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Marine Park Authority

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TropWATER

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Commonly used abbreviations and units

Abbreviations

AIMS = Australian Institute of Marine Science

BOM = Bureau of Meteorology

CDOM = colour dissolved organic matter

Chl-a = chlorophyll a

COTS = crown-of-thorns starfish

CTD = Conductivity Temperature Depth profiler

CYWMP = Cape York Water Monitoring Partnership

DIN = dissolved inorganic nitrogen

DIP = dissolved inorganic phosphorus

DOC = dissolved organic carbon

DON = dissolved organic nitrogen

DOP = dissolved organic phosphorus

ENSO = El Nino – Southern Oscillation cycle

GBR = Great Barrier Reef

GBRMP = Great Barrier Reef Marine Park

GBRMPA = Great Barrier Reef Marine Park Authority

GBRWHA = Great Barrier Reef World Heritage Area

JCU = James Cook University

Kd(PAR) = light attenuation coefficient

LOD = limit of detection

MMP = Marine Monitoring Program

MODIS = Moderate Resolution Imaging Spectroradiometer

NH_3 = ammonia

NO_x = nitrogen oxides

NRM = natural resource management

PN = particulate nitrogen

PP = particulate phosphorus

PSII herbicides = photosystem II inhibiting herbicides

QA/QC = Quality Assurance/Quality Control

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

Units

km^3 = cubic kilometres

kt = kilotonnes

m = metre

mg/L = milligram per litre

ML = million litres

$mol/m^2/d$ = moles of light per square metre per day

ng/L = nanogram per litre

t = tonnes

µg/L = micrograms per litre

µm = micrometres (microns)

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

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Preface

Management of human pressures on regional and local scales, such as increased catchment run-off and direct use of marine resources, is vital to provide corals and reef organisms with the optimum conditions to cope with global stressors, such as climate change (Carpenter et al., 2008; Hughes et al., 2010; Mora, 2008). The management of water quality remains a strategic priority for the Great Barrier Reef Marine Park Authority (Marine Park Authority) to ensure the long-term protection of the coastal and inshore ecosystems of the Great Barrier Reef (GBR) (GBRMPA, 2014a, b). A key policy is the *Reef Water Quality Protection Plan* (Reef Plan; Anon, 2013), now a key component of the *Reef 2050 Long-Term Sustainability Plan* (Reef 2050 Plan; Commonwealth of Australia, 2015)[1], the latter provides the overarching framework for the integrated management of the Great Barrier Reef World Heritage Area (GBRWHA).

The Marine Monitoring Program (MMP) was designed and developed by the GBRMPA in collaboration with science agencies and is currently funded by the Australian Government Reef Program and the Reef 2050 Integrated Monitoring and Reporting Program. A summary of the MMP's overall goals and objectives and a description of the sub-programs are available at http://www.gbrmpa.gov.au/managing-the-reef/how-the-reefs-managed/reef-2050-marine-monitoring-program and http://e-atlas.org.au/rrmmp. The MMP was established in 2005 to help assess the long-term status and health of GBR ecosystems and is a critical component in the assessment of regional water quality as land management practices are changed across GBR catchments. The MMP forms an integral part of the *Paddock to Reef Integrated Monitoring, Modelling and Reporting Program* (Paddock to Reef program), which is a key action of the *Reef Plan* and is designed to evaluate the efficiency and effectiveness of program implementation, and report on progress towards the *Reef Plan* and *Reef 2050 Plan* goals and targets. A key output of the Paddock to Reef program is an annual report card, including an assessment of GBR water quality and ecosystem condition to which the MMP contributes assessments and information. The first annual Great Barrier Reef Report Card for 2009 serves as a baseline for future assessments, and report cards for 2010, 2011, 2012–13, 2014, 2015 and 2016 have since been released (available at www.reefplan.qld.gov.au).

Inshore water quality monitoring in the MMP includes ambient and event sampling (e.g., Waterhouse et al., 2017a) and is carried out in partnership with the other MMP components including pesticide monitoring (Grant and Paxman, 2017), coral monitoring (Thompson et al., 2017) and seagrass monitoring (McKenzie et al., 2017).

The Australian Institute of Marine Science (AIMS) and James Cook University (JCU) entered into a co-investment agreement with the GBRMPA to provide monitoring activities under the MMP. The water quality monitoring activities in the current contract period of the MMP are built on activities established under previous arrangements from 2005 to 2015 through the expansion of monitoring in four focus regions.

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

Executive summary

Monitoring and management of the Great Barrier Reef (GBR) water quality remains important to support the long-term protection of the coastal and inshore ecosystems of the GBR. The land management initiatives under the Australian and Queensland government's *Reef Water Quality Protection Plan* (Reef Plan[2]) and the *Reef 2050 Long-Term Sustainability Plan* (Reef 2050 Plan) are key actions to improve the water quality entering the GBR. The goal of the *Reef Plan* is *'To ensure that by 2020 the quality of water entering the reef from broadscale land use has no detrimental impact on the health and resilience of the Great Barrier Reef'.*

This report summarises the results of water quality monitoring activities carried out by the Australian Institute of Marine Science (AIMS), James Cook University (JCU) and the Cape York Water Monitoring Partnership (CYWMP) as part of the Marine Monitoring Program (MMP) in 2016–17, with reference to previous data from 2005 to 2016. The results of two case studies are also presented in the Appendices.

The overall objective of the MMP is to 'assess trends in ecosystem health and resilience indicators for the Great Barrier Reef in relation to water quality and its linkages to end-of-catchment loads'. The focus of this report is inshore water quality, with the aim to assess temporal and spatial trends in inshore GBR water quality to detect changes over time and ultimately because of the achievement of reductions in end-of-catchment load contributions. 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. The more intensive wet season sampling, combined with remote sensing data and exposure models, is used to characterise the spatial and temporal variability of land-sourced material transport into the GBR. Event response sampling is conducted in the focus regions to capture flood events (at least 'minor' category) throughout the wet season.

Drivers, activities, impacts and pressures

The rainfall and river flow in the GBR catchments is variable between years and heavily driven by the El Nino – Southern Oscillation (ENSO) cycle. The rainfall and river flow across all basins of the GBR during the 2016–17 wet season was close to the long-term median. The total GBR river input was 55,900,000 ML, which was just below the long-term (1986–87 to 2016–17) median of 59,700,000 ML. A number of southern rivers had wet season discharges above their long-term median flow including a majority of rivers in the Mackay Whitsunday, Fitzroy (coastal catchments) and Burnett Mary regions. The only cyclone to influence the GBR during 2016–17 was severe tropical cyclone Debbie, a Category 4 system that passed through the Whitsunday Islands and crossed the mainland at Airlie Beach in the Mackay–Whitsunday region. The cyclone then moved southward over land as a rain depression producing flooding rains across the Bowen-Broken-Bogie catchment of the Burdekin, the basins of the MackayWhitsunday, Fitzroy and Burnett Mary natural resource management (NRM) regions. Event sampling was conducted in the Burdekin and Mackay Whitsunday focus regions, and opportunistically in the Fitzroy region to capture these events.

End-of-catchment pollutant loads calculated for 2016–17 showed distinct variations between the focus areas, with the Proserpine-O'Connell-Pioneer-Plane and the Tully-Murray-Herbert basins dominating the dissolved inorganic nitrogen (DIN) exports. Loads of total suspended solids (TSS) and particulate nitrogen (PN) were dominated by the Burdekin-Haughton basins. To provide context for the water quality monitoring results, calculated end-of-catchment pollutant loads are included in this report and presented for the rivers influencing each sampling region in the regional reports (Section 3.4).

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[2] Note: At the time of writing, the Reef Plan 2013 was being revised and the updated Reef 2050 Water Quality Improvement Plan 2017–2022 was still in draft form.

The eReefs hydrodynamic model is used to run tracer experiments to estimate the extent of river influence in the GBR lagoon (for the rivers where the model is available). These tracer maps indicate the spatial extent of influence of individual rivers. The results showed that the areas exposed to river discharge in 2016–17 were relatively constrained. The results for each region are presented in Section 3.4.

Exposure of the GBR ecosystems to land-sourced pollutants during the wet season is derived from several remote sensing products combined with *in-situ* data. This includes maps of the frequency of occurrence of wet season water types (incorporating river plumes), exposure maps that summarise the likelihood and magnitude (relative to Water Quality Guidelines) of exposure to ecosystems by potentially detrimental pollutant concentrations during the wet season, weekly panels summarising wet season environmental and marine (water type) conditions and models that summarise the predicted transport of land-sourced pollutants. These maps were produced for the Cape York region for the first time this year.

The water type frequency maps are derived from Moderate Resolution Imaging Spectroradiometer (MODIS) satellite imagery to represent water quality patterns during the wet season. In 2016–17, these maps illustrated a well-documented inshore to offshore spatial pattern, with the highest frequency of the Primary water type in the coastal areas (i.e., more turbid conditions) and offshore areas most frequently exposed only to the Tertiary water type. The extent and frequency of the Primary, Secondary and Tertiary water types were variable across regions and across the shelf, reflecting the constituent concentrations and the regional intensity of river discharge and/or resuspension events. In particular, the frequency of occurrence of wet season water types (Primary, Secondary and Tertiary water types combined) recorded along a cross shelf transect from the Pioneer River was similar to the frequency recorded in 2010–11, an unusually high flow year, which is linked to the above average rainfall largely associated with tropical cyclone Debbie in March–April 2017.

Seasonal and long-term surface exposure maps (hereafter, exposure maps) represent the wet season and long-term frequency of exposure to TSS, chlorophyll a (Chl-a), particulate phosphorus (PP) and PN-enriched surface waters assessed against the Water Quality Guidelines. These maps are now developed annually to represent the likelihood and magnitude of pollutant exceedance during the wet season(s). The wet season seasonal and long-term exposure maps were overlaid with information on the spatial distribution of GBR ecosystems (coral reefs and seagrasses) to help identify ecosystems that may experience acute or chronic high exposure to land-sourced pollutants, and thus help to evaluate the susceptibility of GBR ecosystems. In 2016–17, the GBR was mostly influenced by the lowest exposure categories, which was in agreement with long-term trends. The area of the GBR influenced by the highest exposure categories was similar to the long-term areas and consistent with an average wet season.

Panels showing the pressures combined with the wet season water types and frequency maps for each NRM region provide an innovative way to visually assess the combined influence of several drivers on wet season conditions. These have highlighted the need to distinguish the influence of river discharge, as opposed to other processes such as resuspension, in driving water quality. Now established for the Cape York region, this method is being explored further to establish a metric specific to river plumes, distinct from overall wet season conditions.

An ocean colour-based model was used to estimate the dispersion of individual parameters including DIN and TSS loads delivered by river plumes, to examine their exposure and influence across the GBR lagoon. The model combines *in-situ* data, MODIS satellite imagery and modelled annual end-of-catchment loads from all 35 GBR basins (verified using monitoring data). The outer boundary of the modelled river plumes was derived from wet season discharge using the relationship between river discharge and plume extent initially estimated using the eReefs hydrodynamic model (tracer maps). The pollutant loading model produces annual maps of average DIN and TSS concentrations or mass loadings in the GBR waters over the wet season (November to May) with current and pre-development scenarios.

The maps are presented as a time series from 2003 to 2017 and can be used to assess the concentration of pollutants from river plumes as well as the relative contributions of pollutants from individual rivers to different NRM regions. The 2016–17 outputs were similar to those for other years with discharge close to the long-term median. The current year can also be compared to a simulated loading map using estimated pre-development end-of-catchment loads to produce a map output showing the difference between the two scenarios. In both scenarios, the same flow was used for each river; a more comprehensive assessment could have varied pre-development flows in addition to the input loads, although historical changes in hydrology (i.e., rainfall-runoff) are poorly constrained and have not been modelled in the GBR. The DIN loading assessment highlights the Wet Tropics and Mackay–Whitsunday regions as the dominant areas of anthropogenic influence during the 2016–17 wet season and, to a much lesser extent, the Burdekin and Burnett–Mary regions. The TSS loading assessment highlights the Burdekin region as the dominant area of anthropogenic influence during the 2016–17 wet season. The time series from 2003 to 2017 showed distinct differences between years, driven by differences in river flow and pollutant loads. The next step in this method is to establish a reporting metric for future years to represent wet season pollutant load distribution in the GBR.

The analysis of the relative contribution from each river to the NRM regions provided further insight to the extent of influence in relatively high and low discharge years. The outputs highlight many cross-regional influences during the large discharge events between adjoining NRM regions, in some cases contributing almost half of the estimated loading (TSS from the Burdekin River into the Wet Tropics NRM region in 2010–11). In 2016–17, this cross-regional influence was more constrained, except for in the Mackay–Whitsunday region which received TSS loading inputs from the Fitzroy River. This highlights the need to assess and define management priorities at a basin scale, and the importance of recognising cross-regional influences, outside of the administrative marine NRM boundaries.

Trends in key water quality indicators

This report presents detailed information on the temporal trends of water quality relative to the Water Quality Guidelines for the GBR throughout the year. After more than a decade of continuous sampling it is still not clear whether there has been measurable change in the trend of water quality in the GBR lagoon. Most parameters show minor fluctuations over the monitoring period with no clear trend, although there are some exceptions.

Over the monitoring period, an increase in the dissolved organic carbon (DOC) concentrations was found in all regions. DOC constitutes the major carbon pool and source of energy for heterotrophic microbes in marine pelagic systems. The observed increases in DOC have many non-mutually exclusive explanations including: 1) the coral and phytoplankton communities have increased primary production, 2) primary producers are directing more of their production towards DOC release or 3) there is an enhanced export of DOC from the catchment, e.g., from eroded soils and mangroves. The findings suggest either that the mechanisms controlling the production and/or influx have changed, or that cycling of these compounds in the GBR lagoon have undergone changes. The causes and consequences of these changes are still to be explored in detail.

A minor increase in readily available dissolved oxidised nitrogen (NO_x) concentrations was reported in some areas over the monitoring period. Plankton biomass production in the GBR is thought to be limited by the availability of nitrogen, so inorganic nutrients are normally rapidly taken up by microbiota and depleted within hours. Therefore, the reported increase was unexpected. The most likely reason for this increase is that the number of water sampling sites and frequency of sampling has increased from 2015 onwards. Some of these sites are placed further inshore and they are therefore more likely to be affected by river inputs that influence the levels measured.

The key water quality indicators were aggregated into a site-specific Water Quality Index, which is summarised at the scale of NRM regions to provide an overview of major trends in the water quality along sections of the northern, central and southern GBR (Figure i). In this report, the Water Quality Index was calculated in two ways. First, for continuity of the long-term trend, an index score was calculated using the same approach as in previous years (see Appendix D-6 for details). A separate score was calculated to include data collected by both AIMS and JCU and apply wet/dry season guidelines, shown as the square points in Figure i.

The long-term Water Quality Index showed 'good' scores maintained for the **Wet Tropics** region throughout the program, whereas the combined AIMS/JCU score showed a 'moderate' rating. The multi-year trends of the water quality showed a minor overall change over the sampling period.

The long-term Water Quality Index calculated for the **Burdekin** region has remained quite stable with overall index scores of 'good' or 'very good'. Contrary to this, the combined AIMS/JCU index showed a 'moderate' score for this region. The multi-year trends of the water quality showed generally stable levels of dissolved nutrients over the entire sampling period, although with minor increases in NO_x that is most likely linked with the implementation of the new sampling design.

Long-term Water Quality Index scores in the **Mackay–Whitsunday** region steadily declined over the course of the MMP monitoring period with a 'poor' index score in 2016-17. A similar score was found for the combined AIMS/JCU index. These scores reflect Chl-a, turbidity and PP levels above guideline values.

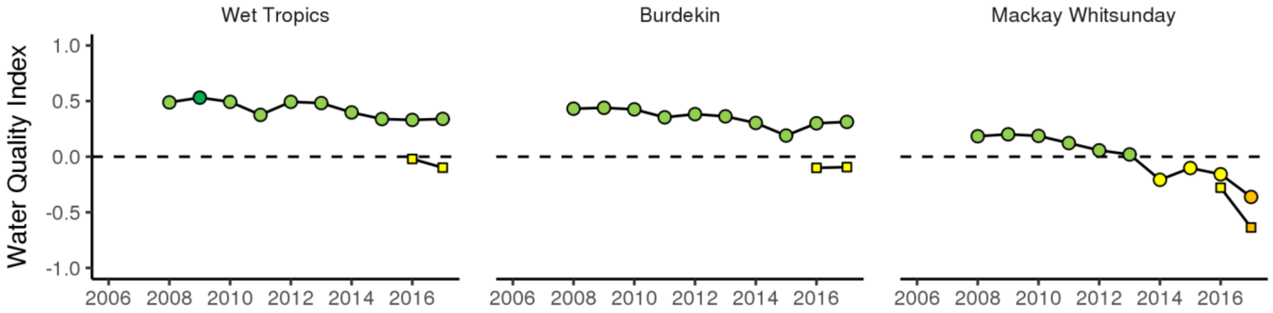


Figure i: Results of the site-specific Water Quality Index from 2006–07 to 2016–17 for the Wet Tropics, Burdekin and Mackay Whitsunday regions. Note that the Water Quality Index was calculated in two ways. First, for continuity of the long-term trend an index score was calculated using the same approach as in previous years (circles). Second, to include data collected by both AIMS and JCU and apply wet/dry guidelines, we calculated a separate score shown as two points in the figures (squares). The Water Quality Index aggregates scores for five variables: concentrations of NO_x, particulate nitrogen and phosphorus, Chl-a and a combined water clarity indicator (TSS, turbidity and Secchi depth), relative to Guideline values (Department of Environment and Resource Management [DERM], 2009; GBRMPA, 2010). Water Quality Index colour coding: dark green – 'very good'; light green – 'good'; yellow – 'moderate; orange – 'poor'; red – 'very poor'.

These regional Water Quality Index scores are currently based on a selected set of variables for which GBR Water Quality Guidelines are available and use data from permanent sites that were sampled from 2005 to 2015 and new sites established in 2015. The scores provide a picture of the water quality condition in the inshore GBR; however, it is important to note that a more comprehensive index should be developed to encompass a wider range of variables, capturing a variety of conditions along environmental gradients.

To set realistic targets and guidelines, more in-depth knowledge of the biogeochemical cycling of carbon, nitrogen and phosphorus in the GBR is required. In addition, the data collected prior to implementation of the new monitoring design in 2015 represented the three tropical seasons equally and stations further offshore. Contrary, the new design has a greater emphasis on wet season data and inshore stations, influencing the overall trend and therefore providing a different perspective of the overall water quality conditions.

This year, event sampling was conducted in all focus areas, with additional sampling conducted in the Fitzroy region in response to tropical cyclone Debbie.

A case study of the link between phytoplankton pigment composition and environmental conditions conducted by AIMS (Appendix A) showed that the phytoplankton community in the inshore GBR is primarily influenced by environmental factors including temperature, irradiance and resuspension events. These preliminary results indicate that phytoplankton pigment analysis could provide insights into the phytoplankton community structure and dynamics in the GBR lagoon. This is a consideration for future monitoring design. The second case study conducted by JCU assessed the continuity of satellite-derived products between previous years and this wet season following a shift in the supply and processing of MODIS true colour images from within JCU to supply to the Bureau of Meteorology (BOM). The analysis provides confidence in the transition of the data supply, which will improve data acquisition and processing efficiency in future years.

Conclusions

The rainfall and river flow across all basins of the GBR during the 2016–17 wet season were close to the long-term median and were amongst the highest discharge recorded over the past 4 to 5 years. A number of southern rivers had wet season discharges above their long-term median flow, which was largely associated with tropical cyclone Debbie. These patterns were evident in the wet season water type mapping, DIN and TSS loading maps and, to a lesser extent, in the surface exposure maps. For example, a greater occurrence of wet season water types (combined Primary, Secondary and Tertiary water types) was measured in the Mackay Whitsunday region, which is comparable to the conditions of the large events experienced in 2010–11.

The addition of the Cape York focus area has been identified as a high priority for inclusion in the MMP for many years. This first year of monitoring provides a strong foundation for continuation as part of the MMP. Routine and event monitoring is not undertaken in the Fitzroy or the Burnett–Mary regions.

The variability in the *in-situ* water quality highlights the combination of complex factors, i.e., biogeochemical processes and the relationship between upwelling events and river inputs to the GBR lagoon. This variability reinforces that a range of monitoring approaches are necessary to capture this variability in GBR water quality and that all outputs must be supported by *in-situ* monitoring of water quality parameters. The wet season mapping products are continuously improving and the inclusion of weekly panels for each focus area provides another step towards characterising, and ultimately distinguishing, wet season and river plume conditions. The final categories of the exposure maps are linked to the GBR Water Quality Guidelines and provide useful information for assessing ecosystem condition. The development of maps that assess the difference between current and pre-development wet season pollutant loading for comparison between years is recommended for incorporation as a metric in the future. Furthermore, collaboration with the eReefs modelling team will assist in improveing the spatial and temporal resolution of these mapping products and strengthen the ability to report water quality trends over time.

1. Introduction

The Great Barrier Reef (GBR) is the most extensive reef system in the world, comprising over 2,900 km^2 of coral reefs. It also includes large areas of seagrass meadows, estimated to be over 43,000 km^2 (~12.5% of the total area of the Great Barrier Reef Marine Park [GBRMP]) from surveys of intertidal areas and predictive modelling of deep-water seagrass beds using knowledge of environmental variables (Figure 1-1). Thirty-five major rivers drain into the GBR, all of which vary considerably in length, catchment area, and flow frequency and intensity. River discharge is the main source of land-based pollutants (i.e., sediments, nutrients and pesticides) in the GBR lagoon. The actual distribution and movement of the individual pollutants varies considerably between the wet (north of Townsville) and dry tropics rivers (e.g., Devlin and Brodie, 2005; Devlin and Schaffelke, 2009; Petus et al., 2014a, 2016).

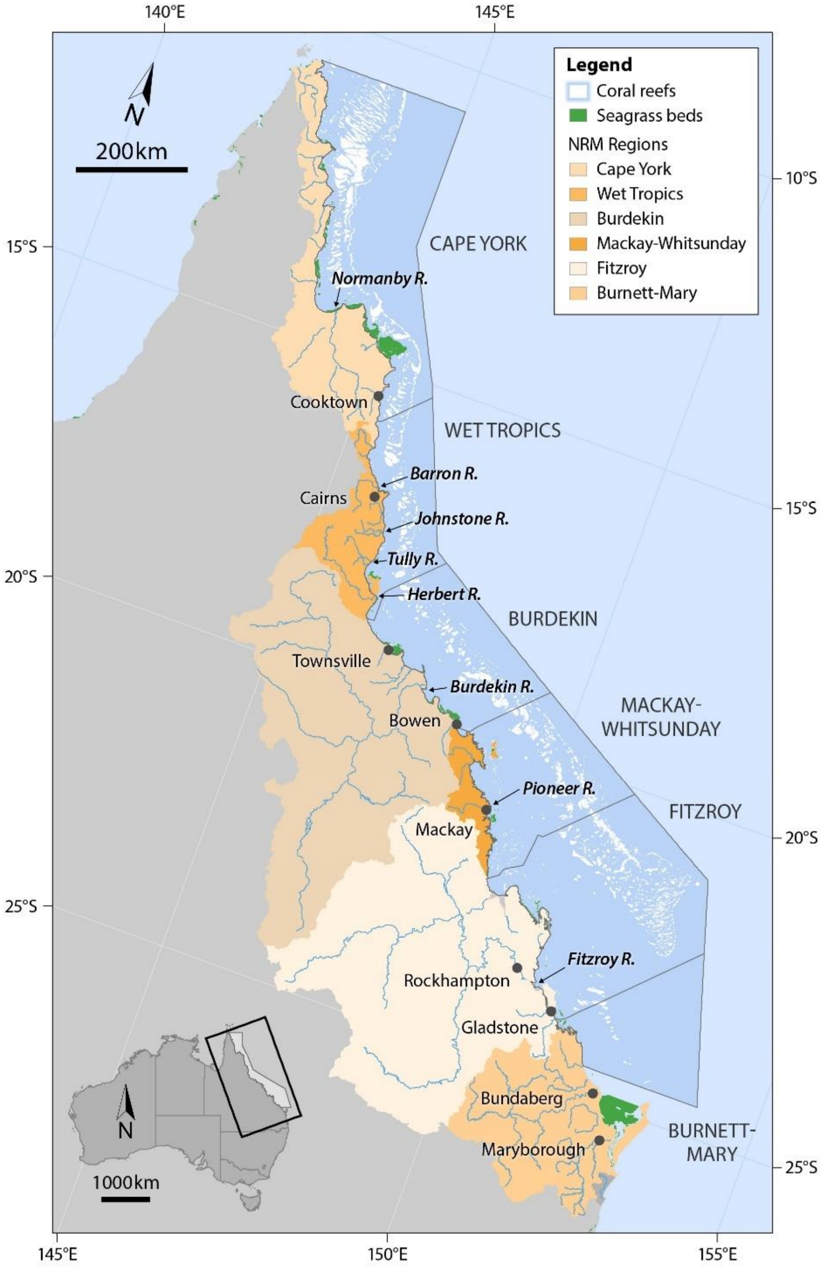


Figure 1-1: The GBRMP, major marine ecosystems (coral reefs and surveyed seagrass beds), NRM regions and marine NRM regions (delineated by dark grey lines) and major rivers.

The GBR catchment is divided into six natural resource management (NRM) regions (Figure 1-1), each defined by a set of land use, biophysical and socio-economic characteristics. The Cape York region is largely undeveloped and is considered to have the least impact on GBR ecosystems from existing land-based activities (Waterhouse et al., 2017b). In contrast, the Wet Tropics, Burdekin, Mackay Whitsunday, Fitzroy and Burnett Mary regions are characterised by more extensive agricultural land uses including sugarcane, grazing, bananas and other horticulture, cropping, mining and urban development, and contribute to discharge of sediments, nutrients and pesticides to the GBR during the wet season (Waterhouse et al., 2017b).

Coastal areas worldwide are under increasing pressure from human population growth, intensifying land use and urban and industrial development. As a result, increased loads of suspended sediment, nutrients and contaminants, such as pesticides and other chemicals, invariably enter coastal waters and may lead to a decline in marine water quality (e.g., Schaffelke et al., 2017). The *2017 Scientific Consensus Statement: A synthesis of the science of land-based water quality impacts on the Great Barrier R*eef (Waterhouse et al., 2017c) concluded that: ‘Key Great Barrier Reef ecosystems continue to be in poor condition. This is largely due to the collective impact of land run-off 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 landbased 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’.

Water quality in the GBR is influenced by an array of both natural and anthropogenic factors including upwelling, sediment resuspension, diffuse source land-based run-off, point source contamination and extreme weather conditions. It has been well documented that sediment and nutrient loads carried by rainfall-driven land run-off into the coastal and inshore zones of the GBR have increased since European settlement (e.g., Kroon et al., 2012; McCloskey et al., 2017; Waters et al., 2014).

Nutrients are naturally occurring in the water, are necessary to sustain the biological productivity of the GBR and are supplied by a number of processes and sources such as upwelling of nutrient-enriched deep water from the Coral Sea and nitrogen fixation, for example, by (cyano-) bacteria (Furnas et al., 2011). However, land run-off is thought to be the largest source of new nutrients to the inshore GBR (Furnas et al., 2011), especially during monsoonal flood events (Devlin and Schaffelke, 2009). These nutrients supplement the regional stocks of nutrients already stored in biomass or detritus (Furnas et al., 2011), which are continuously recycled to supply nutrients for marine plants and bacteria (Lønborg et al., 2017).

Water quality parameters in the GBR vary along cross-shelf, seasonal and latitudinal gradients (e.g., Lønborg et al., 2016; Thompson et al., 2017; Waterhouse et al., 2017a) reflecting differences in inputs and transport. There is also high variability between years, driven by La Niña and El Niño cycles. Chlorophyll-a (Chl-a) concentrations above Water Quality Guidelines in coastal waters have been related to fertilised agriculture (predominantly sugarcane) in the Wet Tropics region, whereas high total suspended solids (TSS) concentrations are mainly linked to grazing activities in the Dry Tropics and in particular the Burdekin catchment (e.g., Waters et al., 2014).

While there is little evidence that elevated nutrient concentrations *per se* increase coral mortality, there is strong evidence that enhanced nutrient availability within the ecosystem can have deleterious indirect effects on reef communities. Examples of these nutrient effects include increased outbreaks of crown-of-thorns starfish (Brodie et al., 2017; Fabricius et al., 2010), macroalgae abundance resulting in lower coral diversity (De’ath and Fabricius, 2010), increased coral bleaching susceptibility (Wooldridge, 2016), increased bioerosion (DeCarlo et al., 2015) and some coral diseases (e.g., Pollock et al., 2016), reduced benthic light due to algal blooms (Collier et al., 2016; Petus et al., 2014b) and increased macroalgae and epiphytes on seagrass (Cebrian et al., 2013). While most effects occur in the wet season during river discharge (plume) conditions, some effects have consequences beyond the wet season and continue for many years, for example crown-of-thorns starfish outbreaks (e.g., Brodie et al., 2017).

