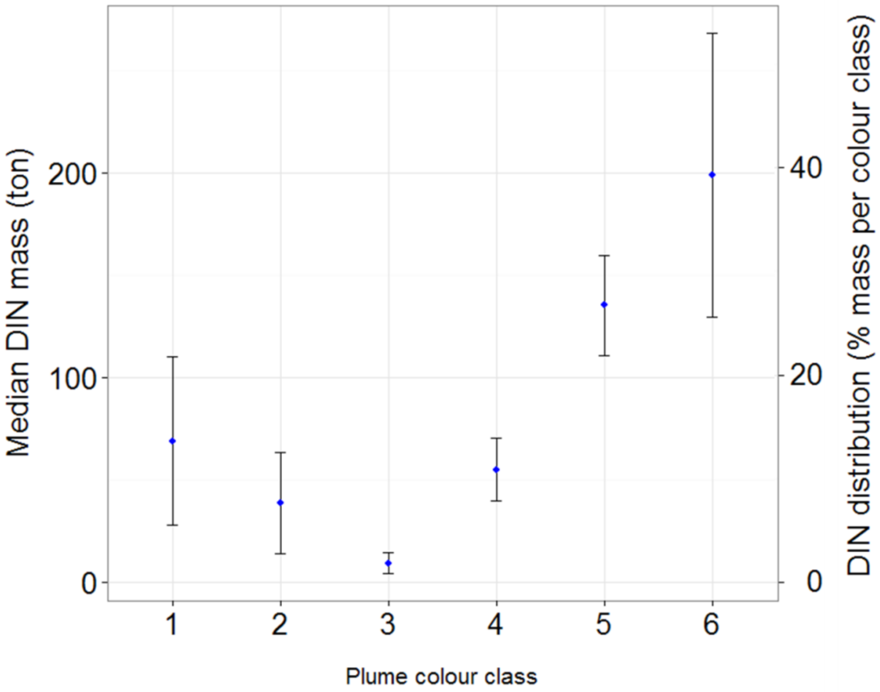

Figure D-9. Median DIN mass and percent contribution across the six-colour class. Error bars represent 95%CI (see text for explanation).

Therefore, the values of 1 to 6 in the ocean colour plumes (raster file) are converted into DIN mass, as per Figure D-9The values of the DIN mass are then normalised by dividing each cell-raster value by the sum of all the values in the raster. This resulted in an annual normalised DIN dispersion map (or DIN dispersion function, no unity) for each river, in which the sum of the cell-raster values is equal to one. Multiplying the load of each river by its respective DIN dispersion function, a map of mass dispersion is produced.

(c) DIN decay function

To account for potential biological uptake of the DIN load discharged by rivers to the Reef lagoon, the variation of *in-situ* DIN concentration against salinity was compared to the theoretical variation of DIN due to the mixing process between freshwater and marine water. The best relationship between DIN concentration and salinity is presented in Figure D-10, which shows an exponential DIN decay.

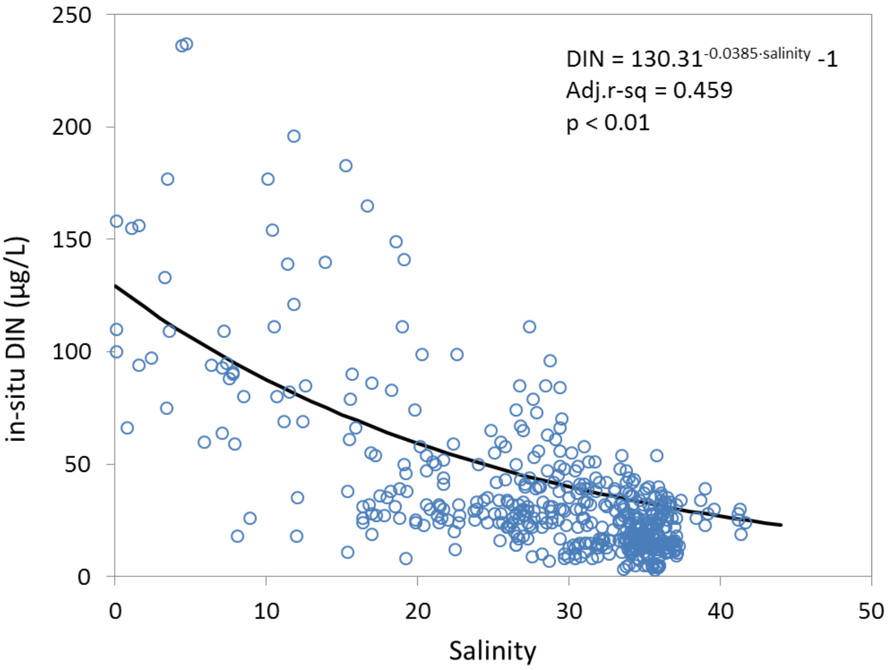

Figure D-10: Relationship between *in-situ* DIN concentration (µg L^{-1}) and salinity opportunistically measured at the surface in river plume waters over the Reef lagoon (2002–03 to 2014–15 wet season) under river discharge >75th percentile (see text for explanation).

The theoretical dilution model (Middelburg and Nieuwenhuize, 2001; Eq. 4) is used to determine the potential DIN concentration at any salinity given the end-member DIN concentrations:

$$DIN = f \times DIN_m + (1 - f) \times DIN_r \ , \qquad \text{(Eq. 4)}$$

where, DIN_m and DIN_r are the *in-situ* DIN concentrations in the marine water (at salinity 36, to be consistent with plume area definition: $\mathrm{DIN_m}$) and at the river mouth (salinity 0: $\mathrm{DIN_r}$), respectively. And *f* is the marine water fraction, which is calculated as:

$$f = \frac{S - S_r}{S_m - S_r} \ , \qquad \text{(Eq. 5)}$$

where, *S* is the sample salinity, S_m stands for the marine salinity (i.e., 36) and S_r is the river mouth salinity (i.e., 0).

For this theoretical model, a steady-state was assumed, which might not be the case for river plumes, but represents a first approach to include DIN uptake in this model. In Figure D-11: both models are plotted together and the ratio between them is associated with a potential DIN uptake (red line). The DIN uptake function reduces the DIN load dispersed as a multiplicative coefficient, ca *1 - Potential DIN uptake*.

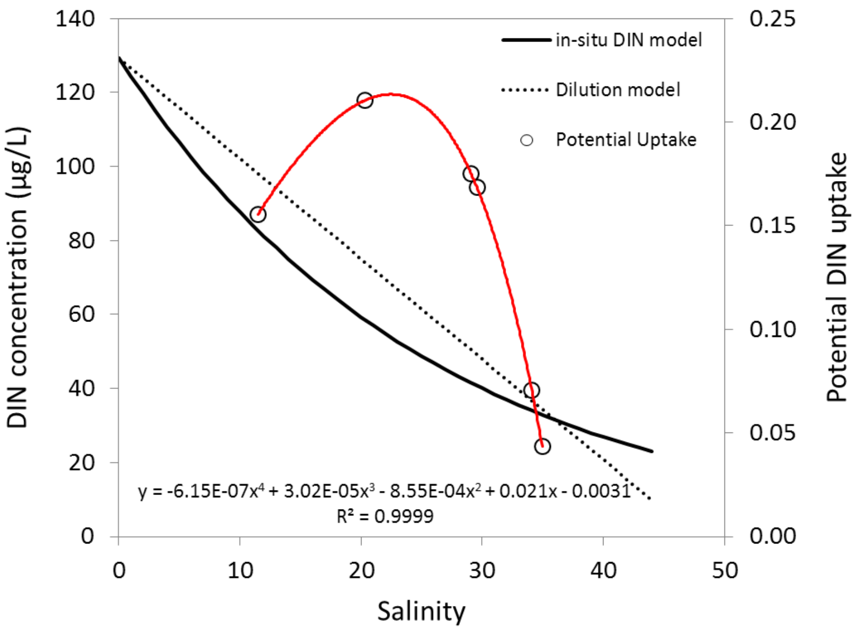

Figure D-11: Potential DIN uptake (red line) derived from the ratio between *in-situ* DIN concentration x salinity (black solid line, as in Figure D-11) and the theoretical dilution model (black dashed line, derived from Eq. 4).

(d) Mapping of DIN concentration over the Reef lagoon

Using the maps of mass dispersion and accounting for the cell-raster size and the depth of the mixing layer for each colour class, a map for the spatial DIN concentration is constructed. DIN concentration maps are calculated for each river per year and annual composite maps are produced by the sum of all river DIN concentration maps within each year.

In this report, we used a combination of modelled and monitored annual DIN loads for rivers. We used the modelled loads from the Lewis et al. (2014) model for basins of the Wet Tropics. Briefly, modelled DIN loads in this method are calculated using existing load monitoring data to develop a relationship between the measured loads with flow volumes (at river monitoring sites) and the amount of fertiliser applied to calculate the percentage of applied nitrogen fertiliser lost as DIN. This relationship is then applied to upscale loads for the entire basin area. This approach provides the most reliable DIN loads for this region. For other regions, the measured DIN loads were used where monitoring data exist at the end-of-catchment sites that cover the vast majority (>95%) of the basin such as the Burdekin, Pioneer and Fitzroy Basins. These measured loads came from a range of different sources including Packett et al. (2009), AIMS (unpublished data) and reports by the Catchment Loads Monitoring Program (Joo et al., 2012; Turner et al., 2013; Wallace et al., 2015). For the other basins, the annual mean concentration (AMC) data (i.e., load divided by flow) from any available load monitoring data within the basin were compared with the Source Catchments model outputs. The most appropriate AMC (or a mean of the monitoring and modelled data) data were chosen and multiplied by the annual discharge to formulate an annual load. The rivers/catchments (Figure D-7) where modelled DIN load and basin discharge data were available for the 14 years are presented in Tables D-4 and D-5, respectively. The pre- development DIN loads were calculated using an AMC of 50 µgL^{-1} for most regions, which is based on monitoring data from pristine locations within the Reef catchment area. A higher DIN AMC (up to 100 µgL^{-1}) was applied for the drier southern catchments that contain legumes such as Brigalow lands, which provide a naturally higher DIN source.

The temporal incompatibility between the annual end-of-catchment DIN loads and the seasonal *in-situ* DIN, depth of the mixing layers and the river plume maps could not be explicitly resolved in the model. Whereas DIN river load represents the total annual DIN delivered by rivers into the Reef lagoon (from October to September, inclusive), the plume maps from satellite imagery, mixing depth and *in-situ* DIN concentration in flood plume waters are constrained to the wet season period (December to April, inclusive). Considering that 78% of the annual river discharge occurs over the wet season period (DNRM, http://watermonitoring.dnrm.qld.gov.au/host.htm), the plume maps, mixing depth and *in-situ* DIN in plume waters potentially represent the majority of the environmental condition when most of the end-of-catchment DIN load is delivered to the Reef waters.

Table D-4: End-of-catchment DIN loads (t/year) from 2003 to 2017 water years (from October 2002 to September 2017).

DIN loads (t)	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18
Jacky Jacky Creek	69	127	116	354	76	79	76	184	237	91	99	190	75	32	119	137
Olive Pascoe River	87	159	144	443	95	99	95	230	296	114	124	237	94	39	149	171
Lockhart River	55	101	91	280	60	63	60	146	187	72	79	150	59	25	94	108
Stewart River	22	68	29	141	50	29	33	55	109	31	26	66	15	16	34	41
Normanby River	18	492	67	489	216	411	266	386	648	112	227	399	170	180	199	141
Jeannie River	1	61	12	89	22	47	29	64	75	28	19	50	38	42	87	86
Endeavour River	1	75	15	109	26	58	35	79	92	34	23	61	47	51	57	56
Daintree River	20	221	75	193	120	150	120	232	361	220	153	470	170	149	177	114
Mossman River	82	182	119	204	118	108	77	99	111	85	66	106	32	69	64	79
Barron River	6	48	19	38	21	79	38	24	92	37	14	29	17	12	19	56
Russell-Mulgrave	280	970	434	760	597	707	549	534	1,199	822	437	711	443	242	291	623
Johnstone River	488	689	846	1,536	1,326	1,292	1,935	1,484	3,798	2,219	1,386	2,043	975	1,431	690	899
Tully River	165	393	264	441	471	361	413	328	710	434	341	432	211	333	598	757
Murray River	124	293	197	329	352	270	308	245	530	324	255	323	158	273	199	253
Herbert River	351	1,407	563	1,632	1,633	1,260	3,821	1,132	4,525	1,648	1,149	1,544	385	681	808	2,258
Black River	8	35	21	41	107	139	230	115	267	140	35	79	3	24	7	50
Ross River	5	39	15	29	93	110	159	100	167	106	22	94	0	2	1	27
Haughton River	87	190	264	312	610	776	1,210	524	1,030	749	209	235	42	114	144	386
Burdekin River	477	353	1,312	350	1,296	2,006	1,798	1,303	2,600	1,200	800	130	150	280	580	916
Don River	22	31	58	27	108	287	171	99	560	143	103	58	31	18	164	24
Proserpine River	49	64	152	168	394	930	503	483	880	317	310	304	46	76	404	130
O'Connell River	52	54	170	201	411	573	427	732	1,312	622	236	199	42	68	363	117
Pioneer River	22	5	43	16	226	347	230	363	836	361	268	146	30	140	450	62
Plane Creek	112	24	167	15	391	854	443	878	1,441	855	584	221	71	250	784	82
Styx River	83	30	6	3	1	54	24	89	171	59	266	48	82	25	51	26
Shoalwater Creek	95	35	7	3	1	61	27	101	194	67	303	55	93	29	58	30
Water Park Creek	55	7	24	13	29	140	55	160	272	83	290	163	113	103	152	79
Fitzroy River	674	382	363	135	176	1,580	367	2,060	3,900	950	920	150	470	680	910	190
Calliope River	98	36	7	3	1	63	28	104	200	69	312	57	96	30	81	28
Boyne River	24	9	1	1	0	19	5	31	53	26	29	4	10	4	21	7
Baffle Creek	112	41	7	6	1	91	23	149	256	124	142	19	50	18	58	129
Kolan River	100	15	0	0	0	31	1	87	234	92	243	14	64	33	44	82

Burrum River	37	70	6	12	2	17	10	19	34	35	27	19	45	100	107	170
Burnett River	114	49	30	15	7	4	5	225	1,884	129	1,516	44	171	76	137	201
Mary River	167	153	61	56	87	300	209	378	1,221	608	1,072	83	231	67	82	266

Table D-5: Total wet season river discharge (GL) from 2003 to 2018 water years (from October 2002 to September 2018).

Discharge (ML)	**2002-03**	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**2008-09**	**2009-10**	**2010-11**	**2011-12**	**2012-13**	**2013-14**	**2014-15**	**2015-16**	**2016-17**	**2017-18**
Jacky Jacky Creek	1,387	2,541	2,311	7,082	1,523	1,588	1,527	3,683	4,735	1,820	1,987	3,791	1,498	631	2,383	2,740
Olive Pascoe River	1,734	3,177	2,889	8,852	1,904	1,985	1,909	4,604	5,919	2,276	2,484	4,739	1,873	788	2,979	3,425
Lockhart River	1,098	2,012	1,830	5,606	1,206	1,257	1,209	2,916	3,749	1,441	1,573	3,001	1,186	499	1,887	2,169
Stewart River	450	1,359	589	2,821	1,003	576	656	1,093	2,181	616	523	1,312	299	312	685	826
Normanby River	153	9,650	1,131	9,572	4,117	8,029	5,129	7,527	12,759	2,050	4,338	7,786	3,201	3,407	3,781	4,333
Jeannie River	11	1,224	250	1,786	431	946	582	1,289	1,506	559	371	997	765	843	1,747	1,721
Endeavour River	14	1,492	305	2,178	526	1,154	710	1,572	1,836	681	452	1,215	932	1,028	1,136	1,119
Daintree River	318	3,439	1,179	3,015	1,721	2,102	1,542	2,927	3,947	2,403	1,673	5,138	1,855	1,628	1,932	1,312
Mossman River	738	1,568	1,037	1,770	1,138	1,261	998	1,541	1,938	1,486	1,160	1,861	564	1,217	1,143	1,504
Barron River	125	1,044	421	819	454	1,765	849	549	2,116	851	328	663	380	183	288	868
Russell-Mulgrave	1,601	5,443	2,530	4,502	3,549	4,655	3,551	3,715	7,499	5,138	2,734	4,447	2,768	1,515	3,016	5,760
Johnstone River	1,812	2,508	3,155	5,898	5,154	4,619	6,026	4,235	9,371	5,475	3,420	5,040	2,406	3,531	4,018	5,940
Tully River	1,730	3,941	2,641	4,349	4,739	3,834	4,308	3,581	7,443	3,425	3,342	4,322	2,660	2,943	3,099	4,237
Murray River	264	1,239	423	1,771	1,353	1,272	1,893	962	4,267	2,062	1,006	1,531	366	974	948	1,683
Herbert River	790	3,787	1,540	4,577	4,572	3,829	10,771	3,627	13,133	4,782	3,334	4,480	1,117	1,977	2,248	6,386
Black River	73	318	194	375	975	1,265	2,094	1,045	2,432	1,276	322	716	30	222	65	457
Ross River	68	482	187	368	1,159	1,381	1,986	1,249	2,093	1,325	277	1,177	3.2	24	12	343
Haughton River	184	393	566	655	1,334	1,838	2,541	1,139	2,396	1,741	486	546	98	266	338	827
Burdekin River	2,096	1,519	4,275	2,204	9,786	27,550	29,403	7,801	34,894	15,544	3,400	1,441	827	1,810	4,165	5,542
Don River	162	202	360	152	610	1,708	908	535	3,136	803	578	324	171	102	921	135
Proserpine River	206	266	633	702	1,643	3,876	2,097	2,012	3,666	1,322	1,290	1,268	192	317	1,684	543

Discharge (ML)	**2002-03**	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**2008-09**	**2009-10**	**2010-11**	**2011-12**	**2012-13**	**2013-14**	**2014-15**	**2015-16**	**2016-17**	**2017-18**
O'Connell River	216	223	707	835	1,713	2,388	1,779	3,049	5,468	2,591	983	831	176	284	1,511	488
Pioneer River	91	20	179	67	941	1,446	956	1,511	3,482	1,504	1,115	609	126	597	1,389	250
Plane Creek	372	79	557	49	1,304	2,848	1,477	2,928	4,802	2,850	1,946	737	238	833	2,613	274
Styx River	834	305	64	28	8.0	537	235	888	1,706	590	2,658	484	819	253	508	264
Shoalwater Creek	949	347	73	32	9.1	612	268	1,010	1,941	671	3,025	551	932	288	578	300
Water Park Creek	549	69	242	127	295	1,398	550	1,596	2,718	826	2,904	1,632	1,128	1,032	1,524	791
Fitzroy River	1,710	970	930	700	830	12,063	2,193	11,667	38,537	7,993	8,530	1,576	2,674	3,589	6,170	955
Calliope River	489	179	37	16	4.7	315	138	521	1,000	346	1,558	284	480	149	406	141
Boyne River	121	43	7	5.8	0.7	94	24	154	264	129	147	20	51	19	103	36
Baffle Creek	1,600	590	97	80	10	1,298	326	2,133	3,650	1,776	2,031	276	710	257	829	1,845
Kolan River	332	50	0	0	0	102	4.1	289	779	308	810	45	214	111	146	273
Burrum River	569	243	151	76	33	18	27	1,125	9,422	643	7,582	218	853	381	536	849
Burnett River	123	233	21	40	6.9	56	32	63	114	118	91	62	150	335	457	670
Mary River	1,194	1,096	434	402	621	2,146	1,493	2,697	8,719	4,340	7,654	595	1,652	481	583	1,903

The same model developed for DIN dispersion was used to model TSS, except that the decay function was not included. Match-ups of TSS against six colour classes were performed as done for DIN and their concentrations are presented in Figure D-12: .

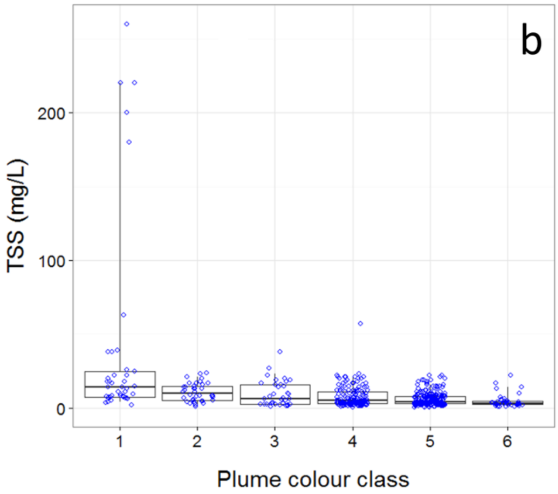

Figure D-12: *In-situ* TSS per colour class, measured over 13 wet seasons (c.a., December to April inclusive) from 2002–03 to 2014–15 wet season. Boxplot presents the median (dark black line), 25th and 75th percentile values (rectangle) and 5th and 95th percentile values (vertical lines). Nudge was applied to data on x-axis for better data visualisation.

Using concentrations for TSS per colour class plus mixing depth layer, plume area and salinity (as presented in Figure D-8), the mass of TSS per colour class was determined (Figure D-14). Then, similarly to DIN concentration maps, TSS maps were produced for each river per year and annual composite TSS maps produced by the sum of all rivers within each year. The annual TSS loads were compiled and calculated by various methods. Measured TSS loads were used where monitoring data exist at the end-of-catchment sites that cover the vast majority (>95%) of the basin such as the Burdekin, Pioneer and Fitzroy Basins. These measured loads came from a range of different sources including Packett et al. (2009), Kuhnert et al. (2012), AIMS (unpublished data) and reported by the Catchment Loads Monitoring Program (e.g. Joo et al., 2012; Turner et al., 2013; Wallace et al., 2015, 2016). For the other basins, the AMC data (i.e., load divided by flow) from any available load monitoring data within the basin were compared with the Source Catchments model outputs. The most appropriate AMC (or a mean of the monitoring and modelled data) data were chosen and multiplied by the annual discharge to formulate an annual load. The pre- development TSS loads were calculated using the AMC of the pre- development Source Catchments model for most regions coupled with additional knowledge in basins where the TSS increase has been better quantified (e.g., Burdekin and Fitzroy Basins) or areas where dams/weirs would have influenced the Source Catchments estimates (e.g., Proserpine, Ross and Burnett Basins). The modelled annual TSS loads for rivers are presented in Table D-6.

Table D-6: End-of-catchment TSS loads (kt/year) from 2003 to 2017 water years (from October 2002 to September 2017).

TSS load (kt)	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18
Jacky Jacky Creek	28	51	46	142	30	32	31	74	95	36	40	76	30	13	48	55
Olive Pascoe River	35	64	58	177	38	40	38	92	118	46	50	95	37	16	60	68
Lockhart River	22	40	37	112	24	25	24	58	75	29	31	60	24	10	38	43
Stewart River	9	27	12	56	20	12	13	22	44	12	10	26	6	6	14	17
Normanby River	8	482	57	479	206	401	256	376	638	102	217	389	160	170	189	217
Jeannie River	0	24	5	36	9	19	12	26	30	11	7	20	15	17	35	34
Endeavour River	1	75	15	109	26	58	35	79	92	34	23	61	47	51	57	56
Daintree River	16	172	59	151	86	105	77	146	197	120	84	257	93	81	97	66
Mossman River	37	78	52	88	57	63	50	77	97	74	58	93	28	61	57	75
Barron River	25	209	84	164	91	353	170	110	423	170	66	133	76	37	58	174
Russell-Mulgrave	48	163	76	135	106	140	107	111	225	154	82	133	83	45	90	173
Johnstone River	181	251	316	590	515	462	603	424	937	548	342	504	241	353	402	594
Tully River	52	118	79	130	142	115	129	107	223	103	100	130	80	88	93	127
Murray River	13	62	21	89	68	64	95	48	213	103	50	77	18	49	47	84
Herbert River	79	379	154	458	457	383	1,077	363	1,313	478	333	448	112	198	225	639
Black River	15	64	39	75	195	253	419	209	486	255	64	143	6	44	13	91
Ross River	7	48	19	37	116	138	199	125	209	132	28	118	0	2	1	34
Haughton River	28	59	85	98	200	276	381	171	359	261	73	82	15	272	51	831
Burdekin River	755	384	4,338	884	7,195	14,806	10,855	1,938	6,200	3,300	2,500	220	700	700	4,000	2,650
Don River	40	50	90	38	153	427	227	134	784	201	145	81	43	25	230	34
Proserpine River	10	13	32	35	82	194	105	101	183	66	64	63	10	16	84	27
O'Connell River	39	40	127	150	308	430	320	549	984	466	177	150	32	51	272	88
Pioneer River	16	4	32	12	156	255	112	374	820	210	130	35	4	44	110	36
Plane Creek	37	8	56	5	130	285	148	293	480	285	195	74	24	83	261	27
Styx River	108	40	8	4	1	70	31	115	222	77	346	63	106	33	66	34
Shoalwater Creek	57	21	4	2	1	37	16	61	116	40	182	33	56	17	35	18
Water Park Creek	33	4	15	8	18	84	33	96	163	50	174	98	68	62	91	47
Fitzroy River	1,800	600	250	140	425	4,530	404	3,564	7,000	1,300	2,500	52	900	670	2,200	322
Calliope River	88	32	7	3	1	57	25	94	180	62	281	51	86	27	73	25
Boyne River	8	3	0	0	0	7	2	11	19	9	10	1	4	1	7	3

Baffle Creek	256	94	16	13	2	208	52	341	584	284	325	44	114	41	133	295
Kolan River	43	7	0	0	0	13	1	38	101	40	105	6	28	14	19	36
Burrum River	80	34	21	11	5	3	4	158	1,319	90	1,061	31	119	53	75	119
Burnett River	12	23	2	4	1	6	3	6	11	12	9	6	15	33	46	67
Mary River	286	263	104	96	149	515	358	647	2,093	1,042	1,837	143	396	115	140	457

General *in-situ* DIN behaviour in plume waters and a critical overview of the DIN dispersion map modelling.

DIN behaviour across the six colour classes presented in Figure D-8 show reducing concentrations moving further from the river mouth, mainly due to dispersion and biological uptake. DIN in the Reef waters up to a salinity of 20–25 commonly displays conservative mixing behaviour (i.e., dilution) (Devlin and Brodie, 2005). However, salinity in colour class 2 is 21.0 ± 9.9 mean (± 1 SD), so the conservative behaviour is taken over by an exponential decay when DIN is considered over the entire plume extent. After colour classes 2 to 3, the plume waters experience a reduction of suspended sediment mass and consequently light conditions improve, favouring primary production and DIN consumption (Bainbridge et al., 2012; Devlin and Brodie, 2005; Devlin et al., 2012a, 2012b). Therefore, the behaviour presented by *in-situ* DIN concentration through the river plume accounts for those processes.

Other processes that may affect DIN concentrations can be nitrogen fixation by (cyano-) bacteria (*Trichodesmium*) and upwelling of nutrient-enriched deep water from the Coral Sea (Furnas et al., 2011). However, land runoff is the largest source of new nutrients to the inshore Reef, especially during monsoonal flood events (Furnas et al., 2011). Moreover, upwelling intrusions are spatially restricted to the Central Reef subsurface waters (Berkelmans et al., 2010), and therefore not captured by the superficial *in-situ* DIN data. Nitrogen fixation is likely to occur across the entire plume area, adding equally to the measured *in-situ* DIN, and not affecting the general behaviour depicted in the DIN function. Otherwise, if intense fixation due to *Trichodesmium* blooms and denitrification followed by decomposition would result in locally elevated DIN concentrations (Devlin and Brodie, 2005; Furnas et al., 2011), the use of a median to describe the central tendency of DIN data across plume colour classes would likely remove this effect.

It is noted that although the highest concentrations are usually associated with water in the colour class 1 (i.e., close to the river mouth, see Figure D-8a), the largest mass of DIN is in colour class 6 (more than 35%, Figure D-9). This is due to the large area of colour class 6 compared to the other colour classes (Figure D-8d). While the DIN contribution from the rivers reaching plume colour class 6 are minor compared to that reaching colour class 1, its larger area and deeper mixing layer results in a larger DIN mass.

The basis for the DIN dispersion model is the calculation of the DIN mass in plume waters over 13 years. A comparison is presented in Table D-7 between the DIN mass against the annual DIN load and also against its fraction in plume water that is likely to be land-sourced (based on a simple dilution model). If the dilution model is not applied, the DIN mass in plume waters (i.e., simple multiplication of DIN concentration by plume area and the mixing layer depth) is on average 1.3 times greater than the annual DIN load. When a dilution factor is accounted for, assuming that part of the measured *in-situ* DIN is land-sourced and the other part is a background concentration, the DIN mass in plume waters represent less than 10% of that relative to the annual watershed input. This number suggests that dispersing the annual DIN load over a median plume size may overestimate the final DIN concentration in the Reef lagoon. This problem can be partially solved if a smaller time-frame is used, namely one that approaches the plume waters residence time. Although an estimation of the plume residence time can be obtained from a hydrodynamic model, DIN loads are not available in a timeframe shorter than annual.

Table D-7: Annual DIN mass (tonne) in the river loads, and in the plume waters, when the total DIN mass is calculated by a simple multiplication of DIN concentration, plume area and the mixing layer depth (Total DIN mass), and when a dilution factor based on salinity is also taken into account (Relative DIN mass).