There is also strong evidence for several effects of sediments on GBR ecosystems, including light reduction for seagrass and coral (Collier et al., 2016; Petus et al., 2014b), sedimentation on coral (Jones et al., 2015), sedimentation in turf algae and herbivore feeding (e.g., Gordon et al., 2016; Tebbett et al., 2017a, b) and fine suspended sediment effects on coral reef fish (e.g., Wenger et al., 2014). Concern about the effects of land-based run-off triggered the Australian and Queensland governments to formulate the *Reef Water Quality Protection Plan* (Reef Plan) for catchments adjacent to the GBR in 2003 (Anon, 2003, 2009). The *Reef Plan* was revised and updated in 2009 and 2013 (Anon, 2013) and is currently under review (*Reef 2050 Water Quality Improvement Plan* [Reef 2050 WQIP]). More recently, UNESCO raised concerns regarding the current state and management of the GBR, which led to the development of the Reef 2050 Long-Term Sustainability Plan (Reef 2050 Plan) to '*ensure the GBR continues to improve on its Outstanding Universal Value every decade between now and 2050 to be a natural wonder for each successive generation to come*'. The actions in the *Reef 2050 Plan* aim to improve land management practices that are expected to result in measurable positive changes in the downstream water quality of creeks and rivers. These actions should, with time, also lead to improved water quality in the coastal and inshore GBR (see Brodie et al., 2012 for a discussion of expected time lags in the ecosystem response). Given that the benthic communities on inshore reefs of the GBR respond to gradients in water quality, especially of water turbidity and sedimentation rate (e.g., Thompson et al., 2010, 2017; Uthicke et al., 2010), improved land management practices may have the potential to reduce levels of environmental stresses that impact coral reef and seagrass communities. However, recent assessments raise the question as to whether these actions will be sufficient to ensure the resilience of the GBR ecosystems into the future (Bartley et al., 2014a, b; Brodie and Pearson, 2016; Kroon et al., 2014) and additional options involving system restoration will be required (Waterhouse et al., 2017c).

Reef 2050 WQIP actions include the continuation of the *Paddock to Reef Integrated Monitoring, Modelling and Reporting Program* (Paddock to Reef program), extending from the paddock to the GBR marine environment, to assess the effectiveness of the implementation of Reef 2050 WQIP actions. The Marine Monitoring Program (MMP) is an integral part of this monitoring program providing physicochemical and biological data to investigate the effects of changes in inputs from the GBR catchments on marine water quality and assess the condition of inshore ecosystems.

The current monitoring of the influence of land-based run-off on the marine environment in the GBR includes intense sampling during the wet season and high flow events to characterise the input of river-derived material (e.g., Lønborg et al., 2016; Waterhouse et al., 2017a). The information gathered under the current MMP inshore water quality sampling program has shown the spatial distribution and temporal variability of water quality variables during flood and non-flood conditions in the coastal and inshore GBR. Separate reports under the MMP provide details on the coral cover and composition (Thompson et al., 2017), seagrass health and extent (McKenzie et al., 2017) and information about herbicide levels in the inshore GBR (Grant and Paxman, 2017).

This report integrates the results of the Australian Institute of Marine Science (AIMS) and James Cook University (JCU) (including the Cape York Water Monitoring Partnership herein referred to as CYWMP) inshore water quality monitoring. This reflects the monitoring design, which is based on co-location of sampling sites, and the overarching objective of the MMP to: '*Assess trends in ecosystem health and resilience indicators for the Great Barrier Reef in relation to water quality and its linkages to end-of-catchment loads'.* This objective supports the ongoing progress toward the *Reef Plan's* single long-term goal for the marine environment: *'To ensure that by 2020 the quality of water entering the reef from broadscale land use has no detrimental impact on the health and resilience of the Great Barrier Reef'.*

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 are to:

i. monitor, assess and report the three-dimensional extent and duration of flood plumes and link concentrations of suspended sediment, nutrients and pesticides to end-of-catchment loads;

ii. monitor, assess and report trends in inshore concentrations of TSS, Chl-a and nutrients against the Water Quality Guidelines for the GBRMP (or other water quality guidelines if appropriate);

iii. monitor, assess and report trends in turbidity and light attenuation for key GBR inshore habitats against established thresholds and/or guidelines; and

iv. monitor, assess and report the extent, frequency and intensity of impacts on GBR inshore seagrass meadows and coral reefs from flood plumes and link to end-of-catchment loads.

The report presents a summary of the program methods (Section 2), results during 2016–17 with GBR-wide and regional interpretation (Section 3), discussion of these results (Section 4) and conclusions (Section 5). Two case studies are presented: one examining the link between phytoplankton pigment composition and environmental conditions (Appendix A) and another assessing the continuity of satellite-derived products between previous years and this wet season following a shift in the data supply to the Bureau of Meteorology (BOM) from processing within JCU (Appendix B). Additional Appendices provide more detailed information on site locations (Appendix C), water quality monitoring methods (Appendix D), detailed results (Appendix E) and QA/QC information (Appendix F). Finally, Appendix G lists the scientific publications and presentations delivered by the project teams related to the MMP inshore water quality monitoring program.

2. Methods summary

2.1 Overview

This section provides a brief overview of the sampling design and indicators that are monitored as part of the MMP. More details of the data collection, preparation and analytical methods are presented in Appendix C, D and F, and in an annually updated QA/QC report (Great Barrier Reef Marine Park Authority [GBRMPA], 2017). The QA/QC report covers the objectives and principles of analyses, step-by-step sample analysis procedures, instrument performance, data management and analyses, and quality control measures.

2.2 Sampling design

The MMP inshore water quality monitoring is designed to quantify temporal and spatial variation in inshore water quality conditions. To facilitate the identification of relationships between the end-of-catchment loads and water quality, it is essential that the environmental setting of each monitoring location is adequately described.

From 2005 to 2014, the following design was used to determine the trends in water quality and included year-round water quality monitoring conducted by AIMS, and additional wet season monitoring conducted by JCU:

- Chl-a and turbidity were continuously monitored with *in-situ* loggers at 14 stations across the Wet Tropics, Burdekin and Mackay Whitsunday regions (see Appendix C);
- A total of 20 stations were sampled three times a year (wet, early and late dry seasons) across the Wet Tropics, Burdekin and Mackay Whitsunday regions (see Appendix C);
- Periodic wet season sampling stations in most NRM areas (Normanby, Russell-Mulgrave, Tully, Herbert, Burdekin and Fitzroy) (9 to 15 sites per location); and
- Specific sampling in response to high flow conditions across all the NRM regions (where relevant) (most frequently in Tully, Russell-Mulgrave, Burdekin, Fitzroy and Normanby).

In 2015, a new sampling design for the inshore water quality monitoring program was implemented, which was intended to increase the potential for detection of links between end-of-catchment loads and marine water quality. The design focused on four focus areas – the Russell-Mulgrave, Tully and Burdekin Rivers and rivers in the Mackay Whitsunday region. This report covers the third year for this integrated design, which formally commenced in February 2015.

The focus areas were targeted for intensive sampling and were chosen as priority areas based on water quality risk assessments reported elsewhere (Brodie et al., 2013). The Tully River catchment is thought to be the ideal location to assess the long-term effectiveness of the *Reef Plan* as it is the wettest catchment in Australia. Repeated sampling in the Tully focus area also adds value to the long-term dataset collected in this area from 1994 to 2012 (Devlin and Schaffelke, 2009). Additional reporting for the Barron-Daintree sub-region of the Wet Tropics is also included due to the continued collection of data along the long-term Cairns transect where sampling started in 1989.

The sites in each focus area were selected along expected water quality gradients (exposure to run-off). This was largely determined by increasing distance from a river mouth in a northerly direction to reflect the predominantly northward flow of surface water forced by the prevailing south-easterly winds (Brinkman et al., 2011). Most of the ambient sampling sites that were monitored from 2005 to 2014 are included, allowing for the continuation of the long-term time series. Most areas are sampled more frequently (typically between 5 and 10 times) compared to only 3 times previously, to improve the ability to detect and interpret trends in water quality in key areas in relation to end-of-catchment loads.

In 2016–17, four transects were added in the Cape York region relevant to the Pascoe, Normanby-Kennedy, Annan-Endeavour and Stewart Rivers. These transects are monitored by the CYWMP and coordinated by Howley Consulting.

The map in Figure 2-1 shows the geographical locations of the current sampling sites. Appendix C (Table C-1) lists all stations included in the MMP, distinguishing the routine and reactive event sampling. The Cape York sampling program did not commence formally until April 2017, although samples collected earlier were included where possible. Weather conditions also restricted access to the Normanby-Kennedy and Pascoe transects during the wet season.

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 Chl-a and turbidity at 15 stations;
- A total of 60 stations sampled during the year with more frequent sampling during the wet season (86 sites in total); and
- A total of 27 additional stations sampled during high flow conditions (flood response).

Table 2-1: List of parameters measured in the ambient and wet season water quality monitoring. Note that +/- signs identifying the charge of the nutrient ions were omitted for brevity. * Not sampled at all sites.

Condition	Parameter	Abbreviation	Units of Measure
Physico-chemical	Salinity	Salinity	PSU
	Temperature	Temperature	Celsius degree
	Light (underwater attenuation)*	Kd(PAR)	m^{-1}
	Total suspended solids	TSS	mg/L
	Coloured dissolved organic matter	CDOM	m^{-1}
	Turbidity	Tur	NTU
Nutrients[2]	Ammonium[1]	NH_4	µg/L
	Nitrite[1]	NO_2	µg/L
	Nitrate[1]	NO_3	µg/L
	Dissolved inorganic phosphorus	DIP	µg/L
	Silica	Si	µg/L
	Dissolved organic carbon	DOC	µg/L
	Dissolved organic nitrogen	DON	µg/L
	Dissolved organic phosphorus	DOP	µg/L
	Particulate organic carbon	POC	µg/L
	Particulate nitrogen	PN	µg/L
	Particulate phosphorus	PP	µg/L
Biological	Chlorophyll-a	Chl-a	µg/L
Pesticides	Photosystem II inhibiting herbicide	PSII herbicides	ng/L
[1] *note that NO_X is the sum of NO_2 and NO_3*			

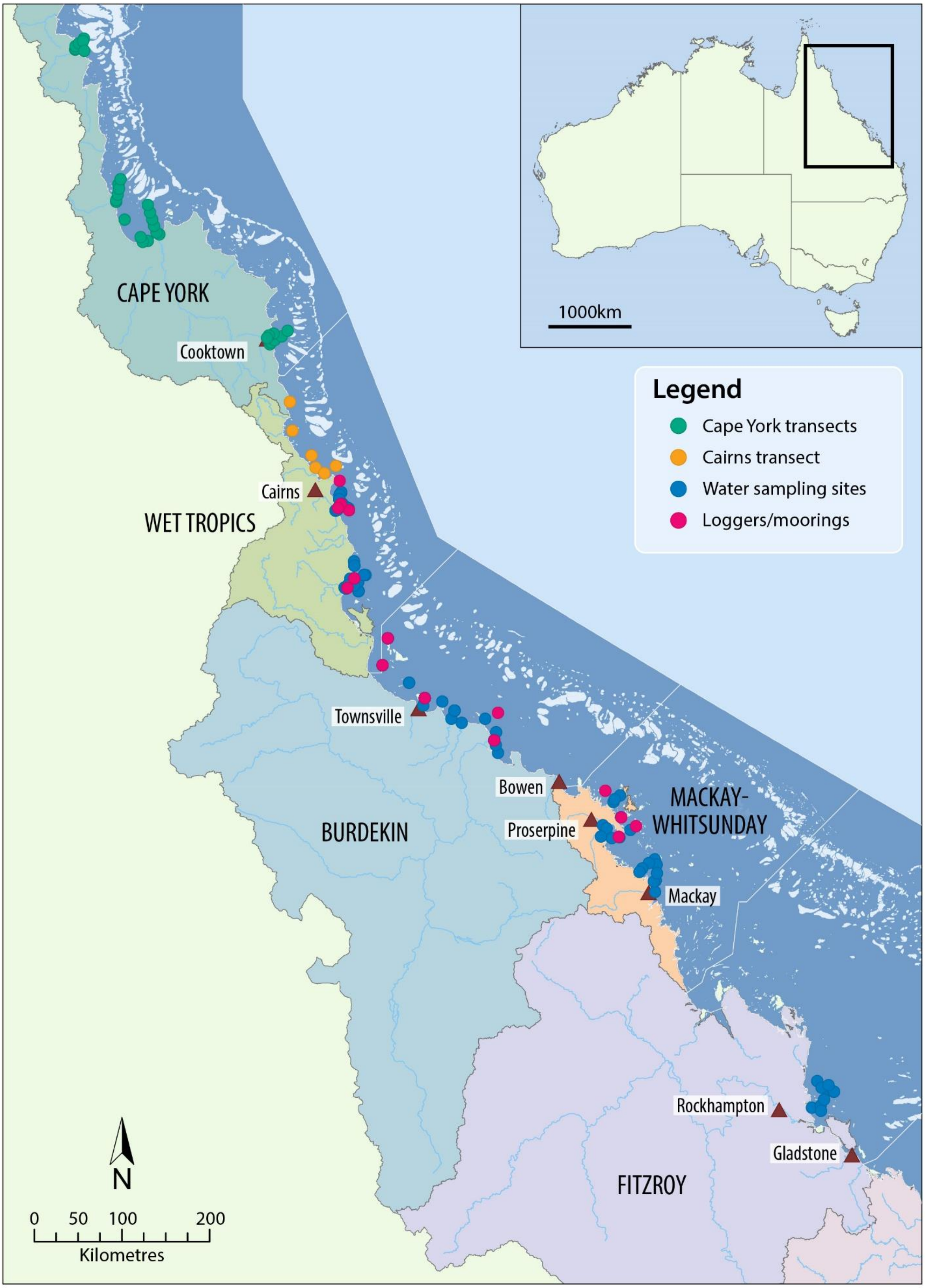


Figure 2-1: Sampling locations of the MMP water quality monitoring sampled from 2015 onwards. Note that the Cape York transect was added in 2016–17. Refer to Figure 1-1 for river names. See Appendix C for details of the monitoring activities undertaken at each location. NRM region boundaries are represented by coloured catchment areas.

2.3 Water quality sampling methods

A more detailed description of methodologies is provided in Appendix D.

At each of the sampling locations (see Appendix C), vertical profiles of water salinity and temperature were measured with a Conductivity Temperature Depth profiler (CTD). CTD casts are used to characterise the water column and to identify how well mixed the water column was and record any stratification. Immediately following the CTD cast, discrete water samples were collected with Niskin bottles. Samples collected by AIMS were from the surface and 1m from the seabed, whereas at some of the stations sampled by JCU during the wet season only surface water was collected. Sub-samples taken from the Niskin bottles were analysed for a broad suite of water quality parameters (Appendix D-1).

In addition to the vessel-based sampling, water samples for analyses of Chl-a and TSS were also collected three times a year by diver-operated Niskin bottle sampling close to the autonomous water quality instruments (see below), for validation purposes.

During the wet season, the underwater light extinction coefficient (Kd(PAR), m^{-1}) was calculated using the Lambert-Beer equation from the CTD light profile.

The three main facets of the focused wet season monitoring are the collection of *in-situ* data (November to April), extraction and processing of remotely sensed data for mapping and modelling river plumes, and integration of both *in-situ* and remote sensed data reflected in the surface loading maps.

In-situ sampling data are made available for the validation of existing models (e.g., eReefs) and regionally based remote sensing algorithms (e.g., Brando et al., 2011).

2.4 In-situ loggers

Continuous *in-situ* measurements of Chl-a fluorescence and turbidity were performed at 15 sites using WET Labs ECO FLNTUSB Combination Fluorometer and Turbidity Sensors; salinity and temperature loggers were deployed at eight locations, with three of these being placed near the Russell-Mulgrave, Tully and Burdekin River mouths (Figure 2-1, Appendix C, Figure D-1).

The Chl-a logger data were used for trend analyses and for assessing relationships with coral reef health and not for comparison against guidelines because the uncertainty is higher than for other measures.

2.5 Data analyses – ambient water quality

Generalised additive mixed effect models were fitted to environmental variables for each NRM region, or focus area, to identify the presence and consistency of trends. More detailed descriptions of the statistical methods and data summaries are presented in Appendix D-5.

Water quality data were summarised as a simple water quality index, which is based on comparisons with existing Water Quality Guidelines (DERM, 2009; GBRMPA, 2010) using 4 years running mean to generate an overall assessment of water quality for the five sampling areas (Barron Daintree – Cairns transect, Russell-Mulgrave, Tully, Burdekin and Mackay Whitsunday). Note that intensive flood sampling data collected by JCU as part of the old design (pre-2015) have not been incorporated in the index due to inconsistencies in the frequency of data collection, i.e., some flood plumes were sampled 10 times in some years, whereas AIMS collected samples 3 times a year. Therefore, including the historical JCU data would skew the dataset and trends, giving a false representation of annual water quality conditions. In this year's report, it has also become apparent that the long-term trends in some water quality variables (e.g., NO_x) have been skewed by the inclusion of JCU data and data collected under the changed sampling design (more stations and sampling), making it challenging to detect any real long-term trend.

Details of the methods used for the calculation of the site-specific Water Quality Index are presented in Appendix D-6.

2.6 Data analyses – wet season water quality

The wet season water quality data were used for several purposes: 1) to characterise water quality gradients during the wet season and during high flow conditions; 2) to investigate the transport and/or transformation of key pollutants when they are discharged into the GBR lagoon; 3) to identify where measured values were above the water quality guideline values (GVs) and 4) 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-7) so that water quality parameters measured during the wet season could be associated to 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-7 and see the following section for the description of the wet season water types). The transport and/or transformation of water quality parameters as well as the pollutant concentration relative to GVs were investigated by plotting the mean water quality concentrations (long-term and 2016–17) against their water type and colour class categories.

The mean water quality concentrations have been calculated for 2016–17 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.

In 2014–15, considerable specific statistical analysis of wet season water quality data was conducted to investigate the transport and/or transformation of water quality parameters in the context of salinity gradients, river discharge and wind characteristics (see Lønborg et al., 2016). This analysis provided a baseline for assessing the mixing behaviour and drivers for each focus region. Similar analysis will be repeated in 2018–19 for comparison and assessment of any significant differences over the sampling years.

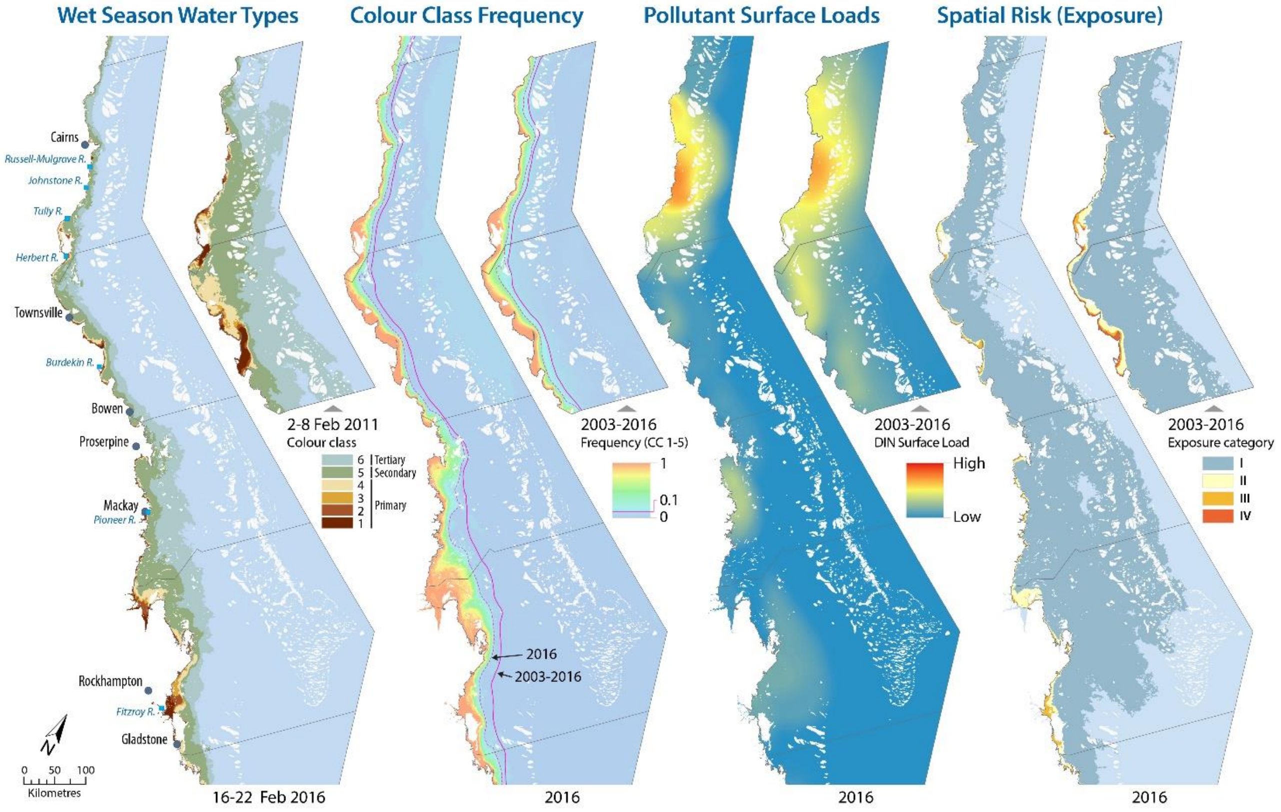
2.7 Remote-sensing modelling – wet season water type classification and exposure maps

Understanding the exposure of the GBR ecosystems to elevated (above guideline) pollutant concentrations during the wet season and resulting changes in ecosystem health conditions is important to facilitate management of the GBR. To illustrate wet season marine conditions and identify where GBR seagrass and coral reefs may be at risk, 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, exposure maps, as well as the extraction of the area (km^2) and percentage (%) of coral reefs and seagrass meadows affected by different categories of exposure (or potential risk). A more detailed description of methodologies is provided in Appendix D-8.

Wet season water type maps were produced using MODIS-Aqua (hereafter, MODIS) quasi true colour (herafter 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 the GBR coastal waters, including river plumes during the wet season (Figure 2-3). To complement this dataset, MODIS-Terra (hereafter, 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 needed in near real time (rapid response mapping of flood events). The MODIS-Terra data are used only for informative purposes and are not included in the processing of the weekly, frequency and exposure composite maps.

Each of the six colour classes were characterised by different colour and concentrations of optically active components (e.g., TSS, CDOM, and Chl-a), which influence the light attenuation, as well as different pollutant concentrations that can vary the impact on the underlying ecological systems. The wet season colour classes were further classified into three wet season water types (Primary, Secondary and Tertiary) with classes 1 to 4 corresponding to the Primary water type, class 5 to the Secondary water type and class 6 to the Tertiary water type. The brownish to brownish-green turbid waters (colour classes 1 to 4 or Primary water type) are typical for inshore regions of GBR river plumes or nearshore marine areas with high concentrations of resuspended sediments found 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 waters (colour class 5 or Secondary water type) is typical of coastal waters rich in algae (Chl-a) and containing dissolved matter and fine sediment. This water body is found in the GBR 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.

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 GBR marine 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 (2016–17 wet season) and long-term (2002–03 to 2016–17 wet seasons) time frames (Figure 2-2). The presence and spatial extent of each wet season water type is the result of the complex physico-chemical transformations occurring across GBR river plumes, but also of local resuspension of sediment and the water circulation in the GBR.



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.

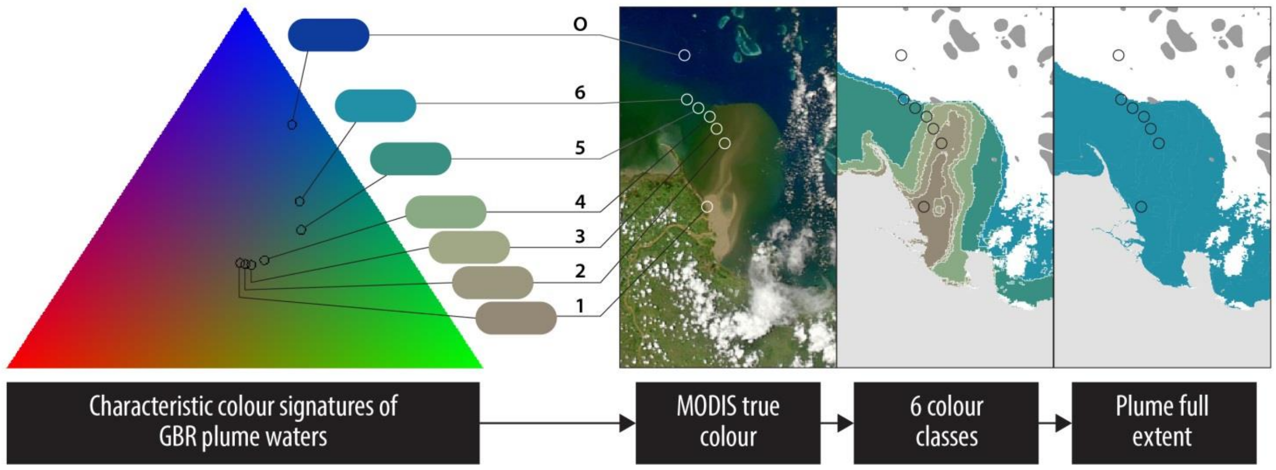


Figure 2-3: Triangular colour plot showing the characteristic colour signatures of the GBR wet season water types in the Red-Green-Blue (RGB or true colour) space. Álvarez-Romero et al. (2013) developed a method to map these characteristic coastal water masses in the GBR using a supervised classification of MODIS true colour data (modified from Devlin et al., 2015). A comparison of the GBR colour classes and approximate RGB colour of the Forel-Ule scale are also presented in Appendix D-7 (Figure D-1).

Exposure maps were produced for the whole of the GBR and for all focus regions over the seasonal (2016–17 wet season) and long-term (2002–03 to 2016–17 wet seasons) time frames. They were produced using the updated 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 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 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 × 500 m) of the GBR:

i. For each pollutant (Poll.) the exposure in each wet season water type (Primary or Secondary or Tertiary, $Poll\_expo_{water\ type}$) is calculated:

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

$$magnitude_{water\ type} = \frac{[Poll.]_{water\ type} - guideline}{guideline}$$

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

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 GBR 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; GBRMPA, 2010).

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

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

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

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

The seasonal overall exposure score (ranging from 0 to 12 in the long-term (15 years) exposure map) 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 types:

$Chla\_exp_{Primary} = \frac{1.8-0.63}{0.63} \times frequency_{water\ type\ (0-1, cell-specific)}$

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

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

The total exposure for Chl-a:

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

Finally, the area (km^2) and percentage (%) of coral reefs and seagrass meadows affected by the different categories of exposure (I to IV) were calculated as a relative measure between regions and years. Areas and percentages of GBR waters and within the Wet Tropics, Burdekin, Mackay Whitsunday and Cape York regions were also reported in recognition of other important habitats and populations that exist in these areas. Figure D-4 presents the marine boundaries used for the GBRMP, each NRM region and the seagrass and coral reefs ecosystems. We assumed in the present study that the seagrass 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.

2.8 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 small proportion of the catchment/basin area. Such disparities mean that this 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 (2,100–2,200 km^2); however, the Daintree River Bairds gauge only measures 43% of the Daintree Basin whereas the Barron River Myola gauge captures 89% of the Barron Basin. If only the 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. Hence, a scaling factor is required 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), the gauge from the nearest neighbouring basin was used coupled with the relevant area adjustment.

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Table 2-2. The 35 basins of the GBR 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	2,963	Pascoe River at Garraway Creek*	0	2.4
	Olive Pascoe River	102	4,180	Pascoe River at Garraway Creek	31	3.0
	Lockhart River	103	2,883	Pascoe River at Garraway Creek*	0	1.9
	Stewart River	104	2,743	Stewart River at Telegraph Road	17	5.8
	Normanby River	105	24,399	Normanby River at Kalpowar Crossing	53	1.9
	Jeannie River	106	3,638	Endeavour River at Flaggy*	0	10.0
	Endeavour River	107	2,182	Endeavour River at Flaggy	15	6.5
Wet Tropics	Daintree River	108	2,107	Daintree River at Bairds	43	2.3
	Mossman River	109	473	Mossman River at Mossman	22	4.5
	Barron River	110	2,188	Barron River at Myola	89	1.1
	Mulgrave-Russell River	111	1,983	Mulgrave River at Peets Bridge + Russell River at Bucklands	42	2.4
	Johnstone River	112	2,325	South Johnstone River at Upstream Central Mill + North Johnstone at Tung Oil	57	1.8
	Tully River	113	1,683	Tully River at Euramo	86	1.2
	Murray River	114	1,107	Murray River at Upper Murray	14	7.1
	Herbert River	116	9,844	Herbert River at Ingham	87	1.1
Burdekin	Black River	117	1,057	Black River at Bruce Highway	24	4.1
	Ross River	118	1,707	Bohle River at Hervey Range Road	8	8.6
	Haughton River	119	4,051	Haughton River at Powerline	44	2.3
	Burdekin River	120	130,120	Burdekin River at Clare	100	1.0
	Don River	121	3,736	Don River at Reeves	27	3.7
Mackay Whitsunday	Proserpine River	122	2,494	O'Connell River at Staffords Crossing*	0	7.8
	O'Connell River	124	2,387	O'Connell River at Staffords Crossing	14	7.0
	Pioneer River	125	1,572	Pioneer River at Dumbleton Weir T/W	95	1.1
	Plane Creek	126	2,539	Sandy Creek at Homebush	13	7.8
Fitzroy	Styx River	127	3,013	Waterpark Creek at Byfield*	0	2.9
	Shoalwater Creek	128	3,601	Waterpark Creek at Byfield*	0	3.3
	Water Park Creek	129	1,836	Waterpark Creek at Byfield	12	8.7
	Fitzroy River	130	142,552	Fitzroy River at The Gap	95	1.0
	Calliope River	132	2,241	Calliope River at Castlehope	57	1.7
	Boyne River	133	2,496	Calliope River at Castlehope*	0	0.43
Burnett Mary	Baffle Creek	134	4,085	Baffle Creek at Mimdale	34	2.9
	Kolan River	135	2,901	Kolan River at Springfield	19	2.0
	Burnett River	136	33,207	Burnett River at Figtree Creek	92	1.1
	Burrum River	137	3,362	Gregory River at Leesons	19	5.3
	Mary River	138	9,466	Mary River at Home Park	72	1.4

* Gauges used that are not in the basin area

2.9 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^-) delivered by river plumes to GBR 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 loads from the GBR catchments. In the ocean colour model, monitored and modelled end-of-catchment DIN loads provide the amount of DIN delivered to the GBR, *in-situ* data provides the DIN mass in river plumes and satellite imagery provides the direction and intensity of the DIN mass dispersed over the GBR lagoon. The eReefs hydrodynamic model also provides an estimate of the boundary of plume extent in the wet season. This model produces annual maps of average DIN concentration in the GBR 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 (Environmental Systems Research Institute [ESRI], 2010).

The main modifications applied to the method presented in Álvarez-Romero et al. (2013) are that 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 the DIN mass exported from the rivers to account for potential biological uptake.

The model is described in detail in Appendix D-9 and 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 GBR lagoon. The conceptual model in Appendix D-9 shows how each model component is set up and how they are combined to produce the DIN dispersion maps. The basic idea of the DIN dispersion maps is to produce river plume maps, similar to those produced for the GBR (see Section Wet season water type maps and exposure assessment), for each individual river in the model. The end-of-catchment load of each river can then 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 determined at the GBR scale is used. 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 is summed together to represent the total annual DIN dispersion over the GBR lagoon discharged by the rivers. These four major steps are described below, starting with the generation of individual river plumes.

As per the 2015–16 report, the difference between the estimated wet season DIN concentration and TSS concentrations in the GBR lagoon for the 2017 water year (1 October 2016 to 30 September 2017) has been 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. It is proposed that this output is developed into a reporting metric for future reports.

The preferential northward movement of the river plumes can result in increased model-predicted DIN concentration in areas that may not directly receive high DIN loads from their catchments. The contribution of DIN from rivers to the waters of each NRM region was determined by the amount of DIN exported from each river that reaches a particular NRM region, divided by the total amount of DIN in that region. Two periods were considered, pre-development and current (2016–17) water years. If a river presents a DIN contribution of 100% to a particular NRM region, this means that no other river included in the model contributes DIN to that NRM region. These data are presented for each NRM region in the Regional reports (Section 3.4).

The method developed for the dispersion of land-based DIN was also applied for PN and TSS; however, PN is not reported here due to lower confidence in our understanding of the processing and transformation of PN in river plumes and the low confidence in the model loading data. Details of the methods used for this study are presented in Appendix D-9.

2.10 '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 GBR lagoon. The cumulative exposure was calculated for a longer period this year, spanning from October 2016 to June 2017 to capture more events. In comparison, previous reports assumed the cumulative exposure calculation was restricted to the wet season (from October to April of the following year). River-tagged passive tracers were released from each of the major gauged rivers discharging in to the GBR. For this report, the extent of influence of the Barron, Russell-Mulgrave, Tully, Burdekin and O'Connell Rivers was examined. 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 GBR lagoon (time = 0 for each wet season) was set to 0.0. Details of the methods used for the eReefs tracer study are presented in Appendix D-10.

3. Results

3.1 Overview

The design of the MMP and the structure of the reporting follows a Driver-Pressure-State-Impact-Response (DPSIR) framework (Figure 3-1) derived from GBR Outlook reporting. The monitoring data is presented in summarised, mostly graphical, form that is considered as being most informative for a general audience. More detailed data are included in Appendix E.

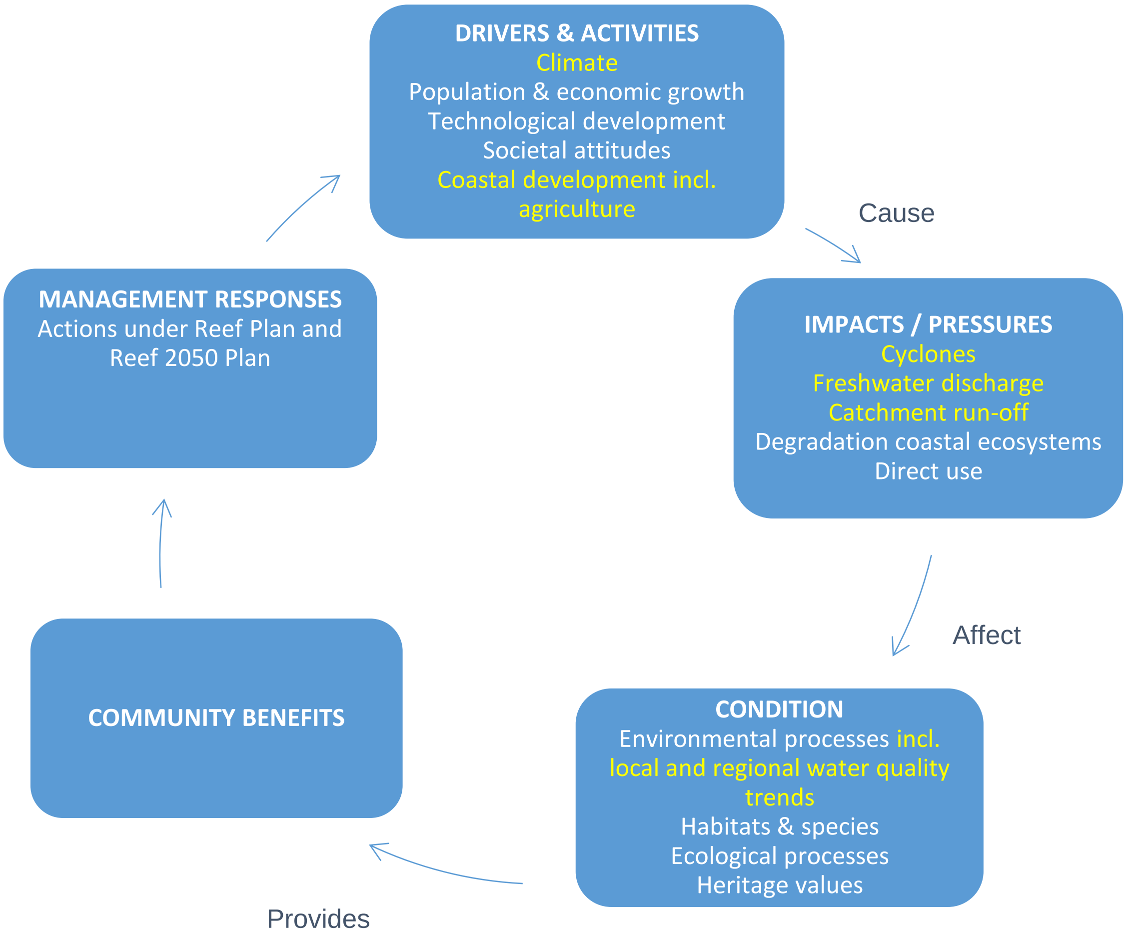

Figure 3-1: DPSIR framework used to guide the structure of the MMP, derived from the Great Barrier Reef Strategic Assessment (GBRMPA, 2014a). The aspects highlighted in yellow are included in this report.

3.2 Drivers, activities, impacts and pressures during 2016–17

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. Global pressures such as ocean warming and acidification are affecting the GBR, where sea surface temperatures have warmed by 0.80°C since the late 19th century and will continue to warm (see explanation in Schaffelke et al., 2017). Record warm sea surface temperatures were observed over the entire GBR in March, April and May 2016. Temperatures in the northern half of the GBR remained extremely high into late summer and autumn, whereas temperatures further south were slightly moderated in February 2016 by two tropical lows bringing cloud cover, rain and wind. The GBR also experienced widespread bleaching again in the summer of 2017.[3]

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). This climatic information is important for understanding the impacts of water quality on GBR ecosystems in the context of drivers and pressures.

3.2.1 Cyclone activity

Several tropical cyclones caused local disturbances on the GBR between 2013 and 2015, including three severe cyclones. No further cyclones were recorded until 2016–17 when severe tropical cyclone Debbie, a Category 4 system, passed through the Whitsunday Islands and crossed the mainland at Airlie Beach in the Mackay Whitsunday region on 28 March 2017. The cyclone then moved southward over land as a rain depression producing flooding rains across the basins of the Mackay Whitsunday region, the Bowen-Broken-Bogie catchment of the Burdekin, as well as the Fitzroy and Burnett Mary NRM regions. Tropical cyclone Debbie caused considerable physical damage to the coral reefs and seagrass meadows in the Mackay Whitsunday region.

Figure 3-2 shows the cyclones that have crossed the GBR coast in the 11 years since the MMP began in 2006–07. Ten of these cyclones have been Category 3 or above and have affected the health of the GBR. All of the Category 5 cyclones that affected the GBR since 1970 have occurred in the last decade (including tropical cyclones Larry, Hamish, Yasi, Ita and Marcia). Many of these cyclones have caused widespread flooding from intensive rainfall events in many parts of the GBR catchment including tropical cyclone Debbie in 2017.

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[3] http://www.gbrmpa.gov.au/media-room/latest-news/coral-bleaching/2017/second-wave-of-mass-bleaching-unfolding-on-great-barrier-reef. Surveys of this repetitive mass coral bleaching event were underway at the time of writing.

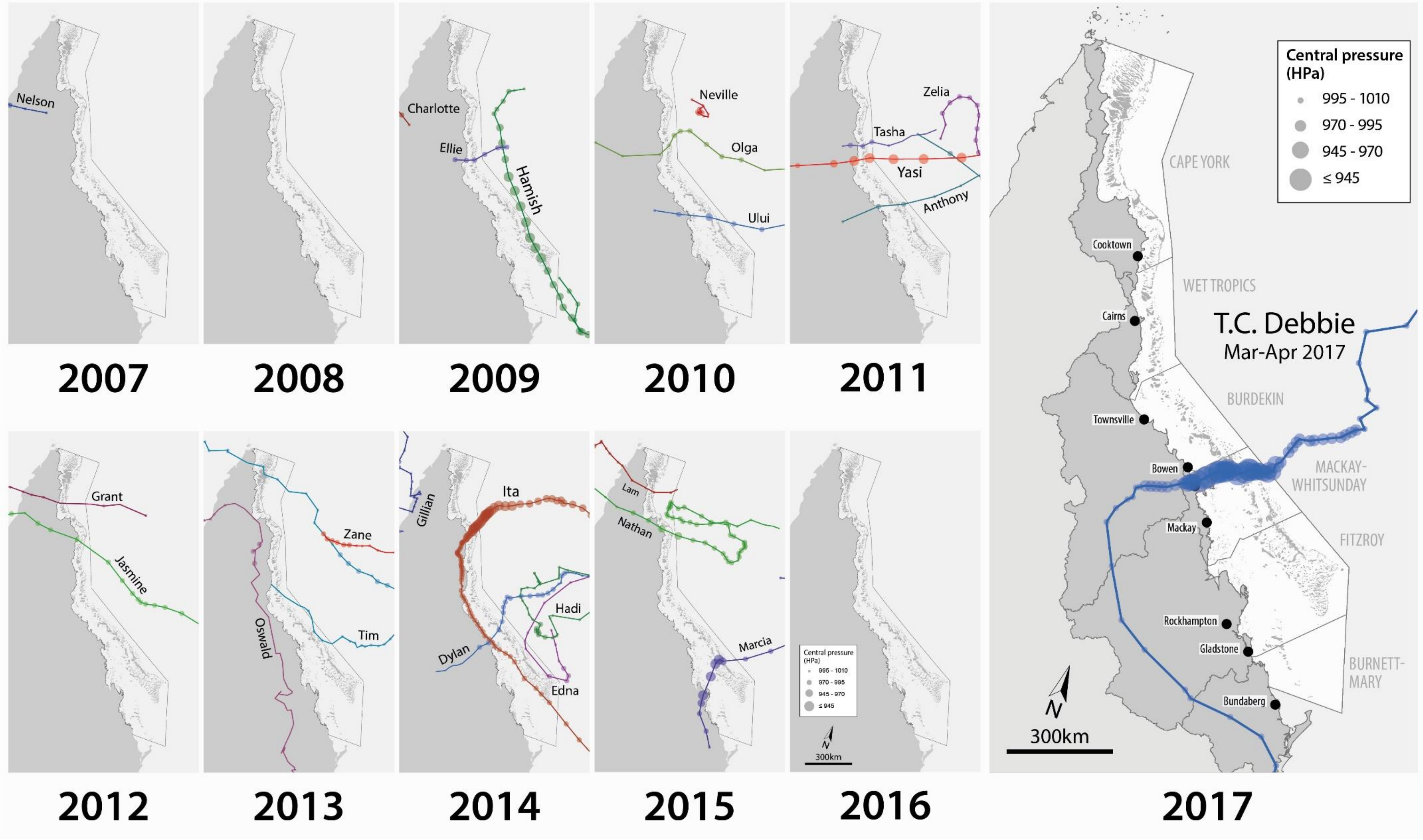


Figure 3-2: Trajectories of tropical cyclones affecting the GBR in 2016–17 and in previous years (2007 to 2016).

3.2.2 Rainfall

Queensland rainfall, and resulting river flows into the GBR, is highly seasonal and highly variable from year to year and on decadal timescales. Annual rainfall across the central and northern GBR catchments continued to be below the wet season averages in 2016–17 with the greatest differences from long-term averages in the catchments in the Cape York, Wet Tropics, Burdekin and Burnett Mary regions (Figure 3-3 and Figure 3-4). The Mackay Whitsunday catchments and coastal catchments of the Fitzroy region had above average rainfall, largely associated with tropical cyclone Debbie (Figure 3-3 and Figure 3-4). Wet season rainfall in the Fitzroy catchment was similar to the long-term average for that area.

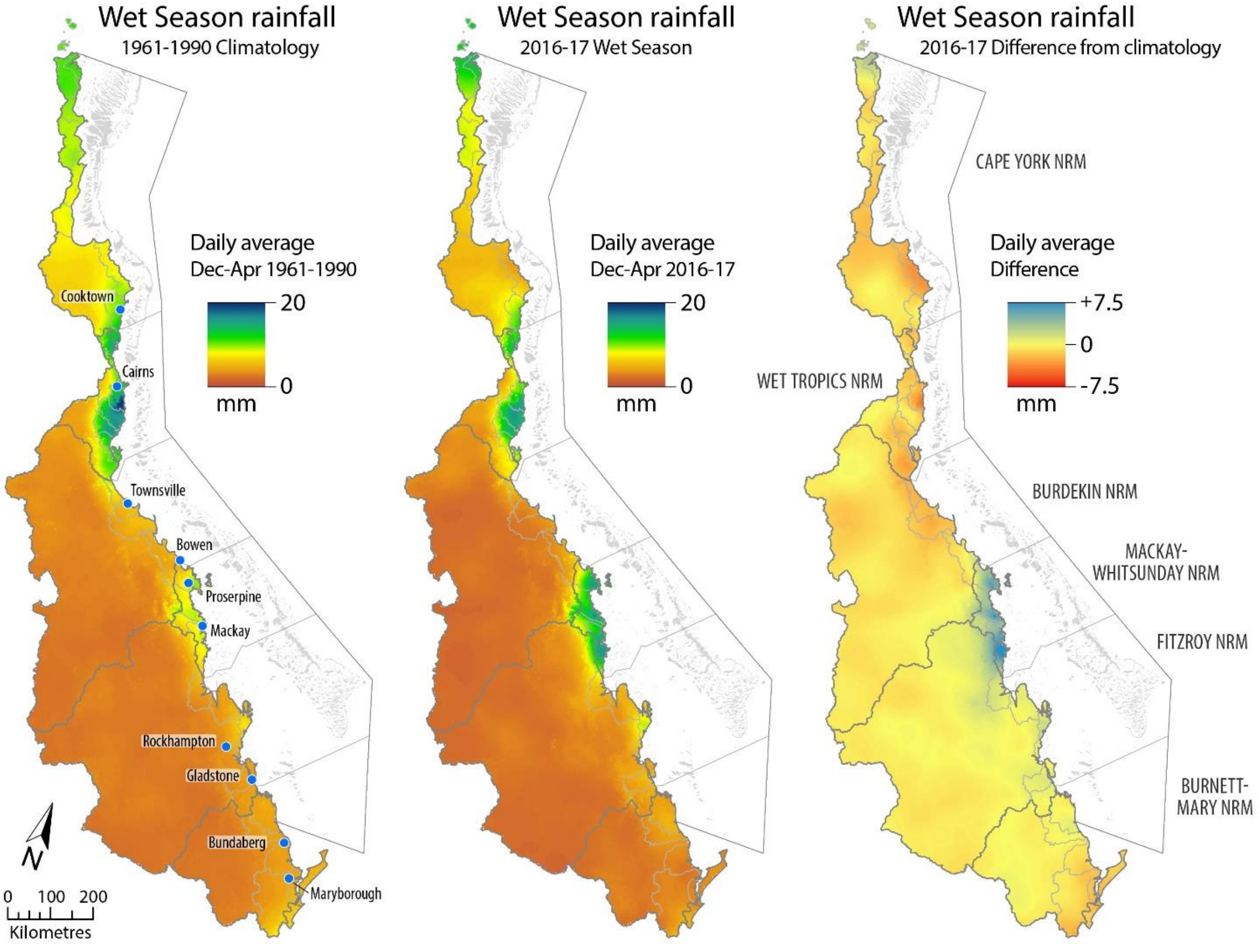


Figure 3-3: Average daily rainfall (mm/day) in the GBR catchment: (left) long-term annual average (1961–1990; time period produced by BOM), (centre) 2016–17 and (right) the difference between the long-term annual average and 2016–17 rainfall patterns.

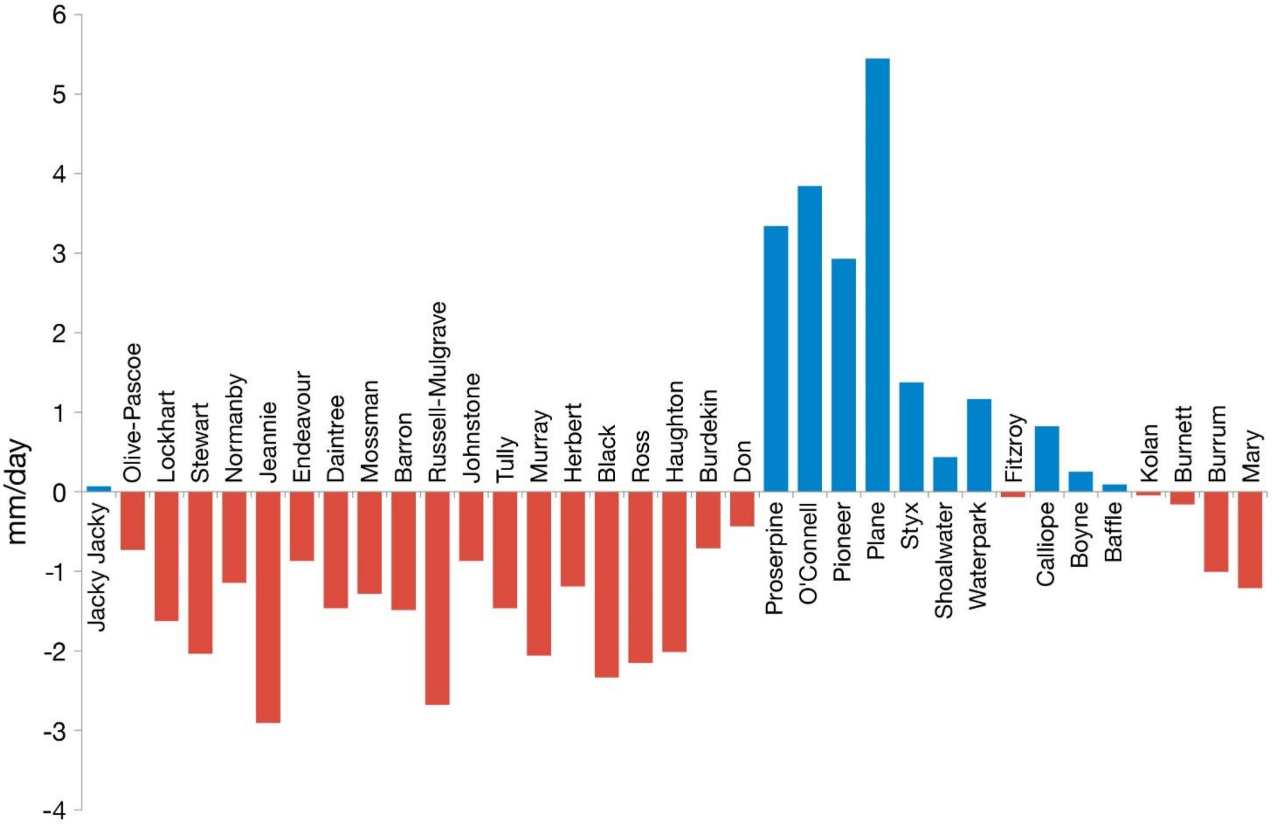


Figure 3-4: Annual average wet season rainfall (December 2016–April 2017) compared to the long-term wet season rainfall average (1961–1990). Red and blue bars denote catchments with rainfall below and above the long-term average, respectively. Note that the catchments are ordered from north to south (left to right).

3.2.3 Freshwater discharge

The trends in freshwater discharge have a significant influence on water quality in the GBR over the period of the MMP. The annual freshwater discharge for each NRM region (based on hydrological year, calculated using the methods described in Section 2.8) is shown in Figure 3-5 and relative to long-term medians in Figure 3-6 and Appendix E (Table E-1). The 2013 water year (October 2012 to September 2013) was the last in a sequence of years with above average river discharge (2007 to 2013). Total river discharge in the 2014, 2015 and 2016 water years was around or below average and no significant river flood events affected the GBR lagoon. In 2017, all regions had annual discharge close to the median and were amongst the highest discharge recorded over the past 4 to 5 years.

Wet season discharge for the 35 GBR basins in 2016–17 is shown in Table 3-1 and compared to long-term median annual flow for that basin. A number of the southern rivers had wet season discharges above their long-term median flow including the following:

- More than 3 times long-term median flow: Burrum River (second year in a row);
- A total of 2 to 3 times long-term median flow: Don River, Plane Creek, Styx River, Shoalwater Creek, Waterpark Creek, Fitzroy River, Calliope River, Boyne River, Baffle Creek, Kolan River and Burnett River; and
- A total of 1.5 to 2 times long-term median flow: Proserpine River, O'Connell River and Pioneer River.

All the other major rivers had a total wet season discharge less than 1.5 times their long-term median (Table 3-1).

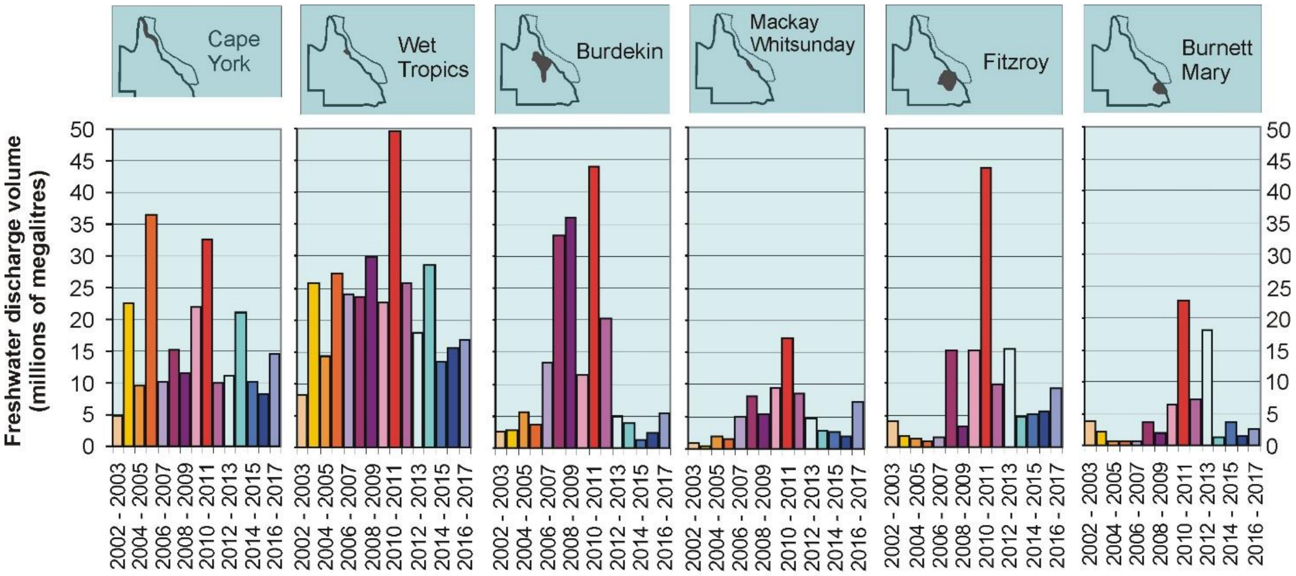


Figure 3-5: Corrected annual hydrological/water year (1 October to 30 September) discharge from each NRM region (using the correction factors in Table 2-2) for 2002–03 to 2016–17 in millions of megalitres per year. Data derived from DNRM (2017).

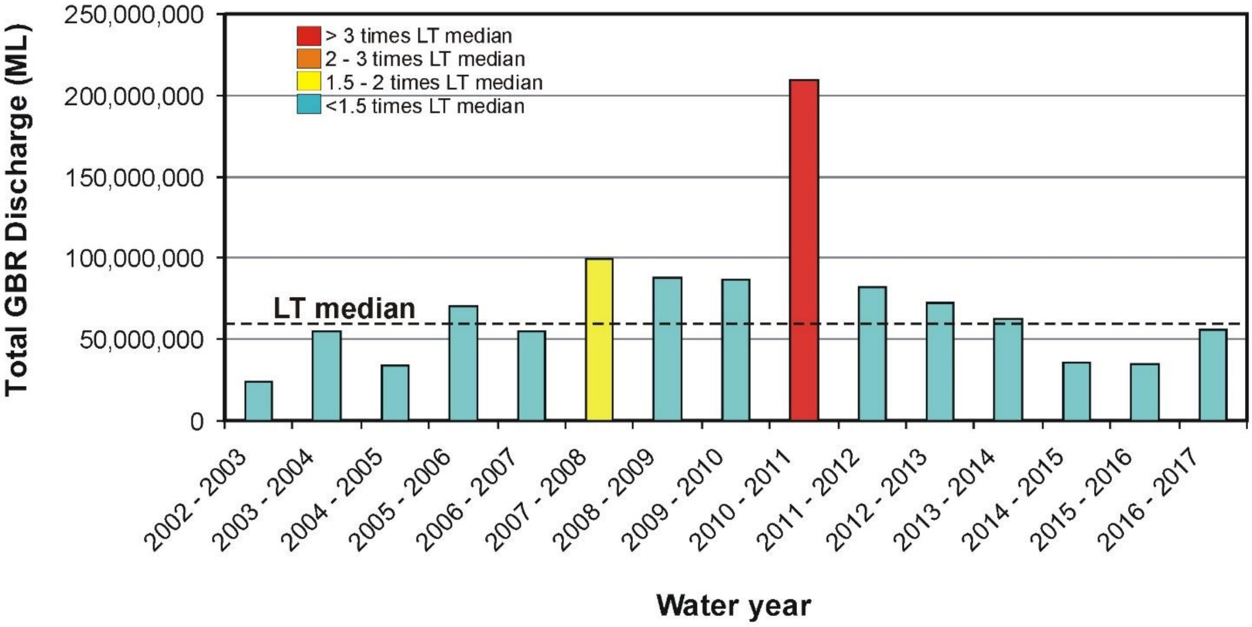


Figure 3-6: Long-term total discharge in ML (hydrological year: 1 October to 30 September) for the 35 main GBR rivers. Source: DNRM, http://watermonitoring.dnrm.qld.gov.au/host.htm.