Water year	Load*	Total DIN mass (tonne)	Relative DIN mass (tonne)	Total/Load	Relative/Load
2003	3,029	8,168	505	2.70	0.17
2004	5,242	9,773	584	1.86	0.11
2005	4,678	8,776	501	1.88	0.11
2006	6,396	9,896	532	1.55	0.08
2007	9,265	6,864	393	0.74	0.04
2008	15,653	7,607	468	0.49	0.03
2009	17,613	8,510	489	0.48	0.03
2010	11,033	8,073	472	0.73	0.04
2011	29,958	9,990	728	0.33	0.02
2012	13,873	6,503	435	0.47	0.03
2013	7,470	10,781	615	1.44	0.08
2014	7,304	9,674	596	1.32	0.08
2015	2,852	9,572	540	3.36	0.19

A simple plot of DIN load against relative DIN mass (Figure D-13) shows there is a weak correlation between these two variables. In the calculation of DIN mass, the only parameter that varied over the 13 years was the area of the plumes; *in-situ* DIN concentration, salinity and the mixing layer depth were constant for all years due to the lack of data. This suggests that plume area variation is not enough to explain DIN concentrations over the Reef lagoon. Future versions of this model should therefore include smaller time scale resolution for superficial salinity, depth of mixing layer and *in-situ* DIN concentration.

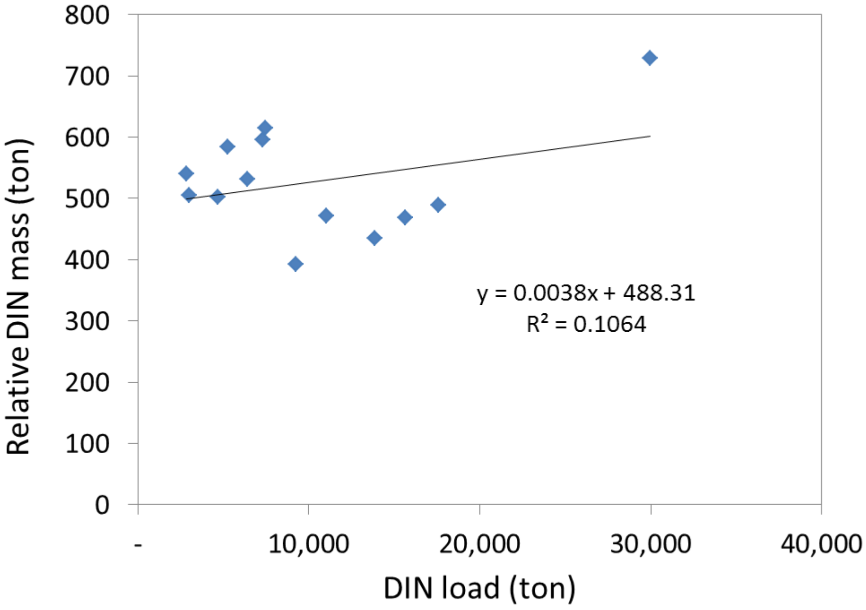

Figure D-13. Relationship between DIN load (tonnes) against the relative DIN mass (tonnes) in plume waters (see text for explanation).

Simulation exercises using virtual tracers in a hydrodynamic model suggest that on an annual basis, the water constituents discharged by rivers can travel further than the edge of colour class six, reaching distances up to 800 km far from the river mouth (Luick et al., 2007). This potential long-distance transport of water constituents has not been considered in the current DIN dispersion model, which would require a complex biogeochemical model able to capture the process controlling variations in the DIN concentration. Nevertheless, this model represents the first attempt to map land-sourced contaminates dispersion over the Reef lagoon.

General *in-situ* PN and TSS behaviour in plume waters and a critical overview of their dispersion map modelling.

The different behaviour exhibited by DIN compared to TSS against six colour classes reflects the nature of these constituents: the dissolved form reduces from its source mainly due to dispersion and biological uptake, whereas TSS is more affected by dispersion and the settling processes. TSS is deposited mainly within colour class 1 and thereafter remains at similar values or even increases by colour class 6 (Figure D-14). The faster reduction of TSS in colour class 1 is due to flocculation and sedimentation. Concentration reduction from 450 to 140 mg L^{-1} within 4 km from the river mouth has been observed for TSS (Bainbridge et al., 2012). However, finer sediments can be transported further offshore in plume waters (Bainbridge et al., 2012).

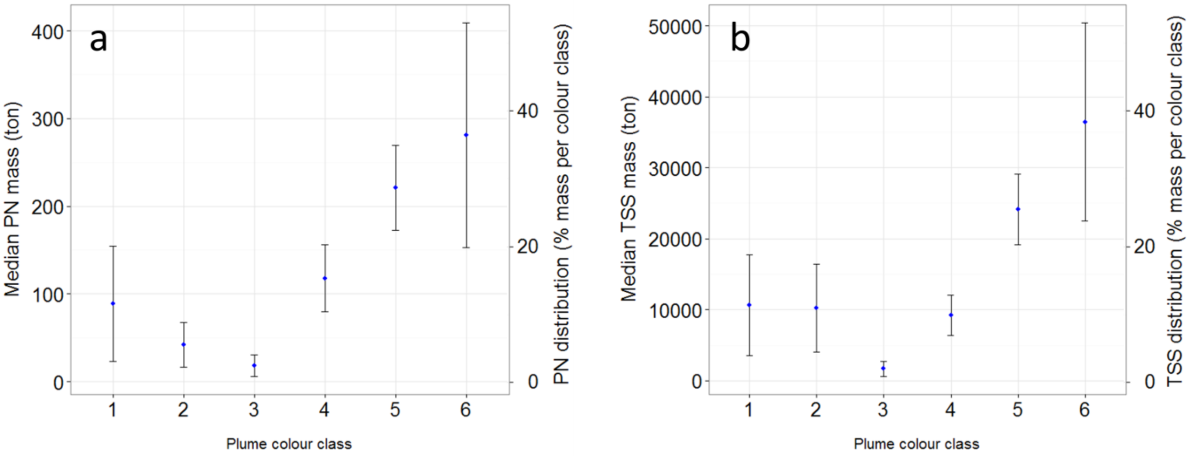

Figure D-14. Median mass of particulate nitrogen (a) and TSS (b), and percent contribution across the six-colour class. Error bars stand for 95%CI (see text for explanation).

Although dispersion load maps were produced for TSS and PN (not shown), it is important to note that there is a higher uncertainty in these two maps compared to the DIN map. Two main sources of uncertainty are (i) the modelled end of basin loads for TSS and PN are not as reliable as DIN loads because of the way hydrology is represented in the model and (b) there is a difference in scale between processes controlling TSS and PN variations and what is mapped in plume waters. For example, most of the particles fall out in the proximal zone of the river mouth, when salinity is normally < 5 within colour class 1. Colour class 1 is the smallest resolution for characterising plume waters at their initial stage of development and encompasses salinity up to 20. Therefore, by taking a median value to estimate TSS and PN concentrations in this water, we underestimate the sedimentation of particles after being discharged into the Reef lagoon. Further, the potential addition of PN and TSS to the plume water due to resuspension and potential biological production may result in overestimating the actual river contribution to areas further away from the river mouth.

D-7 Validation of numerical hydrodynamics modelling of flood plumes

Hydrodynamic models provide a valuable tool for identifying, quantifying and communicating the spatial impact of discharges from various rivers into the Reef lagoon. Hydrodynamic models can simulate the three-dimensional transport and fate of material delivered to the marine environment and deliver benefits over traditional static observations of river plume distributions. While aerial and remote sensing can track the visual extent of river plumes, it is generally difficult to quantify the contribution of individual rivers to the overall observed spatial impact. The impact of the rivers is often confounded by a number of factors including plumes from adjacent rivers that spatially overlap and mix, and inputs of low salinity tropical water advected from the north and low surface salinity due to rainfall, which is rapidly mixed. Numerical models provide a number of solutions to this problem. During flood events, discharges of freshwater are resolved by the model's salinity solution. Passive tracers overcome the problems of using salinity alone as a tracer, as they allow the freshwater from the individual rivers to be tagged and assessed. Passive tracers act as virtual markers and are conservatively advected and diffused in an identical fashion to physical variables such as temperature and salinity; however, they play no dynamic role in physical or biogeochemical processes. Importantly, simulation of the transport of unique tracers 'released' from different rivers enables the identification of marine regions influenced by individual catchments and provides insight into the mixing and retention of river water along various regions within the Reef lagoon

As part of the eReefs project (http://ereefs.org.au/ereefs), a regional implementation of a 3-dimensional, baroclinic hydrodynamic model was developed for the Reef lagoon. Outputs from the model include 3-dimensional distributions of velocity, temperature, salinity, density, passive tracer concentrations, mixing coefficients and sea level. Inputs required by the model include forcing due to wind, atmospheric pressure gradients, surface heat and rainfall fluxes and open-boundary conditions such as tides, low frequency ocean currents and riverine inputs. The model is described in detail by Schiller et al. (2015). For this study, outputs from the regional ~4 km horizontal spatial resolution model were used.

Hindcast simulations were performed for the wet season, which was considered to be the period from 1 November until 31 March of the following year. River-tagged passive tracers were released from each of the major gauged rivers between discharging in to the Reef lagoon. The influence of the Normanby, Baron, Russell-Mulgrave, Tully, and Burdekin Rivers was examined. The discharge concentration of each river's unique tracer was set at 1.0 at the river mouth, while the starting tracer concentration in the Reef lagoon (time = 0 for each wet season) was set to 0.0.

River exposure index

Model simulations of the 3-dimensional distributions of passive tracers were analysed to produce weekly estimates of cumulative exposure to tracers above a threshold of 1% of the source concentration.

A cumulative exposure index was defined that integrates the tracer concentration above a defined threshold. It is a cumulative measurement of the exposure concentration and duration of exposure to dissolved inputs from individual river sources. It is expressed as Concentration × Days (Conc.Days)

For every location in the model domain cumulative exposure is calculated as follows:

$$\text{Conc.Days} = \sum_{t=0}^{T} \text{Conc}_{exceedance} * \text{t}$$

where,

$$\text{Conc}_{exceedance} = \begin{cases} \text{Conc(t) - Conc}_{threshold}, & \text{where Conc(t)} > \text{Conc}_{threshold} \\ 0, & \text{where Conc(t)} \leq \text{Conc}_{threshold} \end{cases}$$

and $\text{Conc}_{threshold}$ is defined here as 1% of the source concentration, Conc(t) represents the time-varying tracer concentration, and t is time in days from the beginning of the wet season (t_0 = 1 November), and $T_{\text{end of wet season}}$ = 31 March. Cumulative exposure is calculated for each grid point in the model domain.

Using this representation, the exposure index integrates both concentration above a defined threshold and the duration of exposure. For example, an exposure of 20 days at a concentration of 1% above the threshold would produce an index value of 0.2, which is equivalent to 10 days exposure at 2% above the concentration threshold. This index provides a consistent approach to assess relative differences in exposure of Reef shelf waters to inputs from various rivers. Spatial maps of river exposure indices were calculated for each of the target rivers simulated by the model.

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Appendix E: Additional information

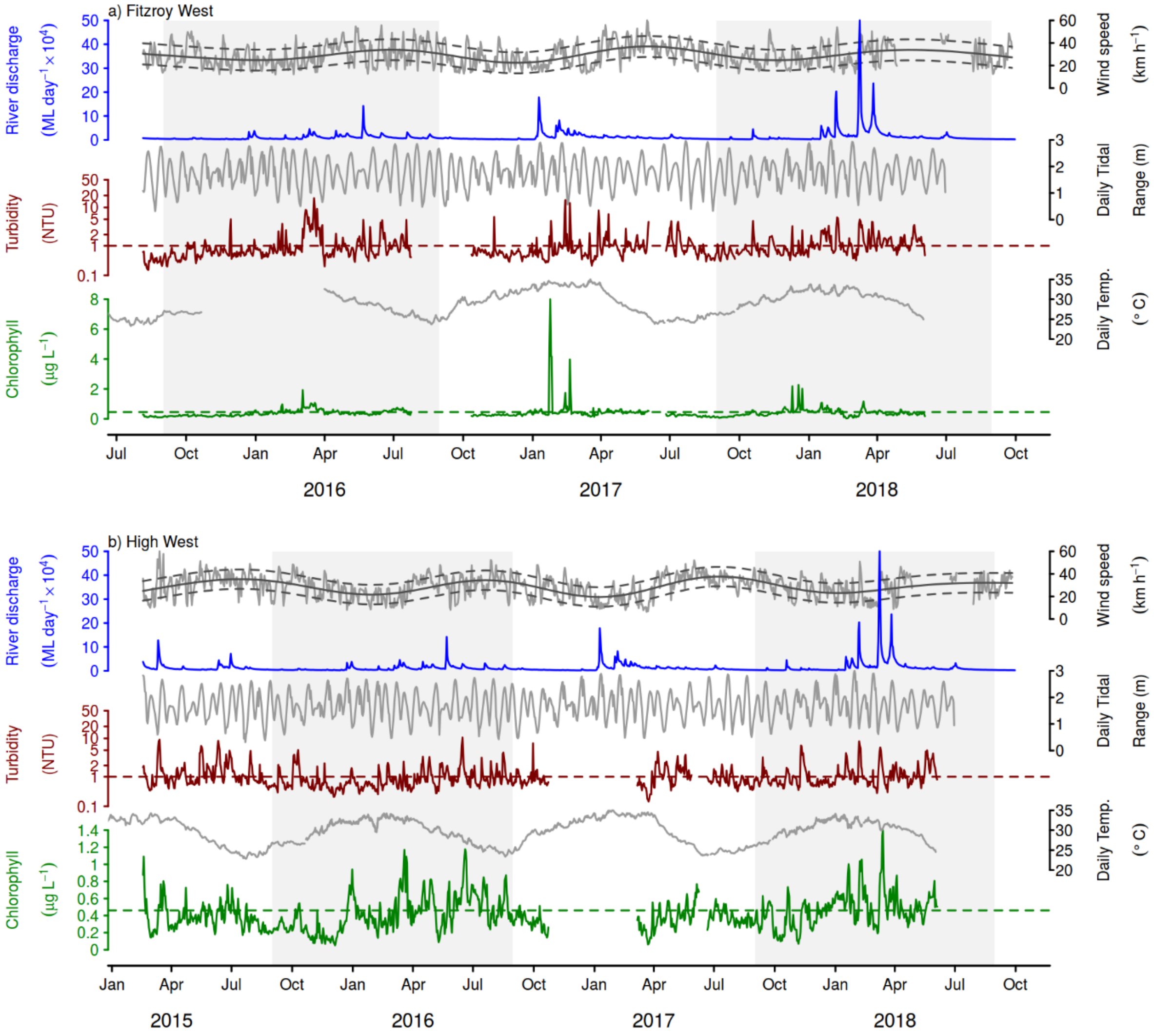
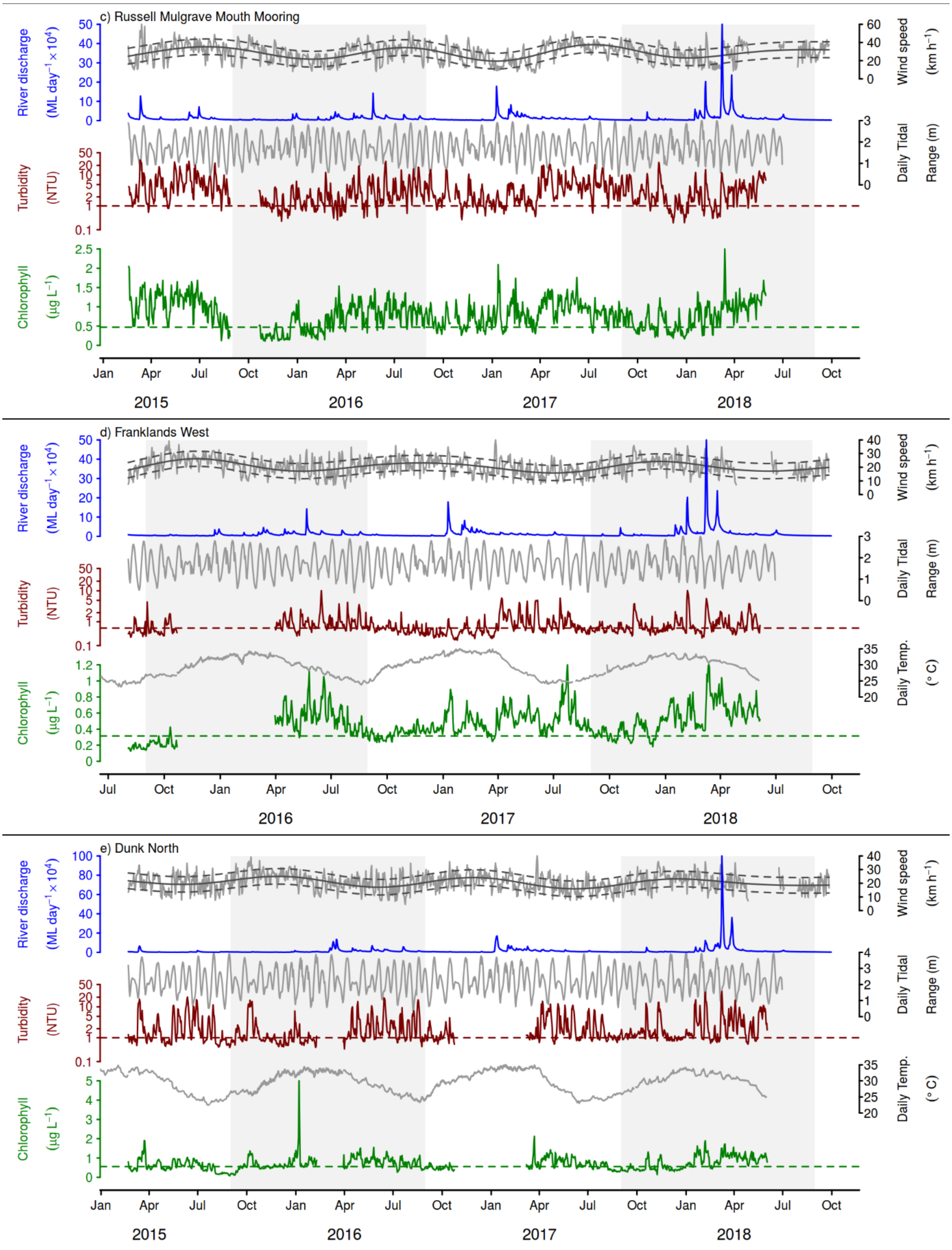
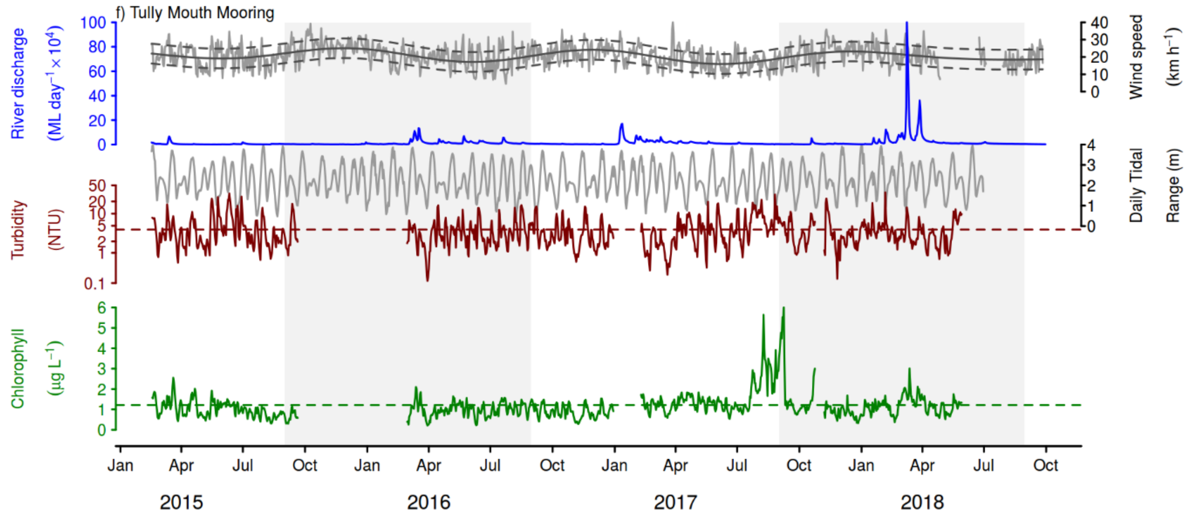
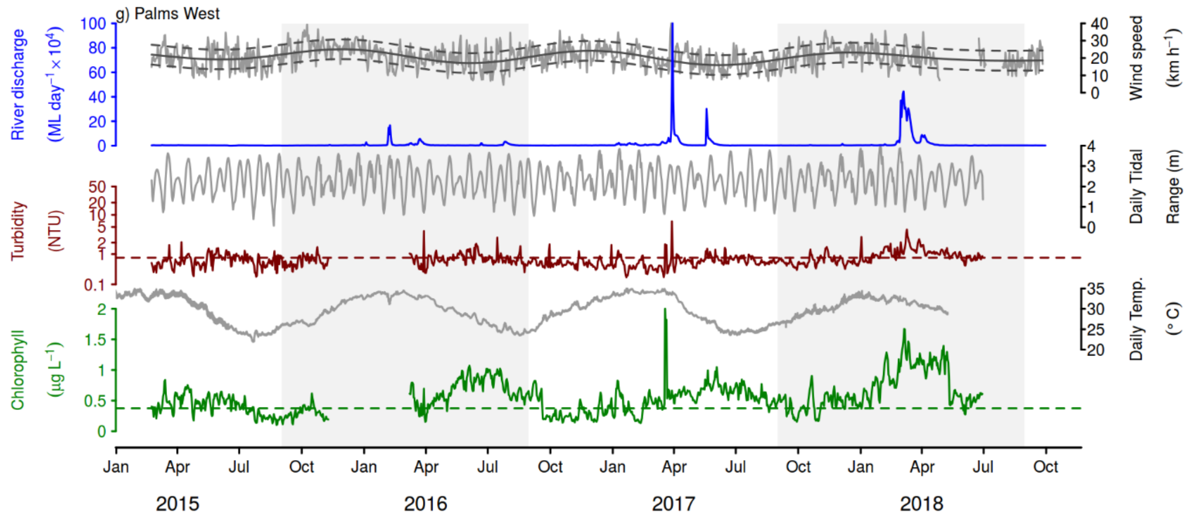
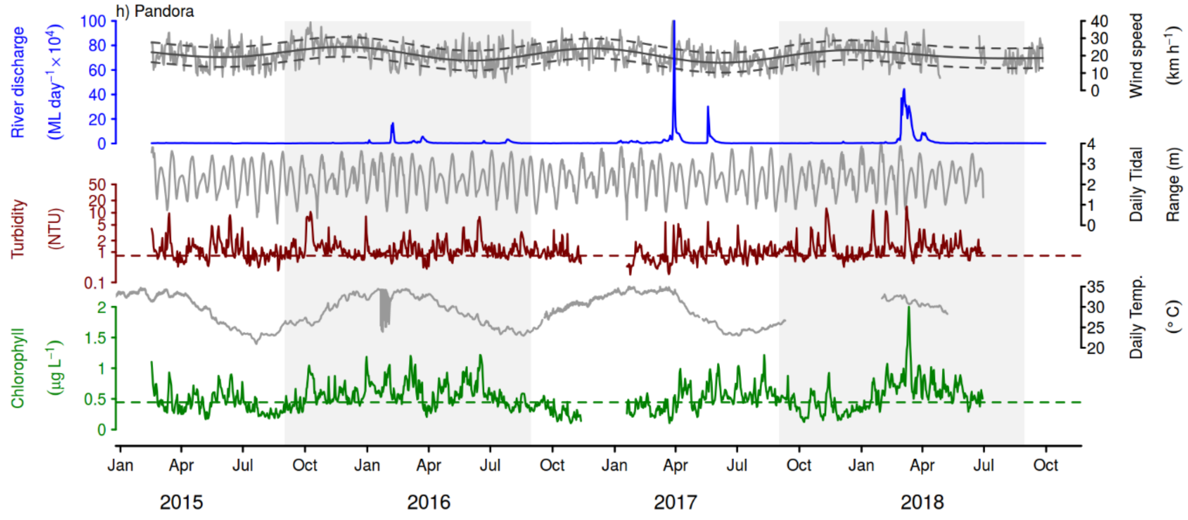


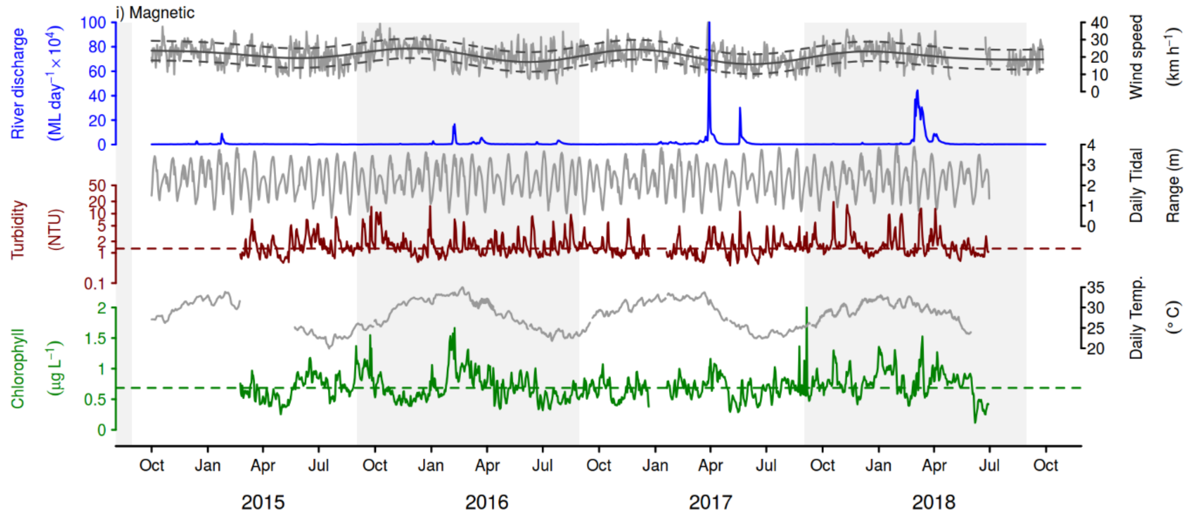
Figure E-1: Time-series of daily means of chlorophyll and turbidity collected by moored ECO FLNTUSB instruments; coloured dashed lines represent the Water Quality Guidelines. Daily river discharge from the nearest river, daily wind speeds from the nearest weather stations, daily tidal range from the nearest tidal gauge, and daily temperature are also shown. Locations of loggers are shown in **Error! Reference source not found.** and panels continue on additional pages below: a) Fitzroy West; b) High West; c) Russell-Mulgrave Mouth Mooring; d) Franklands West; e) Dunk North; f) Tully Mouth Mooring; g) Palms West; h) Pandora; i) Magnetic; j) Burdekin Mouth Mooring; k) Double Cone; l) Pine; m) Seaforth; and n) Repulse.