Table 3-1: Wet season discharge (ML) of the main GBR rivers (1 October 2015 to 30 September 20176, inclusive) compared to the previous four wet seasons and long-term (LT) median discharge (1986–87 to 2016–17). 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 - 2011	2011 - 2012	2012 - 2013	2013 - 2014	2014 - 2015	2015 - 2016	2016 - 2017
Jacky Jacky	2,056,151	4,735,197	1,820,422	1,986,825	3,790,832	1,498,138	630,787	2,383,057
Olive Pascoe	2,570,189	5,918,996	2,275,527	2,483,531	4,738,541	1,872,672	788,484	2,978,821
Lockhart	1,627,786	3,748,697	1,441,167	1,572,903	3,001,076	1,186,026	499,373	1,886,587
Stewart	685,263	2,180,850	616,070	523,353	1,311,775	298,816	311,901	685,263
Normanby	3,860,395	11,333,284	2,181,990	3,462,238	5,059,657	2,914,859	3,407,359	3,780,651
Jeannie	1,434,447	2,824,817	1,048,269	695,195	1,869,982	1,434,447	1,581,015	1,746,929
Endeavour	932,391	1,836,131	681,375	451,877	1,215,488	932,391	1,027,660	1,135,504
Daintree	1,729,411	3,936,470	2,396,905	1,668,302	5,137,023	1,905,224	1,623,478	1,931,878
Mossman	1,195,130	2,014,902	1,526,184	1,147,367	1,918,522	874,068	1,245,275	1,142,698
Barron	516,958	2,119,801	852,055	328,260	663,966	380,395	182,999	287,790
Mulgrave-Russell	4,415,631	7,892,713	5,696,594	3,529,862	5,420,678	3,145,787	3,253,825	3,015,734
Johnstone	4,712,497	9,276,874	5,338,591	3,720,020	5,403,534	3,044,680	3,416,331	4,017,617
Tully	3,490,736	7,442,768	3,425,096	3,341,887	4,322,496	2,659,775	2,942,770	3,098,701
Murray	1,216,289	4,267,125	2,062,103	1,006,286	1,531,172	366,212	974,244	947,985
Herbert	3,478,592	12,593,674	4,545,193	3,189,804	4,281,607	1,095,372	1,895,526	2,248,436
Black	219,909	1,424,283	747,328	188,468	419,290	17,654	129,783	64,873
Ross	445,106	2,092,684	1,324,707	276,584	1,177,255			
Haughton	535,930	2,415,758	1,755,712	517,069	573,976	120,674	267,986	338,245
Burdekin	4,328,245	34,834,316	15,568,159	3,424,572	1,458,772	880,951	1,807,104	4,165,129
Don	360,394	3,136,184	802,738	578,391	324,120	171,305	101,562	920,610
Proserpine	924,039	4,582,697	2,171,287	851,504	720,427	157,123	316,648	1,683,894
O'Connell	829,266	4,112,676	1,948,591	764,170	646,537	141,008	284,171	1,511,187
Pioneer	804,599	3,630,422	1,567,684	1,162,871	635,315	2,028,936	597,117	1,388,687
Plane	1,273,154	4,809,239	2,854,703	1,948,929	737,580	241,254	832,508	2,613,261
Styx	191,279	906,144	275,219	968,106	544,155	376,009	343,877	507,927
Shoalwater	217,663	1,031,129	313,180	1,101,638	619,211	427,872	391,308	577,985
Water Park	573,838	2,718,432	825,657	2,904,319	1,632,466	1,128,027	1,031,630	1,523,780
Fitzroy	2,996,149	37,942,149	7,993,273	8,530,491	1,578,610	2,681,949	3,589,342	6,170,044
Calliope	157,383	1,000,032	345,703	1,558,380	283,790	479,868	148,547	406,321
Boyne	39,809	252,949	87,443	394,178	71,782	121,378	37,574	102,775
Baffle	409,347	3,650,093	1,775,749	2,030,545	275,517	710,352	257,093	829,460
Kolan	50,429	779,168	307,837	810,411	45,304	213,857	111,172	146,154
Burnett	250,839	9,421,517	643,137	7,581,543	218,087	853,349	381,054	536,242
Burrum	64,940	114,492	117,762	90,921	62,188	150,113	334,681	456,549
Mary	1,095,811	8,719,106	4,340,275	7,654,320	594,612	1,651,901	480,854	582,510

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 Section 2.8.

3.3 Exposure of the GBR lagoon to river water

3.3.1 Zones of influence of individual rivers

Total cumulative exposure of shelf waters in the MMP focus regions during the 2016–17 wet season were calculated using numerical tracer experiments within the eReefs hydrodynamic model and are presented in the Regional reports (Section 3.4) for each of the MMP water quality four focus regions. These tracer maps indicate the spatial extent of influence of individual rivers and confirm the patterns seen in the plume exposure maps derived from remote sensing imagery. All regions had annual discharge close to the median and were amongst the highest discharge recorded over the past 4 to 5 years (see Section 3.2).

The results of the tracer simulations confirmed that the areas exposed to water from individual rivers in 2016–17 were smaller, both spatially and for their respective levels of cumulative exposure, for all focus regions than those modelled during the extreme wet season of 2010–11. This information can be used in conjunction with the wet season water type mapping and exposure assessments to provide context for any changes in the local inshore water quality in light of changes in the delivery of run-off from certain catchments. However, in the future the eReefs model will allow for the full consideration of the loads of nutrients and suspended sediments from individual rivers in the interpretation of changes in inshore water quality.

3.3.2 Wet season water type maps and exposure assessment

Frequency maps predicting the GBR marine areas affected by the three wet season water types individually (Primary, Secondary or Tertiary water types) were produced for the 2016–17 (current year) (Figure 3-7). Frequency maps predicting the GBR areas affected by the three wet season water types combined were also produced for the 2016–17 (current year), 2010-11 (wettest wet season monitored) and long-term (2002–03 to 2016–17) (Figure 3-8).

The rainfall and river flow across the GBR during the 2016–17 wet season was close to the long-term median and the 2016–17 results showed trends similar to those of the long-term frequency map in most GBR marine regions (Figure 3-8). The maps illustrated 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. The extent and frequency of the occurrence of the 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 3-7 and Figure 3-8).

The frequencies of occurrence of wet season water types measured across the Tully-offshore and Herbert-offshore transects in 2016–17 were similar to the long-term frequencies and lower than the 2010–11 frequencies (inset Figure 3-8). The one exception was in the Mackay Whitsunday region where the frequency of occurrence of wet season water types recorded along the Pioneer-offshore transect was similar to the frequency recorded in 2010–11 (wettest wet season monitored) close to the coast and greater offshore (east to the 149.5° longitude) (inset Figure 3-8). The Mackay Whitsunday catchments had above average rainfall, largely associated with tropical cyclone Debbie (Figure 3-3 and Figure 3-4).

As a result, the total area (in km^2) of the GBR (including surface areas in Hervey Bay, south of the GBRMP boundary, hereafter GBR+HB) affected by wet season water types (314,612 km^2 or 83% of the GBR+HB) was above the long-term area affected and the 2011 area (Table 3-2). This result was related to larger Tertiary areas mapped in 2016–17 (276,254 km^2 or 72% of the GBR+HB) than in 2010–11 or in the long-term. However, the Primary waters in 2016–17 covered less area (21,704 km^2 or 6% of the GBR+HB) than in 2011 or in the long-term. Similarly, the Secondary waters in 2016–17 covered less area (81,041 km^2 or 21% of the GBR+HB) than in 2011 or in the long-term. 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.

Table 3-2: Areas (km^2) and percentages (%) of the GBR lagoon affected by the wet season water types during the 2016–17 wet season. Surface areas south of the GBRMP boundary (Hervey Bay) are included (GBR+HB).

Water type	2016–17		2010–11		Long-term	
	Area (km^2)	% of GBR+HB	Area (km^2)	% of GBR+HB	Area (km^2)	% of GBR+HB
Combined	314,612	83%	261,835	69%	258,319	68 %
Primary	21,704	6%	58,310	15%	51,500	14%
Secondary	81,041	21%	107,994	28%	110,966	29%
Tertiary	276,254	72%	167,491	44%	221,246	58%

A summary of water quality parameters in the six colour classes in 2016–17 is shown in Figure 3-9 and detailed characteristics are provided in Appendix E for the entire GBR (Table E-6), Cape York (Table E-7), Wet Tropics (Table E- 8), Burdekin (Table E-9) and Mackay Whitsunday (Table E-10). Most of the key water quality parameters in both the long-term dataset (2003 to 2016) and in the reporting year 2016–17 followed long-term and published trends, i.e., decreasing values from the Primary (colour classes 1 to 4) to the Tertiary (colour class 6) water type. Whereas Devlin et al. (2012a) reported higher Chl-a concentration in the Secondary water type than in the Primary water type, the 2016–17 wet season was characterised by higher mean Chl-a concentrations in the Primary water type (2.2 ± 5.0 µg L^{-1}) than in the Secondary water type (0.8 ± 1.1 µg L^{-1}), which was similar to 2015–16. Chl-a concentrations were, greatest in colour class 4 (2.4 ± 6.1 µg L^{-1}) than in colour classes 1 to 3 (1.1 to 2.3 µg L^{-1}) (Figure 3-10). Thus, the sub-classification into colour classes better describes fine-scale coastal processes in Primary 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, measured by increased Secchi depth, by regular nutrient inputs, as well as by the increase in salinity, as the growth rate of marine phytoplankton can be inhibited by lower salinity (Carstensen et al., 2015).

The mean concentration of water quality parameters measured across the wet season water types and colour classes in 2016–17 were generally similar to the long-term average concentrations, except that mean DIP was below the long-term average concentration (Figure 3-9 and Figure 3-10). The mean Chl-a measured in the Primary water type, DIN in the Primary and Secondary water types, PP in the Primary water type and PN in the Secondary water type were all slightly over the long-term average concentrations. The long-term and 2016–17 TSS concentrations were above the wet season GVs in each respective wet season water type (Figure 3-9: $TSS_{Primary}$ = 16.3 ± 21.6 mg L^{-1}, $TSS_{Secondary}$ = 4.3 ± 5.9 mg L^{-1} and $TSS_{Tertiary}$ = 2.6 ± 2.6 mg L^{-1} in 2016–17). The long-term and 2016–17 mean Chl-a, PP and PN concentrations were above the wet season GVs in the Primary and Secondary water types (Figure 3-10).

Mean concentrations of water quality parameters across the three 2016–17 wet season water types showed similar trends between the focus regions, including the Cape York region, with maximum concentrations measured in the Primary water type and minimum concentrations measured in the Tertiary water types. However, there were distinct differences in the concentrations of individual pollutants across regions (Figure 3-11). For example, the Mackay Whitsunday region had the greatest TSS and DIN concentrations in the Primary and Secondary water types, whereas maximum mean CDOM and DIN concentrations were measured in the Burdekin and Wet Tropics regions (especially in the Primary water type). The maximum Chl-a concentration was measured in the Primary water type of the Wet Tropics region. The assessment of the Cape York region showed for the first time the lowest water concentrations of water quality parameters of all regions, although it should be noted that this is based on relatively constrained sampling across the region. 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 section (Section 3.4).

The long-term and wet season mean concentrations of water quality parameters (GBR-wide) measured across the wet season water types were assessed against the GBR Water Quality Guideline for the Open Coastal and Midshelf waters (GBRMPA, 2010), and used in combination with the seasonal and long-term frequency maps to derive wet season and long-term surface exposure maps, respectively (see below and Section 3.3). Note that these assessments incorporate data from all of the surface samples collected between December 2016 and April 2017 by AIMS, JCU and the CYWMP for the first time.

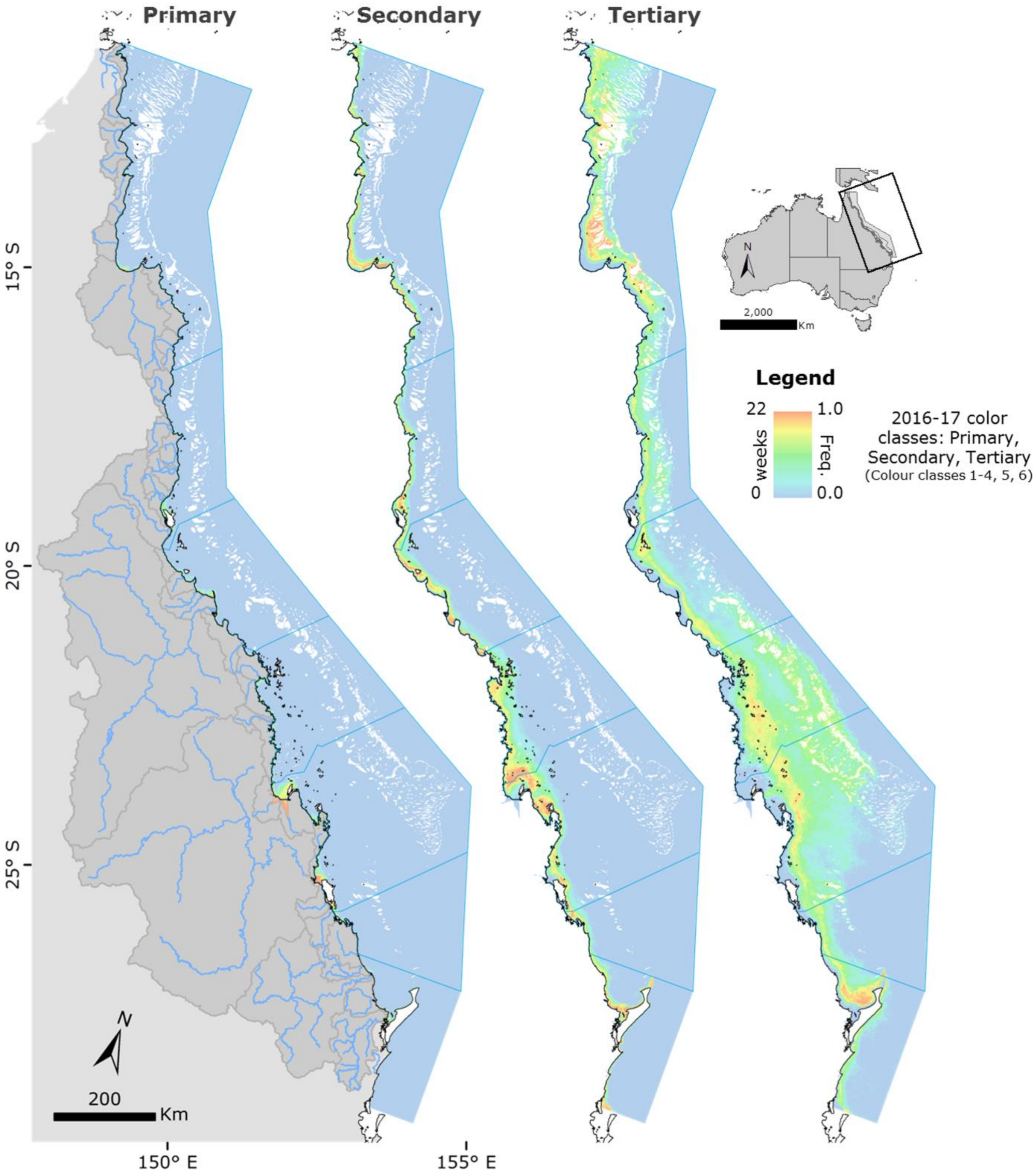


Figure 3-7: Map showing the frequency of Primary, Secondary and Tertiary wet season water types in the 2016–17 wet season (22 weeks), where the highest frequency is shown in orange and the lowest frequency is shown in blue.

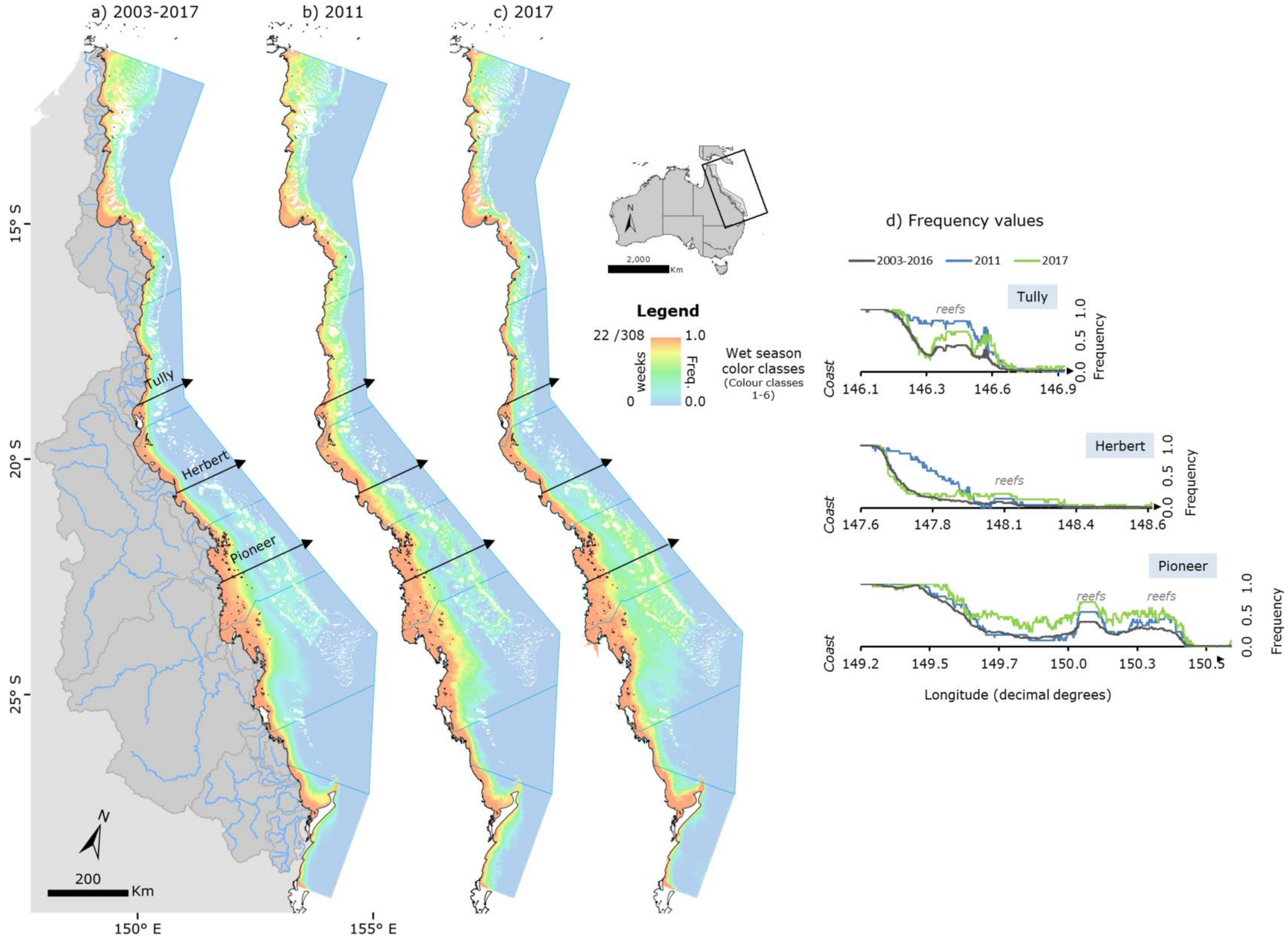


Figure 3-8: Map showing the frequency of wet season water types (Primary, Secondary and Tertiary water types combined) in the a) long-term (2002–03 to 2016–17: 333 weeks), b) 2010–11 wet season (22 weeks) and c) 2016–17 wet season (22 weeks), where the highest frequency is shown in orange and the lowest 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 GBRMP and illustrate the differences in the spatial distribution and frequency of occurrence existing between dry and wet years.

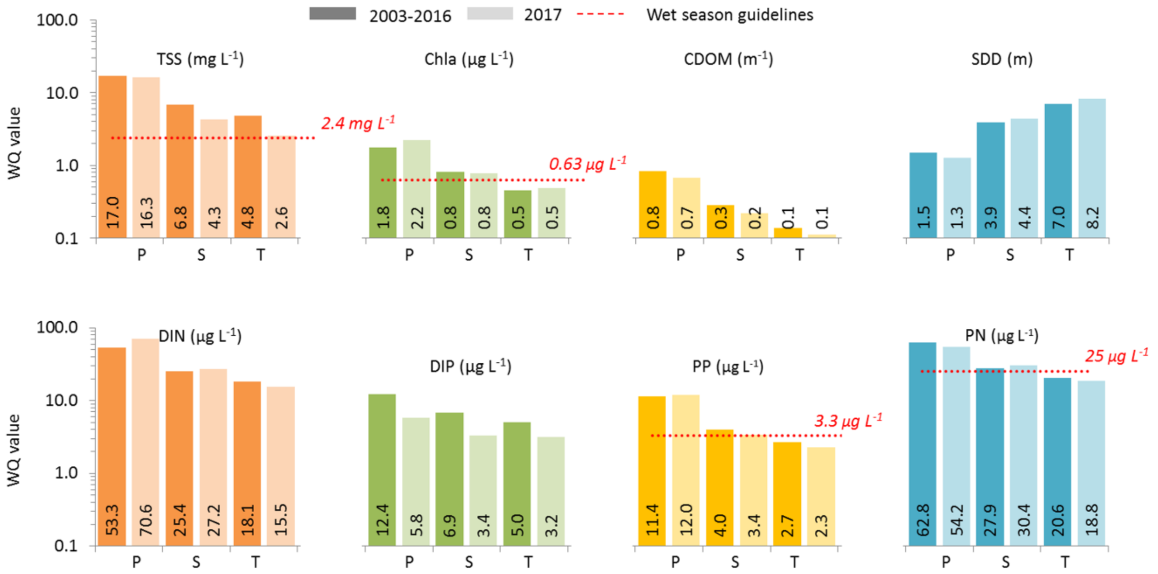


Figure 3-9: Mean water quality concentrations across the three wet season water types: comparison between the mean multi-annual values (2002–03 to 2016–17; dark shaded), the 2016–17 values (light shaded) and wet season guideline values for the open coastal and mid-shelf waters (dotted red lines). Note that this assessment incorporates data from all the surface samples collected between December 2016 and April 2017 by AIMS, JCU and the CYWMP.

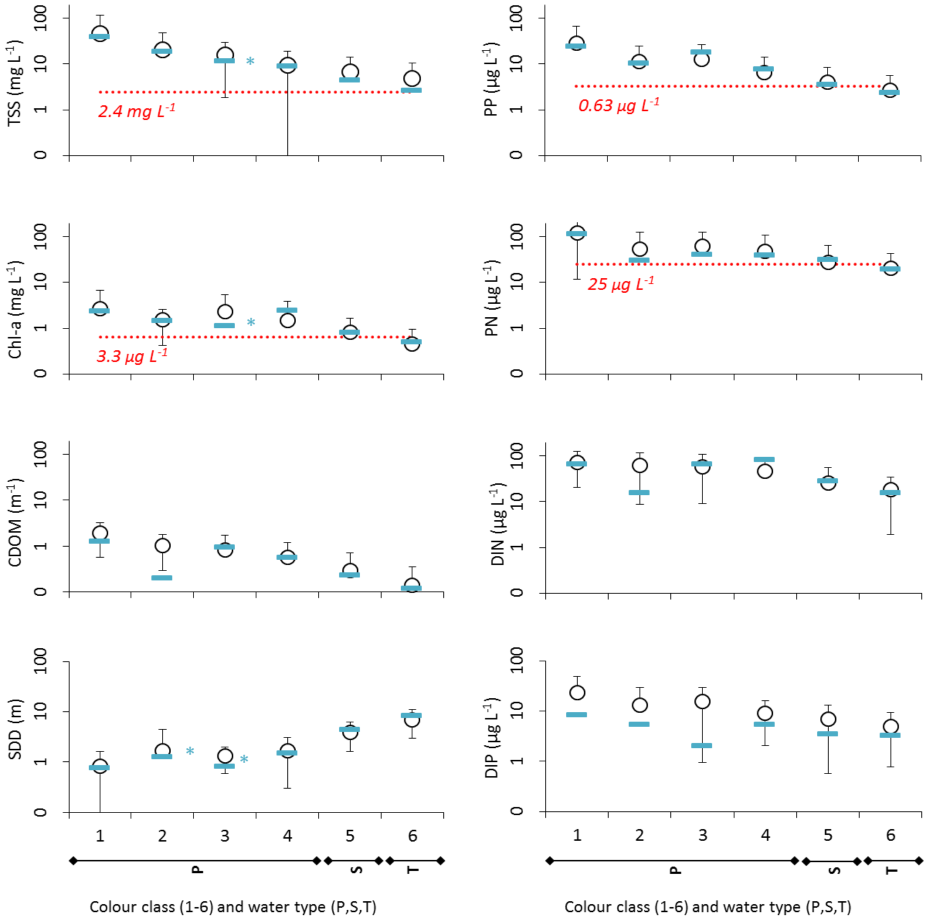


Figure 3-10: Mean water quality concentrations and standard deviation across the six colour classes: comparison between the mean multi-annual values (2002–03 to 2016–17; circles with error bars) and the 2016–17 values (blue rectangles). Blue dots indicate that the number of data was ≤ 3. Note that this assessment incorporates data from all the surface samples collected between December 2016 and April 2017 by AIMS, JCU and CYWMP.

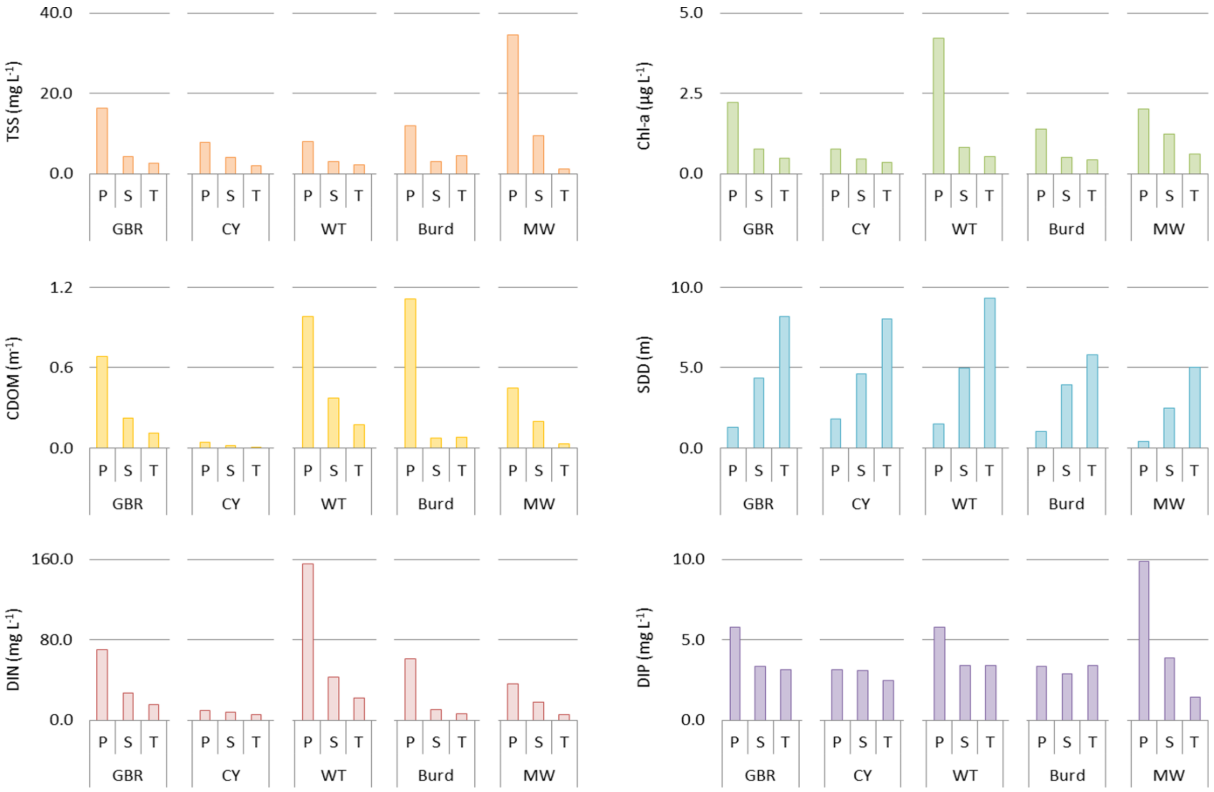


Figure 3-11: Mean 2016–17 water quality concentrations across the three wet season water types: comparison across the focus regions. Note that this assessment incorporates data from all surface samples collected between December 2016 and April 2017 by AIMS, JCU and the CYWMP.

3.3.3 Surface exposure to GBR ecosystems during 2016–17

Exposure maps were produced using methods described in Section 2.7 (Figure 3-12) and overlaid with information on the spatial distribution of GBR ecosystems to help identify ecosystems that may experience acute or chronic high exposure to pollutants during the wet season (exposure assessment, Table 3-3). It is important to note that:

(i) 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.

(ii) Only surface areas inside the GBR marine boundaries are reported.

(iii) This assessment does not take into account the current condition of GBR 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.

(iv) Reporting the areas of coral reefs and seagrass in the highest 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. This also applies for reporting a minimum of one-week exposure where the ecological consequence is not known.

Figure 3-12 presents the exposure map of the 2016–17 wet season and Table 3-3 presents the areas (km^2) and percentage (%) of total area, coral reefs affected by different exposure categories within the GBR. The maps, areas and percentage are presented in the context of the long-term exposure (2003–2017).

In 2016–17, the GBR lagoon was mostly influenced by the lowest exposure categories (categories I and II), in agreement with the long-term trends. Approximately 75% of the total area of the GBR was exposed to wet season water types during at least one week of the wet season. This area was greater than the long-term areas (Table 3-3 – 62% exposed to wet season water types during at least one week of the wet season). However, only 2% of the GBR was in the higher exposure categories (categories III and IV), similar to the long-term areas (Table 3-3 – 1% category I and 1% category II). These characteristics were consistent with an average wet season. Regional reports are presented in Section 3.4.