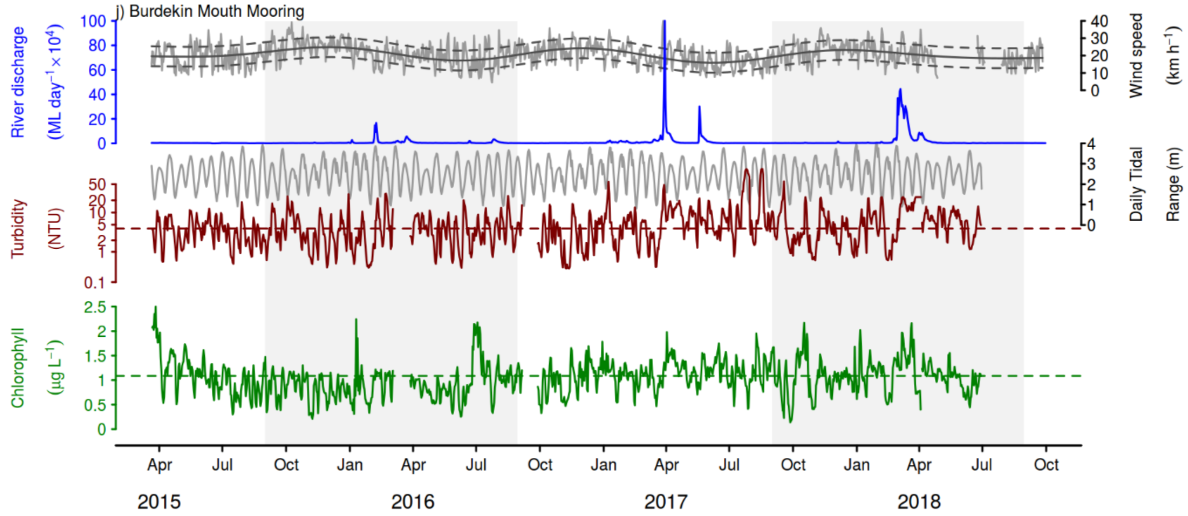

c) Russell Mulgrave Mouth Mooring
River discharge (ML day^{-1} × 10^4)
50 40 30 20 10 0
Turbidity (NTU)
50 20 10 5 2 1 0.1
Chlorophyll (µg L^{-1})
2.5 2 1.5 1 0.5 0
Wind speed (km h^{-1})
60 40 20 0
Daily Tidal Range (m)
3 2 1 0
Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct
2015 2016 2017 2018
d) Franklands West
River discharge (ML day^{-1} × 10^4)
50 40 30 20 10 0
Turbidity (NTU)
50 20 10 5 2 1 0.1
Chlorophyll (µg L^{-1})
1.2 1 0.8 0.6 0.4 0.2 0
Wind speed (km h^{-1})
40 30 20 10 0
Daily Tidal Range (m)
3 2 1 0
Daily Temp. (° C)
35 30 25 20
Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct
2016 2017 2018
e) Dunk North
River discharge (ML day^{-1} × 10^4)
100 80 60 40 20 0
Turbidity (NTU)
50 20 10 5 2 1 0.1
Chlorophyll (µg L^{-1})
5 4 3 2 1 0
Wind speed (km h^{-1})
40 30 20 10 0
Daily Tidal Range (m)
4 3 2 1 0
Daily Temp. (° C)
35 30 25 20
Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct
2015 2016 2017 2018

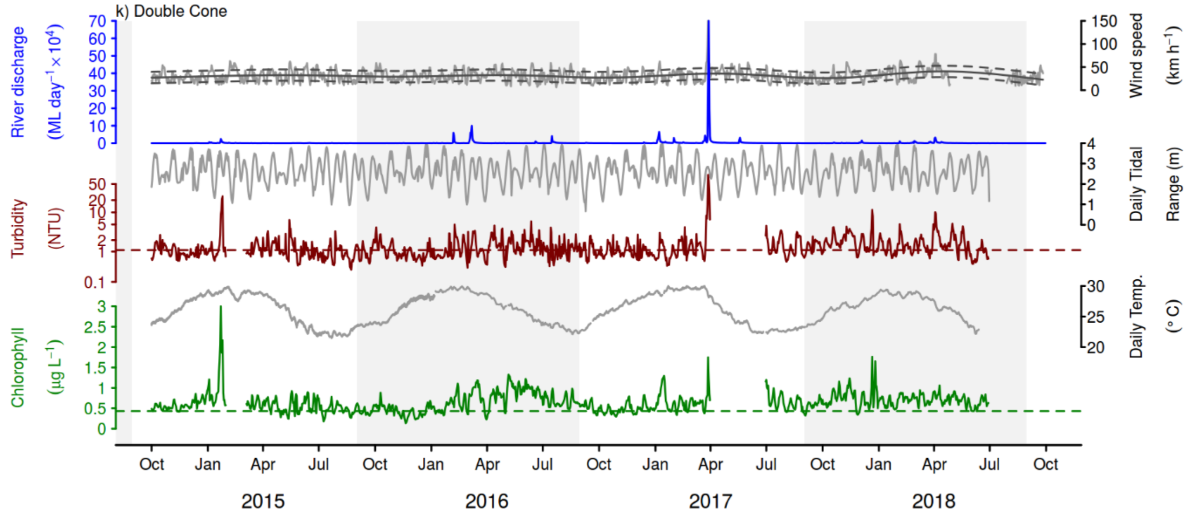

f) Tully Mouth Mooring
River discharge
(ML day^{-1} × 10^4)
100
80
60
40
20
0
Turbidity
(NTU)
50
20
10
5
2
1
0.1
Chlorophyll
(µg L^{-1})
6
5
4
3
2
1
0
Wind speed
(km h^{-1})
40
30
20
10
0
Daily Tidal
Range (m)
4
3
2
1
0
Jan
Apr
Jul
Oct
2015
2016
2017
2018

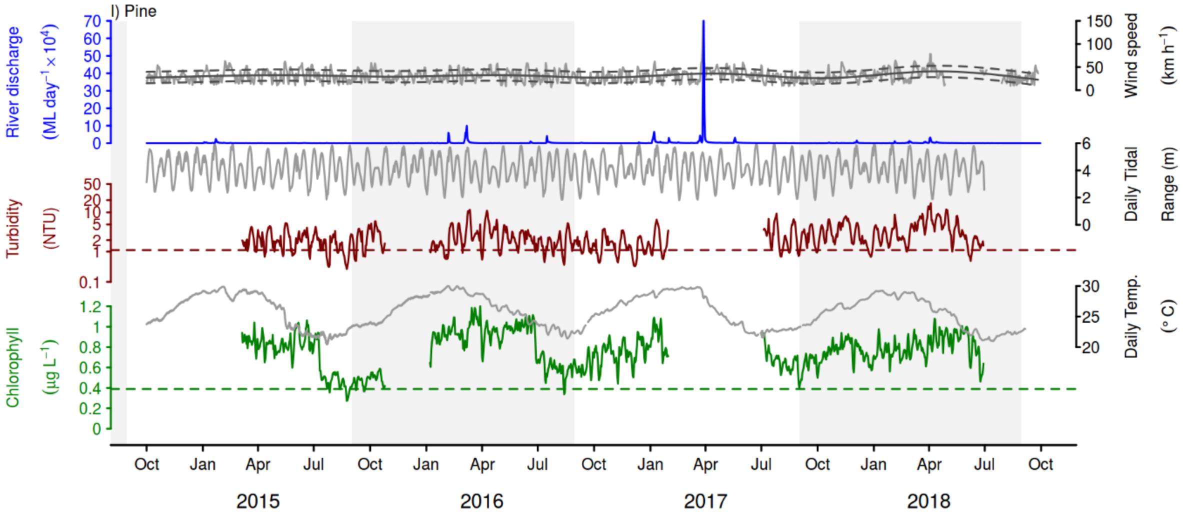

g) Palms West
River discharge
(ML day^{-1} × 10^4)
100
80
60
40
20
0
Turbidity
(NTU)
50
20
10
5
2
1
0.1
Chlorophyll
(µg L^{-1})
2
1.5
1
0.5
0
Wind speed
(km h^{-1})
40
30
20
10
0
Daily Tidal
Range (m)
4
3
2
1
0
Daily Temp.
(° C)
35
30
25
20
Jan
Apr
Jul
Oct
2015
2016
2017
2018

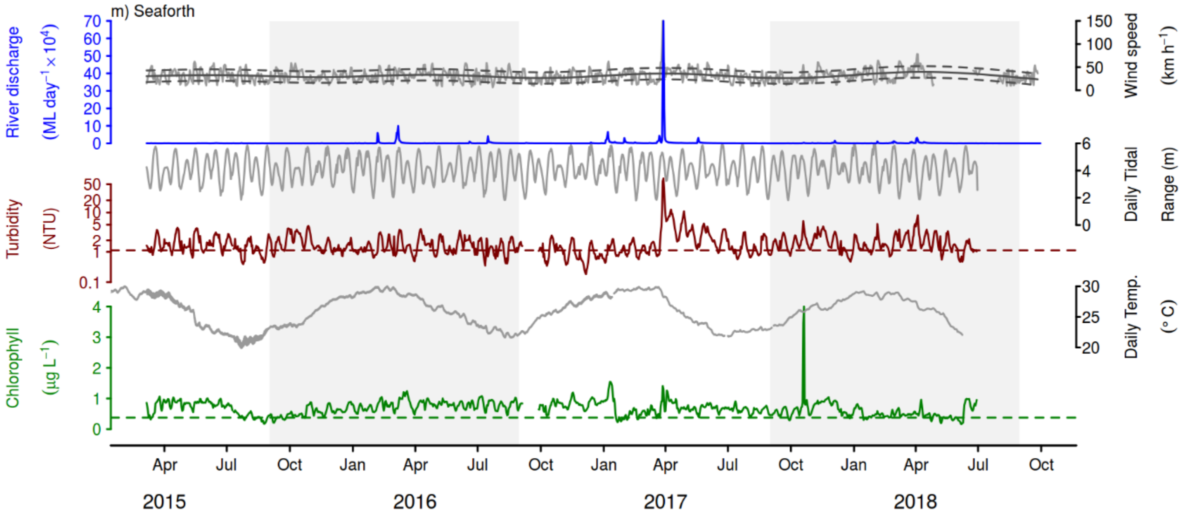

h) Pandora
River discharge
(ML day^{-1} × 10^4)
100
80
60
40
20
0
Turbidity
(NTU)
50
20
10
5
2
1
0.1
Chlorophyll
(µg L^{-1})
2
1.5
1
0.5
0
Wind speed
(km h^{-1})
40
30
20
10
0
Daily Tidal
Range (m)
4
3
2
1
0
Daily Temp.
(° C)
35
30
25
20
Jan
Apr
Jul
Oct
2015
2016
2017
2018

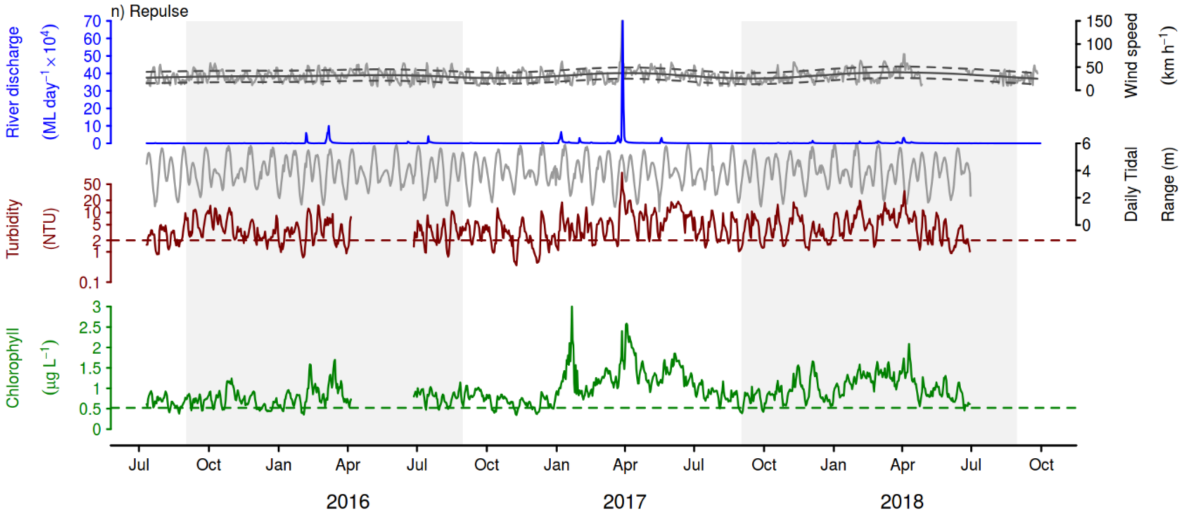

i) Magnetic
River discharge
(ML day^{-1} × 10^4)
100
80
60
40
20
0
Turbidity
(NTU)
50
20
10
5
2
1
0.1
Chlorophyll
(µg L^{-1})
2
1.5
1
0.5
0
Wind speed
(km h^{-1})
40
30
20
10
0
Daily Tidal
Range (m)
4
3
2
1
0
Daily Temp.
(° C)
35
30
25
20
Oct
Jan
Apr
Jul
Oct
Jan
Apr
Jul
Oct
Jan
Apr
Jul
Oct
Jan
Apr
Jul
Oct
2015
2016
2017
2018


j) Burdekin Mouth Mooring
River discharge
(ML day^{-1} × 10^4)
100
80
60
40
20
0
Turbidity
(NTU)
50
20
10
5
2
1
0.1
Chlorophyll
(µg L^{-1})
2.5
2
1.5
1
0.5
0
Wind speed
(km h^{-1})
40
30
20
10
0
Daily Tidal
Range (m)
4
3
2
1
0
Apr
Jul
Oct
Jan
Apr
Jul
Oct
Jan
Apr
Jul
Oct
Jan
Apr
Jul
Oct
2015
2016
2017
2018


k) Double Cone
River discharge
(ML day^{-1} × 10^4)
70
60
50
40
30
20
10
0
Turbidity
(NTU)
50
20
10
5
2
1
0.1
Chlorophyll
(µg L^{-1})
3
2.5
2
1.5
1
0.5
0
Wind speed
(km h^{-1})
150
100
50
0
Daily Tidal
Range (m)
4
3
2
1
0
Daily Temp.
(° C)
30
25
20
Oct
Jan
Apr
Jul
Oct
Jan
Apr
Jul
Oct
Jan
Apr
Jul
Oct
Jan
Apr
Jul
Oct
2015
2016
2017
2018


l) Pine
River discharge (ML day^{-1} × 10^4)
70
60
50
40
30
20
10
0
Turbidity (NTU)
50
20
10
5
2
1
0.1
Chlorophyll (µg L^{-1})
1.2
1
0.8
0.6
0.4
0.2
0
Wind speed (km h^{-1})
150
100
50
0
Daily Tidal Range (m)
6
4
2
0
Daily Temp. (° C)
30
25
20
Oct
Jan
Apr
Jul
2015
2016
2017
2018


m) Seaforth
River discharge (ML day^{-1} × 10^4)
70
60
50
40
30
20
10
0
Turbidity (NTU)
50
20
10
5
2
1
0.1
Chlorophyll (µg L^{-1})
4
3
2
1
0
Wind speed (km h^{-1})
150
100
50
0
Daily Tidal Range (m)
6
4
2
0
Daily Temp. (° C)
30
25
20
Apr
Jul
Oct
Jan
2015
2016
2017
2018


n) Repulse
River discharge (ML day^{-1} × 10^4)
70
60
50
40
30
20
10
0
Turbidity (NTU)
50
20
10
5
2
1
0.1
Chlorophyll (µg L^{-1})
3
2.5
2
1.5
1
0.5
0
Wind speed (km h^{-1})
150
100
50
0
Daily Tidal Range (m)
6
4
2
0
Jul
Oct
Jan
Apr
2016
2017
2018

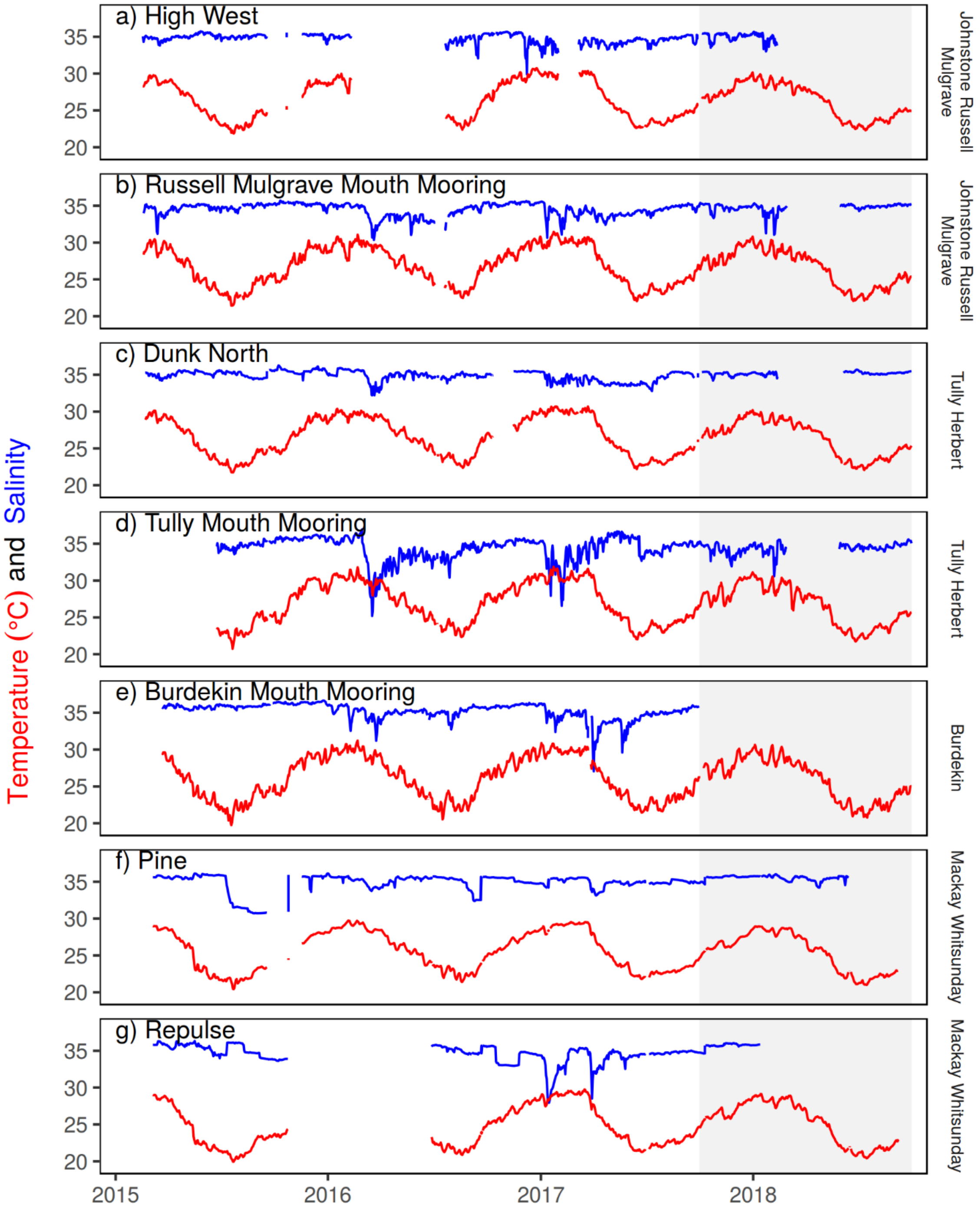


Figure E-2: Time series of daily means of temperature and salinity derived from moored Sea-Bird Electronics (SBE) CTDs. Sub-figures represent instrument locations at: a) High West, b) Russel Mulgrave Mouth Mooring, c) Dunk North, d) Tully River Mouth Mooring, e) Burdekin Mouth Mooring, f) Pine, and g) Repulse.

Table E-1: Relative annual freshwater discharge (fraction of long-term median) for the major rivers influencing the sampling sites of the MMP Inshore Water Quality Monitoring Program. Shaded cells highlight years for which river discharge exceeded the median annual discharge as estimated from available long-term time series for each river (LT median from October 1970 to September 2000): yellow = 1.5 to 2 times LT median, orange = 2 to 3 times LT median, red = >3 times LT median. Records for the 2018 water year are incomplete (to August 2018). Discharge data were supplied by the Queensland Department of Natural Resources and Mines (gauging station codes given after river names).

Region	River (gauging station)	Long-term median discharge (ML)	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Wet Tropics	Barron (110001D)	526,686.5	0.8*	1.6***	0.9	3.4	1.6	1.0	4.0	1.6	0.6	1.3	0.7	0.3	0.5	1.6
	Daintree (108002A)	1,722,934	0.7	1.7	1.0	1.2	0.9	1.6	2.2	1.3	0.9	2.8	1.0	0.9	1.1	0.6
	Herbert (116001F/E)	3,556,376	0.4***	1.2	1.2	1.0	2.9***	1.0	3.6	1.3	0.9	1.2	0.3	0.5	0.6	1.8
	Mossman (109001A)	1,207,012	0.9	1.5	1.0	1.1	0.9	1.3	1.7	1.3	1.0	1.6	0.7	0.9	1.0	1.2
	Mulgrave (111007A)	4,457,940	0.6	1.0	0.8	1.1	0.8	0.8	1.7	1.2	0.6	1.0	0.7	0.4	0.5	1.2
	Murray (114001A)	1,227,888	0.3*	1.4	1.1	1.0	1.5	0.8	3.5	1.7	0.8	1.2	0.3	0.8	0.8	1.4
	Normanby (105107A)															
	North Johnstone (112004A)	4,743,914	0.8	1.1	1.1	1.0	1.0	1.0	1.9	1.1	0.8	1.1	0.7	0.7	0.8	1.2
	Russell (111101D)	4,457,940	0.2	0.3	0.3	0.2	0.3	0.3	0.4	0.3	0.2	0.3	0.2	0.2	0.2	0.3
	South Johnstone (112101B)	4,743,914	0.7	1.2	1.1*	1.0***	1.3	0.9	2.0	1.2	0.7	1.1	0.5	0.7	0.9	1.3
	Stewart (104001A)															
	Tully (113006A)	3,536,054	0.7	1.2	1.3**	1.1**	1.2*	1.0	1.9				0.0	0.8	0.9	1.2
Burdekin	Black (117002A)	228,629	0.8	1.6	4.3	5.5	9.2	4.6	10.6	5.6	1.3	3.4	0.2	0.9	0.5	3.4
	Burdekin (120006B)	4,406,780	1.0	0.5	2.2	6.2	6.7	1.8	7.9	3.6	0.8	0.4	0.2	0.4	1.0	1.3
	Don (121003A)	342,257	1.1	0.4	1.8	5.0	2.7	1.6	9.2	2.3	1.7	0.9	0.5	0.3	2.9	0.4

Region	River (gauging station)	Long-term median discharge (ML)	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	Haughton (119003A)	553,292	1.0	1.2	2.4	3.3	4.6	2.1	4.4	3.2	0.9	1.0	0.2	0.6	0.6	1.5
Mackay Whitsunday	Carmila (126003A)	1,052,831	0.0	0.0	0.1	0.1	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.0
	Gregory (122004A)	887,771.5	0.2	0.2	0.5	1.2	0.7	0.6	1.2	0.4	0.4	0.4	0.1	0.1	1.2	0.3
	OConnell (124001B)	796,718		0.8	1.6	2.3	1.7	2.9	5.2	2.4	1.0	0.8	0.2	0.4	1.9	0.6
	Pioneer (125007A)	776,984	0.3	0.1	1.0	1.8	1.2	1.7	4.7	1.9	1.3	0.7	0.2	0.6	1.7	0.3
	Sandy (126001A)	1,052,831	0.5	0.0	1.2	2.7	1.4	2.8	4.6	2.7	1.9	0.7	0.2	0.8	2.5	0.3
Fitzroy	Fitzroy (130005A)	2,852,306	0.3	0.2	0.4	4.4	0.7	4.1	13.3	2.8	3.0	0.6	0.9	1.2	2.2	0.3
	Waterpark (129001A)	563,267.5	0.4	0.2	0.5	2.5	1.0	2.8	4.8	1.5	5.2	2.9	2.2	1.8	2.6	1.4

* Indicates 5 - 15% of daily observations were missing

** Indicates years for which >15% of daily flow was not available but these missing records are likely have been zero flow and so annual flow estimates are valid

*** Indicates years for which >15% of daily flow estimates were not available

Table E-2: Water quality results for Cape York sampling sites within the enclosed coastal (EC), open coastal (OC), mid-shelf (MS) and offshore (OS) zones compared against the Draft Eastern Cape York Water Quality Guidelines for each zone. Guidelines vary for each zone and sub-region based on available data. For the EC zone, annual baseflow (wet and dry season combined) guidelines have been designated for Endeavour and Normanby Basin enclosed coastal zones. Stewart & Pascoe EC zone results are compared with Endeavour River HEV Water Quality Guidelines due to lack of guidelines for these sub-regions. OC zone guidelines (all sub-regions) include both wet season and dry season guidelines except for NH_3 and Secchi depth which have annual guidelines. As a result, the OC zone results for each sub-region are presented for combined annual results, wet season and dry season. MS and OS zone guidelines (all sub-regions) are based on annual concentrations, therefore only the annual (wet and dry season combined) results are presented for each sub-region in these zones. Flood event sample results are not included in the statistics calculated for these tables. Results that exceed the relevant guidelines are shaded in red. Pascoe river marine waters (all zones) and Normanby transect OS zone sites were only sampled during the wet season, therefore are not representative of annual conditions and these comparisons with annual guidelines are shaded in yellow.

ENCLOSED COASTAL ZONE ANNUAL (WET AND DRY SEASON COMBINED) 2017 - 2018

Region/ Water body	Site	Measure	N	Min	Max	Mean	Quantiles					Guidelines	
							Q5	Q20	Median Q50	Q80	Q95	Statistic	Base Flow/ Annual
Cape York Enclosed Coastal (EC) Zone	Annan - Endeavour	Secchi (m)[1]											
		TSS (mgL^{-1})	9	2	7	4	2	2	3	5	6		
		TN (μgL^{-1})	9	81	155	103	86	93	96	106	136	20th-50th-80th	110–125–200
		NOx (μgL^{-1})	9	1	13	4	1	2	3	5	10	20th-50th-80th	1-2-10
		NH_3 (μgL^{-1})	9	1	6	3	1	2	3	4	6	20th-50th-80th	1-4-10
		DON (μgL^{-1})	9	68	103	85	70	78	82	92	101		
		PN (μgL^{-1})	9	1	35	11	2	5	11	12	26		
		TP (μgL^{-1})	9	5	8	7	6	7	8	8	8	20th-50th-80th	6–8–12
		PO4 (μgL^{-1})	9	2	5	3	2	3	3	4	5	20th-50th-80th	1-1-3
		DOP (μgL^{-1})	9	0	5	3	1	2	4	4	5		
		PP (μgL^{-1})	9	0	4	1	0	0	1	1	3		
		Chla (μgL^{-1})	8	0.10	0.49	0.27	0.10	0.10	0.29	0.41	0.47	20th-50th-80th	0.5-1.0-1.5
	Stewart River	Secchi (m)	12	1.2	5.8	3.3	1.4	1.8	3.0	4.7	5.6		
		TSS (mgL^{-1})	23	1	56	7	2	2	5	7	16		
		TN (μgL^{-1})	21	89	392	136	96	100	121	145	176	20th-50th-80th	110–125–200
		NOx (μgL^{-1})	21	1	48	6	1	1	2	6	20	20th-50th-80th	1-2-10
		NH_3 (μgL^{-1})	21	1	12	4	2	2	3	4	6	20th-50th-80th	1-4-10
		DON (μgL^{-1})	21	75	331	108	81	88	94	112	116		
		PN (μgL^{-1})	21	0	68	18	1	2	5	30	62		
		TP (μgL^{-1})	21	4	20	8	4	5	7	11	17	20th-50th-80th	6–8–12
		PO4 (μgL^{-1})	21	1	5	3	1	2	2	4	4	20th-50th-80th	1-1-3
		DOP (μgL^{-1})	21	0	9	2	1	1	2	3	4		
		PP (μgL^{-1})	21	0	13	3	0	1	2	5	8		

ENCLOSED COASTAL ZONE ANNUAL (WET AND DRY SEASON COMBINED) 2017 - 2018

Region/ Water body	Site	Measure	N	Min	Max	Mean	Quantiles					Guidelines	
							Q5	Q20	Median Q50	Q80	Q95	Statistic	Base Flow/ Annual
Cape York Enclosed Coastal Zone		Chla (µgL^{-1})	23	0.26	1.30	0.45	0.26	0.31	0.39	0.51	0.76	20th-50th-80th	0.5-1.0-1.5
	Pascoe River (Wet Season Only)	Secchi (m)	8	1.0	3.5	2.3	1.0	1.3	2.7	3.0	3.3		
		TSS (mgL^{-1})	12	1	32	9	3	4	6	8	24		
		TN (µgL^{-1})	12	84	221	132	91	102	118	166	201	20th-50th-80th	110–125–200
		NOx (µgL^{-1})	12	1.0	11	3	1	1	1.5	4	7	20th-50th-80th	1-2-10
		NH_3 (µgL^{-1})	12	2	4	3	2	2	3	3	4	20th-50th-80th	1-4-10
		DON (µgL^{-1})	12	67	165	106	75	84	96	127	157		
		PN (µgL^{-1})	12	1	107	20	1	2	9	21	77		
		TP (µgL^{-1})	12	5	13	8	5	6	8	11	12	20th-50th-80th	6–8–12
		PO4 (µgL^{-1})	12	1	4	3	2	2	3	3	4		
		DOP (µgL^{-1})	12	1	8	3	1	2	2	5	6	20th-50th-80th	1-1-3
		PP (µgL^{-1})	12	0	8	3	1	1	2	5	7		
		Chla (µgL^{-1})	12	0.33	1.83	0.88	0.36	0.57	0.72	1.21	1.68	20th-50th-80th	0.5-1.0-1.5
	Normanby River	Secchi (m)	9	0.9	2.7	1.8	1.0	1.2	1.5	2.6	2.7		
		TSS (mgL^{-1})	17	3	24	7	3	3	5	10	17		
		TN (µgL^{-1})	17	97	252	148	103	105	130	172	234	20th-50th-80th	160–224–257
		NH_3 (µgL^{-1})	17	2	10	4	2	3	4	6	8	20th-50th-80th (IMP)	2-8-14
		NOx (µgL^{-1})	17	1.0	12.0	3.5	1.0	1.0	1.5	7.5	9.6	20th-50th-80th (IMP)	5-13-23
		DON (µgL^{-1})	17	75	150	109	81	84	102	132	150		
		PN (µgL^{-1})	17	0	138	32	1	10	17	59	112		
		TP (µgL^{-1})	17	4	19	9	5	7	8	10	14	20th-50th-80th	11–17–26
		PO4 (µgL^{-1})	17	1	4	2	1	1	2	3	4	20th-50th-80th (IMP)	1-1-3
		DOP (µgL^{-1})	17	1	9	4	1	2	4	6	8		
		PP (µgL^{-1})	17	0	10	2	0	0	2	3	7		
		Chla (µgL^{-1})	17	0.1	1.6	0.7	0.2	0.5	0.7	0.9	1.5	Median	1.9

[1] Secchi depth in enclosed coastal zone > water depth (around 3m) at most AE sample locations therefore statistics could not be calculated