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 2016–17, it was estimated that:

- A total of 98% of the GBR coral reefs were exposed to wet season water types (Primary, Secondary and Tertiary water types combined), during at least one week of the wet season. However, only 0.2% of corals were in the highest potential exposure category (IV) and only 0.1% of corals were in category III.
- A total of 98% of the GBR seagrasses were exposed to wet season water types during at least one week of the wet season. Ten percent of seagrasses were in the highest potential exposure category (IV) and 5% were in category III.
- The coral and seagrass areas in the highest category of exposure in 2015–16 were similar to the long-term areas (Table 3-3: 0.2% of reefs and 12% of seagrasses exposed to category IV) and were logical with the characteristic of a relatively dry wet season in most regions.

Table 3-3: Areas (km^2) and percentages (%) of the GBR lagoon affected by different categories of exposure within the GBR during the 2016–17 wet season *(and long-term values in brackets)*. Surface areas south of the GBRMP boundary (Hervey Bay) are not included.

GBR		**Total**	**Exposure category Lowest --------------------- highest**				**Total exposed**	**Total non-exposed**
			I	**II**	**III**	**IV**		
Surface area	Area (km$^{2)}$	348,839	255,648	3,041	1,955	2,497	263,141	85,699
			(203,845)	*(7,133)*	*(2,528)*	*(3,007)*	*(216,513)*	*(132,326)*
	Percentage (%)	*100*	73	1	1	1	75	25
			(58)	*(2)*	*(1)*	*(1)*	*(62)*	*(38)*
Coral reefs	Area (km$^{2)}$	24,149	23,506	77	15	36	23,635	513
			(22,604)	*(167)*	*(31)*	*(38)*	*(22,841)*	*(1,308)*
	Percentage (%)	*100*	97	0.3	0.1	0.2	98	2
			(94)	*(1)*	*(0.1)*	*(0.2)*	*(95)*	*(5)*
Surveyed seagrass	Area (km$^{2)}$	4,640	3,398	445	247	456	4,546	94
			(2,665)	*(1,008)*	*(333)*	*(566)*	*(4,572)*	*(69)*
	Percentage (%)	*100*	73	10	5	10	98	2
			(57)	*(22)*	*(7)*	*(12)*	*(99)*	*(1)*

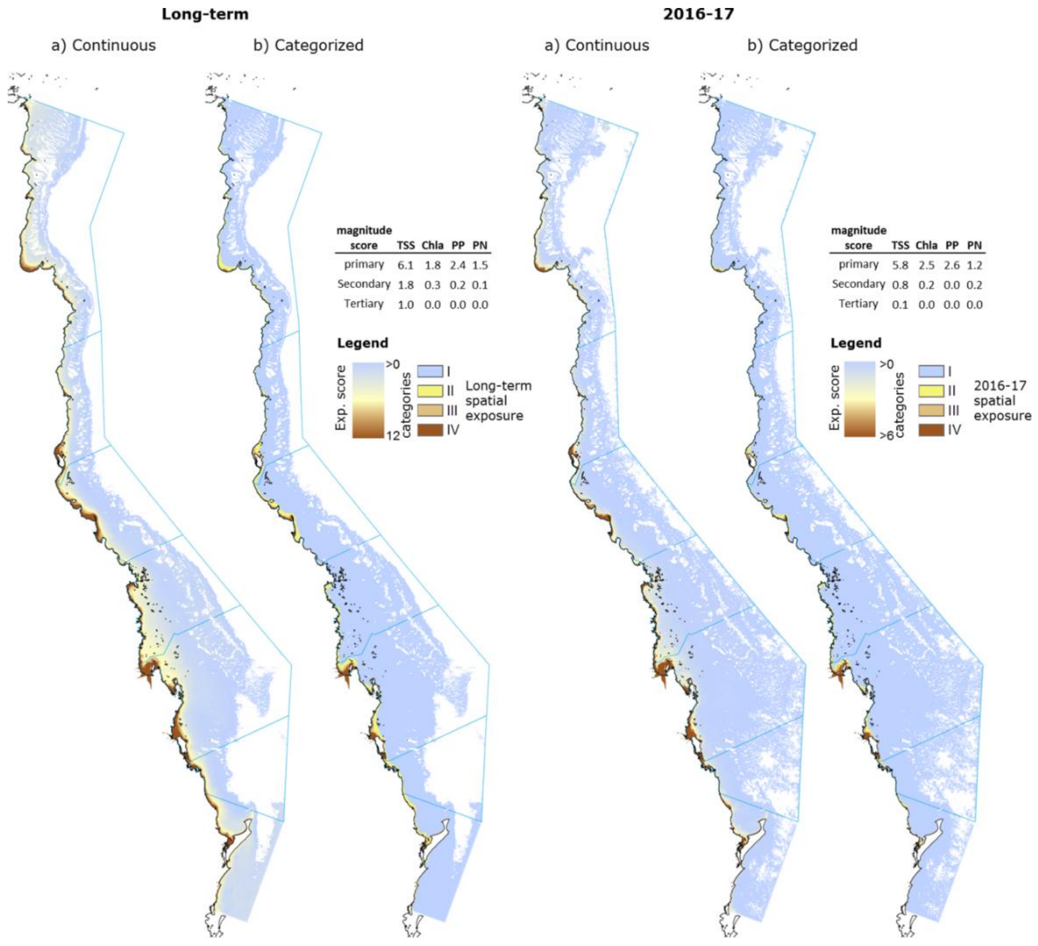


Figure 3-12: Long-term (2003–2017) and 2016–17 maps of exposure produced using the proportional exceedance of the guideline (magnitude score) multiplied by the likelihood of exposure in each of the wet season water types: a) continuous exposure scores and b) categorised exposure scores: [>0-3] = cat. I, [3-6] = cat. II, [6-9] = cat III and [> 9] = cat IV.

3.3.4 Loading maps for DIN and sediment

This section presents the results for the loading maps for DIN and sediment (evaluated as TSS) in plume waters. A detailed description of the methodology and loading maps, their potential uses and limitations are presented in Appendix D-9.

(a) Mapping annual DIN concentration in the GBR during 2003–2017

The model-predicted DIN export to the GBR lagoon is estimated by its annual concentration (DIN, µg/L) over 15 years (Figure 3-13 and Figure 3-14). These maps provide an estimate of dispersion of river-derived DIN in GBR waters and the areas more likely to have higher DIN concentration. The areas covered by model-predicted river-derived DIN vary over the 15 years analysed. Overall, years with very large river discharge (> 65,000,000 ML, which occurred in 2008, 2009, 2011 and 2013) resulted in larger areas of DIN transport and exposure across the GBR. This is in agreement with previous observations about plumes in the GBR, where larger river discharge leads to larger extent of river plumes (e.g., Álvarez-Romero et al., 2013; Brodie et al., 2012; Devlin et al., 2012a, b).

The areas presenting higher DIN concentration 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. Even though the Burdekin River is responsible on average for > 36% of the DIN load accounted for in the model, it is also responsible for 60% of the total discharge. The large Burdekin River discharge results in large plumes and, consequently, relatively low DIN concentrations.

The time series from 2003 to 2017 (Figure 3-13) shows distinct differences between years, driven by river flow and pollutant loads, and region. The areas of influence in 2016–17 are comparable to those years with river discharge close to or below the long-term median, e.g., 2013–14. The highest model-predicted DIN concentration was observed in 2011, with large areas of high DIN values estimated in all areas except for Cape York. The greatest incidence of high DIN values occurred in the Wet Tropics region in all years and, within the Wet Tropics, the greatest areas of high values were correlated with large river discharge events in 2004, 2006, 2007, 2009, 2011 and 2014. High values were also observed in each region during different years. For example, high values occurred in the Mackay Whitsunday region in 2008, each year in 2010 to 2013 and in 2017 (Figure 3-13).

Figure 3-14 shows the difference between the estimated wet season DIN concentration in the GBR lagoon for the 2017 water year (1 October to 30 September) (left panel), compared to the pre-development loads (centre panel) and the difference between the DIN concentration with pre-development end-of-catchment DIN load estimates and the 2017 estimates (right panel). This can be interpreted as ‘anthropogenic’ DIN concentrations, highlighting the areas of greatest change with current land use. This highlights the Wet Tropics and Mackay Whitsunday regions as the dominant areas of anthropogenic influence in the 2016–17 wet season and, to a much lesser extent, the Burdekin and Burnett Mary regions.

Figure 3-15 shows the river contributions (x-axis) to the DIN loading to the six NRM regions in 2010–11 (left column) and 2016–17 (right column). The large 2010–11 wet season represents an extreme year of DIN loading, which is useful as a point of reference for comparison with the current year. The preferential northward movement of the river plumes in the model can result in increased model-predicted DIN concentration in areas that may not directly receive high loads from their catchments.

Overall, rivers located within a marine NRM region were the main contributors to the presence of DIN in its waters, although this varied between years. For example, during the 2010–11 season, the Burdekin River contributed 27% of the DIN in the Wet Tropics region due to the large Burdekin River discharge/plume whereas in 2016–17 the Burdekin did not contribute to the Wet Tropics DIN loading. Similar patterns occurred in the Mackay Whitsunday region in

2010–11 when 28% of DIN in its waters was derived from the Fitzroy River, whereas in 2016–17, the Fitzroy River only had a small DIN contribution to the Mackay Whitsunday region (~5%) and none in the previous year. The Wet Tropics Rivers also contributed to the Cape York NRM region in 2010–11, and the Mossman and Daintree Rivers still contributed to the region in the comparably low discharge year of 2016–17 (8% and 2%, respectively). The adjacent Herbert (14%), Proserpine (14%) and O'Connell (11%) Rivers also contributed to the Burdekin NRM region in 2016–17. The Burnett Mary Rivers contributed to the Fitzroy NRM region during the large flood event of 2010–11 but not in 2016–17. These cross-regional influences are also evident in satellite imagery in the 2010–11 and 2016–17 events.

Analysis of the relative contribution of each river to the concentrations in each NRM region is presented in the Regional reports in Section 3.4. The next step in this method is to establish a reporting metric for future years to represent wet season pollutant load distribution in the GBR.

b) Mapping annual average TSS concentrations in the GBR during 2003–2016

The same model developed for DIN dispersion was used to produce maps for the river-derived TSS in the GBR, except that the decay function was not included. The dispersion function in the model results in some uncertainty in the offshore areas, as seen in the 2008, 2009, 2011 and 2012 assessments. There has been no validation of the results at the outer boundary of the GBR and it is considered unlikely that river-derived TSS would be transported this far offshore. Recent research suggests that riverine flows (and associated TSS) could potentially influence certain parts of the outer GBR 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). This function of the model is currently being revised and would ultimately benefit from input from the eReefs modelling platform.

The annual concentration of model-predicted TSS export to the GBR lagoon was examined over 15 years (Figure 3-16). Similar correlations with river discharge were observed as were seen for DIN. The highest model-predicted TSS concentration was observed in 2011, followed by 2007 and 2008. The areas with high TSS concentration were more variable over the years than for the DIN assessment. The greatest incidence of high TSS values occurred in the Burdekin region and were correlated with large river discharge events in 2005, 2007, 2008, 2009, 2010, 2011, 2013 and 2017. High values were also observed in each region in different years. For example, high values occurred in the Fitzroy region in 2003 and 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 3-16).

The modelled dispersion is driven by average wind conditions that are typically represented in a south-easterly direction. However, in 2017, there was a period of northerly wind conditions soon after the large river flow in the Burdekin River, which drove this plume in an easterly/south-easterly direction. This is not reflected in the predicted dispersion shown in Figure 3-16 and is recognised as a limitation of the model that needs to be addressed (the satellite images in Figure 3-78 also illustrates this difference).

Figure 3-17 shows the difference between the estimated wet season TSS concentration in the GBR lagoon for the 2017 water year (1 October to 30 September) (left panel), compared to the pre-development loads (centre panel) and the difference between the TSS concentration with pre-development end-of-catchment TSS load estimates and the 2017 estimates (right panel). This can be interpreted as 'anthropogenic' TSS concentrations, highlighting the areas of greatest change with current land use. This highlights the Burdekin region as the dominant area of anthropogenic influence in the 2016–17 wet season.

Figure 3-18: shows the river contributions (x-axis) to the TSS loadings for the six NRM regions in 2010–11 (left column) and 2016–17 (right column). The large 2010–11 wet season represents an extreme year of TSS loading, which is useful as a point of reference for comparison with the current 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.

Similar to DIN, rivers located within a marine NRM region were the main contributors to the presence of river-derived TSS in its waters. In the large discharge events of 2010–11, several Wet Tropics Rivers and the Burdekin River contributed to the Cape York region, whereas in 2016–17 only the Daintree (7%) and Mossman (2%) Rivers contributed to the TSS loading. The Burdekin River contributed to the Cape York and Wet Tropics NRM region in 2010–11; however, its influence was constrained to the Burdekin NRM region in 2016–17. The Mackay Whitsunday region received inputs from the Fitzroy River in 2010–11 and again in 2016–17 (25%). There was also cross-regional influence between the Fitzroy and Burnett Mary regions and rivers in 2010–11, which did not occur in 2016–17. These cross-regional influences are also evident in satellite imagery during the 2010–11 and 2016–17 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.

Analysis of the relative contribution of each river to the concentrations in each NRM region is presented in the Regional reports in Section 3.4. The next step in this method is to establish a reporting metric for future years to represent wet season pollutant load distribution in the GBR.

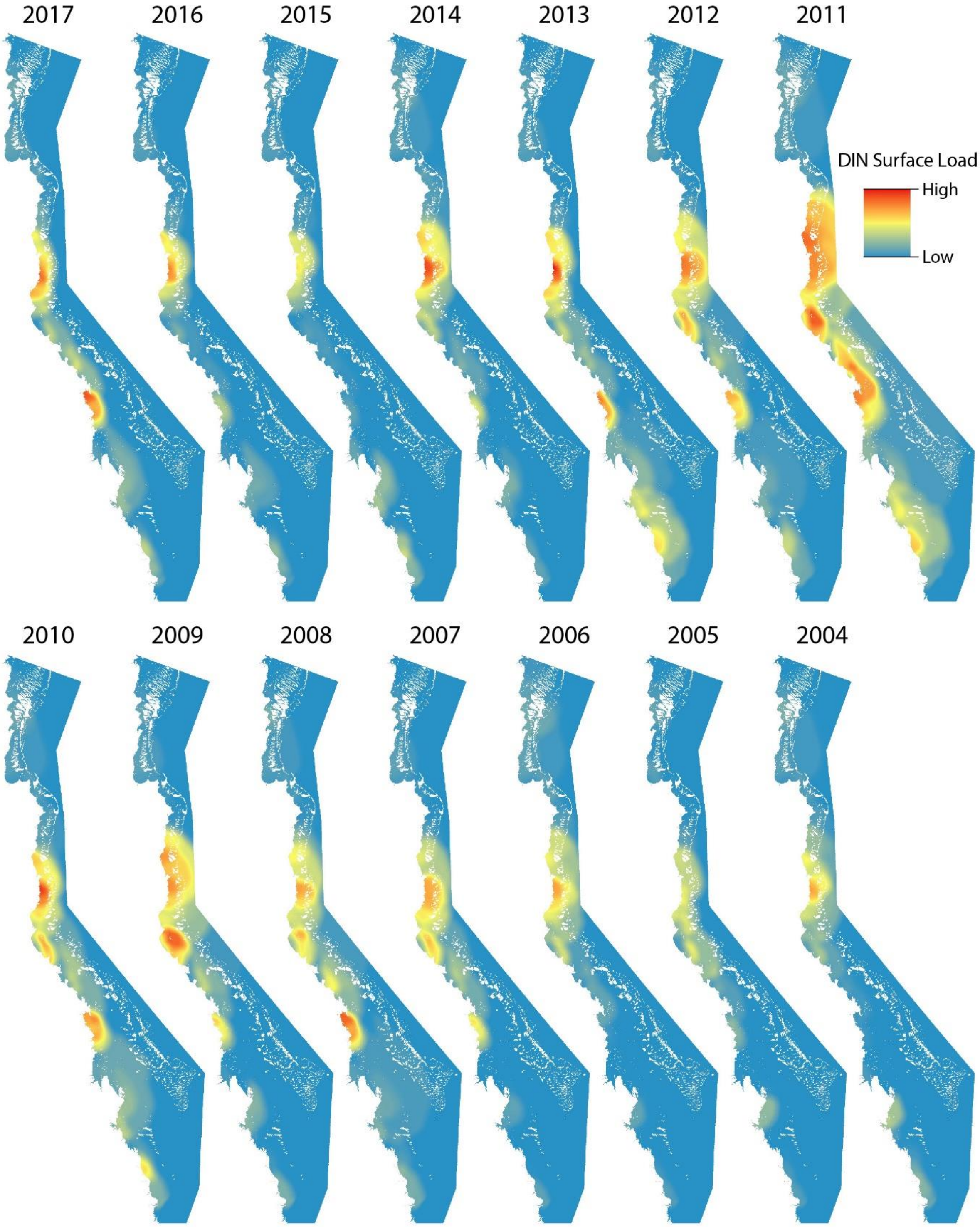


Figure 3-13: DIN over the GBR lagoon for the 2003 to 2017 water years (1 October to 30 September).

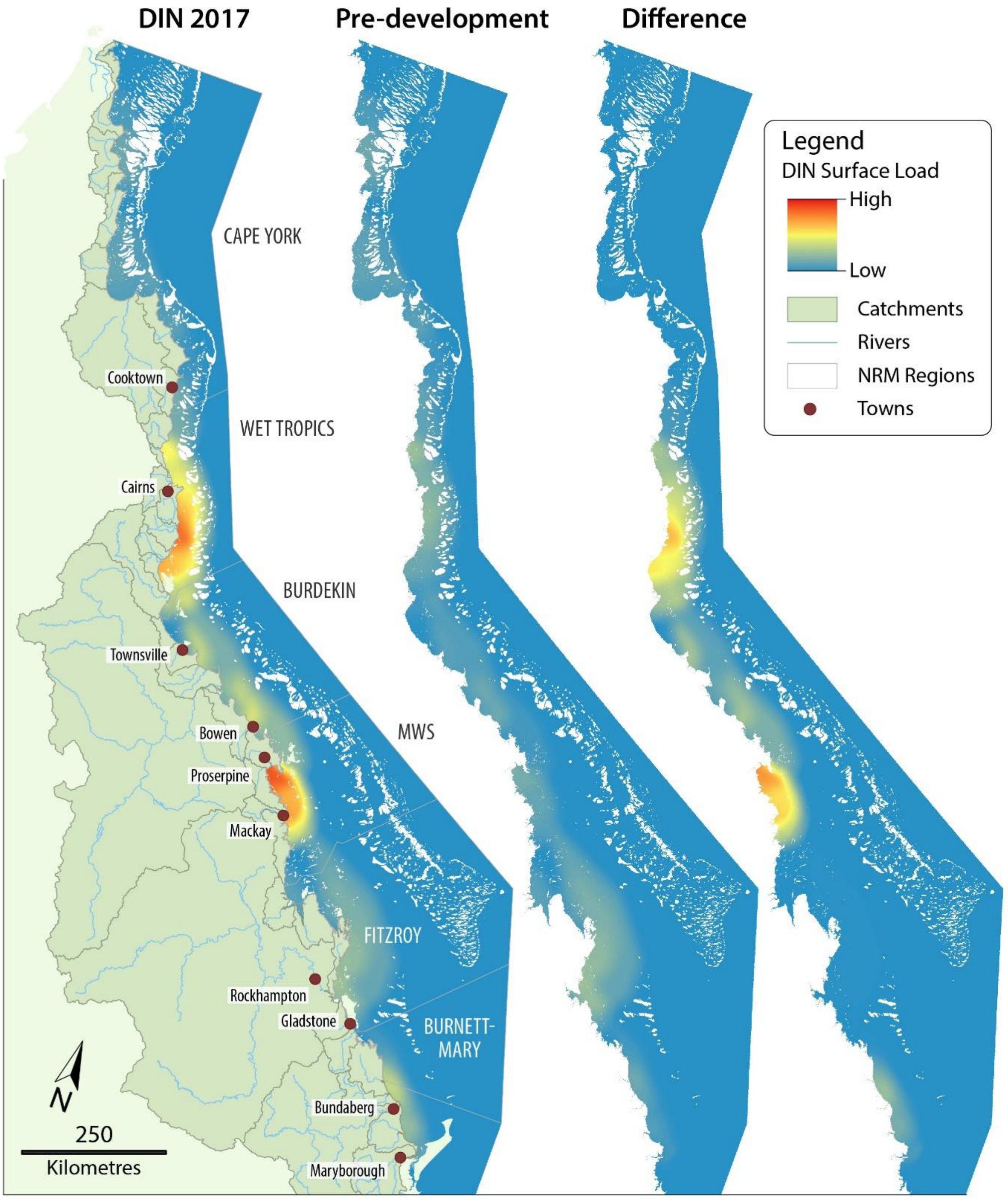


Figure 3-14: DIN concentration in the GBR lagoon, modelled for the (left panel) 2017 water year (1 October to 30 September), (centre panel) pre-development loads and (right panel) difference between the DIN concentration with pre-development end-of-catchment DIN load estimates and the 2017 estimates.

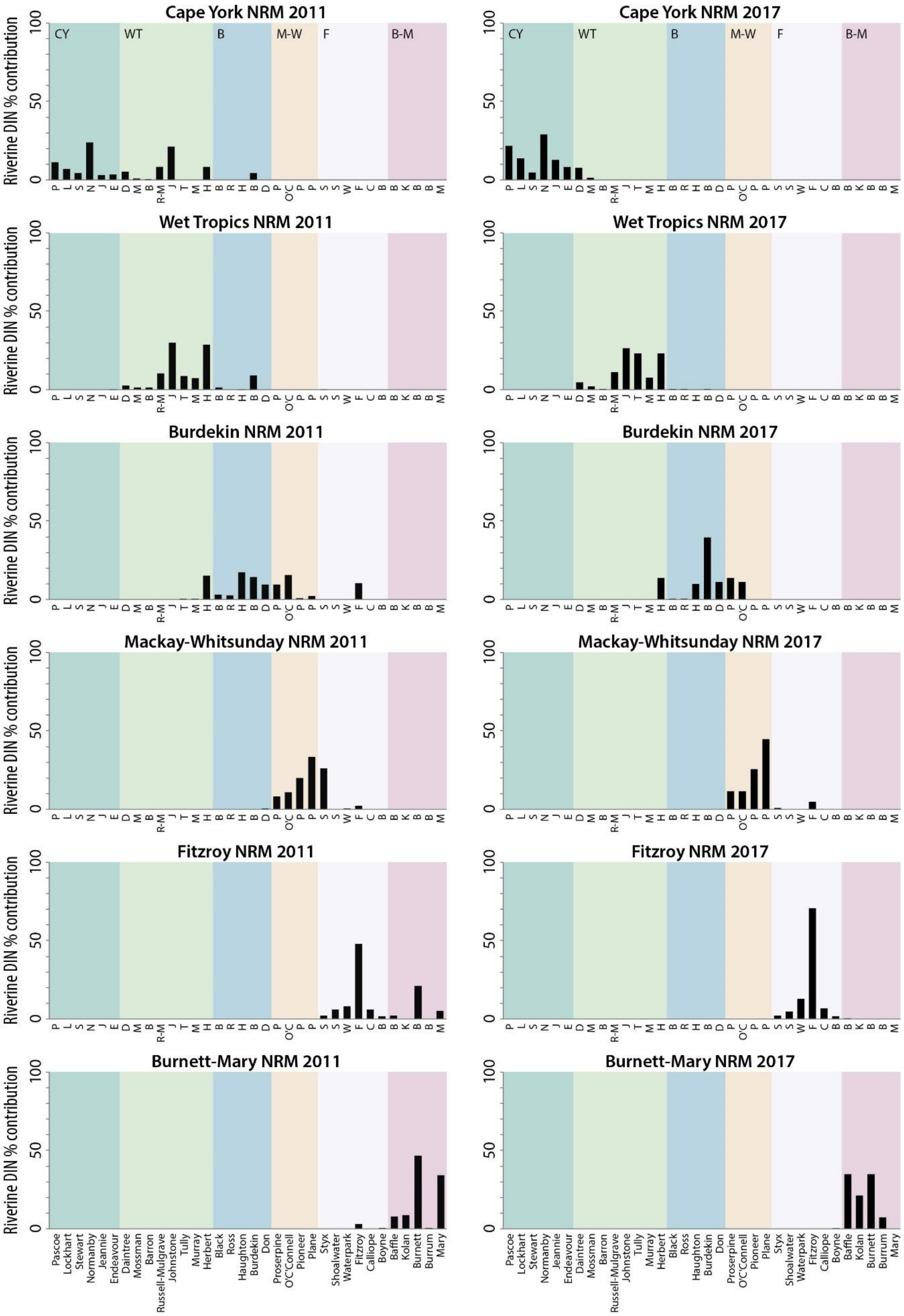


Figure 3-15. River contributions (x-axis) to the DIN loading in the six NRM regions. Shading groups rivers in the same NRM region: Cape York – dark green, Wet Tropics – light green, Burdekin – blue, Mackay Whitsunday – orange, Fitzroy – pink, Burnett Mary - red. The left panels show data for the 2010–11 water year (1 October to 30 September) and right panels for the 2016–17 water year.

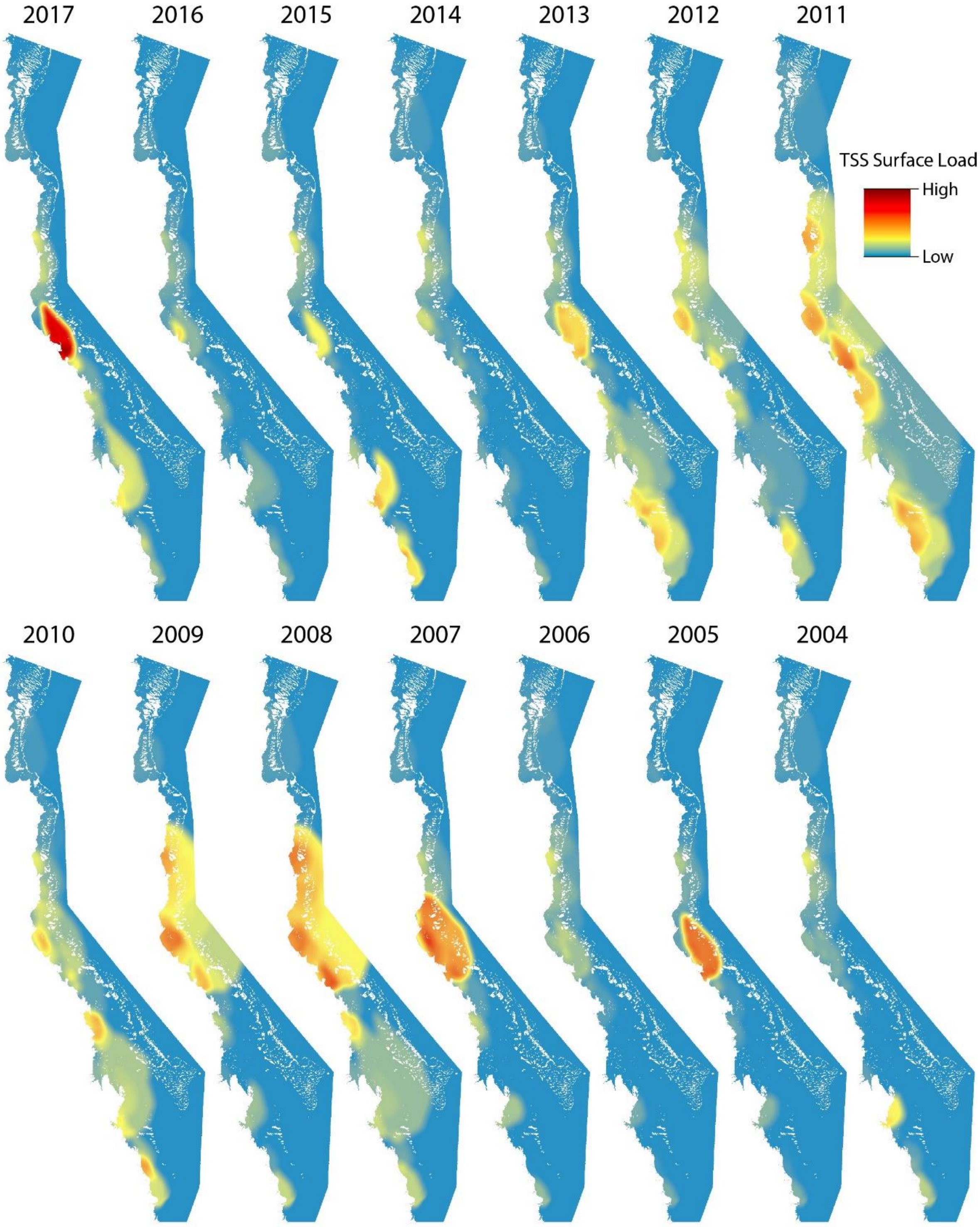


Figure 3-16: TSS over the GBR lagoon for the 2003 to 2017 water years (1 October to 30 September).

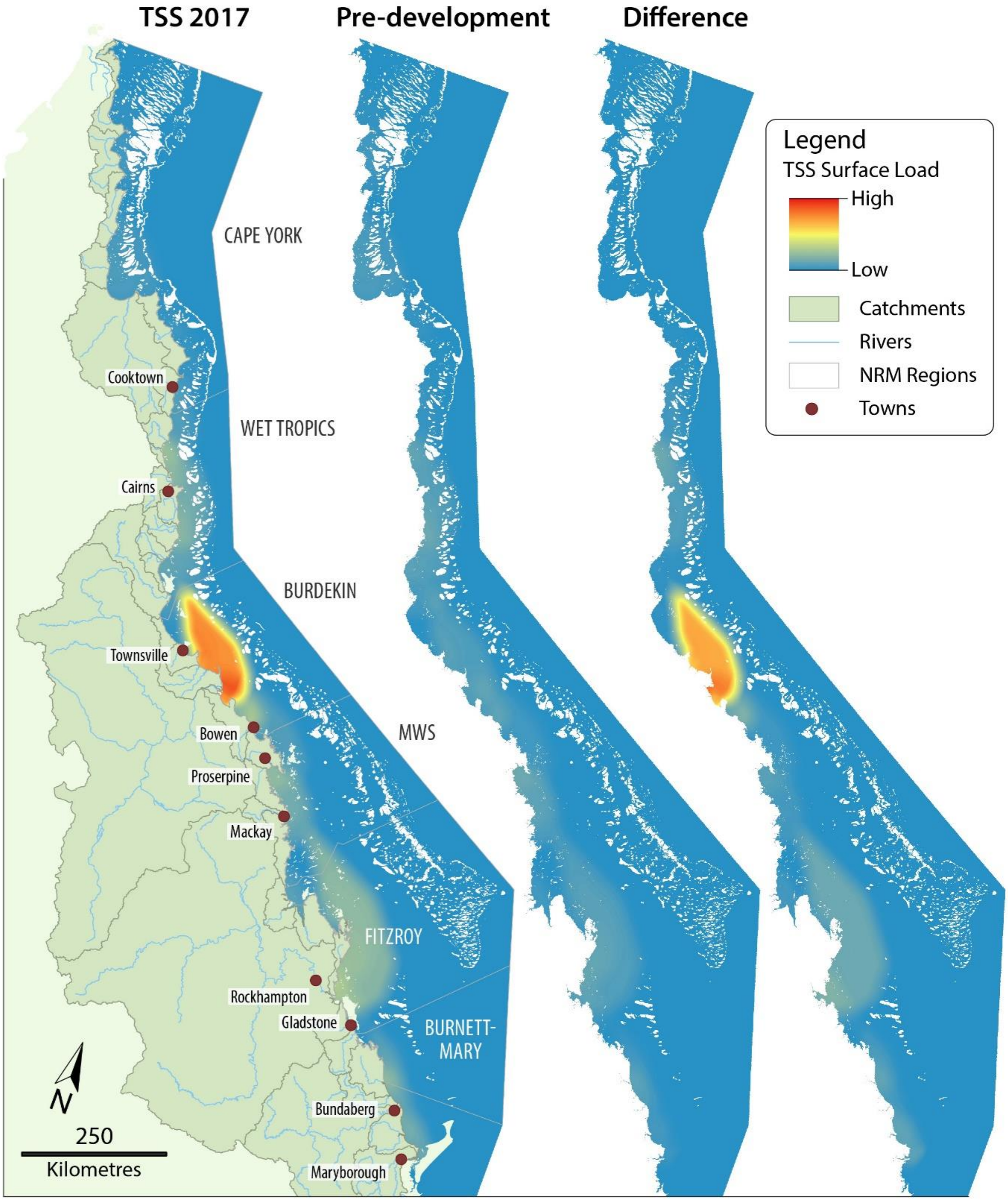


Figure 3-17: TSS (mg/L) in the GBR lagoon, modelled for the (left panel) 2017 water year (1 October to 30 September), (centre panel) pre-development loads and (right panel) the difference between TSS concentration with pre-development end-of-catchment TSS load estimates and the 2016 estimates.

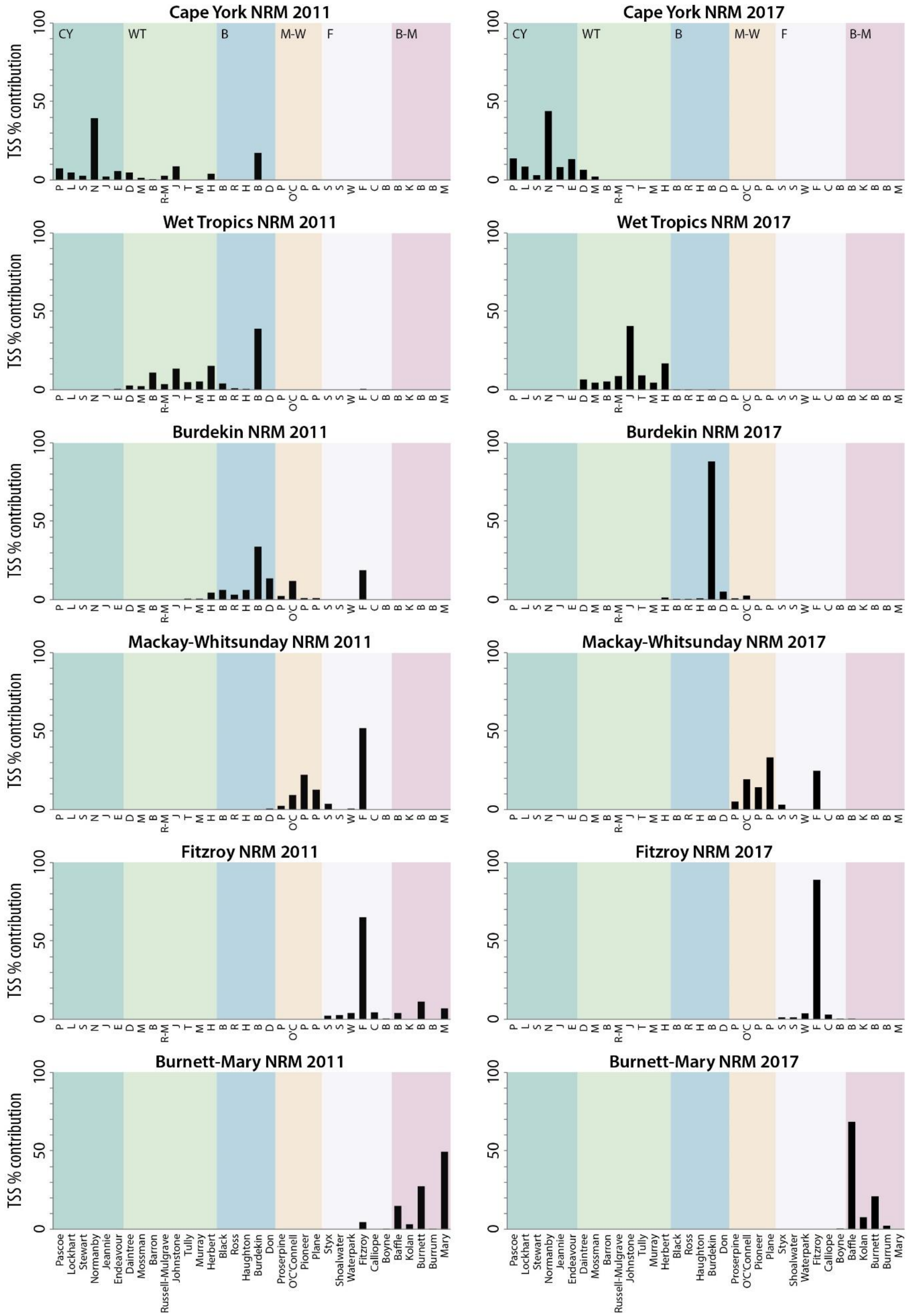


Figure 3-18: River contributions (x-axis) to the TSS loading in the six NRM regions. Shading groups rivers in the same NRM region: Cape York – dark green, Wet Tropics – light green, Burdekin – blue, Mackay Whitsunday – orange, Fitzroy – pink, Burnett Mary - red. The left panels show data for the 2010–11 water year (1 October to 30 September) and right panels for the 2016–17 water year.

3.4 Regional reports

The following sections provide detailed trend analysis of key water quality constituents and other environmental drivers within each region. For the Wet Tropics region, data are presented for sub-regions corresponding to major catchments.

Specifically, the information provided here is focused on identification and interpretation of inter-annual trends observed in the environmental attributes monitored. For each of the four focus regions, the following information is included and discussed:

- A map of the water quality monitoring locations and the water bodies.
- Time-series of the combined discharge from local rivers that influenced the region.
- Regional trends in key water quality parameters and the resultant trend in the Water Quality Index, based on ambient sampling. For the Cape York region, only this first year of results is available so the data is presented differently to the other focus regions.
- Zones of influence for major rivers (excluding Cape York).
- Weekly wet season colour class maps, exposure maps and an analysis of the wet season sampling in this context. For the Wet Tropics region, which contains three sub-regions, these results are presented at the end of the section.

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 where specific detail is required. These more detailed data summaries include:

- Table E-1: Summary of the relative annual discharge for the major GBR catchment rivers.
- Table E-2 (Cape York) and Table E-3 (Wet Tropics, Burdekin and Mackay Whitsunday): Summary statistics for each direct water sampling variable from each monitoring location, June 2016 to June 2017
- Table E-4: Annual summaries of direct water sampling data, August 2005 to June 2016 from inshore lagoon sites.
- Table E-5: Annual summaries of WET Labs ECO FLNTUSB Combination Fluorometer and Turbidity Sensor-derived turbidity for each monitoring location, presented with temperature in Figure E-1.
- Figure E-2: Time-series of temperature and salinity derived from the Sea-Bird Electronics (SBE) CTD profilers deployed at eight stations.
- Figure E-3 to Figure E-6: Temporal trends in water quality for the sub-regions including AIMS data only.
- Table E-6 to Table E-10: Summary of water quality data (collected as part of the JCU event sampling) across the wet season colour classes and water types for GBR-wide results and each focus area.
- Table E-11: Interim Water Quality Index for each water quality sampling location in 2015–16, calculated using wet and dry season samples.

The Wet Tropics region is divided into three sub-regions and results on the pressures and monitoring results are presented separately for each. However, the loading analysis and remote sensing products have been conducted at a regional scale and are presented at the end of Section 3.4.4.

The Cape York region is divided into four sub-regions: Endeavour Basin, Normanby Basin, Stewart River and Pascoe River. Results on the pressures and monitoring results are presented separately for each. Given that this is the first year of sampling in the Cape York region, some of the data is presented differently to the other focus areas.

3.4.1 Cape York region

Overview

Regional water quality monitoring by the MMP was commenced in the Cape York region in 2016–17. The Cape York region is influenced by discharge from several river systems, including the Endeavour Basin, Starke River, Normanby Basin, Stewart River, Jeannie River, Claudie River, Lockhart River and the Olive-Pascoe Basin. The marine waters adjacent to the Endeavour Basin, Normanby Basin, Stewart River and Pascoe River are monitored as part of the MMP. Sampling within Cape York was based on the revised MMP water quality sampling design implemented in 2015.Twenty-seven sites throughout four sub-regions (Figure 3-19) are sampled four to six times per year during ambient conditions. Up to 20 additional flood samples can be collected each year. The timing of ambient sampling is influenced by seasonal winds. Average wind strength from May to October exceeds 25 km/hour, restricting safe access to sampling locations in some areas (BOM, 2011). During November to April the wind speed decreases, so samples for the 2016–17 monitoring period began in January 2017 and ended in April 2017.

As the 2016–17 water year is the initial year of sampling for the Cape York Region, long-term trends have not been analysed. Concentrations of water quality parameters within each sub-region have been assessed relative to distance from river mouths and the results compared against the draft Eastern Cape York Water Quality Guidelines for the enclosed coastal, open coastal and mid-shelf zones (Honchin et al., 2017).

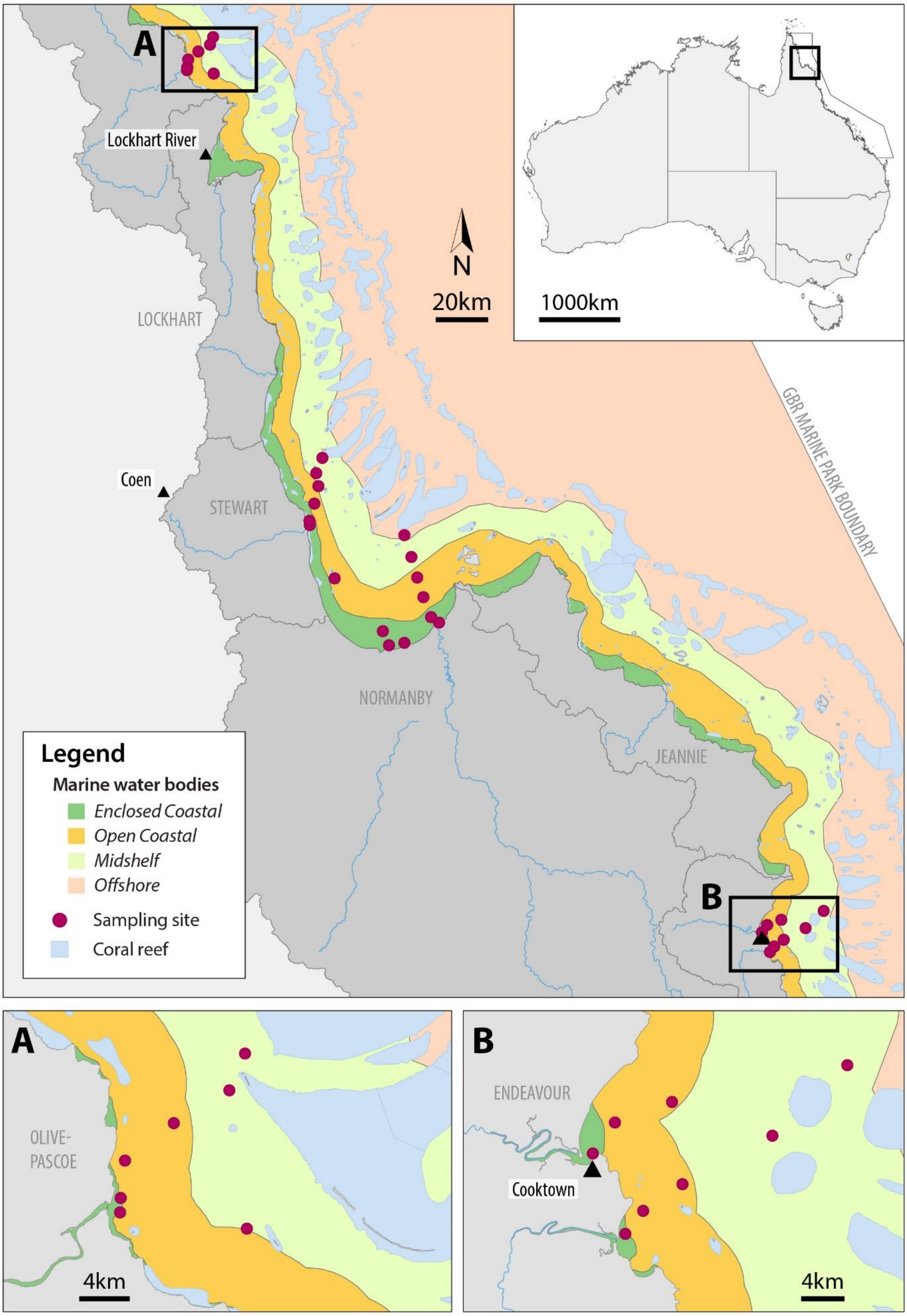


Figure 3-19: MMP water quality sampling sites in the Cape York region shown with water body boundaries.

Cape York region–Endeavour Basin

Overview

The Endeavour Basin is influenced by discharge from the Endeavour and Annan Rivers. The Basin has an area of 2,186 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. Sources of pollution (sediment, nutrients and toxicants) in the Endeavour catchment include the township of Cooktown located at the mouth of the Endeavour River, plus cattle grazing, horticulture and road erosion upstream. Historical mining disturbances, cattle grazing and road erosion are the primary sources of pollution to the Annan River (Shellberg et al., 2015).

Seven sampling stations for the Endeavour and Annan River are located along a transect from the river mouths to open coastal waters, representing a gradient in water quality (Figure 3-20). An eighth sample location, ER05, was discontinued after the initial sampling event due to the difficulty in accessing this location in prevailing weather conditions and distance from the coast; however, it may be sampled in the future under flood conditions. During the 2016–17 wet season, a total of 44 surface and subsurface samples were collected from the Annan and Endeavour transect over 3 days during ambient wet season conditions. Nineteen additional flood samples were collected over 3 days in February 2017 during the first and largest magnitude flood event of the wet season (Figure 3-21).

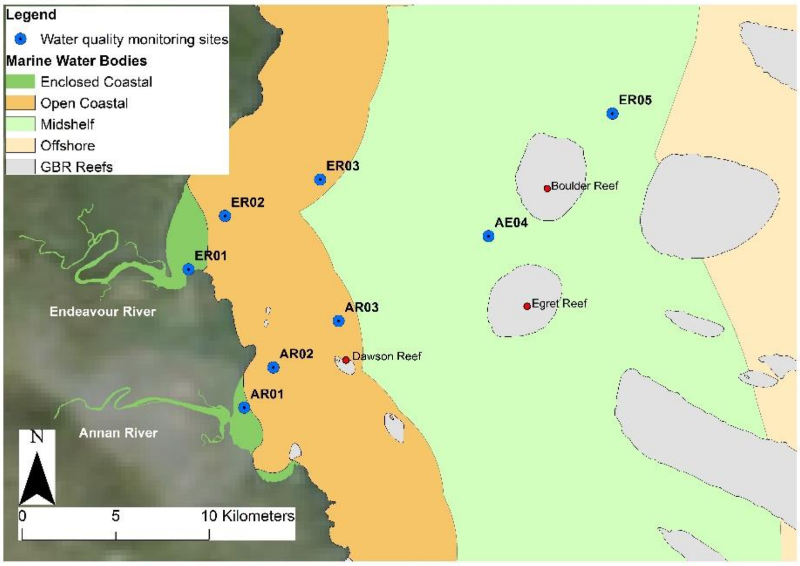


Figure 3-20: MMP sampling sites in the Endeavour Basin focus area with water body boundaries.

The total discharge from the Endeavour Basin for the 2016–17 water year was slightly above the long-term median discharge (Table 3-1, Figure 3-22). Rainfall for the Endeavour Basin was 1,570 mm for the 2016–17 water year, with 85% falling between January and April. This is close to the long-term average rainfall of 1,584 mm (https://water-monitoring.information.qld.gov.au/host.htm).

The combined discharge and loads calculated for the 2016–17 water year from the Endeavour Basin are shown in Figure 3-23, which were in the average range recorded over the previous 10 years (Table 3-1, Figure 3-22). Over the 11-year period from 2006, discharge has varied from 452,000 ML (2012–13) to 1,836,000 ML (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) and PN loads from 36 t (2012–13) to 147 t (2010–11).

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

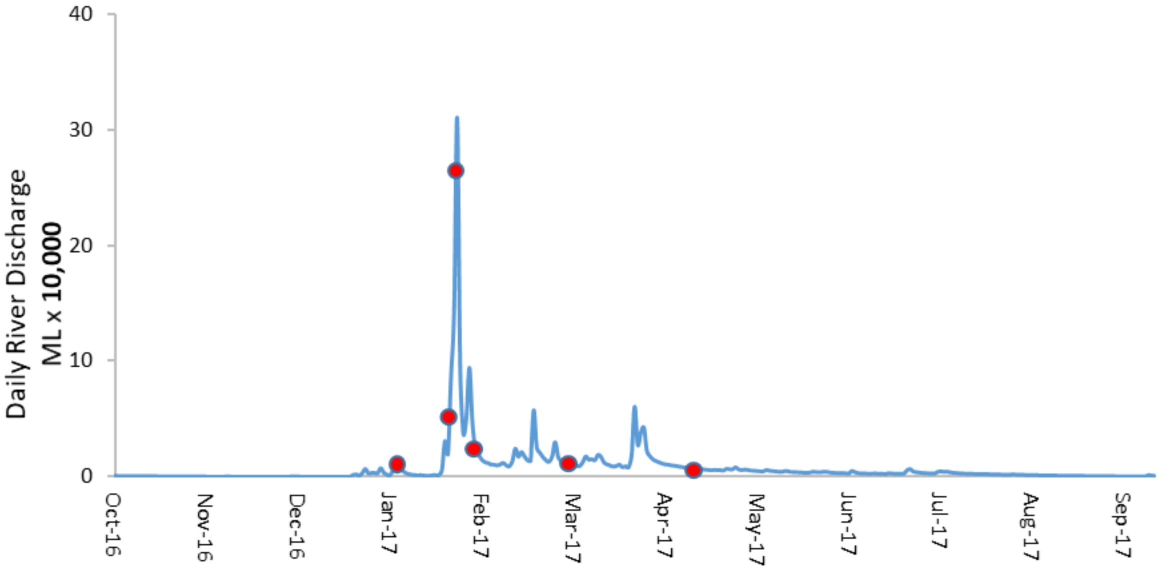


Figure 3-21: Daily discharge for the Annan River (gauge 107003A) for the 2016–17 wet season. Red dots represent sampling dates, including event sampling in February 2017.

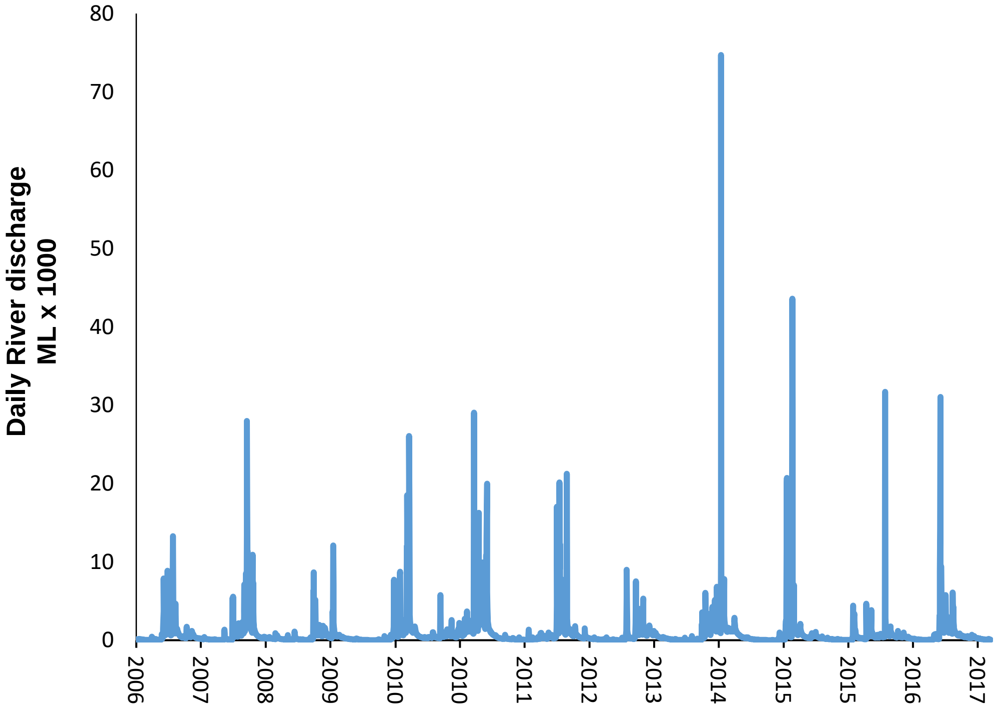


Figure 3-22: Long-term daily discharge for the Annan River (gauge 107003A).

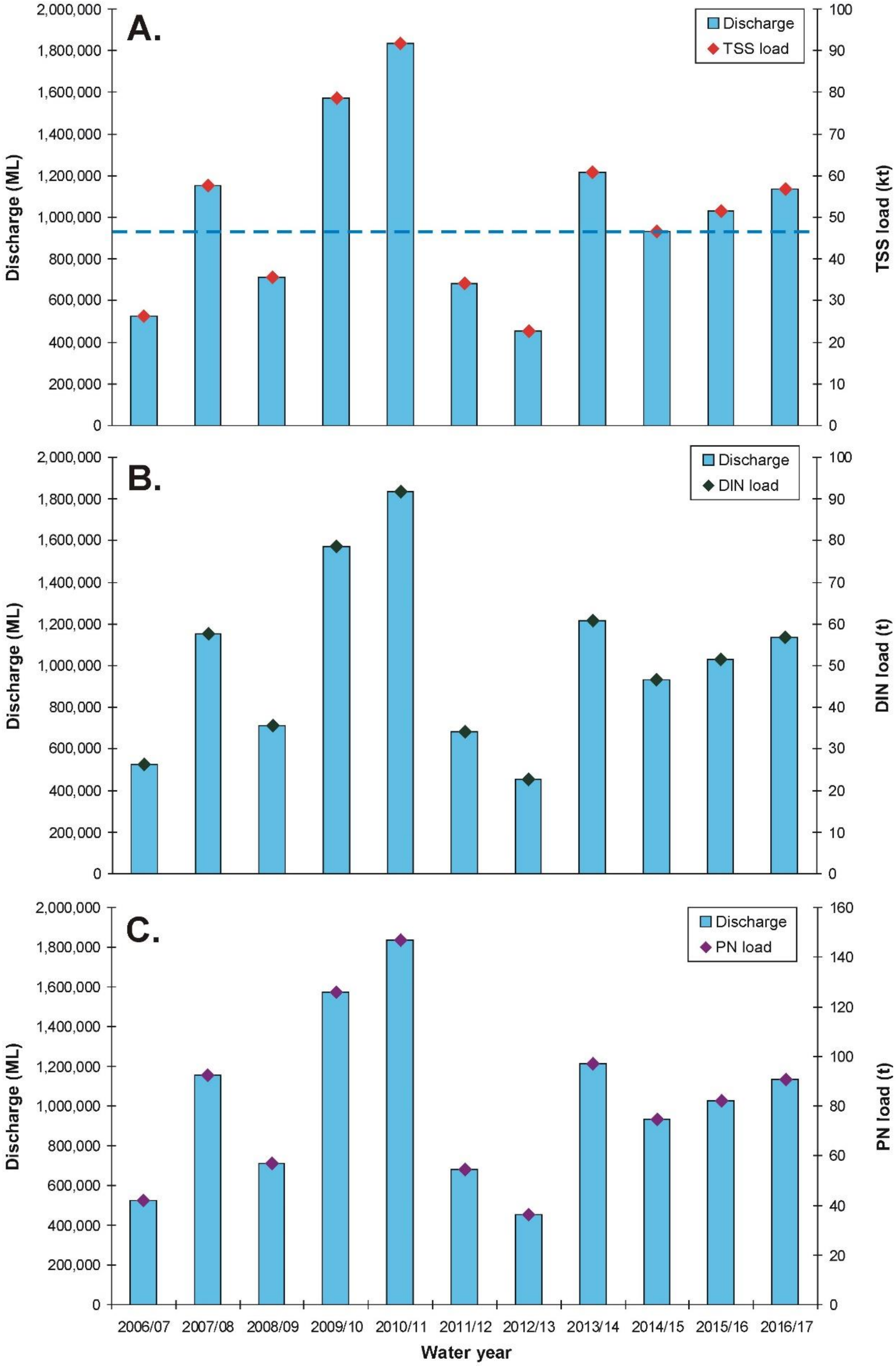


Figure 3-23. (A) Discharge and TSS, (B) DIN and (C) PN loads for the Endeavour Basin from 2006–07 to 2015–16. The loads reported here are based on the annual mean concentration reported in the Source Catchments modelling data and applied to each water year. Dotted line represents the long-term median for basin discharge.

The loading maps presented in Section 3.3 can also be assessed to determine the relative contribution of loads from each river to the Cape York NRM region. Figure 3-24 shows the estimated DIN and TSS contributions for the Cape York region in 2010–11 and 2016–17. According to the model, the Wet Tropics rivers contributed substantially to the DIN and TSS loadings in the Cape York NRM region in 2010–11, with small contributions from the Daintree (7%) and Mossman (2%) Rivers still evident in the comparably low discharge year of 2016–17. The model also predicted influence from the Burdekin River in the large event of 2010–11 although the extent of influence may be overestimated due to an underestimation of actual loads from Cape York rivers (see Howley, 2016). The largest contributions to the DIN and TSS loadings in 2016–17 were from the Normanby River (29% and 44%, respectively). The Pascoe and Endeavour Rivers also contributed 14% each to the regional TSS loading.