OPEN COASTAL ZONE ANNUAL (WET AND DRY SEASON COMBINED) 2017 - 2018															
Region/ Water body	Site	Measure	N	Min	Max	Mean	Quantiles					Guidelines			
							Q5	Q20	Median	Q80	Q95	Statistic	Base Flow/ Annual	Dry	Wet
Cape York Open Coastal Zone	Stewart River	Secchi (m)	6	2.1	7.8	5.6	2.8	4.9	6.0	6.6	7.5	Mean	≥ 10		
		TSS (mgL^{-1})	11	0.9	25.0	4.6	1.1	1.3	2.6	3.8	15.1	Mean		≤ 1.6	1.1-1.7-2.2
		TN (µgL^{-1})	11	87	132	105	91	95	102	108	131				75–105–130
		TDN (µgL^{-1})	11	82	131	99	84	87	96	102	127				55–80–105
		NOx (µgL^{-1})	11	1	6	2	1	1	2	3	5	20th-50th-80th		0-0-1	0-0-1
		NH$_3$ (µgL^{-1})	11	2	10	4	2	2	3	5	8	20th-50th-80th	0-1-3		
		DON (µgL^{-1})	11	76	127	93	78	83	90	98	122				
		PN (µgL^{-1})	11	1	16	6	1	1	6	7	16	Mean		≤ 16	14-20-26
		TP (µgL^{-1})	11	3	8	6	4	5	6	8	8				5–10–20
		TDP (µgL^{-1})	11	3	7	5	4	4	5	6	7				2–5–12
		PO4 (µgL^{-1})	11	1	6	3	2	2	2	3	5	20th-50th-80th		0-2-3	0-1-2
		DOP (µgL^{-1})	11	1	4	2	1	1	2	3	4				
		PP (µgL^{-1})	11	0.0	3.0	1.2	0.5	1.0	1.0	1.0	2.5	Mean		≤ 2.3	2.2-3.0-3.9
		Chla (µgL^{-1})	11	0.10	0.52	0.30	0.10	0.23	0.29	0.42	0.47	20th-50th-80th		0.16-0.25-0.46	0.30-0.46-0.78
	Normanby River	Secchi (m)	10	3.0	10.5	5.3	3.1	3.4	4.5	7.2	9.6	Mean	≥ 10		
		TSS (mgL^{-1})	19	0.9	11.0	3.5	1.2	1.5	3.3	4.8	6.4	Mean		≤ 1.6	1.1-1.7-2.2
		TN (µgL^{-1})	19	85	233	121	86	92	104	142	197				75–105–130
		TDN (µgL^{-1})	19	76	150	104	80	87	94	128	142				55–80–105
		NOx (µgL^{-1})	19	1	11	5	2	3	4	7	9	20th-50th-80th		0-0-1	0-0-1
		NH$_3$ (µgL^{-1})	19	1	20	4	1	1	3	6	11	20th-50th-80th	0-1-3		
		DON (µgL^{-1})	19	66	146	95	71	78	86	117	133				
		PN (µgL^{-1})	19	2	99	18	2	4	6	14	85	Mean		≤ 16	14-20-26
		TP (µgL^{-1})	19	5	13	7	5	5	7	7	9				5–10–20
		TDP (µgL^{-1})	19	3	7	5	3	4	5	6	7				2–5–12
		PO4 (µgL^{-1})	19	1	3	2	1	1	2	3	3	20th-50th-80th		0-2-3	0-1-2
		DOP (µgL^{-1})	19	1	5	3	1	2	3	4	5				
		PP (µgL^{-1})	19	0.0	6.0	1.7	0.0	0.0	1.0	2.4	5.1	Mean		≤ 2.3	2.2-3.0-3.9
		Chla (µgL^{-1})	19	0.1	2.1	0.5	0.1	0.3	0.4	0.6	0.9	20th-50th-80th		0.16-0.25-0.46	0.30-0.46-0.78
	Annan-Endeavour	Secchi (m)	9	3.8	13.0	8.4	4.5	6.1	7.4	11.5	12.4	Annual	≥ 10		
		TSS (mgL^{-1})	20	1.7	11.0	3.4	1.9	2.3	2.9	3.7	6.5	Mean		≤ 1.6	1.1-1.7-2.2

OPEN COASTAL ZONE ANNUAL (WET AND DRY SEASON COMBINED) 2017 - 2018

Region/ Water body	Site	Measure	N	Min	Max	Mean	Quantiles					Guidelines			
							Q5	Q20	Median	Q80	Q95	Statistic	Base Flow/ Annual	Dry	Wet
Cape York Open Coastal Zone		TN (µgL^{-1})	20	89	157	105	89	93	99	109	156				75–105–130
		TDN (µgL^{-1})	20	77	102	89	79	85	90	94	97				55–80–105
		NOx (µgL^{-1})	20	1	12	4	1	2	3	5	9	20th-50th-80th		0-0-1	0-0-1
		NH$_3$ (µgL^{-1})	20	1	20	4	1	2	3	4	11	20th-50th-80th	0-1-3		
		DON (µgL^{-1})	20	69	97	82	69	75	84	87	93				
		TP (µgL^{-1})	20	1	71	16	2	3	9	22	70				14-20-26
		TDP (µgL^{-1})	20	6	11	8	6	6	8	9	10				5–10–20
		PN (µgL^{-1})	20	3	9	7	5	5	7	8	9	Mean		≤ 16	2–5–12
		PO4 (µgL^{-1})	20	1	7	4	2	3	4	5	7	20th-50th-80th		0-2-3	0-1-2
		DOP (µgL^{-1})	20	0	6	3	1	1	3	4	5				
		PP (µgL^{-1})	20	0.0	4.0	1.0	0.0	0.0	1.0	1.2	3.1	Mean		≤ 2.3	2.2-3.0-3.9
		Chla (µgL^{-1})	20	0.10	1.25	0.37	0.10	0.20	0.30	0.42	0.93	20th-50th-80th		0.16-0.25-0.46	0.30-0.46-0.78

OPEN COASTAL ZONE WET SEASON 2017-2018

Region/ Water Body	Site	Measure	N	Min	Max	Mean	Quantiles					Guidelines		
							Q5	Q20	Median/ Q50	Q80	Q95	Statistic	Base Flow/ Annual	Wet Season
	Pascoe River	Secchi (m)	11	2.8	8.0	4.8	2.8	3.3	4.1	6.6	7.6	Mean	≥10	
		TSS (mgL^{-1})	18	1.1	4.4	2.3	1.2	1.5	2.2	2.9	3.6	20th-50th-80th		1.1-1.7-2.2
		TN (µgL^{-1})	18	87	168	105	89	91	99	112	148	20th-50th-80th		75–105–130
		TDN (µgL^{-1})	18	81	130	94	84	87	91	100	109	20th-50th-80th		55–80–105
		NOx (µgL^{-1})	18	1	8	3	1	2	3	4	7	20th-50th-80th		0-0-1
		NH$_3$ (µgL^{-1})	18	1	5	3	2	2	2	4	4	20th-50th-80th	0-1-3	
		DON (µgL^{-1})	18	78	124	88	78	81	87	92	104			
		PN (µgL^{-1})	18	0	40	11	1	2	5	20	38	20th-50th-80th		14-20-26
		TP (µgL^{-1})	18	3	15	7	3	4	6	8	12	20th-50th-80th		5–10–20
		TDP (µgL^{-1})	18	2	13	5	2	3	5	6	10	20th-50th-80th		2–5–12
		PO4 (µgL^{-1})	18	1	4	2	1	1	2	3	3	20th-50th-80th		0-1-2

OPEN COASTAL ZONE WET SEASON 2017-2018

Region/ Water Body							Quantiles					Guidelines		
	Site	Measure	N	Min	Max	Mean	Q5	Q20	Median/ Q50	Q80	Q95	Statistic	Base Flow/ Annual	Wet Season
Cape York Open Coastal Zone		DOP (µgL^{-1})	18	1	11	3	1	1	2	3	8			
		PP (µgL^{-1})	18	0	5	2	0	1	2	3	4	20th-50th-80th		2.2-3.0-3.9
		Chla (µgL^{-1})	18	0.26	0.91	0.51	0.26	0.34	0.41	0.72	0.91	20th-50th-80th		0.30-0.46-0.78
	Stewart River	Secchi (m)	4	4.9	7.8	6.2	5.0	5.3	6.0	7.1	7.6	Mean	≥10	
		TSS (mgL^{-1})	8	0.9	25.0	4.8	1.0	1.2	2.0	3.3	17.6	20th-50th-80th		1.1-1.7-2.2
		TN (µgL^{-1})	8	87	132	107	91	97	104	121	131	20th-50th-80th		75–105–130
		TDN (µgL^{-1})	8	82	131	101	83	87	99	115	128	20th-50th-80th		55–80–105
		NOx (µgL^{-1})	8	1	6	2	1	1	2	3	5	20th-50th-80th		0-0-1
		NH_3 (µgL^{-1})	8	2	5	3	2	2	3	4	5	20th-50th-80th	0-1-3	
		DON (µgL^{-1})	8	79	127	96	80	84	91	109	124			
		PN (µgL^{-1})	8	1	16	6	1	1	4	11	16	20th-50th-80th		14-20-26
		TP (µgL^{-1})	8	3	8	6	4	5	6	7	8	20th-50th-80th		5–10–20
		TDP (µgL^{-1})	8	3	7	5	3	4	5	6	7	20th-50th-80th		2–5–12
		PO4 (µgL^{-1})	8	1	6	3	1	2	2	3	5	20th-50th-80th		0-1-2
		DOP (µgL^{-1})	8	1	4	2	1	1	3	3	4			
		PP (µgL^{-1})	8	0.0	2.0	1.0	0.4	1.0	1.0	1.0	1.7	20th-50th-80th		2.2-3.0-3.9
		Chla (µgL^{-1})	8	0.10	0.52	0.33	0.15	0.25	0.34	0.42	0.49	20th-50th-80th		0.30-0.46-0.78
	Normanby Basin													
		Secchi (m)	7	3.0	10.5	5.8	3.1	3.5	4.5	8.2	9.9	Mean	≥10	
		TSS (mgL^{-1})	13	0.9	5.1	2.7	1.1	1.3	2.4	4.4	5.0	20th-50th-80th		1.1-1.7-2.2
		TN (µgL^{-1})	13	85	233	125	86	91	131	144	183	20th-50th-80th		75–105–130
		TDN (µgL^{-1})	13	76	150	110	78	87	102	131	145	20th-50th-80th		55–80–105
		NOx (µgL^{-1})	13	1	9	4	2	3	4	4	7	20th-50th-80th		0-0-1
		NH_3 (µgL^{-1})	13	1	20	5	1	1	3	6	14	20th-50th-80th	0-1-3	
		DON (µgL^{-1})	13	66	146	101	69	78	97	124	137			
		PN (µgL^{-1})	13	2	83	15	3	4	6	10	61	20th-50th-80th		14-20-26
		TP (µgL^{-1})	13	5	9	6	5	5	6	7	8	20th-50th-80th		5–10–20
		TDP (µgL^{-1})	13	3	6	5	3	3	4	6	6	20th-50th-80th		2–5–12

OPEN COASTAL ZONE WET SEASON 2017-2018

Region/ Water Body	Site	Measure	N	Min	Max	Mean	Q5	Q20	Median/ Q50	Q80	Q95	Statistic	Base Flow/ Annual	Wet Season
							Quantiles					Guidelines		
Cape York Open Coastal Zone		PO4 (μgL^{-1})	13	1	3	2	1	1	2	3	3	20th-50th-80th		0-1-2
		DOP (μgL^{-1})	13	1	4	3	1	2	3	4	4			
		PP (μgL^{-1})	13	0.0	5.0	1.7	0.0	1.0	1.0	2.0	4.4	20th-50th-80th		2.2-3.0-3.9
		Chla (μgL^{-1})	13	0.10	0.75	0.44	0.18	0.29	0.42	0.61	0.71	20th-50th-80th		0.30-0.46-0.78
	Endeavour Basin	Secchi (m)	4	6.4	13.0	9.6	6.6	7.0	9.5	12.1	12.7	Mean	≥10	
		TSS (mgL^{-1})	8	1.9	6.3	3.5	2.3	2.9	3.1	3.9	5.5	20th-50th-80th		1.1-1.7-2.2
		TN (μgL^{-1})	8	89	106	99	90	94	99	104	106	20th-50th-80th		75–105–130
		TDN (μgL^{-1})	8	79	102	91	80	84	92	97	100	20th-50th-80th		55–80–105
		NOx (μgL^{-1})	8	2	9	4	2	2	3	5	8	20th-50th-80th		0-0-1
		NH$_3$ (μgL^{-1})	8	1	4	2	1	2	2	3	3	20th-50th-80th	0-1-3	
		DON (μgL^{-1})	8	75	97	85	75	78	86	91	95			
		PN (μgL^{-1})	8	3	12	8	3	5	8	11	12	20th-50th-80th		14-20-26
		TP (μgL^{-1})	8	6	8	6	6	6	6	6	7	20th-50th-80th		5–10–20
		TDP (μgL^{-1})	8	3	6	5	4	5	5	6	6	20th-50th-80th		2–5–12
		PO4 (μgL^{-1})	8	1	4	2	1	2	3	3	4	20th-50th-80th		0-1-2
		DOP (μgL^{-1})	8	1	6	3	1	1	3	4	5			
		PP (μgL^{-1})	8	0.0	3.0	1.1	0.0	0.4	1.0	1.6	2.7	20th-50th-80th		2.2-3.0-3.9
		Chla (μgL^{-1})	8	0.10	0.91	0.44	0.17	0.30	0.42	0.57	0.82	20th-50th-80th		0.30-0.46-0.78

OPEN COASTAL ZONE DRY SEASON 2017-2018

							Quantiles					Statistics		
Region/ Water body	Site	Measure	N	Min	Max	Mean	Q5	Q20	Median	Q80	Q95	Statistic	Base Flow/ Annual	Dry
Cape York Open Coastal Zone	Stewart River	Secchi (m)	2	2.1	6.5	4.3	2.3	3.0	4.3	5.6	6.3	Mean	≥ 10	
		TSS (mgL^{-1})	3	3.3	5.2	4.0	3.3	3.3	3.4	4.5	5.0	Mean		≤ 1.6
		TN (μgL^{-1})	3	94	102	97	94	94	95	99	101			70–100–120
		TDN (μgL^{-1})	3	87	96	91	87	89	91	94	96			50–80–100
		NOx (μgL^{-1})^{2}	3	1	2	1	1	1	1	1	1	20th-50th-80th		0-0-1
		NH$_3$ (μgL^{-1})	3	3	10	6	3	4	5	8	10	20th-50th-80th	0-1-3	

OPEN COASTAL ZONE DRY SEASON 2017-2018

							Quantiles					Statistics		
Region/ Water body	Site	Measure	N	Min	Max	Mean	Q5	Q20	Median	Q80	Q95	Statistic	Base Flow/ Annual	Dry
Cape York Open Coastal Zone		DON (µgL^{-1})	3	76	92	84	77	79	85	89	91			
		PN (µgL^{-1})	3	4	7	6	4	5	6	7	7	Mean		≤ 16
		TP (µgL^{-1})	3	5	8	7	5	6	8	8	8			8–10–16
		TDP (µgL^{-1})	3	4	7	5	4	4	5	6	7			3–7–13
		PO4 (µgL^{-1})	3	2	4	3	2	2	3	4	4	20th-50th-80th		0-2-3
		DOP (µgL^{-1})	3	2	3	2	2	2	2	3	3			
		PP (µgL^{-1})	3	1.0	3.0	1.7	1.0	1.0	1.0	2.2	2.8	Mean		≤ 2.3
		Chla (µgL^{-1})	3	0.10	0.33	0.23	0.12	0.16	0.26	0.30	0.32	20th-50th-80th		0.16-0.25-0.46
	Normanby River	Secchi (m)	3	3.3	4.8	4.2	3.4	3.7	4.4	4.6	4.8	Mean	≥ 10	
		TSS (mgL^{-1})	6	2.9	11.0	5.2	3.0	3.3	4.1	5.9	9.7	Mean		≤ 1.6
		TN (µgL^{-1})	6	91	193	114	91	92	97	114	173			70–100–120
		TDN (µgL^{-1})	6	87	95	91	87	87	91	94	95			50–80–100
		NOx (µgL^{-1})	6	1	7	3	1	1	2	5	6	20th-50th-80th		0-0-1
		NH$_3$ (µgL^{-1})	6	2	11	7	3	6	7	9	11	20th-50th-80th	0-1-3	
		DON (µgL^{-1})	6	74	87	81	75	79	80	86	87			
		PN (µgL^{-1})	6	2	99	23	3	4	7	19	79	Mean		≤ 16
		TP (µgL^{-1})	6	5	13	8	6	7	7	8	12			8–10–16
		TDP (µgL^{-1})	6	4	7	6	4	5	7	7	7			3–7–13
		PO4 (µgL^{-1})	6	1	3	2	1	2	2	3	3	20th-50th-80th		0-2-3
		DOP (µgL^{-1})	6	1	5	4	2	4	5	5	5			
		PP (µgL^{-1})	6	0.0	6.0	1.7	0.0	0.0	0.5	3.0	5.3	Mean		≤ 2.3
		Chla (µgL^{-1})	6	0.10	2.05	0.60	0.14	0.26	0.38	0.42	1.64	20th-50th-80th		0.16-0.25-0.46
	Annan-Endeavour	Secchi (m)	4	3.8	9.0	6.4	4.1	4.9	6.4	7.9	8.7	Mean	≥ 10	
		TSS (mgL^{-1})	12	1.7	11.0	3.3	1.9	2.2	2.5	2.9	7.4	Mean		≤ 1.6
		TN (µgL^{-1})	12	89	157	110	91	93	100	115	156			70–100–120
		TDN (µgL^{-1})	12	77	96	88	79	86	90	92	94			50–80–100
		NOx (µgL^{-1})	12	1	20	5	1	2	3	6	15	20th-50th-80th		0-0-1
		NH$_3$ (µgL^{-1})	12	1	12	4	1	1	4	5	8	20th-50th-80th	0-1-3	
		DON (µgL^{-1})	12	69	88	80	69	74	82	86	87			
		PN (µgL^{-1})	12	1	71	21	2	2	15	26	70	Mean		≤ 16
		TP (µgL^{-1})	12	7	11	8	7	7	8	9	10			8–10–16

OPEN COASTAL ZONE DRY SEASON 2017-2018

							Quantiles					Statistics		
Region/ Water body	Site	Measure	N	Min	Max	Mean	Q5	Q20	Median	Q80	Q95	Statistic	Base Flow/ Annual	Dry
		TDP (µgL⁻¹)	12	7	9	8	7	7	7	8	9			3–7–13
		PO4 (µgL⁻¹)	12	3	7	5	3	4	5	7	7	20th-50th-80th		0-2-3
		DOP (µgL⁻¹)	12	0	5	3	1	1	3	4	4			
		PP (µgL⁻¹)	12	0.0	4.0	0.8	0.0	0.0	0.0	1.0	3.5	Mean		≤ 2.3
		Chla (µgL⁻¹)	12	0.10	1.25	0.32	0.10	0.13	0.25	0.35	0.76	20th-50th-80th		0.16-0.25-0.46

[2] NOx concentrations of 1 µg L^{-1} represent half the detection limit (<2 µg L^{-1}); actual concentrations may not exceed the guidelines.

MID-SHELF ZONE ANNUAL (WET and DRY SEASON COMBINED) 2017-2018

							Quantiles					Guidelines	
Region/ Water body	Site	Measure	N	Min	Max	Mean	Q5	Q20	Median	Q80	Q95	Statistic	Base Flow/ Annual
Cape York Mid Shelf Zone	Pascoe River (wet season only)	Secchi (m)	12	2.9	16.9	8.0	3.8	4.9	7.8	10.1	13.3	Mean	≥10
		TSS (mgL⁻¹)	18	0.8	5.0	2.4	1.0	1.6	2.6	2.9	3.8	20th-50th-80th	0.9-1.5-2.3
		TN (µgL⁻¹)	18	83	139	99	84	89	93	109	135	20th-50th-80th	75–100–130
		TDN (µgL⁻¹)	18	78	133	94	80	82	89	97	132	20th-50th-80th	60–80–110
		NOx (µgL⁻¹)	18	1	13	4	1	1	3	6	11	20th-50th-80th	0-0-1
		NH₃ (µgL⁻¹)	18	1	6	3	2	2	2	4	4	20th-50th-80th	0-1-3
		DON (µgL⁻¹)	18	73	121	87	75	78	85	91	118		
		PN (µgL⁻¹)	18	1	20	6	1	2	3	9	17	20th-50th-80th	14-18-22
		TP (µgL⁻¹)	18	3	8	5	3	4	6	6	7	20th-50th-80th	6–9–15
		TDP (µgL⁻¹)	18	2	6	4	2	3	4	5	6	20th-50th-80th	3–7–10
		PO4 (µgL⁻¹)	18	1	4	2	1	1	2	3	3	20th-50th-80th	0-1-2
		DOP (µgL⁻¹)	18	0	5	2	1	1	2	3	4		
		PP (µgL⁻¹)	18	0.0	3.0	1.2	0.0	0.4	1.0	1.6	3.0	20th-50th-80th	1.5-2.0-2.8
		Chla (µgL⁻¹)	17	0.23	0.95	0.44	0.23	0.33	0.39	0.51	0.84	20th-50th-80th	0.18-0.27-0.45
	Stewart River	Secchi (m)	9.0	5.8	10.3	7.3	5.8	5.9	7.0	8.6	9.7	Mean	≥10
		TSS (mgL⁻¹)	18	0.6	10.0	3.1	0.9	1.7	2.8	3.9	5.7	20th-50th-80th	0.9-1.5-2.3
		TN (µgL⁻¹)	18	77	142	104	84	90	104	111	138	20th-50th-80th	75–100–130
		TDN (µgL⁻¹)	18	71	127	96	80	88	94	103	118	20th-50th-80th	60–80–110
		NH₃ (µgL⁻¹)	18	1	21	5	1	2	3	6	14	20th-50th-80th	0-1-3

MID-SHELF ZONE ANNUAL (WET and DRY SEASON COMBINED) 2017-2018													
							Quantiles					Guidelines	
Region/ Water body	Site	Measure	N	Min	Max	Mean	Q5	Q20	Median	Q80	Q95	Statistic	Base Flow/ Annual
Cape York Mid Shelf Zone		NOx (µgL⁻¹)	18	1	21	4	1	1	3	6	15	20th-50th-80th	0-0-1
		DON (µgL⁻¹)	18	59	126	87	64	74	85	98	112		
		PN (µgL⁻¹)	18	0	28	8	0	1	3	16	25	20th-50th-80th	14-18-22
		TP (µgL⁻¹)	18	5	22	7	5	5	6	7	11	20th-50th-80th	6–9–15
		TDP (µgL⁻¹)	18	3	8	5	4	4	5	6	6	20th-50th-80th	3–7–10
		PO4 (µgL⁻¹)	18	1	4	2	1	1	2	3	3	20th-50th-80th	0-1-2
		DOP (µgL⁻¹)	18	1	6	3	1	2	3	3	5		
		PP (µgL⁻¹)	18	0.0	17.0	2.0	0.0	1.0	1.0	1.6	5.9	20th-50th-80th	1.5-2.0-2.8
		Chla (µgL⁻¹)	17	0.10	1.08	0.38	0.10	0.23	0.36	0.46	0.82	20th-50th-80th	0.18-0.27-0.45
	Normanby Basin	Secchi (m)	3	5.7	17.3	10.2	5.9	6.4	7.5	13.4	16.3	Mean	≥10
		TSS (mgL⁻¹)	6	0.5	3.6	2.2	0.9	1.9	2.3	2.5	3.3	20th-50th-80th	0.9-1.5-2.3
		TN (µgL⁻¹)	6	88	131	103	89	90	99	108	125	20th-50th-80th	75–100–130
		TDN (µgL⁻¹)	6	83	120	96	84	86	92	105	116	20th-50th-80th	60–80–110
		NH_3 (µgL⁻¹)	6	2	4	3	2	3	3	3	4	20th-50th-80th	0-1-3
		NOx (µgL⁻¹)	6	1	17	6	1	1	4	9	15	20th-50th-80th	0-0-1
		DON (µgL⁻¹)	6	66	114	87	69	79	85	94	109		
		PN (µgL⁻¹)	6	1	17	6	1	1	4	11	16	20th-50th-80th	14-18-22
		TP (µgL⁻¹)	6	5	11	7	5	6	7	7	10	20th-50th-80th	6–9–15
		TDP (µgL⁻¹)	6	5	7	6	5	5	6	7	7	20th-50th-80th	3–7–10
		PO4 (µgL⁻¹)	6	2	3	3	2	2	3	3	3	20th-50th-80th	0-1-2
		DOP (µgL⁻¹)	6	2	4	3	2	2	4	4	4		
		PP (µgL⁻¹)	6	0.0	4.0	1.2	0.0	0.0	1.0	1.0	3.3	20th-50th-80th	1.5-2.0-2.8
		Chla (µgL⁻¹)	6.0	0.10	0.65	0.29	0.10	0.10	0.23	0.42	0.59	20th-50th-80th	0.18-0.27-0.45
	Endeavour Basin	Secchi (m)	3	8.8	16.1	11.3	8.8	8.8	8.9	13.2	15.4	Mean	≥10
		TSS (mgL⁻¹)	6	2.2	9.5	4.0	2.3	2.7	3.1	3.6	8.0	20th-50th-80th	0.9-1.5-2.3
		TN (µgL⁻¹)	6	86	116	97	86	87	95	102	113	20th-50th-80th	75–100–130
		TDN (µgL⁻¹)	6	73	99	90	76	86	92	99	99	20th-50th-80th	60–80–110
		NH_3 (µgL⁻¹)	6	1	8	4	1	3	5	5	7	20th-50th-80th	0-1-3
		NOx (µgL⁻¹)	6	1	4	2	1	1	2	3	3	20th-50th-80th	0-0-1
		DON (µgL⁻¹)	6	68	92	84	71	81	87	90	91		

MID-SHELF ZONE ANNUAL (WET and DRY SEASON COMBINED) 2017-2018

							Quantiles					Guidelines	
Region/ Water body	Site	Measure	N	Min	Max	Mean	Q5	Q20	Median	Q80	Q95	Statistic	Base Flow/ Annual
		PN (µgL^{-1})	6	1	17	7	2	3	4	13	16	20th-50th-80th	14-18-22
		TP (µgL^{-1})	6	4	30	10	5	6	6	9	25	20th-50th-80th	6–9–15
		TDP (µgL^{-1})	6	3	8	6	4	5	6	6	8	20th-50th-80th	3–7–10
		PO4 (µgL^{-1})	6	2	4	3	2	2	4	4	4	20th-50th-80th	0-1-2
		DOP (µgL^{-1})	6	1	4	2	1	1	2	3	4		
		PP (µgL^{-1})	6	0.0	22.0	4.7	0.0	0.0	1.0	4.0	17.5	20th-50th-80th	1.5-2.0-2.8
		Chla (µgL^{-1})	6	0.10	0.56	0.32	0.14	0.26	0.28	0.42	0.53	20th-50th-80th	0.18-0.27-0.45

OFFSHORE ZONE ANNUAL[1] 2017-2018

							Quantiles					Guidelines	
Region/ Water body	Site	Measure	N	Min	Max	Mean	Q5	Q20	Median	Q80	Q95	Statistic	Base Flow/ Annual
Cape York Offshore Zone	Normanby Basin (wet season only)	Secchi (m)	2	7.9	10.1	9.0	8.0	8.4	9.0	9.6	9.9	Mean	≥17
		TSS (mgL^{-1})	4	0.8	2.2	1.4	0.9	1.1	1.4	1.7	2.1	20th-50th-80th	0.3–0.5–1.0
		TN (µgL^{-1})	4	89	141	118	94	108	121	129	138		90–100–120
		TDN (µgL^{-1})	4	81	130	104	82	85	103	123	128		50–70–90
		NH$_3$ (µgL^{-1})	4	2	4	3	2	3	3	3	4	20th-50th-80th	0–0–1
		NOx (µgL^{-1})	4	1	7	3	1	2	3	4	6	20th-50th-80th	0–0–1
		DON (µgL^{-1})	4	77	123	98	77	78	95	116	121		
		PN (µgL^{-1})	4	2	40	14	2	2	7	23	36	20th-50th-80th	10–16–25
		TP (µgL^{-1})	4	3	8	6	3	4	6	7	8		
		TDP (µgL^{-1})	4	3	7	5	3	4	5	6	7		
		PO4 (µgL^{-1})	4	2	4	3	2	3	3	3	4	20th-50th-80th	5–8–10
		DOP (µgL^{-1})	4	0	3	2	0	1	2	3	3		
		PP (µgL^{-1})	4	0.0	2.0	0.8	0.0	0.0	0.5	1.4	1.9	20th-50th-80th	1.1–1.9–2.8
		Chla (µgL^{-1})	4.0	0.36	1.11	0.59	0.36	0.36	0.44	0.76	1.02	20th-50th-80th	0.17–0.26–0.39

[1] Samples were only collected during the wet season in the Normanby Basin offshore zone however Cape York Offshore zone guidelines are for annual percentiles.

Table E-3: Summary statistics for water quality parameters at individual monitoring sites (other than those in the Cape York region) from June 2017 to June 2018. N = number of sampling occasions. See Section 2 for descriptions of each analyte and its abbreviation. Mean and median values that exceed available Water Quality Guidelines (DERM, 2009; Great Barrier Reef Marine Park Authority, 2010) are shaded in red.

						Quantiles				Guidelines			
Region	**Site**	**Measure**	**N**	**Mean**	**Median**	**Q5**	**Q20**	**Q80**	**Q95**	**Statistic**	**Annual**	**Dry**	**Wet**
Wet Tropics	Cape Tribulation(C1)	DIN (µg L^{-1})	3	2.08	2.05	1.65	1.79	2.36	2.52				
		DOC (µg L^{-1})	3	22	20	7	9	4	4				
		DON (µg L^{-1})	3	81.21	83.31	74.23	77.25	85.58	86.72				
		DOP (µg L^{-1})	3	4.00	3.83	3.44	3.57	4.39	4.68				
		Chl a (µg L^{-1})	3	0.58	0.54	0.40	0.45	0.71	0.80	Mean	0.45		
		NO$_x$ (µg L^{-1})	3	0.48	0.41	0.23	0.29	0.65	0.78	Median	0.35		
		PN (µg L^{-1})	3	13.48	12.57	12.24	12.35	14.43	15.36	Mean	20.00		
		PO$_4$(µg L^{-1})	3	2.14	2.22	1.76	1.91	2.38	2.46	Median	2.00		
		POC (mg L^{-1})	3	126.70	113.23	109.21	110.55	140.16	153.62				
		PP (µg L^{-1})	3	3.60	3.03	2.96	2.98	4.10	4.64	Mean	2.80		
		Secchi (m)	3	6.17	3.50	2.15	2.60	9.20	12.05	Mean	10.00		
		SiO$_4$	3	89.51	72.22	60.25	64.24	111.33	130.89				
		TSS (mg L^{-1})	3	2.34	1.92	1.32	1.52	3.08	3.66	Mean	2.00		
	Port Douglas(C4)	DIN (µg L^{-1})	3	1.68	1.72	0.80	1.11	2.27	2.54				
		DOC (µg L^{-1})	3	20	15	6	7	2	5				
		DON (µg L^{-1})	3	84.89	80.96	60.62	67.40	101.59	111.90				
		DOP (µg L^{-1})	3	4.29	4.51	3.82	4.05	4.58	4.62				
		Chl a (µg L^{-1})	3	0.40	0.37	0.30	0.32	0.47	0.52	Median	0.30	0.32	0.63
		NO$_x$ (µg L^{-1})	3	0.35	0.40	0.17	0.24	0.46	0.49	Median	0.31		
		PN (µg L^{-1})	3	11.57	11.46	10.25	10.66	12.47	12.97	Median	14.00	16.00	25.00
		PO$_4$(µg L^{-1})	3	1.89	2.10	1.46	1.68	2.14	2.16	Median	2.00		
		POC (mg L^{-1})	3	92.06	89.31	78.62	82.18	101.39	107.43				
		PP (µg L^{-1})	3	2.87	2.60	2.54	2.56	3.12	3.38	Median	2.00	2.30	3.30
		Secchi (m)	3	5.50	3.50	3.05	3.20	7.40	9.35	Median	13.00		
		SiO$_4$	3	87.37	103.27	59.56	74.13	103.80	104.06				
		TSS (mg L^{-1})	3	1.53	1.73	1.03	1.27	1.83	1.87	Median	1.20	1.60	2.40
		DIN (µg L^{-1})	3	1.86	2.14	1.32	1.59	2.19	2.21				

						Quantiles				Guidelines			
Region	**Site**	**Measure**	**N**	**Mean**	**Median**	**Q5**	**Q20**	**Q80**	**Q95**	**Statistic**	**Annual**	**Dry**	**Wet**
	Double(C5)	DOC (µg L^{-1})	3	1	17	16	12	10	11				
		DON (µg L^{-1})	3	73.84	73.03	59.01	63.68	83.83	89.23				
		DOP (µg L^{-1})	3	4.27	4.22	4.12	4.15	4.38	4.46				
		Chl a (µg L^{-1})	3	0.47	0.56	0.31	0.39	0.57	0.57	Median	0.30	0.32	0.63
		NO$_x$ (µg L^{-1})	3	0.84	0.83	0.64	0.70	0.98	1.06	Median	0.31		
		PN (µg L^{-1})	3	10.67	10.67	10.00	10.22	11.12	11.34	Median	14.00	16.00	25.00
		PO$_4$ (µg L^{-1})	3	1.92	1.77	1.64	1.68	2.13	2.31	Median	2.00		
		POC (mg L^{-1})	3	78.58	83.51	63.72	70.32	87.83	89.99				
		PP (µg L^{-1})	3	3.56	3.48	2.85	3.06	4.04	4.33	Median	2.00	2.30	3.30
		Secchi (m)	3	7.00	3.00	3.00	3.00	10.20	13.80	Median	13.00		
		SiO$_4$	3	67.32	66.50	53.30	57.70	76.79	81.93				
		TSS (mg L^{-1})	3	1.76	2.03	1.23	1.50	2.07	2.09	Median	1.20	1.60	2.40
	Green(C11)	DIN (µg L^{-1})	3	2.83	2.21	2.07	2.12	3.43	4.03				
		DOC (µg L^{-1})	3	5	13	15	17	15	19				
		DON (µg L^{-1})	3	83.43	74.03	66.38	68.93	96.05	107.06				
		DOP (µg L^{-1})	3	4.68	4.69	3.89	4.16	5.20	5.45				
		Chl a (µg L^{-1})	3	0.28	0.28	0.23	0.25	0.31	0.33	Median	0.30	0.32	0.63
		NO$_x$ (µg L^{-1})	3	1.42	1.56	0.60	0.92	1.95	2.14	Median	0.31		
		PN (µg L^{-1})	3	9.35	9.05	8.76	8.85	9.78	10.14	Median	14.00	16.00	25.00
		PO$_4$ (µg L^{-1})	3	2.08	1.86	1.79	1.81	2.30	2.52	Median	2.00		
		POC (mg L^{-1})	3	56.67	54.60	44.39	47.79	65.14	70.42				
		PP (µg L^{-1})	3	2.04	1.77	1.67	1.70	2.32	2.60	Median	2.00	2.30	3.30
		Secchi (m)	3	11.67	14.00	5.90	8.60	15.20	15.80	Median	13.00		
		SiO$_4$	3	35.98	35.03	32.83	33.56	38.20	39.78				
		TSS (mg L^{-1})	3	0.42	0.28	0.19	0.22	0.60	0.76	Median	1.20	1.60	2.40
	Yorkey's Knob(C6)	DIN (µg L^{-1})	3	2.86	2.34	1.40	1.71	3.90	4.68				
		DOC (µg L^{-1})	3	18	19	20	16	8	10				
		DON (µg L^{-1})	3	75.35	73.17	66.81	68.93	81.33	85.41				
		DOP (µg L^{-1})	3	4.04	4.08	3.95	3.99	4.10	4.11				
		Chl a (µg L^{-1})	3	0.74	0.67	0.43	0.51	0.95	1.09	Mean	0.45		
		NO$_x$ (µg L^{-1})	3	0.71	0.46	0.46	0.46	0.91	1.14	Median	0.35		
		PN (µg L^{-1})	3	13.39	12.74	11.49	11.90	14.75	15.76	Mean	20.00		

						Quantiles				Guidelines			
Region	**Site**	**Measure**	**N**	**Mean**	**Median**	**Q5**	**Q20**	**Q80**	**Q95**	**Statistic**	**Annual**	**Dry**	**Wet**
		PO_4(µg L^{-1})	3	2.45	2.51	2.06	2.21	2.71	2.81	Median	2.00		
		POC (mg L^{-1})	3	121.83	123.28	117.03	119.12	124.84	125.62				
		PP (µg L^{-1})	3	7.10	8.33	4.27	5.62	8.82	9.06	Mean	2.80		
		Secchi (m)	3	2.73	1.00	1.00	1.00	4.12	5.68	Mean	10.00		
		SiO_4	3	133.43	146.09	80.95	102.67	166.72	177.04				
		TSS (mg L^{-1})	3	7.75	8.61	2.57	4.59	11.09	12.32	Mean	2.00		
	Fairlead Buoy(C8)	DIN (µg L^{-1})	3	2.61	2.38	2.19	2.25	2.93	3.20				
		DOC (µg L^{-1})	3	17	5	10	15	11	8				
		DON (µg L^{-1})	3	78.64	70.92	66.64	68.06	87.67	96.05				
		DOP (µg L^{-1})	3	4.01	4.00	3.87	3.92	4.10	4.14				
		Chl a (µg L^{-1})	3	0.70	0.72	0.36	0.48	0.92	1.03	Mean	0.45		
		NO_x(µg L^{-1})	3	0.88	1.02	0.39	0.60	1.20	1.29	Median	0.35		
		PN (µg L^{-1})	3	13.45	11.99	11.72	11.81	14.80	16.20	Mean	20.00		
		PO_4(µg L^{-1})	3	2.40	2.39	2.05	2.16	2.63	2.74	Median	2.00		
		POC (mg L^{-1})	3	118.21	114.05	107.73	109.83	125.76	131.61				
		PP (µg L^{-1})	3	5.57	4.34	4.08	4.17	6.73	7.92	Mean	2.80		
		Secchi (m)	3	2.60	3.00	1.20	1.80	3.48	3.72	Mean	10.00		
		SiO_4	3	102.85	94.45	78.67	83.93	120.08	132.90				
		TSS (mg L^{-1})	3	4.81	3.66	2.18	2.68	6.71	8.24	Mean	2.00		
	Fitzroy West(RM1)	DIN (µg L^{-1})	4	4.01	2.89	1.67	2.03	5.54	7.92				
		DOC (µg L^{-1})	4	3	22	9	11	13	18				
		DON (µg L^{-1})	4	96.68	87.51	83.04	84.71	104.99	123.18				
		DOP (µg L^{-1})	4	4.42	4.50	3.83	4.18	4.69	4.89				
		Chl a (µg L^{-1})	4	0.49	0.55	0.27	0.40	0.60	0.63	Mean	0.45		
		NO_x(µg L^{-1})	4	0.94	0.99	0.37	0.58	1.32	1.45	Median	0.35		
		PN (µg L^{-1})	4	20.53	21.12	12.91	14.93	26.37	27.33	Mean	20.00		
		PO_4(µg L^{-1})	4	1.50	1.38	1.08	1.17	1.79	2.09	Median	2.00		
		POC (mg L^{-1})	4	193.54	191.72	114.34	129.97	256.39	275.29				
		PP (µg L^{-1})	4	2.59	2.47	1.77	2.03	3.09	3.57	Mean	2.80		
		Secchi (m)	4	9.12	8.25	5.07	5.30	12.60	14.40	Mean	10.00		
		SiO_4	4	105.22	98.64	94.40	96.50	111.32	125.27				

						Quantiles				Guidelines			
Region	**Site**	**Measure**	**N**	**Mean**	**Median**	**Q5**	**Q20**	**Q80**	**Q95**	**Statistic**	**Annual**	**Dry**	**Wet**
		TSS (mg L^{-1})	4	1.09	1.10	0.63	0.80	1.38	1.55	Mean	2.00		
	RM2(RM2)	DIN (µg L^{-1})	5	15.93	10.18	5.65	8.57	19.54	35.71				
		DOC (µg L^{-1})	5	27	25	28	27	29	29				
		DON (µg L^{-1})	5	98.78	92.66	58.77	83.26	114.15	145.04				
		DOP (µg L^{-1})	5	2.76	3.28	0.93	1.28	4.02	4.31				
		Chl a (µg L^{-1})	5	1.43	1.01	0.46	0.46	1.78	3.45	Median	0.30	0.32	0.63
		NO$_x$ (µg L^{-1})	5	9.77	5.88	3.20	3.62	13.50	22.65	Median	0.31		
		PN (µg L^{-1})	5	7.21	6.35	2.00	2.00	12.58	13.12	Median	14.00	16.00	25.00
		PO$_4$ (µg L^{-1})	5	2.36	1.78	1.69	1.73	3.15	3.44	Median	2.00		
		POC (mg L^{-1})	5										
		PP (µg L^{-1})	5	2.40	1.62	1.19	1.47	3.80	3.92	Median	2.00	2.30	3.30
		Secchi (m)	5	4.30	3.00	2.10	2.40	4.60	9.40	Median	13.00		
		SiO$_4$	5	851.70	829.70	55.98	73.97	1475.47	1823.35				
		TSS (mg L^{-1})	5	2.31	2.20	1.82	2.03	2.54	2.96	Median	1.20	1.60	2.40
	RM3(RM3)	DIN (µg L^{-1})	7	7.21	5.87	1.82	2.25	9.69	15.74				
		DOC (µg L^{-1})	7	26	17	17	14	5	12				
		DON (µg L^{-1})	7	87.03	81.65	76.83	78.85	97.10	105.78				
		DOP (µg L^{-1})	7	3.77	4.24	1.79	3.49	4.46	4.62				
		Chl a (µg L^{-1})	7	0.72	0.79	0.44	0.46	0.84	1.10	Median	0.30	0.32	0.63
		NO$_x$ (µg L^{-1})	7	4.12	0.80	0.33	0.47	7.56	12.23	Median	0.31		
		PN (µg L^{-1})	7	27.56	33.95	13.38	14.50	36.46	41.31	Median	14.00	16.00	25.00
		PO$_4$ (µg L^{-1})	7	2.04	1.94	0.85	1.22	2.93	3.57	Median	2.00		
		POC (mg L^{-1})	7	248.16	246.47	114.27	118.64	377.01	384.43				
		PP (µg L^{-1})	7	2.28	2.82	0.62	1.27	3.05	3.43	Median	2.00	2.30	3.30
		Secchi (m)	7	5.64	5.00	2.65	3.40	5.00	11.30	Median	13.00		
		SiO$_4$	7	338.24	177.81	99.30	140.30	644.17	847.20				
		TSS (mg L^{-1})	7	2.42	1.06	0.60	0.78	3.31	6.45	Median	1.20	1.60	2.40
	RM4(RM4)	DIN (µg L^{-1})	3	6.05	4.96	3.96	4.29	7.59	8.91				
		DOC (µg L^{-1})	3	27	25	28	27	29	29				
		DON (µg L^{-1})	3	116.02	93.66	86.19	88.68	138.89	161.51				
		DOP (µg L^{-1})	3	3.64	2.65	2.03	2.23	4.85	5.96				
		Chl a (µg L^{-1})	3	0.65	0.58	0.32	0.41	0.88	1.03	Mean	0.45		

						Quantiles				Guidelines			
Region	**Site**	**Measure**	**N**	**Mean**	**Median**	**Q5**	**Q20**	**Q80**	**Q95**	**Statistic**	**Annual**	**Dry**	**Wet**
		NO$_x$ (µg L^{-1})	3	2.51	1.63	1.53	1.56	3.29	4.11	Median	0.35		
		PN (µg L^{-1})	3	10.30	5.00	4.01	4.34	15.20	20.30	Mean	20.00		
		PO$_4$ (µg L^{-1})	3	2.84	3.08	2.28	2.54	3.18	3.23	Median	2.00		
		POC (mg L^{-1})	3										
		PP (µg L^{-1})	3	6.17	1.83	0.98	1.26	10.20	14.39	Mean	2.80		
		Secchi (m)	3	2.67	2.50	2.50	2.50	2.80	2.95	Mean	10.00		
		SiO$_4$	3	823.04	1029.63	318.89	555.80	1131.60	1182.58				
		TSS (mg L^{-1})	3	6.00	3.80	2.36	2.84	8.72	11.18	Mean	2.00		
	High East(RM5)	DIN (µg L^{-1})	3	9.85	6.10	5.58	5.75	13.20	16.76				
		DOC (µg L^{-1})	3	27	25	28	27	29	29				
		DON (µg L^{-1})	3	95.92	97.91	77.62	84.38	107.86	112.83				
		DOP (µg L^{-1})	3	2.46	1.31	1.24	1.26	3.43	4.49				
		Chl a (µg L^{-1})	3	0.73	0.78	0.34	0.49	0.98	1.08	Median	0.30	0.32	0.63
		NO$_x$ (µg L^{-1})	3	6.79	3.47	2.35	2.73	10.20	13.56	Median	0.31		
		PN (µg L^{-1})	3	6.57	5.00	2.30	3.20	9.62	11.93	Median	14.00	16.00	25.00
		PO$_4$ (µg L^{-1})	3	2.97	4.02	1.18	2.13	4.02	4.02	Median	2.00		
		POC (mg L^{-1})	3										
		PP (µg L^{-1})	3	1.80	1.21	0.15	0.50	2.99	3.88	Median	2.00	2.30	3.30
		Secchi (m)	3	3.17	3.00	3.00	3.00	3.30	3.45	Median	13.00		
		SiO$_4$	3	709.75	659.76	299.89	419.85	989.65	1154.59				
		TSS (mg L^{-1})	3	3.37	3.90	2.37	2.88	3.96	3.99	Median	1.20	1.60	2.40
	High West(RM8)	DIN (µg L^{-1})	7	4.96	4.12	2.61	2.94	7.11	9.06				
		DOC (µg L^{-1})	7	17	21	13	13	6	13				
		DON (µg L^{-1})	7	103.81	94.87	83.78	87.17	119.79	139.13				
		DOP (µg L^{-1})	7	3.70	4.46	0.86	2.13	4.75	5.29				
		Chl a (µg L^{-1})	7	0.62	0.54	0.44	0.49	0.79	0.87	Mean	0.45		
		NO$_x$ (µg L^{-1})	7	2.35	0.82	0.58	0.65	4.06	6.02	Median	0.35		
		PN (µg L^{-1})	7	19.23	17.00	10.56	13.94	24.69	28.69	Mean	20.00		
		PO$_4$ (µg L^{-1})	7	2.32	2.17	1.04	1.28	2.60	4.58	Median	2.00		
		POC (mg L^{-1})	7	217.18	223.46	138.32	170.46	266.41	287.25				
		PP (µg L^{-1})	7	2.12	2.52	0.30	0.89	2.63	3.70	Mean	2.80		

						Quantiles				Guidelines			
Region	**Site**	**Measure**	**N**	**Mean**	**Median**	**Q5**	**Q20**	**Q80**	**Q95**	**Statistic**	**Annual**	**Dry**	**Wet**
		Secchi (m)	7	5.00	4.50	2.50	2.50	6.60	9.80	Mean	10.00		
		SiO$_4$	7	389.07	229.92	134.90	189.64	464.45	1013.14				
		TSS (mg L^{-1})	7	2.69	1.81	0.89	1.30	3.38	6.04	Mean	2.00		
	Palmer Point(RM9)	DIN (µg L^{-1})	3	25.14	33.47	6.31	15.36	36.58	38.13				
		DOC (µg L^{-1})	3	27	25	28	27	29	29				
		DON (µg L^{-1})	3	109.20	99.54	87.10	91.24	125.23	138.08				
		DOP (µg L^{-1})	3	2.05	0.99	0.44	0.62	3.26	4.40				
		Chl a (µg L^{-1})	3	0.52	0.49	0.31	0.37	0.66	0.75	Mean	0.45		
		NO$_x$ (µg L^{-1})	3	21.89	26.10	4.31	11.57	33.05	36.52	Median	0.35		
		PN (µg L^{-1})	3	13.33	13.00	12.10	12.40	14.20	14.80	Mean	20.00		
		PO$_4$ (µg L^{-1})	3	3.51	2.82	1.95	2.24	4.65	5.56	Median	2.00		
		POC (mg L^{-1})	3										
		PP (µg L^{-1})	3	2.12	1.53	0.90	1.11	3.01	3.76	Mean	2.80		
		Secchi (m)	3	2.33	2.50	2.05	2.20	2.50	2.50	Mean	10.00		
		SiO$_4$	3	2505.77	2699.04	503.82	1235.56	3814.64	4372.44				
		TSS (mg L^{-1})	3	2.83	2.80	2.62	2.68	2.98	3.07	Mean	2.00		
	Normanby(RM6)	DIN (µg L^{-1})	3	7.05	5.76	5.00	5.25	8.59	10.00				
		DOC (µg L^{-1})	3	27	25	28	27	29	29				
		DON (µg L^{-1})	3	95.89	92.54	76.66	81.95	109.16	117.48				
		DOP (µg L^{-1})	3	2.41	0.67	0.25	0.39	4.09	5.80				
		Chl a (µg L^{-1})	3	1.14	0.88	0.70	0.76	1.47	1.76	Median	0.30	0.32	0.63
		NO$_x$ (µg L^{-1})	3	5.57	4.31	2.61	3.18	7.71	9.40	Median	0.31		
		PN (µg L^{-1})	3	22.74	24.00	8.88	13.92	31.80	35.70	Median	14.00	16.00	25.00
		PO$_4$ (µg L^{-1})	3	3.63	4.81	1.58	2.65	4.84	4.85	Median	2.00		
		POC (mg L^{-1})	3										
		PP (µg L^{-1})	3	0.92	1.13	0.27	0.55	1.33	1.43	Median	2.00	2.30	3.30
		Secchi (m)	3	4.00	4.00	4.00	4.00	4.00	4.00	Median	13.00		
		SiO$_4$	3	746.40	649.77	388.86	475.83	997.64	1171.58				
		TSS (mg L^{-1})	3	2.17	2.10	1.56	1.74	2.58	2.82	Median	1.20	1.60	2.40
		DIN (µg L^{-1})	7	20.61	11.87	3.33	7.47	34.32	52.07				
		DOC (µg L^{-1})	7	15	12	23	2	24	24				

						Quantiles				Guidelines			
Region	**Site**	**Measure**	**N**	**Mean**	**Median**	**Q5**	**Q20**	**Q80**	**Q95**	**Statistic**	**Annual**	**Dry**	**Wet**
	Russell-Mulgrave Mouth Mooring(RM10)	DON (µg L^{-1})	7	97.10	85.39	79.35	80.68	115.08	131.37				
		DOP (µg L^{-1})	7	3.69	4.18	1.65	2.70	5.04	5.40				
		Chl a (µg L^{-1})	7	1.01	1.05	0.37	0.70	1.40	1.48	Mean	0.45		
		NO$_x$(µg L^{-1})	7	16.93	9.66	1.40	3.47	29.61	46.43	Median	0.35		
		PN (µg L^{-1})	7	32.42	26.13	16.85	21.09	46.19	50.00	Mean	20.00		
		PO$_4$(µg L^{-1})	7	2.74	2.61	1.94	2.03	3.28	3.84	Median	2.00		
		POC (mg L^{-1})	7	260.65	227.00	137.45	167.68	340.16	430.96				
		PP (µg L^{-1})	7	6.03	6.19	2.94	3.60	6.91	9.62	Mean	2.80		
		Secchi (m)	7	3.21	2.50	2.00	2.10	2.90	6.50	Mean	10.00		
		SiO$_4$	7	1358.60	424.37	181.17	277.44	2867.37	4113.54				
		TSS (mg L^{-1})	7	3.96	4.22	1.22	3.02	5.61	5.79	Mean	2.00		
	Russell Mulgrave Mouth(RM11)	DIN (µg L^{-1})	3	109.53	125.95	21.42	56.26	166.09	186.16				
		DOC (µg L^{-1})	3	27	25	28	27	29	29				
		DON (µg L^{-1})	3	113.81	123.07	97.06	105.73	123.75	124.09				
		DOP (µg L^{-1})	3	4.77	0.98	0.48	0.64	8.13	11.71				
		Chl a (µg L^{-1})	3	1.24	0.59	0.56	0.57	1.78	2.38				
		NO$_x$(µg L^{-1})	3	100.93	115.75	19.23	51.40	153.43	172.27				
		PN (µg L^{-1})	3	20.33	7.00	1.60	3.40	34.60	48.40				
		PO$_4$(µg L^{-1})	3	4.48	4.34	3.39	3.71	5.23	5.68				
		POC (mg L^{-1})	3										
		PP (µg L^{-1})	3	7.04	8.17	2.44	4.35	9.95	10.84				
		Secchi (m)	3	1.00	1.00	0.55	0.70	1.30	1.45				
		SiO$_4$	3	7903.85	9466.63	5184.15	6611.65	9508.62	9529.61				
		TSS (mg L^{-1})	3	7.73	8.00	5.48	6.32	9.20	9.80				
	Franklands West(RM7)	DIN (µg L^{-1})	5	4.94	5.22	2.01	4.00	6.53	6.97				
		DOC (µg L^{-1})	5	10	13	27	26	16	23				
		DON (µg L^{-1})	5	89.70	88.31	72.98	73.22	106.47	107.55				
		DOP (µg L^{-1})	5	3.84	4.28	1.52	3.41	4.64	5.33				
		Chl a (µg L^{-1})	5	0.82	0.53	0.25	0.29	0.97	2.06	Median	0.30	0.32	0.63
		NO$_x$(µg L^{-1})	5	1.49	1.44	0.44	0.87	2.33	2.37	Median	0.31		
		PN (µg L^{-1})	5	18.77	16.64	10.96	15.21	24.03	27.01	Median	14.00	16.00	25.00
		PO$_4$(µg L^{-1})	5	1.86	1.21	0.80	1.10	2.38	3.82	Median	2.00		

						Quantiles				Guidelines			
Region	**Site**	**Measure**	**N**	**Mean**	**Median**	**Q5**	**Q20**	**Q80**	**Q95**	**Statistic**	**Annual**	**Dry**	**Wet**
		POC (mg L^{-1})	5	164.29	172.22	96.73	133.71	198.05	220.75				
		PP (µg L^{-1})	5	2.42	2.40	1.79	1.87	2.94	3.11	Median	2.00	2.30	3.30
		Secchi (m)	5	6.00	6.00	4.22	4.90	7.10	7.77	Median	13.00		
		SiO_4	5	247.53	112.61	65.57	74.44	329.18	655.84				
		TSS (mg L^{-1})	5	0.89	0.63	0.27	0.45	1.27	1.82	Median	1.20	1.60	2.40
	Russell Mulgrave Junction(RM12)	DIN (µg L^{-1})	3	137.86	178.12	48.41	91.65	192.12	199.12				
		DOC (µg L^{-1})	3	27	25	28	27	29	29				
		DON (µg L^{-1})	3	153.83	142.57	115.06	124.23	181.17	200.47				
		DOP (µg L^{-1})	3	0.98	1.02	0.38	0.59	1.38	1.56				
		Chl a (µg L^{-1})	3	1.64	0.85	0.79	0.81	2.31	3.05	Median	2.00	0.32	0.63
		NO_x(µg L^{-1})	3	126.63	168.12	37.96	81.35	180.20	186.24	Median	15.00		
		PO_4(µg L^{-1})	3	5.62	5.15	3.40	3.99	7.16	8.17	Median	3.00		
		POC (mg L^{-1})	3										
		Secchi (m)	3	0.50	0.50	0.50	0.50	0.50	0.50	Median	1.50		
		SiO_4	3	9090.10	8956.81	7571.30	8033.14	10120.40	10702.19				
		TSS (mg L^{-1})	3	11.57	8.10	5.85	6.60	15.84	19.71	Median	7.00	1.60	2.40
	King(TUL1)	DIN (µg L^{-1})	3	10.58	10.52	7.33	8.40	12.75	13.87				
		DOC (µg L^{-1})	3	27	25	28	27	29	29				
		DON (µg L^{-1})	3	114.43	97.49	96.84	97.05	128.41	143.88				
		DOP (µg L^{-1})	3	2.14	1.58	1.55	1.56	2.60	3.12				
		Chl a (µg L^{-1})	3	1.09	1.47	0.38	0.74	1.51	1.52	Mean	0.45		
		NO_x(µg L^{-1})	3	5.71	5.63	4.29	4.74	6.67	7.19	Median	0.35		
		PN (µg L^{-1})	3	3.67	1.00	1.00	1.00	5.80	8.20	Mean	20.00		
		PO_4(µg L^{-1})	3	3.24	2.99	2.69	2.79	3.64	3.97	Median	2.00		
		POC (mg L^{-1})	3										
		PP (µg L^{-1})	3	1.60	1.25	0.67	0.87	2.27	2.78	Mean	2.80		
		Secchi (m)	3	3.67	2.50	2.05	2.20	4.90	6.10	Mean	10.00		
		SiO_4	3	823.04	719.74	368.87	485.83	1139.59	1349.52				
		TSS (mg L^{-1})	3	3.47	3.00	2.64	2.76	4.08	4.62	Mean	2.00		
	Clump Point East(TUL2)	DIN (µg L^{-1})	4	4.52	4.58	2.16	3.29	5.77	6.79				
		DOC (µg L^{-1})	4	25	1	19	22	3	3				
		DON (µg L^{-1})	4	87.60	88.14	82.90	85.08	90.33	91.54				

						Quantiles				Guidelines			
Region	**Site**	**Measure**	**N**	**Mean**	**Median**	**Q5**	**Q20**	**Q80**	**Q95**	**Statistic**	**Annual**	**Dry**	**Wet**
		DOP (µg L^{-1})	4	4.34	4.43	3.65	4.04	4.68	4.92				
		Chl a (µg L^{-1})	4	0.40	0.43	0.25	0.31	0.50	0.52	Median	0.30	0.32	0.63
		NO$_x$ (µg L^{-1})	4	1.83	1.47	0.42	0.85	2.67	3.74	Median	0.31		
		PN (µg L^{-1})	4	23.57	25.45	17.69	21.08	26.82	26.84	Median	14.00	16.00	25.00
		PO$_4$ (µg L^{-1})	4	1.12	0.99	0.59	0.72	1.46	1.83	Median	2.00		
		POC (mg L^{-1})	4	256.81	257.87	153.72	202.42	311.62	358.42				
		PP (µg L^{-1})	4	2.50	2.60	2.03	2.27	2.77	2.84	Median	2.00	2.30	3.30
		Secchi (m)	4	10.25	11.00	5.82	8.30	12.50	13.62	Median	13.00		
		SiO$_4$	4	72.13	71.90	31.09	39.66	104.50	113.49				
		TSS (mg L^{-1})	4	0.87	1.00	0.41	0.66	1.12	1.14	Median	1.20	1.60	2.40
	Dunk North(TUL3)	DIN (µg L^{-1})	8	10.59	8.10	1.19	2.12	16.78	25.87				
		DOC (µg L^{-1})	8	19	16	11	10	27	28				
		DON (µg L^{-1})	8	94.65	86.24	63.79	78.96	107.80	141.93				
		DOP (µg L^{-1})	8	3.54	3.92	1.16	1.80	5.04	5.60				
		Chl a (µg L^{-1})	8	0.88	0.90	0.43	0.55	1.18	1.35	Mean	0.45		
		NO$_x$ (µg L^{-1})	8	4.76	3.75	0.19	0.45	9.07	11.24	Median	0.35		
		PN (µg L^{-1})	8	14.44	13.22	7.98	11.04	19.95	20.64	Mean	20.00		
		PO$_4$ (µg L^{-1})	8	2.35	2.12	0.95	1.45	3.44	4.05	Median	2.00		
		POC (mg L^{-1})	8	194.32	214.16	137.31	177.36	219.22	223.57				
		PP (µg L^{-1})	8	3.47	3.02	1.93	2.17	5.12	5.29	Mean	2.80		
		Secchi (m)	8	3.36	3.00	2.00	2.00	4.20	6.25	Mean	10.00		
		SiO$_4$	8	448.94	232.29	112.82	151.74	441.84	1413.75				
		TSS (mg L^{-1})	8	3.72	3.64	1.18	1.77	5.62	6.32	Mean	2.00		
	Mission Beach South(TUL4)	DIN (µg L^{-1})	3	18.03	11.16	9.09	9.78	24.90	31.77				
		DOC (µg L^{-1})	3	27	25	28	27	29	29				
		DON (µg L^{-1})	3	119.35	115.85	82.01	93.29	144.71	159.14				
		DOP (µg L^{-1})	3	5.19	4.98	3.69	4.12	6.23	6.85				
		Chl a (µg L^{-1})	3	1.28	1.27	0.78	0.94	1.62	1.80	Mean	0.45		
		NO$_x$ (µg L^{-1})	3	14.37	6.19	4.31	4.94	22.17	30.16	Median	0.35		
		PN (µg L^{-1})	3	49.97	17.90	3.59	8.36	85.17	118.80	Mean	20.00		
		PO$_4$ (µg L^{-1})	3	3.34	3.73	1.89	2.50	4.25	4.52	Median	2.00		