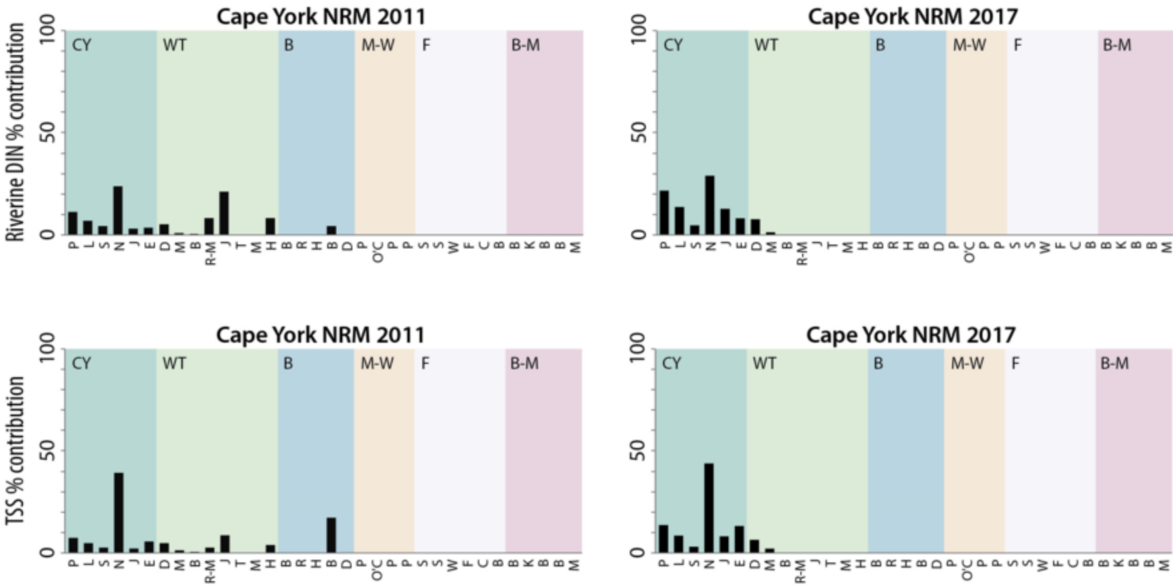


Figure 3-24. River contributions (x-axis, fully labelled in Figure 3-15) to the (top) DIN and (bottom) TSS loadings to the Cape York NRM region in 2010–11 (left column) and 2015–16 (right column). Shading groups rivers in the same NRM region: Cape York – dark green, Wet Tropics – light green, Burdekin - blue, Mackay Whitsunday – orange, Fitzroy – pink, Burnett Mary - red.

Ambient water quality

The assessment of water quality parameters based on distance from river mouth (Figure 3-25) showed that concentrations of NH_3 (ammonia), Chl-a, NO_x (nitrogen oxides), PN, PP, TSS, DON, DOP and DIN decreased with distance from the Annan and Endeavour Rivers. Secchi depth increased over distance from the river mouth (Figure 3-25).

Analyses of wet season sampling results against East Cape York regional guidelines (Table E-2) show that concentrations of NO_x (20th percentile only), NH_3 and filterable reactive phosphorus (FRP) in enclosed coastal waters exceed the draft Water Quality Guidelines for Cape York base flow conditions. In the open coastal zone, concentrations of NH_3, NO_x, FRP and TSS exceed the wet season guidelines. Secchi depth results for open coastal waters are analysed against an annual mean guideline, which was exceeded in 2016–17 sampling; however, the samples from this Basin were all collected during the wet season therefore may not be representative of an annual mean. In the mid-shelf region, TSS, NH_3, NO_x and FRP concentrations exceeded the guidelines; however, the mid-shelf guidelines are also for annual percentiles, whereas samples in this sub-region were only collected during the wet season.

No sampling was conducted during the dry season for the Endeavour Basin.

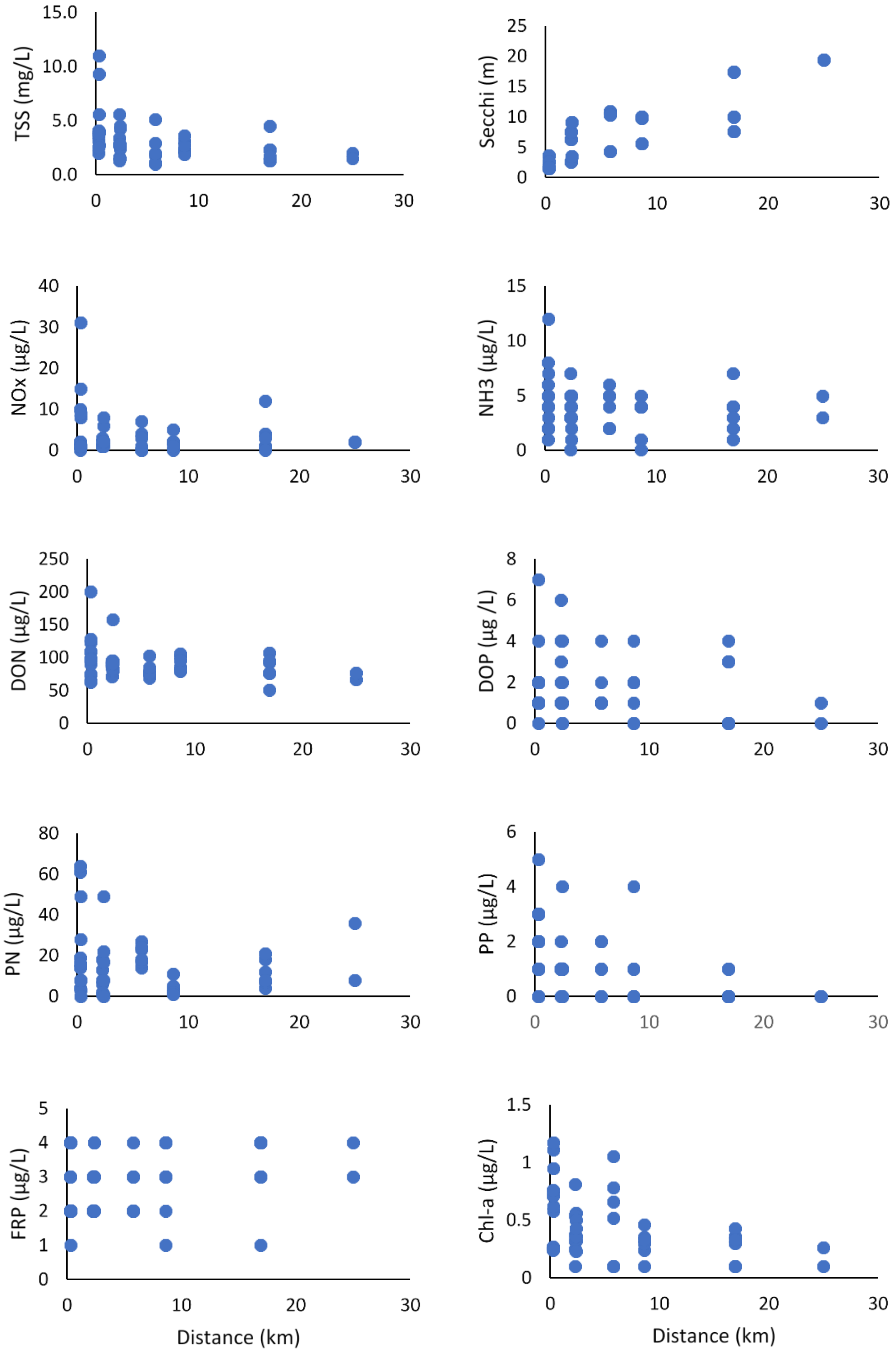


Figure 3-25: Water quality concentrations (surface and subsurface samples) and Secchi depth over distance (km) from river mouth for the Endeavour Basin sub-region. The Water Quality Index has not been calculated for Cape York due to the lack of long-term data.

Event water quality

Additional flood samples were collected over 3 days during the first and largest magnitude flood event of the wet season on 3, 6 and 8 February 2017 (Figure 3-21). The results for these samples are shown in Figure 3-26.

Figure 3-26 (top panel) shows the slow decline of the TSS concentrations over the salinity gradient for the flood plume sampled over 3 days (3, 6 and 8 February 2017). The TSS concentrations were highest during the initial mixing stages of the plume (200 and 180 mg L^{-1} in the 0.20 and 0.50 PSU reaches, respectively). The outer reaches of the plume had TSS concentrations less than 4 mg L^{-1} at 32–-33 PSU and a sample outside the visible plume boundary yielded a TSS concentration of 2.7 mg L^{-1} at 33.6 PSU.

In contrast, Chl-a levels generally increased over the salinity gradient as TSS concentrations declined allowing greater light for primary production (Figure 3-26, bottom panel). This is a commonly observed trend for flood plumes across the GBR (Devlin and Brodie, 2005).

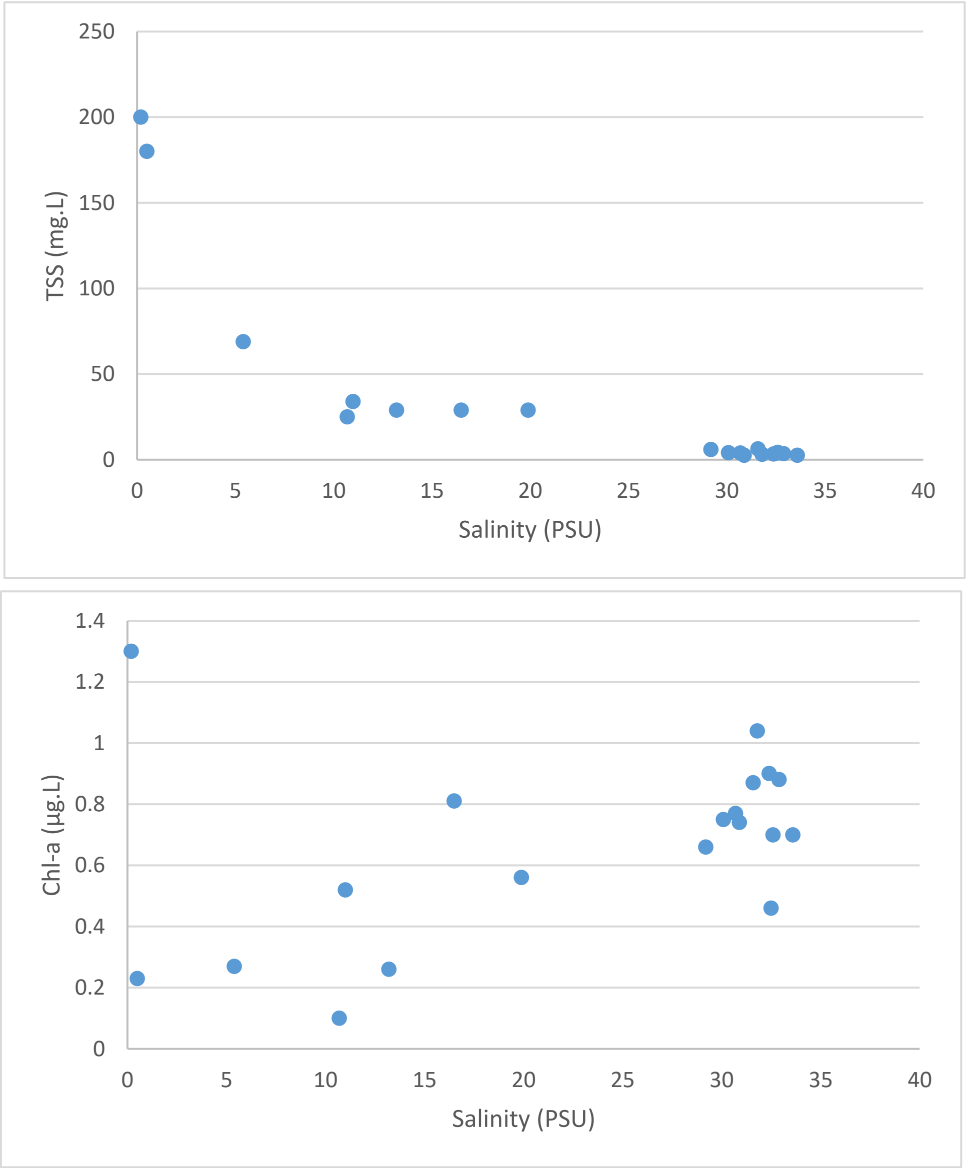


Figure 3-26: TSS concentrations (top) and Chl-a concentrations (bottom) over the salinity gradient for the Annan-Endeavour transect on 3, 6 and 8 February 2017.

Cape York Region–Normanby Basin

Overview

The Normanby Basin is influenced by discharge from the Normanby, Laura, Kennedy, Hann, Mossman, Morehead and Annie Rivers, plus three distributaries—the North Kennedy, Normanby and Bizant. The 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), with additional lands shifting from grazing to conservation in recent years. Current and former cattle grazing, land clearing for agricultural development and road construction and maintenance are the primary pressures affecting water quality (sediment 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).

Six of ten sampling stations for the Normanby Basin are located along a transect from the Normanby river mouth to open coastal waters (Figure 3-27). Two additional samples are located near the Kennedy River and Bizant River mouths. These eight sampling stations were sampled only once during ambient wet season conditions in 2016–17 but will be sampled up to four times in future years. Sample locations CL-01 and KR02 were not sampled during the 2016–17 wet season.

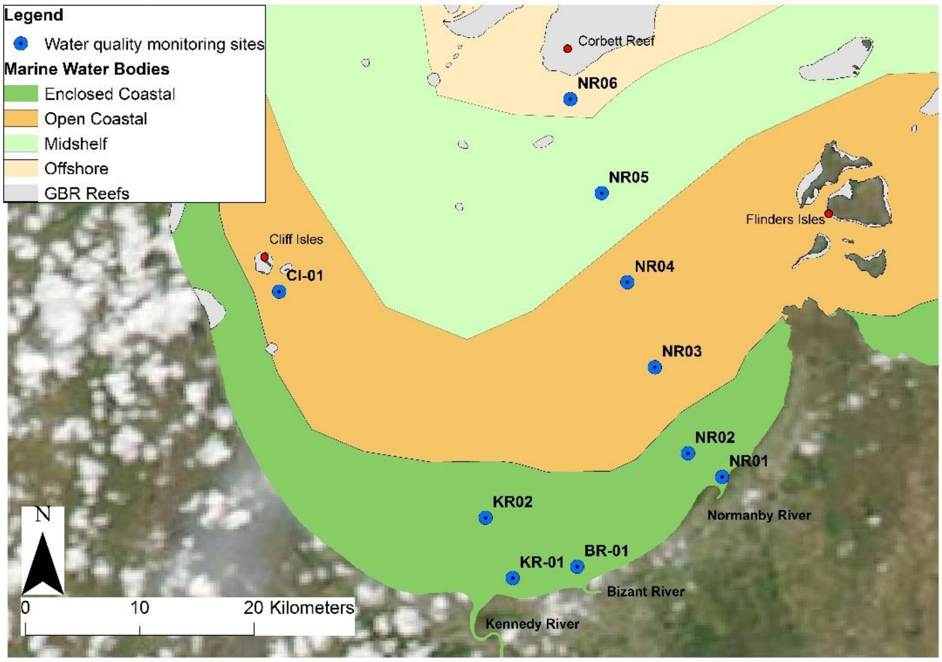


Figure 3-27: MMP water quality sampling sites in the Normanby Basin focus area with water body boundaries.

Long term daily discharge measured at the Normanby River gauge 105107A (at Kalpowar Crossing located approximately 70 km upstream from the mouth) is shown in Figure 3-28. Total discharge for the 2016-17 water year was approximately 1,990 GL with 98% of discharge between the months of January and April (Figure 3-29; 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. However, “whole of Basin” discharge volumes have been estimated in Figure 3-30 based on discharge measured at the Kalpowar gauge upscaled to the entire Basin area.

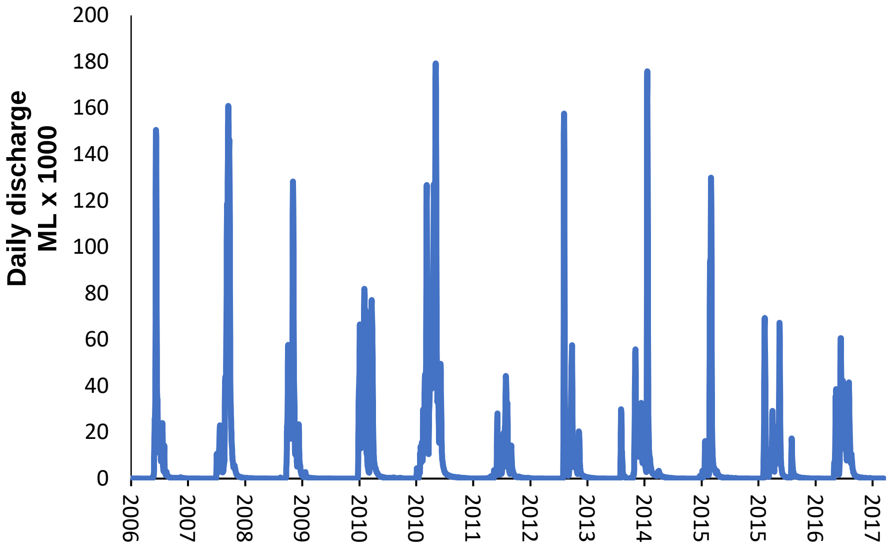


Figure 3-28: Long-term daily discharge for the Normanby River (Kalpowar gauge 105107A).

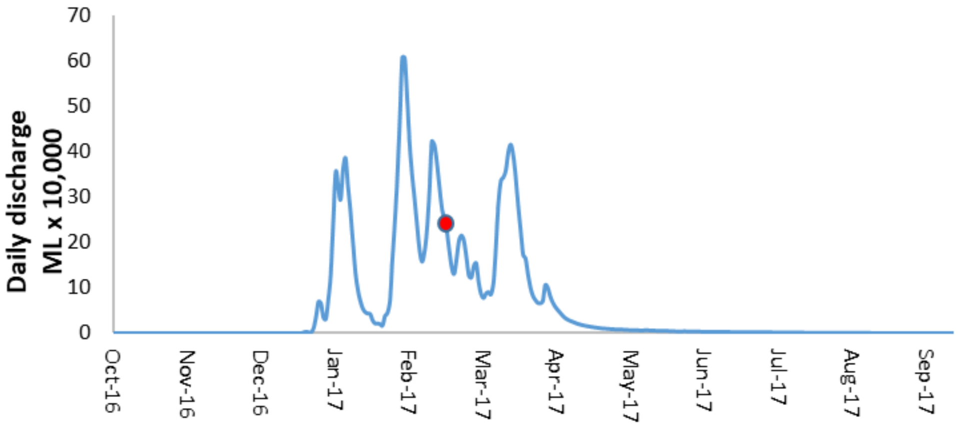


Figure 3-29: Daily discharge for the Normanby River (gauge 105107A) for the 2016–17 water year. Red dot represents sampling date.

The combined discharge and loads calculated for the 2016–17 water year from the Normanby Basin are shown in Figure 3-30. The combined discharge and loads calculated for the 2016–17 water year from the Normanby Basin were in the lower range recorded over the past 10 years. The past three water years all had very similar discharge and TSS and PN loads. Over the 11-year period from 2006, discharge has varied from 2,182,000 ML (2011–12) to 11,333,000 ML (2010–11), TSS loads have ranged from 55 kt (2014–15) to 509 kt (2010–11), DIN loads from 42 t (2011–12) to 270 t (2010–11) and PN loads from 124 t (2009–10) to 1,184 t (2013–14).

Figure 3-24 shows that the Normanby River was the greatest contributor to the river-derived DIN and TSS loading in the Cape York region in 2016–17. 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).

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

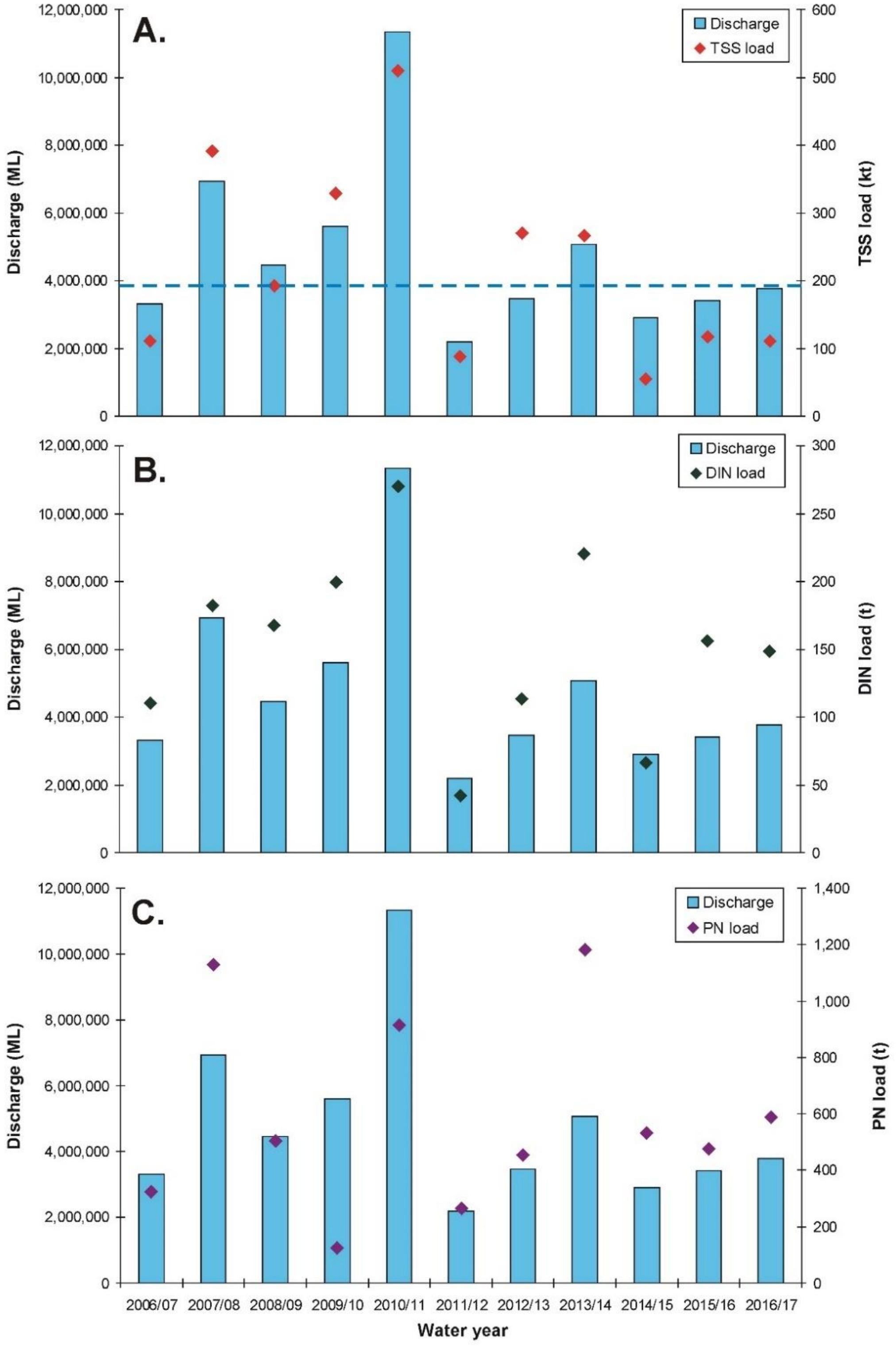


Figure 3-30: (A) Discharge and TSS, (B) DIN and (C) PN loads for the Normanby Basin from 2006–07 to 2016–17. The loads reported here are a combination of 'best estimates' based on 'up-scaled' discharge and monitoring data from the Normanby River at Kalpower gauging station (covers ~50% of the basin area). Dotted line represents the long-term median for basin discharge.

Ambient water quality

The Normanby results represent one sampling event during the wet season, conducted during a period of rain and freshwater discharge that influenced samples close to the river mouths. As a result of this freshwater influence, concentrations of NH_3, Chl-a, FRP, PP, TSS, DON and DIN decrease over distance from the river mouths (Figure 3-31). PN also shows a general decrease in concentrations over distance, except for one data point showing an increase at 40 m. Secchi depth increased over distance from the river mouths, whereas DOP showed no distinguishable changes. Both maximum and minimum NO_x concentrations were measured at sample locations closest to the river mouths.

Analyses of variables against East Cape York regional guidelines for wet season sampling (Table E-2) show concentrations of NH_3 (80th percentile only) and FRP in enclosed coastal waters exceed the guidelines. The Normanby Basin enclosed coastal waters guidelines are based on targets for a 10% reduction of current conditions, therefore it is not surprising that the actual concentrations exceed these targets. Concentrations of Chl-a, FRP, PP and TSS in the open coastal zone exceed the wet season guidelines. Secchi depth and NH_3 in open coastal waters are analysed against an annual mean that was also exceeded; however, the one wet season sampling event at the Normanby sub-region is not likely to represent mean annual conditions. For the mid-shelf zone samples, Chl-a, NH_3 (20th percentile only), NOx, FRP, PP and TSS concentrations and Secchi depths exceeded the annual Water Quality Guidelines. As with Secchi depth and NH_3 in the open coastal zone, this is not surprising as the wet season results are not likely to represent annual conditions.

No sampling was conducted during the dry season for the Normanby Basin.

Event water quality

No specific event sampling was conducted for the Normanby transect.

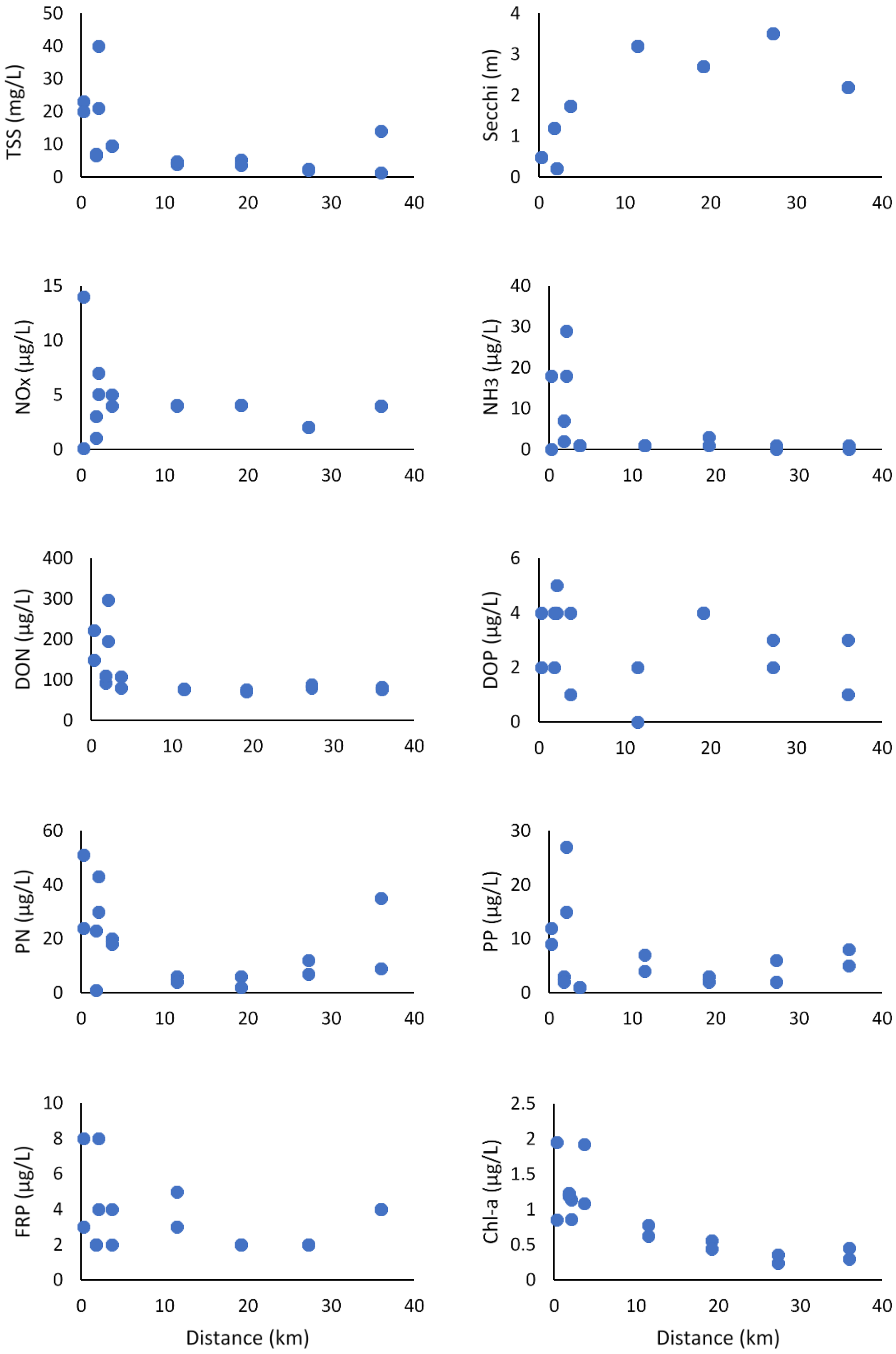


Figure 3-31: Water quality concentrations (surface and subsurface samples) and Secchi depth over distance (km) from river mouth for the Normanby Basin sub-region. The Water Quality Index has not been calculated for Cape York due to lack of long-term data. Single points at some distances (i.e., FRP, NO_x, DON) represent two sample points (surface and subsurface) with same concentration.

Cape York Region–Stewart River

Overview

The Stewart River transect is influenced primarily by discharge from the Stewart River, although during flood conditions it can be influenced by floodwater from the Normanby and Kennedy Rivers. The Stewart River catchment has an area of 2,770 km^2 and is mostly nature/conservation land use (94%) with approximately 2% grazing (QLUMP, 2015). Cattle grazing and road erosion are current pressures affecting sediment loads within the catchment.

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 3-32). These sampling stations were sampled only once during the 2016–17 wet season during ambient conditions, although there had been some rain preceding the March sampling event, which affected water quality conditions in the enclosed coastal zone.