						Quantiles				Guidelines			
Region	**Site**	**Measure**	**N**	**Mean**	**Median**	**Q5**	**Q20**	**Q80**	**Q95**	**Statistic**	**Annual**	**Dry**	**Wet**
		POC (mg L^{-1})	3										
		PP (µg L^{-1})	3	1.22	1.01	0.87	0.91	1.48	1.72	Mean	2.80		
		Secchi (m)	3	2.00	2.00	1.55	1.70	2.30	2.45	Mean	10.00		
		SiO$_4$	3	1429.49	1859.34	491.82	947.66	1997.29	2066.26				
		TSS (mg L^{-1})	3	4.00	4.00	2.83	3.22	4.78	5.17	Mean	2.00		
	Dunk South(TUL5)	DIN (µg L^{-1})	7	8.12	9.86	2.08	3.32	13.30	14.17				
		DOC (µg L^{-1})	7	4	4	21	25	14	16				
		DON (µg L^{-1})	7	116.89	87.48	83.11	83.88	147.04	200.57				
		DOP (µg L^{-1})	7	4.96	5.39	2.88	4.23	5.62	6.48				
		Chl a (µg L^{-1})	7	0.72	0.57	0.42	0.46	0.98	1.26	Mean	0.45		
		NO$_x$ (µg L^{-1})	7	3.53	1.29	0.41	0.66	7.03	10.33	Median	0.35		
		PN (µg L^{-1})	7	25.65	23.90	15.71	21.69	28.94	37.89	Mean	20.00		
		PO$_4$ (µg L^{-1})	7	2.08	1.92	0.96	1.27	2.99	3.63	Median	2.00		
		POC (mg L^{-1})	7	198.44	205.18	125.86	161.29	238.28	261.58				
		PP (µg L^{-1})	7	2.58	2.39	0.99	1.62	3.84	4.01	Mean	2.80		
		Secchi (m)	7	4.79	5.00	2.30	3.20	5.40	7.95	Mean	10.00		
		SiO$_4$	7	399.34	168.83	70.20	88.20	266.62	1408.00				
		TSS (mg L^{-1})	7	3.08	2.76	0.84	1.18	4.25	6.34	Mean	2.00		
	Between Tam O'Shanter and Timana(TUL6)	DIN (µg L^{-1})	8	24.67	16.39	1.30	2.88	24.24	79.79				
		DOC (µg L^{-1})	8	9	6	18	23	21	22				
		DON (µg L^{-1})	8	111.36	97.29	89.58	90.84	134.98	161.49				
		DOP (µg L^{-1})	8	4.46	3.94	2.39	3.23	5.09	7.69				
		Chl a (µg L^{-1})	8	1.32	1.37	0.44	0.78	1.51	2.35	Mean	0.45		
		NO$_x$ (µg L^{-1})	8	19.99	10.16	0.32	0.61	16.37	74.50	Median	0.35		
		PN (µg L^{-1})	8	27.10	24.29	14.21	19.50	33.71	45.10	Mean	20.00		
		PO$_4$ (µg L^{-1})	8	2.49	2.29	1.59	1.84	2.78	4.02	Median	2.00		
		POC (mg L^{-1})	8	221.61	230.54	116.72	171.20	275.58	314.00				
		PP (µg L^{-1})	8	5.14	3.51	1.79	3.12	7.42	11.19	Mean	2.80		
		Secchi (m)	8	2.38	1.75	0.18	0.70	3.90	5.80	Mean	10.00		
		SiO$_4$	8	1078.23	648.77	117.13	192.06	2094.25	2496.36				
		TSS (mg L^{-1})	8	12.49	8.10	1.05	2.01	15.62	37.89	Mean	2.00		

						Quantiles				Guidelines			
Region	**Site**	**Measure**	**N**	**Mean**	**Median**	**Q5**	**Q20**	**Q80**	**Q95**	**Statistic**	**Annual**	**Dry**	**Wet**
	Hull Mouth(TUL7)	DIN (µg L^{-1})	4	54.87	28.54	8.57	10.82	88.39	138.02				
		DOC (µg L^{-1})	4	27	25	28	27	29	29				
		DON (µg L^{-1})	4	108.14	100.82	76.49	86.39	126.97	150.06				
		DOP (µg L^{-1})	4	3.64	2.70	1.01	1.07	5.84	7.60				
		Chl a (µg L^{-1})	4	1.60	1.39	0.88	1.09	2.04	2.64	Median	1.10	0.32	0.63
		NO$_x$(µg L^{-1})	4	46.70	22.64	1.38	1.46	82.33	125.71	Median	3.00		
		PO$_4$(µg L^{-1})	4	2.74	2.37	1.42	1.71	3.62	4.56	Median	3.00		
		POC (mg L^{-1})	4										
		Secchi (m)	4	1.00	0.75	0.50	0.50	1.40	1.85	Median	1.60		
		SiO$_4$	4	2346.66	2684.04	681.76	1527.46	3300.82	3539.24				
		TSS (mg L^{-1})	4	15.88	15.00	5.92	10.20	21.20	27.05	Median	5.00	1.60	2.40
	Bedarra(TUL8)	DIN (µg L^{-1})	8	27.37	7.51	2.76	3.69	14.13	115.00				
		DOC (µg L^{-1})	8	2	2	26	24	7	6				
		DON (µg L^{-1})	8	92.72	92.34	39.21	63.76	125.04	137.57				
		DOP (µg L^{-1})	8	3.93	4.66	1.53	1.88	5.60	5.77				
		Chl a (µg L^{-1})	8	0.92	0.65	0.34	0.42	1.60	1.87	Mean	0.45		
		NO$_x$(µg L^{-1})	8	22.02	3.53	0.32	0.50	6.29	103.41	Median	0.35		
		PN (µg L^{-1})	8	21.10	18.55	6.57	12.87	23.74	44.50	Mean	20.00		
		PO$_4$(µg L^{-1})	8	2.88	3.13	1.13	1.39	4.15	4.57	Median	2.00		
		POC (mg L^{-1})	8	202.62	227.26	128.52	174.46	240.64	242.23				
		PP (µg L^{-1})	8	2.90	3.21	0.57	1.95	4.00	4.37	Mean	2.80		
		Secchi (m)	8	3.86	4.00	1.50	1.80	4.90	6.75	Mean	10.00		
		SiO$_4$	8	1003.06	243.80	124.97	168.20	2143.24	3385.04				
		TSS (mg L^{-1})	8	2.89	2.34	0.73	1.26	4.84	5.79	Mean	2.00		
	Tully(TUL11)	DIN (µg L^{-1})	4	193.62	183.76	44.18	113.78	269.51	356.85				
		DOC (µg L^{-1})	4	27	25	28	27	29	29				
		DON (µg L^{-1})	4	99.40	91.58	76.33	83.11	112.57	133.43				
		DOP (µg L^{-1})	4	6.43	3.58	1.27	1.38	10.34	15.58				
		Chl a (µg L^{-1})	4	0.65	0.36	0.23	0.23	0.95	1.46	Median	2.00	0.32	0.63
		NO$_x$(µg L^{-1})	4	177.38	170.41	38.15	106.28	245.69	326.36	Median	15.00		
		PO$_4$(µg L^{-1})	4	6.28	6.03	3.97	5.05	7.41	8.94	Median	3.00		

						Quantiles				Guidelines			
Region	**Site**	**Measure**	**N**	**Mean**	**Median**	**Q5**	**Q20**	**Q80**	**Q95**	**Statistic**	**Annual**	**Dry**	**Wet**
		POC (mg L^{-1})	4										
		Secchi (m)	4	0.62	0.50	0.07	0.30	0.90	1.35	Median	1.50		
		SiO_4	4	9786.52	10796.16	6453.70	8540.96	11435.93	11705.83				
		TSS (mg L^{-1})	4	13.60	13.50	6.39	9.36	17.80	20.95	Median	7.00	1.60	2.40
	Tully Mouth Mooring(TUL10)	DIN (µg L^{-1})	8	28.85	12.07	2.12	3.67	64.14	70.73				
		DOC (µg L^{-1})	8	11	10	22	3	17	15				
		DON (µg L^{-1})	8	100.78	101.52	82.82	85.86	113.49	118.37				
		DOP (µg L^{-1})	8	4.10	4.41	0.70	1.87	5.42	7.43				
		Chl a (µg L^{-1})	8	1.24	1.02	0.67	0.72	1.75	2.30	Median	1.10	0.32	0.63
		NO_x (µg L^{-1})	8	21.34	5.24	0.45	0.89	49.78	55.67	Median	3.00		
		PO_4 (µg L^{-1})	8	3.67	4.08	1.20	1.49	5.13	6.34	Median	3.00		
		POC (mg L^{-1})	8	219.59	154.32	128.16	138.10	274.98	402.42				
		Secchi (m)	8	1.93	1.50	0.15	0.60	3.40	3.85	Median	1.60		
		SiO_4	8	1902.30	678.28	186.54	252.23	3871.62	5666.23				
		TSS (mg L^{-1})	8	17.05	10.94	2.10	2.27	27.10	46.75	Median	5.00	1.60	2.40
	Triplets(TUL9)	DIN (µg L^{-1})	2	14.42	14.42	12.75	13.30	15.54	16.10				
		DOC (µg L^{-1})	2	27	25	28	27	29	29				
		DON (µg L^{-1})	2	102.54	102.54	84.37	90.42	114.65	120.71				
		DOP (µg L^{-1})	2	2.42	2.42	2.16	2.25	2.60	2.69				
		Chl a (µg L^{-1})	2	1.16	1.16	0.79	0.91	1.40	1.52	Mean	0.45		
		NO_x (µg L^{-1})	2	4.91	4.91	2.90	3.57	6.25	6.92	Median	0.35		
		PN (µg L^{-1})	2	12.00	12.00	5.70	7.80	16.20	18.30	Mean	20.00		
		PO_4 (µg L^{-1})	2	3.98	3.98	3.23	3.48	4.47	4.72	Median	2.00		
		POC (mg L^{-1})	2										
		PP (µg L^{-1})	2	4.03	4.03	3.10	3.41	4.65	4.96	Mean	2.80		
		Secchi (m)	2	4.75	4.75	2.28	3.10	6.40	7.22	Mean	10.00		
		SiO_4	2	1949.31	1949.31	239.91	809.71	3088.90	3658.70				
		TSS (mg L^{-1})	2	2.30	2.30	1.40	1.70	2.90	3.20	Mean	2.00		
Burdekin	Palms West(BUR1)	DIN (µg L^{-1})	8	5.99	4.29	1.42	1.65	10.83	13.02				
		DOC (µg L^{-1})	8	16	11	1	4	22	17				
		DON (µg L^{-1})	8	92.26	86.30	70.66	82.65	90.77	132.09				

						Quantiles				Guidelines			
Region	**Site**	**Measure**	**N**	**Mean**	**Median**	**Q5**	**Q20**	**Q80**	**Q95**	**Statistic**	**Annual**	**Dry**	**Wet**
		DOP (μg L^{-1})	8	4.31	4.53	2.23	3.39	5.28	5.95				
		Chl a (μg L^{-1})	8	0.45	0.43	0.32	0.39	0.52	0.58	Median	0.35	0.32	0.63
		NO$_x$ (μg L^{-1})	8	2.89	2.22	0.22	0.41	5.52	6.57	Median	0.28		
		PN (μg L^{-1})	8	17.32	13.08	5.15	11.19	27.01	32.14	Median	12.00	16.00	25.00
		PO$_4$ (μg L^{-1})	8	1.83	1.79	0.54	0.65	2.57	3.57	Median	1.00		
		POC (mg L^{-1})	8	127.72	93.12	70.78	78.22	170.29	208.88				
		PP (μg L^{-1})	8	2.02	1.91	0.70	1.23	2.72	3.56	Median	2.20	2.30	3.30
		Secchi (m)	8	5.43	5.00	4.30	5.00	6.00	6.70	Mean	10.00		
		SiO$_4$	8	179.46	134.95	58.31	76.69	159.44	469.46				
		TSS (mg L^{-1})	8	2.18	2.48	0.70	1.11	3.15	3.41	Median	1.20	1.60	2.40
	Pandora(BUR2)	DIN (μg L^{-1})	8	7.71	5.68	1.41	3.18	9.00	19.59				
		DOC (μg L^{-1})	8	7	9	12	21	18	1				
		DON (μg L^{-1})	8	91.15	83.32	65.38	72.66	99.35	136.77				
		DOP (μg L^{-1})	8	4.29	4.40	2.70	3.81	5.12	5.34				
		Chl a (μg L^{-1})	8	0.56	0.57	0.25	0.29	0.79	0.99	Median	0.35	0.32	0.63
		NO$_x$ (μg L^{-1})	8	4.44	2.50	0.99	2.07	5.07	12.25	Median	0.28		
		PN (μg L^{-1})	8	16.04	13.54	4.55	10.03	24.86	30.39	Median	12.00	16.00	25.00
		PO$_4$ (μg L^{-1})	8	2.18	1.43	0.52	0.65	4.18	4.63	Median	1.00		
		POC (mg L^{-1})	8	152.45	122.06	103.86	109.93	188.90	222.33				
		PP (μg L^{-1})	8	2.27	2.67	0.55	0.84	3.30	3.91	Median	2.20	2.30	3.30
		Secchi (m)	8	4.71	4.00	3.30	4.00	4.80	7.80	Mean	10.00		
		SiO$_4$	8	225.76	174.44	75.10	114.27	308.89	458.09				
		TSS (mg L^{-1})	8	2.94	3.10	1.10	1.86	3.90	4.61	Median	1.20	1.60	2.40
	Magnetic(BUR4)	DIN (μg L^{-1})	8	9.36	9.65	1.73	4.09	14.35	15.81				
		DOC (μg L^{-1})	8	23	23	3	6	9	9				
		DON (μg L^{-1})	8	94.85	93.25	72.78	77.02	98.65	130.69				
		DOP (μg L^{-1})	8	3.49	3.69	1.34	2.31	4.74	4.87				
		Chl a (μg L^{-1})	8	0.82	0.67	0.41	0.52	1.20	1.37	Median	0.59	0.32	0.63
		NO$_x$ (μg L^{-1})	8	5.41	5.62	0.72	1.99	8.39	10.52	Median	0.28		
		PN (μg L^{-1})	8	16.48	13.58	7.08	10.40	20.20	33.20	Median	17.00	16.00	25.00
		PO$_4$ (μg L^{-1})	8	3.07	2.46	1.53	1.73	4.33	5.93	Median	1.00		

						Quantiles				Guidelines			
Region	**Site**	**Measure**	**N**	**Mean**	**Median**	**Q5**	**Q20**	**Q80**	**Q95**	**Statistic**	**Annual**	**Dry**	**Wet**
		POC (mg L^{-1})	8	140.85	121.64	114.47	116.86	161.00	180.67				
		PP (µg L^{-1})	8	3.27	2.97	1.76	2.39	4.20	5.49	Mean	2.80		
		Secchi (m)	8	3.69	3.75	2.67	3.00	4.00	4.97	Median	4.00		
		SiO_4	8	277.30	251.16	83.42	132.07	430.53	522.81				
		TSS (mg L^{-1})	8	3.69	3.86	1.79	3.37	4.38	5.04	Median	1.90	1.60	2.40
	Cape Cleveland(BUR6)	DIN (µg L^{-1})	4	8.74	10.26	3.62	6.40	11.68	11.73				
		DOC (µg L^{-1})	4	27	25	28	27	29	29				
		DON (µg L^{-1})	4	80.48	80.51	74.55	75.93	85.05	86.37				
		DOP (µg L^{-1})	4	4.64	5.01	2.83	3.88	5.54	5.93				
		Chl a (µg L^{-1})	4	1.11	0.49	0.34	0.38	1.59	2.74	Mean	0.45		
		NO_x (µg L^{-1})	4	4.82	5.22	1.67	2.41	7.39	7.41	Median	1.00		
		PN (µg L^{-1})	4	29.16	30.80	7.74	11.32	47.66	48.29	Median	13.00	16.00	25.00
		PO_4 (µg L^{-1})	4	2.29	2.28	0.86	1.42	3.16	3.72	Median	2.00		
		POC (mg L^{-1})	4										
		PP (µg L^{-1})	4	1.88	1.57	0.64	1.04	2.60	3.55	Median	2.10	2.30	3.30
		Secchi (m)	4	3.62	3.75	3.08	3.30	4.00	4.00	Mean	10.00		
		SiO_4	4	237.42	234.92	209.93	209.93	263.91	268.40				
		TSS (mg L^{-1})	4	4.23	3.90	2.83	3.24	5.08	6.07	Median	1.20	1.60	2.40
	Cleveland Bay(BUR5)	DIN (µg L^{-1})	5	9.36	9.41	8.41	8.83	9.91	10.25				
		DOC (µg L^{-1})	5	27	25	28	27	29	29				
		DON (µg L^{-1})	5	99.77	94.74	81.09	89.76	106.07	127.18				
		DOP (µg L^{-1})	5	3.79	3.84	2.42	2.75	4.44	5.53				
		Chl a (µg L^{-1})	5	0.56	0.56	0.37	0.48	0.63	0.77	Median	0.60	0.32	0.63
		NO_x (µg L^{-1})	5	4.72	4.81	2.54	2.74	6.05	7.48	Median	0.50		
		PN (µg L^{-1})	5	31.08	35.40	5.00	17.00	48.40	49.60	Mean	20.00		
		PO_4 (µg L^{-1})	5	2.73	2.43	1.64	1.92	3.27	4.40	Median	2.00		
		POC (mg L^{-1})	5										
		PP (µg L^{-1})	5	2.58	2.88	1.05	1.28	3.66	4.05	Mean	2.80		
		Secchi (m)	5	2.30	2.00	1.60	1.90	2.70	3.30	Median	3.00		
		SiO_4	5	383.86	299.89	149.95	239.91	593.79	635.77				
		TSS (mg L^{-1})	5	5.78	4.70	4.02	4.38	7.36	8.44	Median	5.00	1.60	2.40

						Quantiles				Guidelines			
Region	**Site**	**Measure**	**N**	**Mean**	**Median**	**Q5**	**Q20**	**Q80**	**Q95**	**Statistic**	**Annual**	**Dry**	**Wet**
	Haughton(BUR7)	DIN (µg L^{-1})	8	11.75	10.75	1.16	2.50	20.64	23.56				
		DOC (µg L^{-1})	8	6	8	8	19	19	20				
		DON (µg L^{-1})	8	89.95	82.56	66.52	72.85	100.80	120.75				
		DOP (µg L^{-1})	8	3.90	4.47	2.17	2.34	5.08	5.30				
		Chl a (µg L^{-1})	8	0.51	0.50	0.31	0.40	0.64	0.67	Mean	0.45		
		NO_x (µg L^{-1})	8	7.02	2.49	0.18	0.32	15.21	20.34	Median	1.00		
		PN (µg L^{-1})	8	18.63	14.42	3.61	8.62	23.32	46.68	Median	13.00	16.00	25.00
		PO_4(µg L^{-1})	8	2.23	1.86	0.97	1.09	3.43	4.08	Median	2.00		
		POC (mg L^{-1})	8	149.79	148.71	145.50	146.57	152.79	154.83				
		PP (µg L^{-1})	8	2.10	2.20	0.52	0.61	3.27	4.04	Median	2.10	2.30	3.30
		Secchi (m)	8	4.00	3.50	3.15	3.50	3.90	6.10	Mean	10.00		
		SiO_4	8	188.56	194.93	50.03	93.71	242.91	333.30				
		TSS (mg L^{-1})	8	3.25	3.40	1.15	1.86	4.36	5.22	Median	1.20	1.60	2.40
	Yongala(BUR10)	DIN (µg L^{-1})	9	2.06	1.67	1.16	1.34	2.81	3.80				
		DOC (µg L^{-1})	9	12	20	24	19	28	26				
		DON (µg L^{-1})	9	79.49	80.87	62.51	68.62	86.65	97.13				
		DOP (µg L^{-1})	9	4.89	5.03	3.97	4.43	5.36	5.51				
		Chl a (µg L^{-1})	9	0.24	0.23	0.17	0.19	0.28	0.33	Median	0.33	0.32	0.63
		NO_x (µg L^{-1})	9	0.58	0.53	0.25	0.31	0.85	1.07	Median	0.28		
		PN (µg L^{-1})	9	11.78	10.23	9.42	9.66	14.07	15.27	Median	14.00	16.00	25.00
		PO_4(µg L^{-1})	9	1.35	1.33	0.56	0.93	1.76	1.99	Median	1.00		
		POC (mg L^{-1})	9	98.79	94.92	64.27	66.59	131.74	140.20				
		PP (µg L^{-1})	9	1.70	1.54	1.37	1.43	1.74	2.54	Median	2.00	2.30	3.30
		Secchi (m)	9	13.56	13.00	11.40	12.00	14.80	17.80	Mean	10.00		
		SiO_4	9	29.45	27.55	20.70	24.11	31.16	45.65				
		TSS (mg L^{-1})	9	0.40	0.34	0.18	0.24	0.53	0.74	Median	0.80	1.60	2.40
	Haughton Mouth(BUR8)	DIN (µg L^{-1})	1	10.72	10.72	10.72	10.72	10.72	10.72				
		DOC (µg L^{-1})	1	27	25	28	27	29	29				
		DON (µg L^{-1})	1	70.29	70.29	70.29	70.29	70.29	70.29				
		DOP (µg L^{-1})	1	6.18	6.18	6.18	6.18	6.18	6.18				
		Chl a (µg L^{-1})	1	0.84	0.84	0.84	0.84	0.84	0.84	Median	1.00	0.32	0.63
		NO_x (µg L^{-1})	1	8.55	8.55	8.55	8.55	8.55	8.55	Median	4.00		

						Quantiles				Guidelines			
Region	**Site**	**Measure**	**N**	**Mean**	**Median**	**Q5**	**Q20**	**Q80**	**Q95**	**Statistic**	**Annual**	**Dry**	**Wet**
		PO_4(µg L^{-1})	1	1.21	1.21	1.21	1.21	1.21	1.21	Median	1.00		
		POC (mg L^{-1})	1										
		Secchi (m)	1	1.50	1.50	1.50	1.50	1.50	1.50	Median	1.50		
		SiO_4	1	349.88	349.88	349.88	349.88	349.88	349.88				
		TSS (mg L^{-1})	1	6.20	6.20	6.20	6.20	6.20	6.20	Median	2.00	1.60	2.40
	Barratta Creek(BUR9)	DIN (µg L^{-1})	5	10.52	10.47	4.14	4.55	15.71	17.71				
		DOC (µg L^{-1})	5	27	25	28	27	29	29				
		DON (µg L^{-1})	5	116.95	119.54	91.70	94.92	138.90	139.70				
		DOP (µg L^{-1})	5	4.19	4.27	2.83	3.40	4.80	5.66				
		Chl a (µg L^{-1})	5	0.92	0.98	0.67	0.73	1.08	1.13	Median	1.00	0.32	0.63
		NO_x(µg L^{-1})	5	5.68	5.18	2.10	3.16	7.71	10.27	Median	4.00		
		PO_4(µg L^{-1})	5	3.60	3.53	2.63	3.17	4.25	4.43	Median	1.00		
		POC (mg L^{-1})	5										
		Secchi (m)	5	1.50	1.00	1.00	1.00	1.80	2.70	Median	1.50		
		SiO_4	5	507.82	419.85	299.89	329.88	549.80	939.67				
		TSS (mg L^{-1})	5	12.54	10.00	8.58	9.12	13.60	21.40	Median	2.00	1.60	2.40
	Burdekin Mouth Mooring(BUR13)	DIN (µg L^{-1})	8	10.63	9.82	2.64	5.00	12.97	22.07				
		DOC (µg L^{-1})	8	24	24	25	20	26	2				
		DON (µg L^{-1})	8	106.48	97.34	85.43	91.28	120.54	141.98				
		DOP (µg L^{-1})	8	3.79	4.40	2.03	2.75	4.54	4.73				
		Chl a (µg L^{-1})	8	0.79	0.77	0.35	0.46	1.13	1.37	Median	1.00	0.32	0.63
		NO_x(µg L^{-1})	8	6.32	3.70	0.82	2.32	8.71	16.95	Median	4.00		
		PO_4(µg L^{-1})	8	3.19	2.84	2.16	2.35	4.12	4.71	Median	1.00		
		POC (mg L^{-1})	8	498.00	496.70	221.96	313.54	682.20	774.95				
		Secchi (m)	8	2.04	1.50	0.76	0.94	3.20	3.80	Median	1.50		
		SiO_4	8	382.43	209.93	124.83	174.00	661.76	868.27				
		TSS (mg L^{-1})	8	6.46	5.73	2.25	3.46	8.60	12.50	Median	2.00	1.60	2.40
Mackay Whitsunday	Double Cone(WHI1)	DIN (µg L^{-1})	4	3.54	3.70	2.34	2.94	4.21	4.53				
		DOC (µg L^{-1})	4	21	18	5	1	1	7				
		DON (µg L^{-1})	4	76.88	77.86	59.26	67.42	86.74	93.15				
		DOP (µg L^{-1})	4	4.35	4.21	3.86	3.99	4.66	5.04				
		Chl a (µg L^{-1})	4	0.60	0.60	0.52	0.54	0.66	0.68	Median	0.36	0.32	0.63

						Quantiles				Guidelines			
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	Statistic	Annual	Dry	Wet
		NO_x (µg L^{-1})	4	1.35	0.89	0.41	0.49	2.04	2.95	Median	1.00		
		PN (µg L^{-1})	4	27.86	29.24	13.55	19.68	36.59	40.23	Mean	14.00		
		PO_4 (µg L^{-1})	4	1.99	1.71	0.80	0.87	3.00	3.57	Median	1.00		
		POC (mg L^{-1})	4	262.21	291.49	137.56	206.64	329.49	345.87				
		PP (µg L^{-1})	4	2.82	2.91	2.15	2.51	3.16	3.36	Median	2.30	2.30	3.30
		Secchi (m)	4	5.62	5.50	4.00	4.00	7.20	7.42	Mean	10.00		
		SiO_4	4	61.00	52.81	48.66	49.08	69.64	84.79				
		TSS (mg L^{-1})	4	1.46	1.44	0.68	0.80	2.11	2.25	Median	1.40	1.60	2.40
	Pine(WHI4)	DIN (µg L^{-1})	4	5.56	4.71	2.53	3.40	7.39	9.80				
		DOC (µg L^{-1})	4	14	2	4	8	25	27				
		DON (µg L^{-1})	4	72.35	75.22	55.20	63.49	82.36	85.49				
		DOP (µg L^{-1})	4	4.89	4.09	3.62	3.83	5.62	7.28				
		Chl a (µg L^{-1})	4	0.70	0.74	0.46	0.55	0.86	0.87	Median	0.36	0.32	0.63
		NO_x (µg L^{-1})	4	3.40	1.92	0.82	1.27	4.95	8.07	Median	1.00		
		PN (µg L^{-1})	4	19.81	15.05	11.81	11.96	25.76	34.47	Mean	14.00		
		PO_4 (µg L^{-1})	4	2.78	2.19	1.42	1.49	3.84	4.97	Median	1.00		
		POC (mg L^{-1})	4	179.77	159.75	90.60	99.85	251.68	296.95				
		PP (µg L^{-1})	4	3.81	3.76	2.51	3.05	4.55	5.20	Median	2.30	2.30	3.30
		Secchi (m)	4	4.12	3.75	2.50	2.50	5.60	6.27	Mean	10.00		
		SiO_4	4	75.39	54.81	49.47	52.21	90.34	130.11				
		TSS (mg L^{-1})	4	3.02	2.29	1.44	1.54	4.21	5.62	Median	1.40	1.60	2.40
	Seaforth(WHI5)	DIN (µg L^{-1})	4	3.34	2.63	1.27	1.73	4.67	6.41				
		DOC (µg L^{-1})	4	21	14	2	5	12	14				
		DON (µg L^{-1})	4	67.85	70.84	55.53	62.86	74.04	75.98				
		DOP (µg L^{-1})	4	3.84	3.79	3.65	3.65	4.01	4.11				
		Chl a (µg L^{-1})	4	0.64	0.58	0.56	0.56	0.69	0.80	Median	0.36	0.32	0.63
		NO_x (µg L^{-1})	4	1.85	1.19	0.29	0.73	2.71	4.35	Median	1.00		
		PN (µg L^{-1})	4	28.80	20.27	12.16	16.04	38.14	57.36	Mean	14.00		
		PO_4 (µg L^{-1})	4	2.09	2.07	1.25	1.29	2.89	2.97	Median	1.00		
		POC (mg L^{-1})	4	267.13	197.61	102.08	151.65	354.80	529.51				
		PP (µg L^{-1})	4	3.63	3.73	2.25	2.76	4.53	4.86	Median	2.30	2.30	3.30

						Quantiles				Guidelines			
Region	**Site**	**Measure**	**N**	**Mean**	**Median**	**Q5**	**Q20**	**Q80**	**Q95**	**Statistic**	**Annual**	**Dry**	**Wet**
		Secchi (m)	4	5.00	4.75	3.65	4.10	5.80	6.70	Mean	10.00		
		SiO_4	4	60.03	54.81	52.76	53.46	64.52	74.61				
		TSS (mg L^{-1})	4	2.27	2.32	0.90	1.22	3.34	3.56	Median	1.40	1.60	2.40
	O'Connell Mouth(WHI6)	DIN (µg L^{-1})	4	3.43	3.13	2.44	2.74	3.99	4.84				
		DOC (µg L^{-1})	4	13	7	14	20	23	25				
		DON (µg L^{-1})	4	101.60	103.46	88.82	95.62	108.32	111.78				
		DOP (µg L^{-1})	4	5.17	5.24	4.81	4.96	5.42	5.45				
		Chl a (µg L^{-1})	4	1.10	1.13	0.78	0.95	1.27	1.37	Median	1.30	0.32	0.63
		NO_x (µg L^{-1})	4	1.68	1.21	0.72	0.88	2.29	3.30	Median	4.00		
		PO_4 (µg L^{-1})	4	5.77	5.60	3.96	4.44	7.03	7.82	Median	3.00		
		POC (mg L^{-1})	4	295.92	324.12	210.25	265.92	337.21	342.12				
		Secchi (m)	4	2.62	2.25	1.50	1.50	3.60	4.27	Median	1.60		
		SiO_4	4	352.97	308.67	169.45	181.86	506.36	598.52				
		TSS (mg L^{-1})	4	3.51	2.91	1.42	1.60	5.18	6.44	Median	5.00	1.60	2.40
	Repulse(WHI7)	DIN (µg L^{-1})	4	2.99	2.60	2.23	2.34	3.48	4.28				
		DOC (µg L^{-1})	4	8	3	13	18	20	21				
		DON (µg L^{-1})	4	80.28	80.57	67.42	72.70	87.97	92.71				
		DOP (µg L^{-1})	4	4.53	4.49	4.15	4.22	4.83	4.98				
		Chl a (µg L^{-1})	4	0.70	0.70	0.44	0.58	0.83	0.96	Mean	0.45		
		NO_x (µg L^{-1})	4	1.49	1.07	0.70	0.79	2.02	2.87	Median	0.25		
		PN (µg L^{-1})	4	28.45	26.25	12.57	14.27	41.74	47.41	Median	18.00	16.00	25.00
		PO_4 (µg L^{-1})	4	3.29	3.06	2.07	2.25	4.24	4.83	Median	2.00		
		POC (mg L^{-1})	4	266.60	240.62	130.05	134.00	388.81	439.53				
		PP (µg L^{-1})	4	4.50	4.93	2.62	3.47	5.70	5.78	Median	2.10	2.30	3.30
		Secchi (m)	4	3.88	4.00	2.72	3.40	4.40	4.85	Mean	10.00		
		SiO_4	4	147.30	85.66	81.17	82.21	187.75	299.73				
		TSS (mg L^{-1})	4	2.63	2.34	1.09	1.32	3.83	4.59	Median	1.60	1.60	2.40

Table E-4: Summary of turbidity measurements from moored ECO FLNTUSB instruments in all regions (site locations in **Error! Reference source not found.**) for the last two water years (Oct – Sept). N = number of daily means in the time-series; SE = standard error; '% d> Trigger' refers to the percentage of days each year with mean values above the Water Quality Guidelines for the Reef (Great Barrier Reef Marine Park Authority, 2010). Red shading indicates the annual means or medians that exceeded guidelines. '% d> 5 NTU' refers to the percentage of days above 5 NTU, a threshold suggested by Cooper et al. (2007, 2008) above which hard corals are likely to experience photo-physiological stress.

		Oct2016 - Sept2017						Oct2017 - Sept2018					
Region	**Reef**	**N**	**Annual Mean**	**SE**	**Annual Median**	**%d > Trigger***	**%d > 5 NTU**	**N**	**Annual Mean**	**SE**	**Annual Median**	**%d > Trigger***	**%d > 5 NTU**
Johnstone Russell Mulgrave	Fitzroy West	332	1.14	0.08	0.80	30.21	1.81	264	1.35	0.06	1.07	53.66	1.22
	Franklands West	365	0.94	0.05	0.66	59.18	1.37	272	1.10	0.07	0.76	73.79	2.02
	High West	231	1.12	0.04	0.92	40.38	0.00	272	1.42	0.07	1.00	49.39	2.83
	Russell Mulgrave Mouth Mooring	365	4.31	0.22	2.74	91.04	28.01	242	3.44	0.22	2.15	79.34	20.66
Tully Herbert	Dunk North	231	2.60	0.18	1.36	83.98	14.72	272	3.55	0.27	1.59	83.27	20.00
	Tully Mouth Mooring	325	4.61	0.23	3.31	41.23	32.92	241	4.23	0.25	3.22	34.21	22.81
Burdekin	Burdekin Mouth Mooring	365	10.38	1.00	5.23	58.36	52.33	272	7.23	0.39	5.29	58.30	52.03
	Magnetic	337	1.75	0.07	1.38	57.57	2.08	272	2.38	0.17	1.53	64.34	8.82
	Palms West	365	0.73	0.02	0.67	24.93	0.27	272	1.08	0.03	0.98	69.85	0.00
	Pandora	298	1.18	0.05	0.98	69.46	1.01	272	1.86	0.13	1.20	88.60	5.88
Mackay Whitsunday	Double Cone	275	2.12	0.39	1.16	53.45	2.55	272	1.94	0.08	1.55	76.47	2.57
	Pine	210	2.34	0.11	1.80	76.67	9.05	272	3.95	0.16	3.34	95.22	25.74
	Repulse	365	6.10	0.36	4.42	81.10	45.75	272	5.73	0.26	4.65	81.99	47.79
	Seaforth	365	2.50	0.27	1.42	65.75	7.40	272	2.04	0.07	1.67	86.40	2.21

* The turbidity Guideline Value (1.5 NTU) was derived by transforming the TSS Guideline Value (2 mg L^{-1}) using an equation based on a comparison between direct water samples and instrumental turbidity readings (see QA/QC Report for details).

Table E-5: Summary of water quality data collected across the wet season colour classes (CC1, CC2, CC3, CC4, CC5, CC6) and water types (primary, secondary, tertiary) as part of the JCU wet season response sampling of the MMP. No Data: nd.

				TSS (mg L^{-1})	Chla (µg L^{-1})	CDOM (m^{-1})	SDD (m)	DIN (µg L^{-1})	PO4 (µg L^{-1})	PP (µg L^{-1})	PN (µg L^{-1})
Great Barrier Reef region	multi-annual	CC1	mean	44.80	2.37	1.78	0.76	69.80	20.11	26.60	113.45
			SD	73.97	3.81	1.29	0.70	50.62	24.24	35.65	110.10
			min	1.40	0.20	0.00	0.00	2.00	1.00	0.00	1.00
			max	430.00	26.70	6.03	3.60	325.00	98.00	167.00	573.00
			count	89	97	67	39	85	88	85	87
	2017-18	CC1	mean	38.21	0.84	0.97	0.64	53.66	4.18	13.36	60.93
			SD	84.61	0.46	0.57	0.47	36.88	2.68	16.82	84.10
			min	6.00	0.20	0.21	0.00	10.47	1.00	0.30	1.00
			max	340.00	1.98	1.87	2.00	125.94	12.30	70.40	354.00
			count	14.00	14.00	8.00	14.00	14.00	14.00	14.00	14.00
	multi-annual	CC2	mean	18.90	1.35	1.02	1.30	57.93	10.03	10.31	51.92
			SD	24.38	1.03	0.70	1.88	52.84	14.47	11.66	62.47
			min	0.43	0.20	0.03	0.00	2.00	0.21	0.00	1.00
			max	150.00	5.34	4.40	12.00	237.00	80.00	73.00	282.00
			count	87	85	70	40	76	78	77	75
	2017-18	CC2	mean	14.38	0.92	1.00	1.06	48.48	3.52	7.65	47.14
			SD	11.26	0.69	0.55	0.85	50.05	1.27	6.90	36.13
			min	3.40	0.20	0.07	0.00	2.70	0.21	0.28	2.00
			max	51.00	2.84	2.37	3.00	192.84	5.77	32.76	135.00
			count	24.00	24.00	19.00	24.00	24.00	24.00	24.00	24.00
	multi-annual	CC3	mean	15.79	2.24	0.84	1.17	57.52	15.00	12.17	61.98
			SD	13.81	3.14	0.88	0.71	48.69	14.28	13.81	63.77
			min	1.40	0.20	0.05	0.50	2.00	2.00	0.00	1.00
			max	67.00	22.43	4.19	3.00	218.00	75.00	75.00	296.00
			count	69	69	55	12	59	62	58	58
	2017-18	CC3	mean	17.95	1.29	1.15	0.50	31.26	5.04	3.04	24.50
			SD	11.05	0.21	0.28	0.00	13.01	0.16	0.46	20.50
			min	6.90	1.08	0.88	0.50	18.25	4.88	2.58	4.00
			max	29.00	1.50	1.43	0.50	44.26	5.20	3.50	45.00
			count	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
	multi-annual	CC4	mean	9.00	1.40	0.56	1.87	41.69	8.02	6.00	45.16
			SD	9.11	2.20	0.58	1.30	47.40	6.79	7.36	57.10
			min	0.00	0.20	0.00	0.00	0.14	0.00	0.00	0.00
			max	73.00	30.90	3.71	9.50	357.00	55.00	63.00	374.00
			count	364	360	314	141	340	344	330	333
	2017-18	CC4	mean	5.53	1.05	0.51	2.25	18.90	2.73	3.17	27.62
			SD	4.91	0.60	0.27	1.09	22.53	1.44	3.59	32.57
			min	1.40	0.26	0.01	0.50	0.14	0.04	0.00	1.00
			max	30.00	3.29	1.11	5.97	112.04	5.87	19.46	138.00
			count	52.00	50.00	38.00	51.00	52.00	52.00	52.00	52.00
	multi-annual	P	mean	16.41	1.64	0.82	1.55	49.83	10.91	10.44	58.59
			SD	33.27	2.57	0.86	1.39	49.97	13.74	17.91	73.59
			min	0.00	0.20	0.00	0.00	0.14	0.00	0.00	0.00
			max	430.00	30.90	6.03	12.00	357.00	98.00	167.00	573.00
			count	609	611	506	232	560	572	550	553

			TSS (mg L^{-1})	Chla (µg L^{-1})	CDOM (m^{-1})	SDD (m)	DIN (µg L^{-1})	PO4 (µg L^{-1})	PP (µg L^{-1})	PN (µg L^{-1})
2017-18	P	mean	13.08	0.98	0.72	1.65	32.17	3.21	5.88	37.71
		SD	35.61	0.61	0.48	1.17	37.28	1.75	8.74	46.82
		min	1.40	0.20	0.01	0.00	0.14	0.04	0.00	1.00
		max	340.00	3.29	2.37	5.97	192.84	12.30	70.40	354.00
		count	92.00	90.00	67.00	91.00	92.00	92.00	92.00	92.00
multi-annual	S (or CC5)	mean	6.29	0.78	0.27	3.94	22.45	5.93	3.53	25.44
		SD	8.09	0.79	0.40	2.20	29.39	6.03	4.46	34.46
		min	0.00	0.02	-0.08	0.20	0.00	0.00	0.00	0.00
		max	130.00	12.50	3.25	13.60	369.00	63.00	47.90	456.00
		count	814	844	626	483	828	835	817	817
2017-18	S (or CC5)	mean	4.54	0.63	0.18	4.01	11.42	2.28	1.76	16.17
		SD	10.35	0.41	0.29	2.04	23.25	2.52	3.93	24.51
		min	0.27	0.20	0.01	0.20	0.01	0.01	0.00	0.00
		max	130.00	3.13	1.98	11.00	245.68	27.90	47.90	146.00
		count	174.00	162.00	113.00	166.00	173.00	173.00	172.00	173.00
multi-annual	T (or CC6)	mean	4.16	0.47	0.12	7.21	15.75	4.24	2.34	17.88
		SD	5.25	0.50	0.19	3.83	15.49	4.02	2.88	21.62
		min	0.00	0.02	-0.09	0.50	0.04	0.02	0.00	0.00
		max	31.00	5.34	1.38	19.00	104.00	21.00	18.00	174.00
		count	270	274	196	181	273	273	269	273
2017-18	T (or CC6)	mean	2.17	0.53	0.08	7.59	7.94	1.78	1.24	8.86
		SD	1.67	0.55	0.11	3.37	9.32	1.58	2.21	10.89
		min	0.00	0.15	0.00	1.50	0.04	0.02	0.00	0.00
		max	10.00	4.01	0.69	17.30	45.88	6.35	15.80	57.90
		count	64.00	60.00	45.00	62.00	64.00	64.00	64.00	64.00

Table E-6: Summary of water quality data collected in the Cape York region across the wet season colour classes (CC1, CC2, CC3, CC4, CC5, CC6) and water types (primary, secondary, tertiary) as part of the JCU wet season response sampling of the MMP. No Data: nd.

				TSS (mg L^{-1})	Chla (µg L^{-1})	CDOM (m^{-1})	SDD (m)	DIN (µg L^{-1})	PO4 (µg L^{-1})	PP (µg L^{-1})	PN (µg L^{-1})
Cape York	multi-annual	CC1	mean	16.87	1.21	3.35	0.96	37.44	5.06	11.83	71.50
			SD	12.75	1.29	2.06	0.89	19.51	3.14	10.63	54.36
			min	2.50	0.20	0.00	0.21	4.00	1.00	1.00	14.00
			max	54.00	5.34	6.03	3.60	82.00	12.00	35.00	205.00
			count	13	18	10	13	18	18	18	18
	2017-18	CC1	mean	21.17	0.77	nd.	0.57	30.17	3.00	5.50	41.83
			SD	16.32	0.24		0.17	10.61	1.41	3.10	13.91
			min	9.40	0.39		0.30	11.00	1.00	2.00	17.00
			max	54.00	1.11		0.85	43.00	5.00	10.00	56.00
			count	6.00	6.00		6.00	6.00	6.00	6.00	6.00
	multi-annual	CC2	mean	30.12	0.98	1.99	2.80	39.15	4.21	8.21	36.71
			SD	39.98	0.64	1.33	3.85	22.25	2.34	9.96	40.78
			min	3.70	0.31	0.03	0.35	8.05	2.00	0.00	1.00
			max	150.00	2.37	4.40	12.00	80.00	10.00	35.00	136.00
			count	13	13	6	7	14	14	14	14
	2017-18	CC2	mean	18.96	0.42	nd.	1.28	31.00	3.40	3.00	31.60
			SD	9.51	0.14		1.01	11.87	1.02	1.67	32.23

			TSS (mg L^{-1})	Chla (µg L^{-1})	CDOM (m^{-1})	SDD (m)	DIN (µg L^{-1})	PO4 (µg L^{-1})	PP (µg L^{-1})	PN (µg L^{-1})
		min	3.80	0.31		0.35	10.00	2.00	1.00	2.00
		max	31.00	0.68		2.89	45.00	5.00	5.00	84.00
		count	5.00	5.00		5.00	5.00	5.00	5.00	5.00
multi-annual	CC3	mean	6.33	4.06	3.10	0.80	40.00	5.60	7.00	79.50
		SD	1.86	3.01	0.87	0.05	28.80	2.15	2.55	102.62
		min	3.80	0.79	2.33	0.75	17.00	3.00	3.00	2.00
		max	8.20	8.82	4.19	0.85	89.00	9.00	10.00	253.00
		count	3	5	5	2	5	5	4	4
2017-18	CC3	mean	nd.							
		SD								
		min								
		max								
		count								
multi-annual	CC4	mean	6.13	1.02	1.65	2.65	22.34	3.27	2.94	49.94
		SD	3.50	1.10	1.32	1.95	18.53	1.99	1.94	63.74
		min	1.50	0.25	0.00	0.75	4.00	1.00	0.00	2.00
		max	17.00	5.18	3.71	9.50	73.00	11.00	7.00	318.00
		count	28	33	16	22	33	33	33	33
2017-18	CC4	mean	6.69	0.68	nd.	2.65	12.50	2.36	2.57	39.93
		SD	4.30	0.43		1.49	8.61	1.04	1.68	47.11
		min	1.50	0.26		0.75	4.00	1.00	0.00	2.00
		max	17.00	1.56		5.97	38.00	4.00	6.00	138.00
		count	14.00	14.00		13.00	14.00	14.00	14.00	14.00
multi-annual	P	mean	14.06	1.28	2.36	2.09	30.85	4.09	6.57	54.59
		SD	22.42	1.54	1.70	2.28	21.98	2.56	8.12	62.03
		min	1.50	0.20	0.00	0.21	4.00	1.00	0.00	1.00
		max	150.00	8.82	6.03	12.00	89.00	12.00	35.00	318.00
		count	57	69	37	44	70	70	69	69
2017-18	P	mean	12.62	0.65	nd.	1.85	20.44	2.72	3.36	38.72
		SD	11.73	0.37		1.50	13.30	1.22	2.43	38.86
		min	1.50	0.26		0.30	4.00	1.00	0.00	2.00
		max	54.00	1.56		5.97	45.00	5.00	10.00	138.00
		count	25.00	25.00		24.00	25.00	25.00	25.00	25.00
multi-annual	S (or CC5)	mean	4.42	0.50	0.21	4.50	10.37	2.68	1.79	19.61
		SD	4.96	0.36	0.66	2.29	6.86	1.32	2.31	29.89
		min	0.60	0.07	0.00	0.48	3.00	1.00	0.00	0.00
		max	32.00	2.36	3.25	10.30	32.00	8.00	13.00	179.00
		count	90	99	26	87	98	98	98	98
2017-18	S (or CC5)	mean	4.28	0.44	0.04	4.46	8.80	2.26	1.72	18.06
		SD	5.26	0.24	0.02	2.26	5.73	1.01	2.07	28.35
		min	0.60	0.20	0.02	0.90	3.00	1.00	0.00	1.00
		max	32.00	1.56	0.07	10.30	27.00	6.00	13.00	107.00
		count	66.00	66.00	6.00	61.00	65.00	65.00	65.00	65.00
multi-annual	T (or CC6)	mean	2.49	0.27	0.06	8.75	12.67	2.44	1.60	13.88
		SD	1.69	0.20	0.17	3.83	14.82	1.03	1.51	17.57
		min	0.50	0.02	0.00	2.19	3.00	1.00	0.00	0.00
		max	10.00	0.91	0.76	17.40	104.00	6.00	5.00	84.00
		count	50	50	21	36	52	52	52	52

			TSS (mg L^{-1})	Chla (µg L^{-1})	CDOM (m^{-1})	SDD (m)	DIN (µg L^{-1})	PO4 (µg L^{-1})	PP (µg L^{-1})	PN (µg L^{-1})
2017-18	T (or CC6)	mean	2.56	0.35	0.03	9.25	8.04	2.17	0.92	5.63
		SD	1.81	0.19	0.01	3.68	3.34	1.14	0.91	4.91
		min	0.50	0.20	0.02	3.07	3.00	1.00	0.00	0.00
		max	10.00	0.91	0.06	17.30	15.00	6.00	3.00	17.00
		count	24.00	22.00	6.00	23.00	24.00	24.00	24.00	24.00

Table E-7: Summary of water quality data collected in the Wet Tropics region across the wet season colour classes (CC1, CC2, CC3, CC4, CC5, CC6) and water types (primary, secondary, tertiary) as part of the JCU wet season response sampling of the MMP. No Data: nd.

				TSS (mg L^{-1})	Chla (µg L^{-1})	CDOM (m^{-1})	SDD (m)	DIN (µg L^{-1})	PO4 (µg L^{-1})	PP (µg L^{-1})	PN (µg L^{-1})
Wet Tropics	multi-annual	CC1	mean	11.94	1.14	1.11	0.85	68.89	4.12	10.86	43.30
			SD	8.08	1.42	0.47	0.59	45.18	1.97	9.68	44.09
			min	2.10	0.20	0.26	0.00	18.00	1.78	0.00	1.00
			max	38.00	6.14	1.82	2.00	140.00	8.00	32.00	167.00
			count	17	17	17	12	10	10	9	10
	2017-18	CC1	mean	11.25	0.41	0.94	0.88	89.98	3.54	13.19	21.75
			SD	4.97	0.17	0.26	0.74	31.08	1.52	4.92	16.25
			min	6.00	0.20	0.67	0.00	47.87	1.78	6.35	1.00
			max	19.00	0.59	1.36	2.00	125.94	5.83	19.43	46.00
			count	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
	multi-annual	CC2	mean	14.02	1.43	1.00	0.89	72.87	6.82	9.83	50.26
			SD	15.65	1.08	0.43	0.71	62.16	4.43	9.85	53.41
			min	2.30	0.20	0.33	0.00	11.16	1.97	0.00	2.00
			max	92.00	5.34	2.37	2.25	237.00	18.00	52.00	263.00
			count	50	48	49	27	40	40	39	39
	2017-18	CC2	mean	12.98	1.05	1.13	0.88	61.67	3.73	9.78	53.75
			SD	12.01	0.77	0.49	0.70	55.85	1.16	7.43	37.40
			min	3.40	0.20	0.46	0.00	11.16	1.97	1.01	2.00
			max	51.00	2.84	2.37	2.00	192.84	5.77	32.76	135.00
			count	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
	multi-annual	CC3	mean	11.41	1.50	0.55	0.90	65.60	11.21	6.85	46.71
			SD	8.31	1.53	0.32	0.44	58.16	5.86	5.16	35.57
			min	1.40	0.20	0.10	0.50	6.00	2.00	0.00	2.00
			max	34.00	7.48	1.43	1.80	218.00	21.00	21.00	134.00
			count	37	36	33	6	29	29	26	28
	2017-18	CC3	mean	17.95	1.29	1.15	0.50	31.26	5.04	3.04	24.50
			SD	11.05	0.21	0.28	0.00	13.01	0.16	0.46	20.50
			min	6.90	1.08	0.88	0.50	18.25	4.88	2.58	4.00
			max	29.00	1.50	1.43	0.50	44.26	5.20	3.50	45.00
			count	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
	multi-annual	CC4	mean	7.46	1.30	0.54	1.69	50.45	7.56	5.75	37.52
			SD	7.65	2.16	0.45	1.01	55.73	5.07	7.91	53.55
			min	0.00	0.20	0.00	0.00	0.14	0.00	0.00	0.00
			max	70.00	30.90	3.11	5.00	357.00	21.00	63.00	374.00
			count	242	238	229	92	216	216	205	212
	2017-	CC4	mean	5.08	1.20	0.55	2.06	22.61	2.90	3.42	23.02
			SD	5.13	0.62	0.25	0.81	26.02	1.49	4.14	24.45

			TSS (mg L^{-1})	Chla (µg L^{-1})	CDOM (m^{-1})	SDD (m)	DIN (µg L^{-1})	PO4 (µg L^{-1})	PP (µg L^{-1})	PN (µg L^{-1})
		min	1.40	0.36	0.01	0.50	0.14	0.04	0.03	1.00
		max	30.00	3.29	1.11	4.00	112.04	5.87	19.46	130.00
		count	35.00	33.00	35.00	35.00	35.00	35.00	35.00	35.00
multi-annual	P	mean	9.05	1.33	0.64	1.42	55.60	7.70	6.59	40.33
		SD	9.66	1.95	0.48	0.98	57.23	5.17	8.23	51.98
		min	0.00	0.20	0.00	0.00	0.14	0.00	0.00	0.00
		max	92.00	30.90	3.11	5.00	357.00	21.00	63.00	374.00
		Count	346	339	328	137	295	295	279	289
2017-18	P	mean	8.18	1.10	0.80	1.59	38.60	3.25	5.88	31.61
		SD	8.89	0.67	0.43	0.96	43.11	1.47	6.30	31.38
		min	1.40	0.20	0.01	0.00	0.14	0.04	0.03	1.00
		max	51.00	3.29	2.37	4.00	192.84	5.87	32.76	135.00
		count	57.00	55.00	57.00	57.00	57.00	57.00	57.00	57.00
multi-annual	S (or CC5)	mean	5.37	0.81	0.30	3.93	27.34	6.13	3.33	24.56
		SD	5.26	0.71	0.42	2.31	35.68	4.82	3.69	30.98
		min	0.00	0.02	-0.08	0.50	0.08	0.00	0.00	0.00
		max	33.00	11.24	2.74	13.00	369.00	22.00	29.00	372.00
		count	446	459	402	253	439	440	426	427
2017-18	S (or CC5)	mean	3.23	0.82	0.20	4.00	11.15	2.20	1.19	11.46
		SD	2.55	0.42	0.21	2.12	12.75	1.76	1.42	16.45
		min	0.27	0.23	0.01	1.00	0.08	0.03	0.03	0.00
		max	12.00	1.92	1.08	11.00	66.88	6.55	5.57	77.00
		count	62.00	55.00	62.00	62.00	62.00	62.00	62.00	62.00
multi-annual	T (or CC6)	mean	4.77	0.54	0.15	7.41	18.72	4.72	2.23	18.78
		SD	5.97	0.62	0.19	4.00	16.98	4.38	2.65	24.09
		min	0.00	0.02	0.00	0.50	0.04	0.03	0.00	0.00
		max	31.00	5.34	1.38	19.00	82.00	21.00	17.00	174.00
		count	156	156	128	105	153	153	151	152
2017-18	T (or CC6)	mean	1.85	0.68	0.10	7.21	8.73	1.74	1.78	9.76
		SD	1.59	0.78	0.13	2.95	12.02	1.67	3.11	13.18
		min	0.00	0.15	0.00	1.50	0.04	0.03	0.05	0.70
		max	7.00	4.01	0.69	15.00	45.88	4.91	15.80	57.90
		count	28.00	26.00	27.00	27.00	28.00	28.00	28.00	28.00

Table E-8: Summary of water quality data collected in the Burdekin region across the wet season colour classes (CC1, CC2, CC3, CC4, CC5, CC6) and water types (primary, secondary, tertiary) as part of the JCU wet season response sampling of the MMP. No Data: nd.

				TSS (mg L^{-1})	Chla (µg L^{-1})	CDOM (m^{-1})	SDD (m)	DIN (µg L^{-1})	PO4 (µg L^{-1})	PP (µg L^{-1})	PN (µg L^{-1})
Burdekin	multi-annual	CC1	mean	75.35	1.52	1.69	0.60	79.63	11.40	39.08	128.71
			SD	92.86	1.22	1.00	0.56	60.02	7.20	47.14	124.31
			min	1.40	0.20	0.21	0.10	2.00	1.00	0.00	14.00
			max	340.00	5.48	3.48	2.00	325.00	29.00	167.00	573.00
			count	29	32	19	9	29	31	30	31
	2017-18	CC1	mean	90.73	1.36	1.00	0.53	52.58	6.59	25.34	128.75
			SD	143.92	0.39	0.76	0.35	38.43	3.41	26.75	132.35
			min	6.10	0.98	0.21	0.10	10.47	3.58	0.30	14.00

			TSS (mg L^{-1})	Chla (µg L^{-1})	CDOM (m^{-1})	SDD (m)	DIN (µg L^{-1})	PO4 (µg L^{-1})	PP (µg L^{-1})	PN (µg L^{-1})
		max	340.00	1.98	1.87	1.00	108.77	12.30	70.40	354.00
		count	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
multi-annual	CC2	mean	19.47	1.31	0.36	1.43	26.06	5.58	12.25	49.59
		SD	31.06	0.88	0.35	0.80	26.64	4.26	19.66	66.49
		min	0.43	0.20	0.04	0.50	2.00	0.21	0.00	1.00
		max	120.00	3.40	1.06	3.00	90.00	16.00	73.00	255.00
		count	12	13	7	6	12	12	12	12
2017-18	CC2	mean	14.22	1.07	0.29	1.67	7.25	2.64	4.02	37.82
		SD	6.94	0.30	0.28	0.94	5.54	1.74	2.77	23.01
		min	8.66	0.75	0.07	1.00	2.70	0.21	0.28	6.46
		max	24.00	1.47	0.68	3.00	15.04	4.19	6.89	61.00
		count	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
multi-annual	CC3	mean	14.25	1.89	0.55	1.00	35.25	8.00	17.13	74.38
		SD	17.96	2.61	0.65	0.20	33.39	6.50	23.09	85.37
		min	2.90	0.53	0.05	0.80	2.00	2.00	0.00	4.00
		max	66.00	9.25	1.66	1.20	96.00	20.00	75.00	289.00
		count	10	9	4	2	8	8	8	8
2017-18	CC3	mean	nd.							
		SD								
		min								
		max								
		count								
multi-annual	CC4	mean	9.16	1.29	0.22	1.88	12.08	4.23	4.54	45.40
		SD	12.03	2.40	0.32	0.98	10.22	3.28	3.99	45.36
		min	0.43	0.20	0.03	1.00	0.26	0.09	0.00	3.00
		max	73.00	13.78	1.38	4.00	62.00	14.00	18.00	239.00
		count	34	30	19	19	33	33	33	33
2017-18	CC4	mean	5.42	1.07	0.11	2.67	5.50	2.49	2.98	23.85
		SD	3.95	0.34	0.02	1.25	4.65	1.97	2.71	9.16
		min	2.56	0.65	0.09	1.00	0.26	0.09	0.33	16.00
		max	11.00	1.48	0.14	4.00	11.56	4.92	6.70	36.70
		count	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
multi-annual	P	mean	33.80	1.45	0.84	1.44	40.28	7.43	19.35	79.50
		SD	63.87	1.87	0.97	0.99	49.28	6.35	33.95	96.53
		min	0.43	0.20	0.03	0.10	0.26	0.09	0.00	1.00
		max	340.00	13.78	3.48	4.00	325.00	29.00	167.00	573.00
		count	85	84	49	36	82	84	83	84
2017-18	P	mean	42.18	1.18	0.55	1.51	24.86	4.17	12.23	70.00
		SD	99.43	0.38	0.64	1.26	33.46	3.26	20.13	97.58
		min	2.56	0.65	0.07	0.10	0.26	0.09	0.28	6.46
		max	340.00	1.98	1.87	4.00	108.77	12.30	70.40	354.00
		count	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
multi-annual	S (or CC5)	mean	5.31	0.63	0.14	3.78	16.08	3.58	3.02	25.45
		SD	10.52	0.42	0.26	1.89	23.59	3.80	4.50	24.68
		min	0.27	0.10	0.00	0.20	0.00	0.01	0.00	0.00
		max	130.00	3.13	1.98	13.60	245.68	27.90	47.90	146.00
		count	154	153	101	112	153	153	152	153
20		mean	7.85	0.66	0.19	3.38	19.70	3.05	3.19	24.39

			TSS (mg L^{-1})	Chla (µg L^{-1})	CDOM (m^{-1})	SDD (m)	DIN (µg L^{-1})	PO4 (µg L^{-1})	PP (µg L^{-1})	PN (µg L^{-1})
	S (or CC5)	SD	20.97	0.50	0.42	1.29	46.29	4.63	7.69	28.50
		min	0.56	0.20	0.01	0.20	0.01	0.01	0.07	0.97
		max	130.00	3.13	1.98	7.00	245.68	27.90	47.90	146.00
		count	36.00	36.00	35.00	33.00	36.00	36.00	36.00	36.00
multi-annual	T (or CC6)	mean	3.58	0.43	0.11	5.37	11.57	4.09	2.34	20.81
		SD	2.59	0.22	0.21	2.53	9.15	3.20	2.51	20.54
		min	0.15	0.17	-0.09	1.40	0.11	0.02	0.00	0.00
		max	12.00	1.14	1.11	13.00	40.00	12.00	11.00	80.96
		count	44	43	35	32	44	44	42	44
2017-18	T (or CC6)	mean	2.54	0.47	0.07	5.57	9.95	1.83	0.99	18.21
		SD	1.56	0.16	0.11	1.76	11.37	2.10	0.78	13.07
		min	0.43	0.29	0.01	4.00	0.11	0.02	0.06	3.31
		max	5.60	0.78	0.35	9.00	29.73	6.35	1.98	39.90
		count	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00

Table E-9: Summary of water quality data collected in the Mackay-Whitsunday region across the wet season colour classes (CC1, CC2, CC3, CC4, CC5, CC6) and water types (primary, secondary, tertiary) as part of the JCU wet season response sampling of the MMP. No Data: nd.

				TSS (mg L^{-1})	Chla (µg L^{-1})	CDOM (m^{-1})	SDD (m)	DIN (µg L^{-1})	PO4 (µg L^{-1})	PP (µg L^{-1})	PN (µg L^{-1})
Mackay-Whitsunday	multi-annual	CC1	mean	73.00	3.69	1.13	0.35	44.00	13.67	25.67	73.67
			SD	36.12	2.26	0.44	0.12	26.99	8.38	7.72	40.20
			min	24.00	1.42	0.76	0.20	15.00	5.00	15.00	32.00
			max	110.00	6.78	1.75	0.50	80.00	25.00	33.00	128.00
			count	3	3	3	3	3	3	3	3
	2017-18	CC1	mean		nd.						
			SD								
			min								
			max								
			count								
	multi-annual	CC2	mean	22.35	0.92	0.11		27.50	8.00	14.50	32.00
			SD	16.65	0.65	0.03		5.50	2.00	9.50	27.00
			min	5.70	0.27	0.07		22.00	6.00	5.00	5.00
			max	39.00	1.56	0.14		33.00	10.00	24.00	59.00
			count	2	2	2		2	2	2	2
	2017-18	CC2	mean		nd.						
			SD								
			min								
			max								
			count								
	multi-	CC3	mean	14.00	1.35	0.14		58.50	8.00	12.50	15.00
			SD	0.00	0.05	0.00		25.50	6.00	3.50	5.00

			TSS (mg L-1)	Chla (µg L-1)	CDOM (m-1)	SDD (m)	DIN (µg L-1)	PO4 (µg L-1)	PP (µg L-1)	PN (µg L-1)
		min	14.00	1.30	0.14		33.00	2.00	9.00	10.00
		max	14.00	1.40	0.15		84.00	14.00	16.00	20.00
		count	2	2	2		2	2	2	2
2017-18	CC3	mean		nd.						
		SD								
		min								
		max								
		count								
multi-annual	CC4	mean	8.37	1.34	0.24	0.71	29.44	13.67	12.41	35.76
		SD	7.24	1.04	0.13	0.26	7.04	5.20	8.28	44.60
		min	1.00	0.27	0.03	0.35	14.00	2.00	3.00	2.00
		max	22.00	4.81	0.45	1.00	40.00	23.00	30.00	169.00
		count	18	15	18	5	18	18	17	17
2017-18	CC4	mean		nd.						
		SD								
		min								
		max								
		count								
multi-annual	P	mean	17.69	1.62	0.32	0.58	33.36	12.76	14.25	38.46
		SD	25.48	1.47	0.35	0.28	15.98	5.95	9.13	43.40
		min	1.00	0.27	0.03	0.20	14.00	2.00	3.00	2.00
		max	110.00	6.78	1.75	1.00	84.00	25.00	33.00	169.00
		count	25	22	25	8	25	25	24	24
2017-18	P	mean		nd.						
		SD								
		min								
		max								
		count								
multi-annual	S (or CC5)	mean	6.82	1.05	0.18	2.82	16.86	5.20	4.89	21.37
		SD	8.13	0.63	0.18	1.49	14.70	3.84	5.16	17.24
		min	0.10	0.24	0.01	0.40	0.00	0.00	0.10	0.00
		max	41.00	3.88	0.88	6.00	64.00	15.00	37.00	85.00
		count	78	73	49	26	78	78	77	78
v	S (or CC5)	mean	2.42	0.89	0.09	3.40	0.29	0.13	0.15	3.53
		SD	0.99	0.21	0.11	1.14	0.19	0.07	0.04	1.44
		min	1.14	0.51	0.01	1.50	0.12	0.04	0.10	1.17
		max	4.03	1.15	0.38	5.00	0.66	0.30	0.24	5.67
		count	10.00	5.00	10.00	10.00	10.00	10.00	9.00	10.00

			TSS (mg L^{-1})	Chla (µg L^{-1})	CDOM (m^{-1})	SDD (m)	DIN (µg L^{-1})	PO4 (µg L^{-1})	PP (µg L^{-1})	PN (µg L^{-1})
multi-annual	T (or CC6)	mean	1.92	0.67	0.03	4.94	4.97	1.90	2.33	16.46
		SD	2.78	0.21	0.01	1.10	8.29	1.85	2.33	9.99
		min	0.11	0.25	0.01	4.00	0.10	0.02	0.09	2.20
		max	12.00	1.19	0.05	7.00	35.00	7.00	10.00	36.87
		count	17	17	8	8	16	16	17	17
2017-18	T (or CC6)	mean	1.60	0.68	0.02	4.90	0.16	0.04	0.12	6.27
		SD	0.74	0.15	0.01	1.11	0.05	0.02	0.03	2.47
		min	0.43	0.50	0.01	4.00	0.10	0.02	0.09	2.20
		max	2.68	0.96	0.05	7.00	0.23	0.07	0.18	9.78
		count	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00

Table E-10: Site-specific Guideline Values (GVs) used for comparison with water quality monitoring data. These GVs are used to calculate the annual condition version of the WQ Index for each water quality sampling location and are derived from the Water Quality Guidelines for the Great Barrier Reef Marine Park (Great Barrier Reef Marine Park Authority, 2010), see Table D-1. See Section 2.4 for details on Index calculation. DOF is direction of failure ('H' indicates that high values fail, while 'L' indicates that low values fail). The type of GV ('mean' or 'median') indicates whether the GV should be applied to mean or median values from monitoring data. Bold GVs are those applied to monitoring data.

					Annual		Dry	Wet
GBRMPA group	**GBRMPA sites**	**Water Body**	**Measure**	**DOF**	**Mean**	**Median**	**Median**	**Median**
1	C1,C6,C8,RM1,RM4,RM8,TUL1	Open Coastal waters	Chla (µgL^{-1})	H	0.45		**0.32**	**0.63**
			NOx (µgL^{-1})	H		**0.35**		
			Turbidity (NTU)	H		**1.00**		
			PN (µgL^{-1})	H	20.00		**16.00**	**25.00**
			PO4 (µgL^{-1})	H		**2.00**		
			PP (µgL^{-1})	H	2.80		**2.30**	**3.30**
			Secchi (m)	L	**10.00**			
			TSS (mgL^{-1})	H	2.00		**1.60**	**2.40**
2	RM9,RM10,TUL3,TUL4,TUL5,TUL6,TUL8,TUL9	Open Coastal waters	Chla (µgL^{-1})	H	0.45		**0.32**	**0.63**
			NOx (µgL^{-1})	H		**0.35**		
			Turbidity (NTU)	H		**1.00**		
			PN (µgL^{-1})	H	20.00		**16.00**	**25.00**
			PO4 (µgL^{-1})	H		**2.00**		
			PP (µgL^{-1})	H	2.80		**2.30**	**3.30**
			Secchi (m)	L	**10.00**			
			TSS (mgL^{-1})	H	2.00		**1.60**	**2.40**
3	C4,C5,C11,RM2,RM3,RM5,RM6,RM7,TUL2	Midshelf waters	Chla (µgL^{-1})	H		0.30	**0.32**	**0.63**
			NOx (µgL^{-1})	H		**0.31**		
			Turbidity (NTU)	H		**0.60**		
			PN (µgL^{-1})	H		14.00	**16.00**	**25.00**
			PO4 (µgL^{-1})	H		**2.00**		
			PP (µgL^{-1})	H		2.00	**2.30**	**3.30**
			Secchi (m)	L		**13.00**		
			TSS (mgL^{-1})	H		1.20	**1.60**	**2.40**
4	RM12,TUL11	Midestuarine waters	Chla (µgL^{-1})	H		2.00	**0.32**	**0.63**
			NOx (µgL^{-1})	H		**15.00**		
			Turbidity (NTU)	H		**5.00**		
			PN (µgL^{-1})	H			**16.00**	**25.00**
			PO4 (µgL^{-1})	H		**3.00**		
			PP (µgL^{-1})	H			**2.30**	**3.30**
			Secchi (m)	L		**1.50**		
			TSS (mgL^{-1})	H		7.00	**1.60**	**2.40**
5	TUL7,TUL10	Lower estuarine waters	Chla (µgL^{-1})	H		1.10	**0.32**	**0.63**
			NOx (µgL^{-1})	H		**3.00**		
			Turbidity (NTU)	H		**4.00**		
			PN (µgL^{-1})	H			**16.00**	**25.00**
			PO4 (µgL^{-1})	H		**3.00**		
			PP (µgL^{-1})	H			**2.30**	**3.30**

					Annual		Dry	Wet
GBRMPA group	**GBRMPA sites**	**Water Body**	**Measure**	**DOF**	**Mean**	**Median**	**Median**	**Median**
			Secchi (m)	L		**1.60**		
			TSS (mgL⁻¹)	H		5.00	**1.60**	**2.40**
6	BUR1,BUR2	Open Coastal waters	Chla (µgL⁻¹)	H		0.35	**0.32**	**0.63**
			NOx (µgL⁻¹)	H		**0.28**		
			Turbidity (NTU)	H		**0.80**		
			PN (µgL⁻¹)	H		12.00	**16.00**	**25.00**
			PO4 (µgL⁻¹)	H		**1.00**		
			PP (µgL⁻¹)	H		2.20	**2.30**	**3.30**
			Secchi (m)	L	**10.00**			
			TSS (mgL⁻¹)	H		1.20	**1.60**	**2.40**
7	BUR3	Open Coastal waters	Chla (µgL⁻¹)	H	0.45		**0.32**	**0.63**
			NOx (µgL⁻¹)	H		**0.28**		
			Turbidity (NTU)	H		**0.80**		
			PN (µgL⁻¹)	H	20.00		**16.00**	**25.00**
			PO4 (µgL⁻¹)	H		**1.00**		
			PP (µgL⁻¹)	H	2.80		**2.30**	**3.30**
			Secchi (m)	L	**10.00**			
			TSS (mgL⁻¹)	H	2.00		**1.60**	**2.40**
8	BUR4	Open Coastal waters	Chla (µgL⁻¹)	H		0.59	**0.32**	**0.63**
			NOx (µgL⁻¹)	H		**0.28**		
			Turbidity (NTU)	H		**1.30**		
			PN (µgL⁻¹)	H		17.00	**16.00**	**25.00**
			PO4 (µgL⁻¹)	H		**1.00**		
			PP (µgL⁻¹)	H	2.80		**2.30**	**3.30**
			Secchi (m)	L		**4.00**		
			TSS (mgL⁻¹)	H		1.90	**1.60**	**2.40**
9	BUR5	Open Coastal waters	Chla (µgL⁻¹)	H		0.60	**0.32**	**0.63**
			NOx (µgL⁻¹)	H		**0.50**		
			Turbidity (NTU)	H		**3.00**		
			PN (µgL⁻¹)	H	20.00		**16.00**	**25.00**
			PO4 (µgL⁻¹)	H		**2.00**		
			PP (µgL⁻¹)	H	2.80		**2.30**	**3.30**
			Secchi (m)	L		**3.00**		
			TSS (mgL⁻¹)	H		5.00	**1.60**	**2.40**
10	BUR6.BUR7	Open Coastal waters	Chla (µgL⁻¹)	H	0.45		**0.32**	**0.63**
			NOx (µgL⁻¹)	H		**1.00**		
			Turbidity (NTU)	H	**2.00**			
			PN (µgL⁻¹)	H		13.00	**16.00**	**25.00**
			PO4 (µgL⁻¹)	H		**2.00**		
			PP (µgL⁻¹)	H		2.10	**2.30**	**3.30**
			Secchi (m)	L	**10.00**			
			TSS (mgL⁻¹)	H		1.20	**1.60**	**2.40**
11	BUR8,BUR9	Enclosed Coastal waters	Chla (µgL⁻¹)	H		1.00	**0.32**	**0.63**

					Annual		Dry	Wet
GBRMPA group	GBRMPA sites	Water Body	Measure	DOF	Mean	Median	Median	Median
			NOx (µgL^{-1})	H		**4.00**		
			Turbidity (NTU)	H		**4.00**		
			PN (µgL^{-1})	H			**16.00**	**25.00**
			PO4 (µgL^{-1})	H		**1.00**		
			PP (µgL^{-1})	H			**2.30**	**3.30**
			Secchi (m)	L		**1.50**		
			TSS (mgL^{-1})	H		2.00	**1.60**	**2.40**
12	BUR10	Midshelf waters	Chla (µgL^{-1})	H		0.33	**0.32**	**0.63**
			NOx (µgL^{-1})	H		**0.28**		
			Turbidity (NTU)	H		**0.50**		
			PN (µgL^{-1})	H		14.00	**16.00**	**25.00**
			PO4 (µgL^{-1})	H		**1.00**		
			PP (µgL^{-1})	H		2.00	**2.30**	**3.30**
			Secchi (m)	L	**10.00**			
			TSS (mgL^{-1})	H		0.80	**1.60**	**2.40**
13	BUR11,BUR12	Open Coastal waters	Chla (µgL^{-1})	H	0.45		**0.32**	**0.63**
			NOx (µgL^{-1})	H		**1.00**		
			Turbidity (NTU)	H		**2.00**		
			PN (µgL^{-1})	H	20.00		**16.00**	**25.00**
			PO4 (µgL^{-1})	H		**2.00**		
			PP (µgL^{-1})	H	2.80		**2.30**	**3.30**
			Secchi (m)	L	**10.00**			
			TSS (mgL^{-1})	H	2.00		**1.60**	**2.40**
14	BUR13,BUR14,BUR15	Enclosed Coastal waters	Chla (µgL^{-1})	H		1.00	**0.32**	**0.63**
			NOx (µgL^{-1})	H		**4.00**		
			Turbidity (NTU)	H		**4.00**		
			PN (µgL^{-1})	H			**16.00**	**25.00**
			PO4 (µgL^{-1})	H		**1.00**		
			PP (µgL^{-1})	H			**2.30**	**3.30**
			Secchi (m)	L		**1.50**		
			TSS (mgL^{-1})	H		2.00	**1.60**	**2.40**
15	WHI1,WHI2,WHI3,WHI4,WHI5	Open Coastal waters	Chla (µgL^{-1})	H		0.36	**0.32**	**0.63**
			NOx (µgL^{-1})	H		**1.00**		
			Turbidity (NTU)	H		**1.10**		
			PN (µgL^{-1})	H	14.00		**16.00**	**25.00**
			PO4 (µgL^{-1})	H		**1.00**		
			PP (µgL^{-1})	H		2.30	**2.30**	**3.30**
			Secchi (m)	L	**10.00**			
			TSS (mgL^{-1})	H		1.40	**1.60**	**2.40**
16	WHI6	Enclosed Coastal waters	Chla (µgL^{-1})	H		1.30	**0.32**	**0.63**
			NOx (µgL^{-1})	H		**4.00**		
			Turbidity (NTU)	H		**4.00**		
			PN (µgL^{-1})	H			**16.00**	**25.00**

					Annual		Dry	Wet
GBRMPA group	GBRMPA sites	Water Body	Measure	DOF	Mean	Median	Median	Median
			PO4 (µgL^{-1})	H		**3.00**		
			PP (µgL^{-1})	H			**2.30**	**3.30**
			Secchi (m)	L		**1.60**		
			TSS (mgL^{-1})	H		5.00	**1.60**	**2.40**
17	WHI7,WHI10	Open Coastal waters	Chla (µgL^{-1})	H	0.45		**0.32**	**0.63**
			NOx (µgL^{-1})	H		**0.25**		
			Turbidity (NTU)	H	**2.00**			
			PN (µgL^{-1})	H		18.00	**16.00**	**25.00**
			PO4 (µgL^{-1})	H		**2.00**		
			PP (µgL^{-1})	H		2.10	**2.30**	**3.30**
			Secchi (m)	L	**10.00**			
			TSS (mgL^{-1})	H		1.60	**1.60**	**2.40**
18	WHI8,WHI11	Open Coastal waters	Chla (µgL^{-1})	H	0.45		**0.32**	**0.63**
			NOx (µgL^{-1})	H		**1.00**		
			Turbidity (NTU)	H	**2.00**			
			PN (µgL^{-1})	H	20.00		**16.00**	**25.00**
			PO4 (µgL^{-1})	H		**2.00**		
			PP (µgL^{-1})	H	2.80		**2.30**	**3.30**
			Secchi (m)	L	**10.00**			
			TSS (mgL^{-1})	H	2.00		**1.60**	**2.40**
19	WHI9	Open Coastal waters	Chla (µgL^{-1})	H	0.45		**0.32**	**0.63**
			NOx (µgL^{-1})	H		**0.25**		
			Turbidity (NTU)	H	**1.00**			
			PN (µgL^{-1})	H		18.00	**16.00**	**25.00**
			PO4 (µgL^{-1})	H		**2.00**		
			PP (µgL^{-1})	H		2.10	**2.30**	**3.30**
			Secchi (m)	L	**10.00**			
			TSS (mgL^{-1})	H		1.60	**1.60**	**2.40**
20	WHI10.1,WHI10.2	Open Coastal waters	Chla (µgL^{-1})	H	0.45		**0.32**	**0.63**
			NOx (µgL^{-1})	H		**1.00**		
			Turbidity (NTU)	H			**2.00**	**12.00**
			PN (µgL^{-1})	H	20.00		**16.00**	**25.00**
			PO4 (µgL^{-1})	H		**2.00**		
			PP (µgL^{-1})	H	2.80		**2.30**	**3.30**
			Secchi (m)	L	**10.00**			
			TSS (mgL^{-1})	H	2.00		**1.60**	**2.40**

Appendix E References

Cooper TF, Uthicke S, Humphrey C, Fabricius KE (2007). Gradients in water column nutrients, sediment parameters, irradiance and coral reef development in the Whitsunday Region, central Great Barrier Reef. Estuarine, Coastal and Shelf Science 74:458-470.

Cooper TF, Ridd PV, Ulstrup KE, Humphrey C, Slivkoff M, Fabricius KE (2008). Temporal dynamics in coral bioindicators for water quality on coastal coral reefs of the Great Barrier Reef. Marine and Freshwater Research 59:703-716.

Department of Environment and Resource Management (DERM) (2009). Queensland Water Quality Guidelines, Version 3. 167 p. Available at www.derm.qld.gov.au. ISBN 978-0-9806986-0-2.

Great Barrier Reef Marine Park Authority (2010). Water Quality Guidelines for the Great Barrier Reef Marine Park. Revised Edition 2010. Great Barrier Reef Marine Park Authority, Townsville. 100pp.

Appendix F. Quality assurance/quality control (QA/QC) information

F-1 Method performance and QA/QC information for water quality monitoring activities

Information pertaining to QA/QC generally includes the assessment of the limit of detection (LOD), measurements of accuracy (e.g. using reference materials to assess the recovery of a known amount of analyte) and precision (the repeated analyses of the same concentration of analyte to check for reproducibility).

F-2 Limits of detection

LOD or detection limit is the lowest concentration level that can be determined to be statistically different from a blank (99% confidence). LOD of water quality parameters sampled under the MMP are summarised below (Table F-1):

Table F-1: Limits of detection (LODs) for analyses of marine water quality parameters.

Parameter (analyte)	LOD
NO_2	0.28 µg L^{-1}*
NO_3+ NO_2	0.28 µg L^{-1}*
NH_3	0.84 µg L^{-1}*
NH_3 by OPA	0.28 µg L^{-1}
TDN	0.28 µg L^{-1}*
PN	1.0 µg $filter^{-1}$
PO_4	0.62 µg L^{-1}*
TDP	0.62 µg L^{-1}*
PP	0.09 µg L^{-1}
Si	1.9 µg L^{-1}*
DOC	0.1 mg L^{-1}
POC	1.0 µg $filter^{-1}$
Chl-*a*	0.004 µg L^{-1}
SS	0.15mg $filter^{-1}$
Salinity	0.03

*LOD for analysis of dissolved nutrients is estimated for each individual analytical batch, the range given is the range of LODs from batches analysed with samples collected in 2014/15.

F-3 Precision

The variation between results for replicate analyses of standards or reference material is used as a measure for the precision of an analysis. Reproducibility of samples was generally within a CV of 20%, with the majority of analyses delivering precision of results within 10% (Table F-2).

Table F-2: Summary of coefficients of variation (CV) of replicate measurements (N) of a standard or reference material.

Parameter (analyte)	CV (%)	N
PN	9–18*	53–68
PP	7	8
POC	8–13*	52–56
Chl-*a*	0.7	48
TSS	n/a**	
Salinity	<0.1	2–5

* Two different reference materials used in each batch

**No standard material exists for analysis of this parameter.

F-4 Accuracy

Analytical accuracy is measured as the recovery (%) of a known concentration of a certified reference material or analyte standard (where no suitable reference material is available, e.g., for PP), which is usually analysed interspersed between samples in each analytical run. The recovery of known amounts of reference material is expected to be within 90%–110% (i.e., the percent difference should be ≤20%) of their expected (certified) value for results to be considered accurate. The accuracy of analytical results for PN, PP, POC, Chl-*a*, TSS and salinity were generally within this limit (Table F-3). Analytical results for PP are adjusted using a batch-specific recovery factor that is determined with each sample batch.

Table F-3: Summary of average recovery of known analyte concentrations.

Parameter (analyte)	Average recovery (%)	N
PN	102–110	53–68
PP	92*	9
POC	105–109	53–56
Chl-*a*	99.5	24
TSS	n/a**	
Salinity	100	11

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*Data are adjusted using a batch-specific efficiency factor (recovery)

**No suitable reference material exists for analysis of this parameter

F-5 Procedural blanks

Wet filter blanks (filter placed on filtration unit and wetted with filtered seawater, then further handled like samples) were prepared during the on-board sample preparation to measure contamination during the preparation procedure for PN, PP, POC and Chl-a. The instrument readings (or actual readings in the case of Chl-*a*) from these filters were compared to instrument readings from actual water samples. On average, the wet filter blank values were below 1% of the measured values for Chl-*a* (Table F-4) and we conclude that contamination due to handling was minimal.

Wet filter blanks (as well as filter blanks using pre-combusted filters) for PN, PP and POC generally returned measurable readings, which indicates that the filter material contains phosphorus and organic carbon. The blank values are relatively constant and were subtracted from sample results to adjust for the inherent filter component.

Wet filter blanks for TSS analysis (filter placed on filtration unit and wetted with filtered seawater, rinsed with distilled water, then further handled like samples) were prepared during the on-board sample preparation. The mean weight difference of these filter blanks (final weight - initial filter weight) was 0.00010 g (n = 32). This value indicated the average amount of remnant salt in the filters (‘salt blank’). The salt blank was approximately 3.5% of the average sample filter weight (Table F-4). This value was included in the calculation of the amount of TSS per litre of water by subtraction from the sample filter weight differences.

Table F-4: Comparison of instrument readings of wet filter blanks to actual sample readings.

	PP (absorbance readings)	**PN (instrument readings)**	**Chl-*a* (µg L^{-1})**	**TSS (mg filter^{-1})**	**POC (µg filter^{-1})**
Average of blank readings	0.007	1.09	0.005	0.08	7.43
N of blank readings	44	37	42	8	36
Average of sample readings	0.12	5.61	0.58	2.28	44.31
N of sample readings	510	494	638	572	493
Average of blanks as % of average sample readings	5.4%	19.36%	0.94%	3.51%	16.8%

Appendix G. Scientific publications and presentations associated with the program, 2017–18

G-1 Publications

Blondeau-Patissier D, Brando V, Lønborg C, Dekker A (in press). Phenology of *Trichodesmium* spp. blooms in the Great Barrier Reef Lagoon, Australia, from the ESA-MERIS 10-year mission. *PloS One*.

Lewis SE, Lough JM, Cantin NE, Matson EG, Kinsley L, Bainbridge ZT, Brodie JE (2018). A critical evaluation of coral Ba/Ca, Mn/Ca and Y/Ca ratios as indicators of terrestrial input: new data from the Great Barrier Reef, Australia. *Geochimica et Cosmochimica Acta* 237, 131-154.

Lonborg C, Alvarez-Salgado XA, Duggan S, Carreira C. (2017). Organic matter bioavailability in tropical coastal waters: The Great Barrier Reef. *Limnology and Oceanography* 63(2): 1015-1035.

Petus C, Devlin M, Teixera da Silva E, Lewis S, Waterhouse J, Wenger A, Bainbridge Z, Tracey D (2018). Defining wet season water quality target concentrations for ecosystem conservation using empirical light attenuation models: a case study in the Great Barrier Reef (Australia). Journal of Environmental Management 213:451-466.

Waterhouse J, Lønborg C, Logan M, Petus C, Tracey D, Lewis S, Howley C, Harper E, Tonin H, Skuza M, Doyle J, Costello P, Davidson J, Gunn K, Wright M, Zagorskis I, Kroon F, Gruber, R (2018). Marine Monitoring Program: Annual Report for inshore water quality monitoring 2016-2017. Report for the Great Barrier Reef Marine Park Authority, Great Barrier Reef Marine Park Authority, Townsville.

G-2 Presentations

Kroon F, et al. Nitrogen and the Great Barrier Reef. Presented at the 'Innovative Nitrogen Use in Sugarcane' Forum, Cairns, QLD, November 2018.

Gruber R, et al. Inshore water quality monitoring in the Great Barrier Reef 2017-2018: Preliminary results. Presented at the Marine Monitoring Program Annual MERI Workshop, Townsville, QLD, November 2018.

Gruber R, et al. Inshore water quality monitoring in the Great Barrier Reef. Presented to Indigenous Reef Advisory Committee (IRAC) at AIMS, Townsville, QLD, May 2018.

Gruber R, et al. Inshore water quality monitoring in the Great Barrier Reef. Presented to Burdekin Cane Extension Group at AIMS, Townsville, QLD, June 2018.

Gruber R, et al. Inshore water quality monitoring in the Great Barrier Reef. Presented to QLD Department of Agriculture and Fisheries and Great Barrier Reef Operational Management Group at AIMS, Townsville, QLD, May 2018.

Gruber R, et al. Inshore water quality monitoring in the Great Barrier Reef 2017-2018: Preliminary results. Presented at Great Barrier Reef Marine Park Authority lunchtime seminar, Townsville, QLD, November 2018.

Robson B, et al. Great Barrier Reef water qualtiy. Presented to NQ Dry Tropics, Burdekin and Fitzroy Graziers at AIMS, Townsville, QLD, September 2018.

Waterhouse J, Lewis S, Petus C, Tracey D, Mellors, J, Howley C, Langlois, L.. Inshore wet season water quality monitoring in the Great Barrier Reef 2017-2018: Preliminary results. Presented at the Marine Monitoring Program Annual MERI Workshop, November 2018.