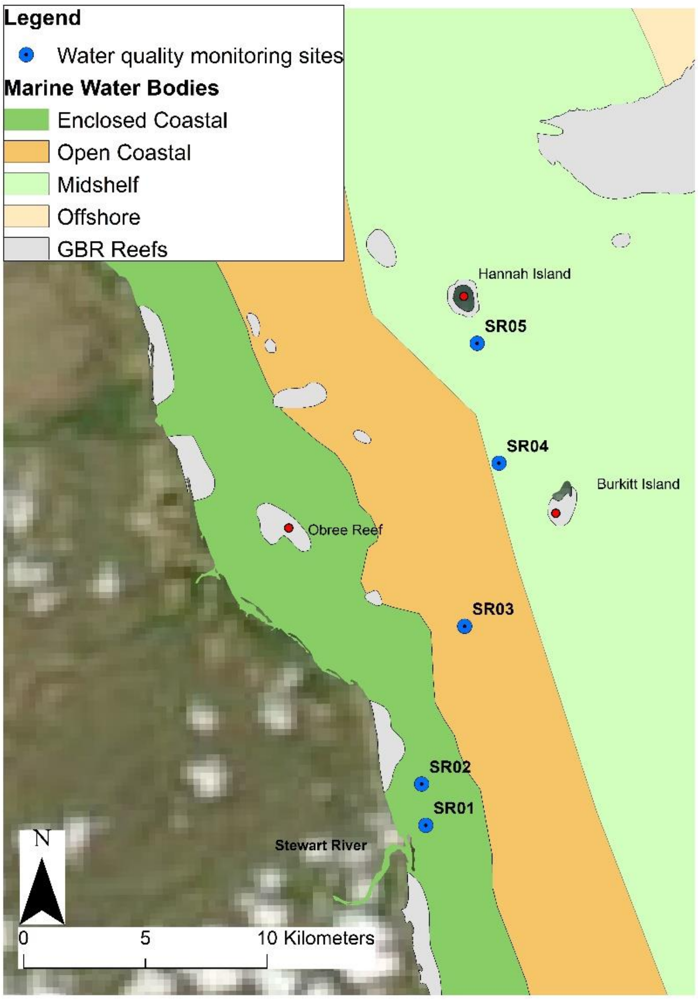


Figure 3-32: MMP water quality sampling sites in the Stewart River transect with water body boundaries.

Over the period of 2010 to 2017, annual discharge for the Stewart River has fluctuated above and below the long-term median discharge level (Table 3-1, Figure 3-33). The total annual discharge for 2016–17 water year (685 GL) was also the long-term median annual discharge volume (Table 3-1) with 99% of discharge occurring during the wet season from the end of December through to April (Figure 3-34).

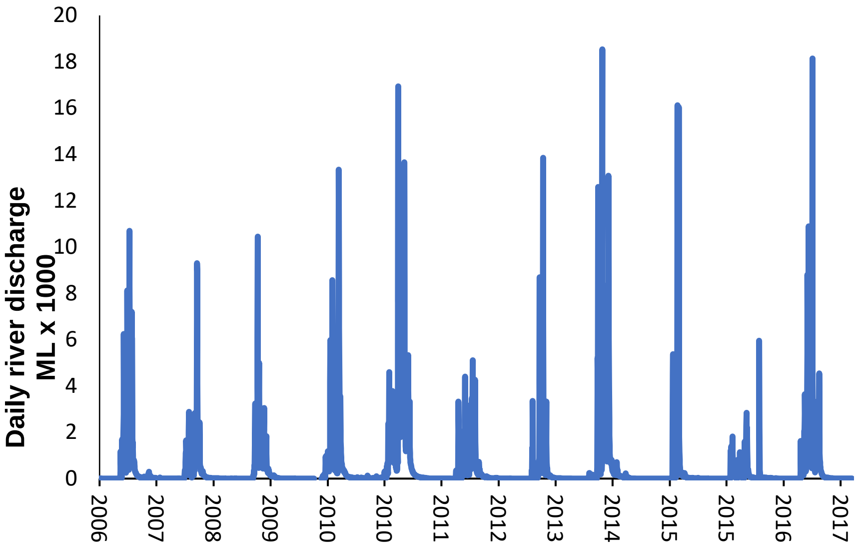


Figure 3-33: Long-term daily discharge for the Stewart River (gauge 104001A).

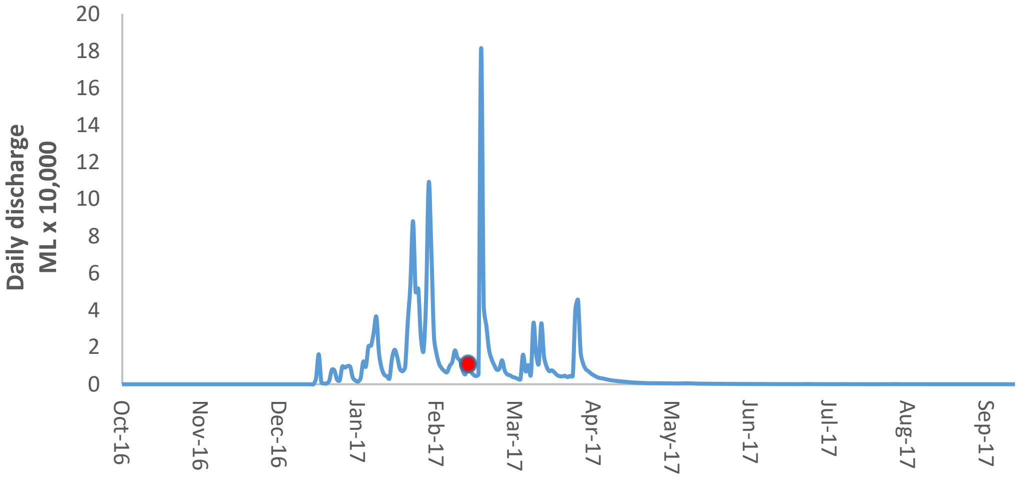


Figure 3-34: Daily discharge for the Stewart River (gauge 104001A) for the 2016–17 water year. Red dot represents sampling date.

The combined discharge and loads calculated for the 2016–17 water year from the Stewart Basin are shown in Figure 3-35. The discharge and loads calculated for the 2016–17 water year from the Stewart Basin were in the average range recorded over the previous 10 years. Over the 11-year period from 2006, discharge has varied from 299,000 ML (2014–15) to 2,181,000 ML (2010–11), TSS loads have ranged from 6 kt (2014–15) to 44 kt (2010–11), DIN loads from 15 t (2014–15) to 109 t (2010–11) and PN loads from 18 t (2015–16) to 131 t (2010–11).

Figure 3-24 shows that the Stewart River contributed less than 5% to the river-derived DIN and TSS loading in the Cape York region in 2016–17.

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

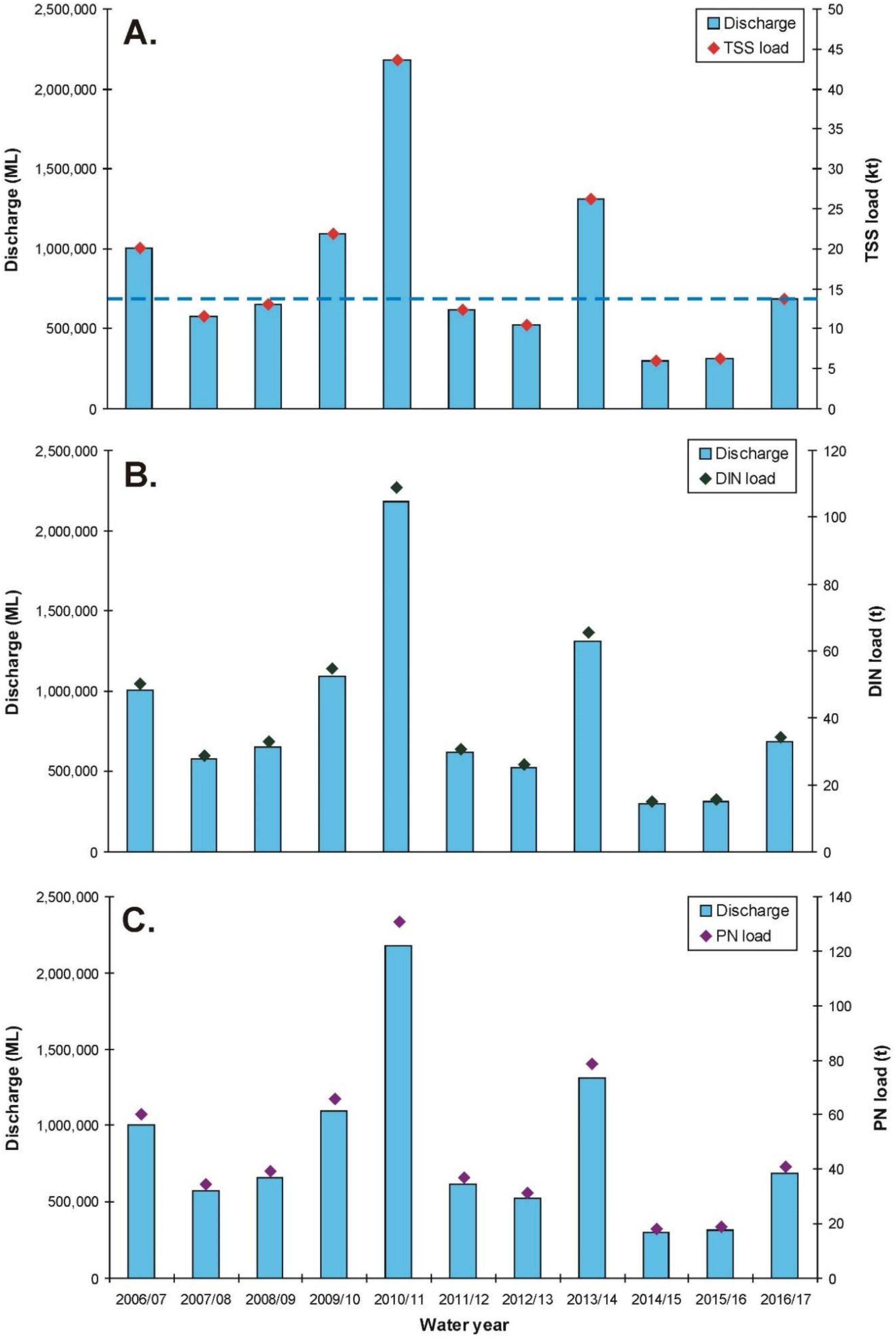


Figure 3-35. (A) Discharge and TSS, (B) DIN and (C) PN loads for the Stewart Basin from 2006–07 to 2015–16. The loads reported here are based on the annual mean concentration reported in the Source Catchments modelling data and applied to each water year. Dotted line represents the long-term median for basin discharge.

Ambient water quality

During the one wet season sampling event at the Stewart River transect, concentrations of Chl-a, PN, TSS and DON decreased over distance from the river mouth while DOP and Secchi depth increased over distance from the river mouth. Concentrations of NH_3, NO_x, FRP, PP and DIN showed no distinguishable changes (Figure 3-36).

Analyses of variables against East Cape York regional guidelines for wet season sampling (Table E-2) show concentrations of Chl-a (20th percentile only), NO_x and FRP in enclosed coastal waters exceed the baseflow guidelines. Open coastal concentrations of Chl-a (20th percentile only), TSS, NO_x and FRP exceed the wet season guidelines for this zone. Chl-a in open coastal waters exceeds in the 20th percentile only. Secchi depths for open coastal waters are analysed against an annual mean guideline, which was exceeded in the 2016-17 sampling; however, the one wet season sampling event at the Stewart River sub-region is not likely to represent mean annual conditions. In the mid-shelf region, mean concentrations of NO_x, FRP, Chl-a and TSS also exceeded the annual guidelines.

No sampling was conducted during the dry season for the Stewart River.

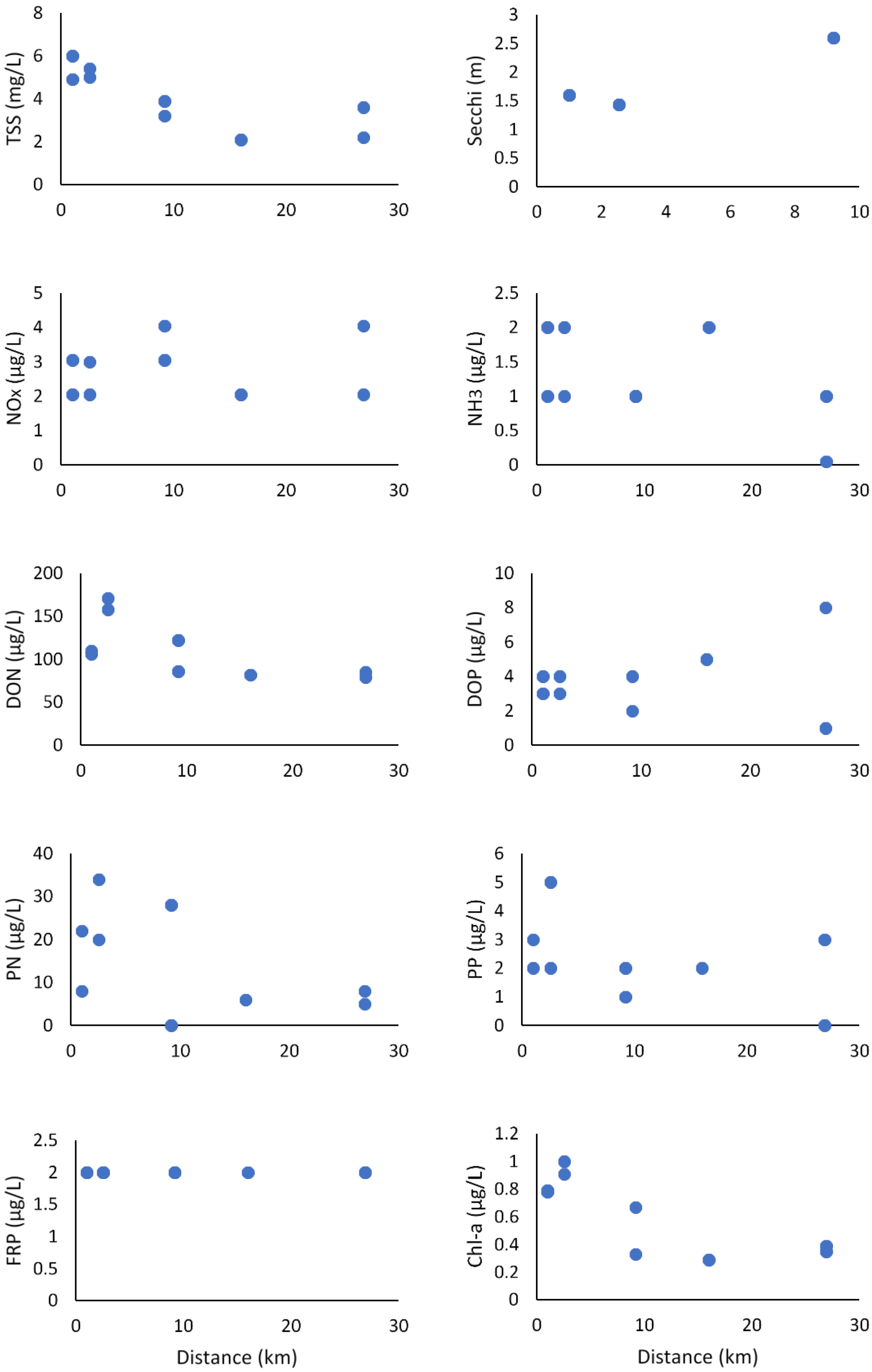


Figure 3-36: Water quality concentrations (surface and subsurface samples) and Secchi depth over distance (km) from river mouth for the Stewart River sub-region. The Water Quality Index has not been calculated for Cape York due to lack of long-term data. Single points at some distances (i.e., FRP) represent two sample points (surface and subsurface) with the same concentration.

Cape York Region–Pascoe River

Overview

The Olive-Pascoe Basin is comprised of the Pascoe River and the Olive River. The Pascoe River has an area of 2,088 km^2 with a high proportion of nature/conservation land use (84%) with some closed grazing (15%) (QLUMP, 2015). The Olive River has an area of 2,084km^2 with 73% nature/conservation land use and 26% grazing. Cattle grazing and road erosion are current pressures affecting water quality; however, the impacts are considered to be minimal in this sub-region and marine waters are considered to be of High Environmental Value (Cape York NRM and South Cape York Catchments, 2016).

Six sampling stations for the Olive-Pascoe Basin are located along a transect from the mouth of the Pascoe River to open coastal waters, representing a gradient in water quality (Figure 3-37). A seventh station at Middle Reef (locally known as Blue Bells) (PR-BB) was discontinued after the initial sampling event due to difficulties with access (weather conditions and travel time), but may be re-sampled during flood events that flow east. The Pascoe transect stations were sampled once during ambient wet season conditions and once during the dry season in 2017.

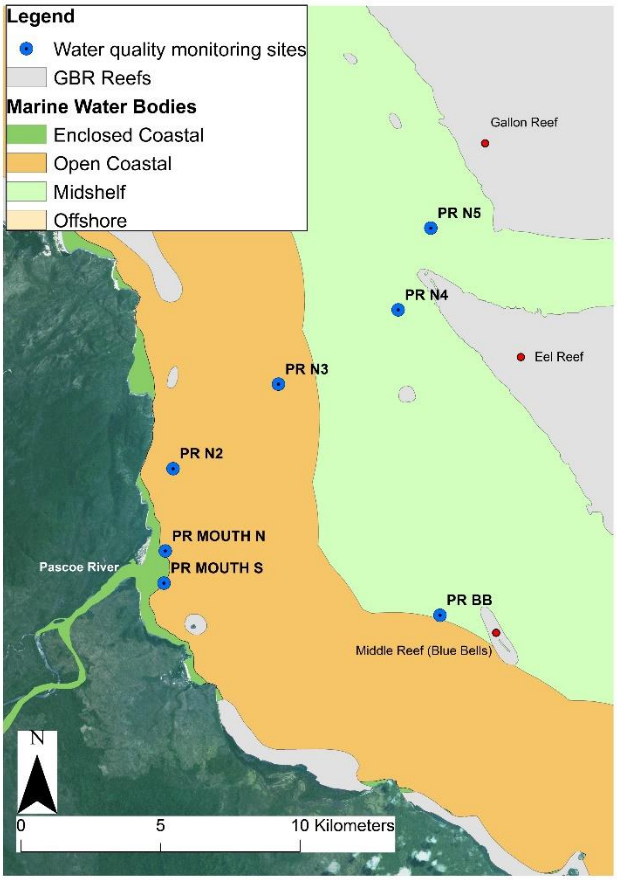


Figure 3-37: MMP water quality sampling sites in the Pascoe River transect with water body boundaries.

Over the period 2010 to 2017, annual discharge for the Olive-Pascoe Basin has fluctuated above and below the long-term median discharge (Table 3-1, Figure 3-38 and Figure 3-39). The annual discharge for the 2015–16 water year was less than half the long-term annual median discharge volume (2,570 GL), whereas the total discharge in the 2016–17 water year was above the long-term median (Table 3-1). Total discharge for the Olive-Pascoe Basin over the 2016–17 water year was estimated as 2,979 GL (Table 3-1), with 993 GL discharge recorded at the Pascoe gauge site 102102A, of which 93% occurred between December and April (Figure 3-39).

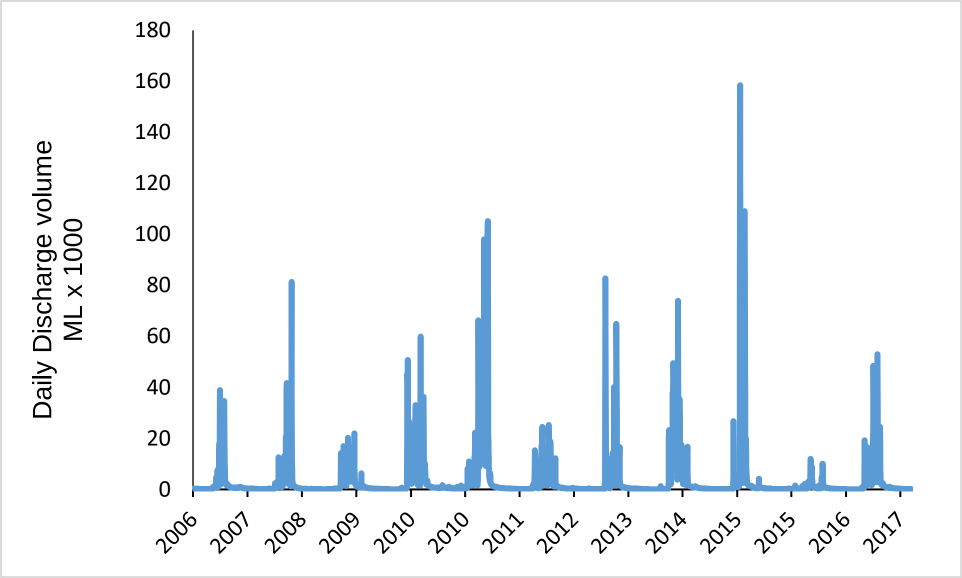


Figure 3-38: Long-term daily discharge for the Pascoe River (gauge 102102A).

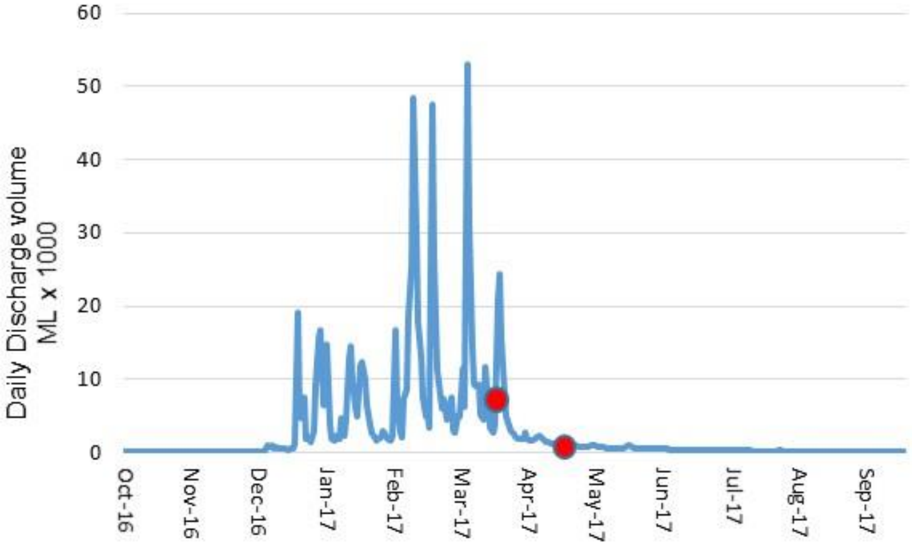


Figure 3-39: Daily discharge for the Pascoe River (gauge 102102A) for the 2016–17 water year. Red dots represent sampling dates.

The combined discharge and loads calculated for the 2016–17 water year from the Pascoe Basin are shown in Figure 3-40. The loads calculated for the 2016–17 water year from the Pascoe catchment (does not include the Olive catchment) were in the upper range recorded over the past 10 years. Over the 11-year period from 2006, discharge has varied from 425,000 ML (2015–16) to 3,191,000 ML (2010–11), TSS loads have ranged from 20 kt (2015–16) to 147 kt (2010–11), DIN loads from 30 t (2014–15) to 229 t (2010–11) and PN loads from 55 t (2015–16) to 414 t (2010–11).

Figure 3-24 shows that the Pascoe River had the second largest contributions to the regional river-derived DIN (22%) and TSS (14%) loading in the Cape York region in 2016–17.

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

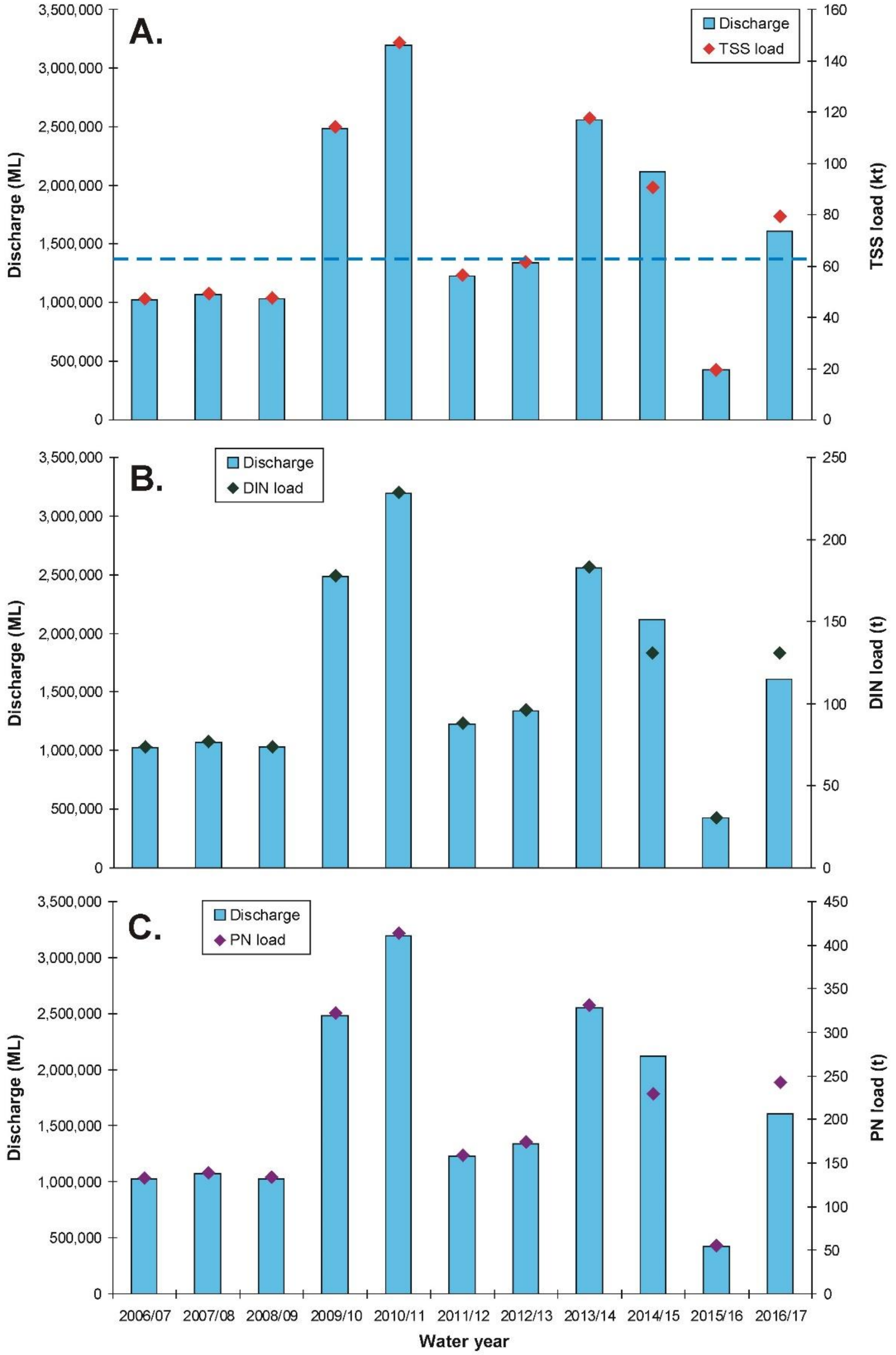


Figure 3-40: (A) Discharge and TSS, (B) DIN and (C) PN loads for the Pascoe catchment (note Pascoe catchment only, does not include Olive catchment) from 2006–07 to 2016–17. The loads reported here are a combination of ‘best estimates’ based on ‘up-scaled’ discharge data from gauging stations and monitoring 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.

Ambient water quality

Concentrations of PN and TSS in the Pascoe River transect decrease over distance from the river mouth. Secchi depth increased over distance from the river mouth. NH_3, Chl-a, NO_x, FRP, PP, DOP, DON and DIN show no distinguishable patterns in concentration in relation to distance from the river (Figure 3-41).

One wet season (April 2017) and one dry season (May 2017) sampling event occurred in this sub-region. The Water Quality Guidelines for Cape York vary due to the available datasets, with some zones split into wet season and dry season guidelines while others only have baseflow or annual guidelines (Table E-2). Results from the Pascoe transect wet season sampling event are compared against wet season guidelines for the open coastal zone, whereas the combined results are compared with annual and baseflow guidelines from the enclosed coastal and mid-shelf zones, plus NH_3 and Secchi depth in the open coastal zone. Dry season results are compared against dry season guidelines for the open coastal zone. Comparison of the combined wet and dry season results from the Pascoe sub-region enclosed coastal waters against regional baseflow Water Quality Guidelines show concentrations of NO_x and FRP exceeding the guidelines. Open coastal wet season concentrations exceeded the wet season guidelines for Chl-a, NO_x, FRP and TSS. Dry season open coastal zone Chl-a, NO_x, FRP and TSS concentrations also exceeded the dry season guidelines. Combined (wet and dry season) NH_3 concentrations exceeded the annual guidelines and the mean Secchi depth (5.1 m) was less than the annual mean guideline (≥ 10 m) for open coastal waters. In the mid-shelf region, combined wet and dry season results for Chl-a, NO_x, NH_3, FRP and TSS all exceeded the annual Water Quality Guidelines. Mean combined (wet and dry season) Secchi depth in the mid-shelf region was also less than the annual guideline.

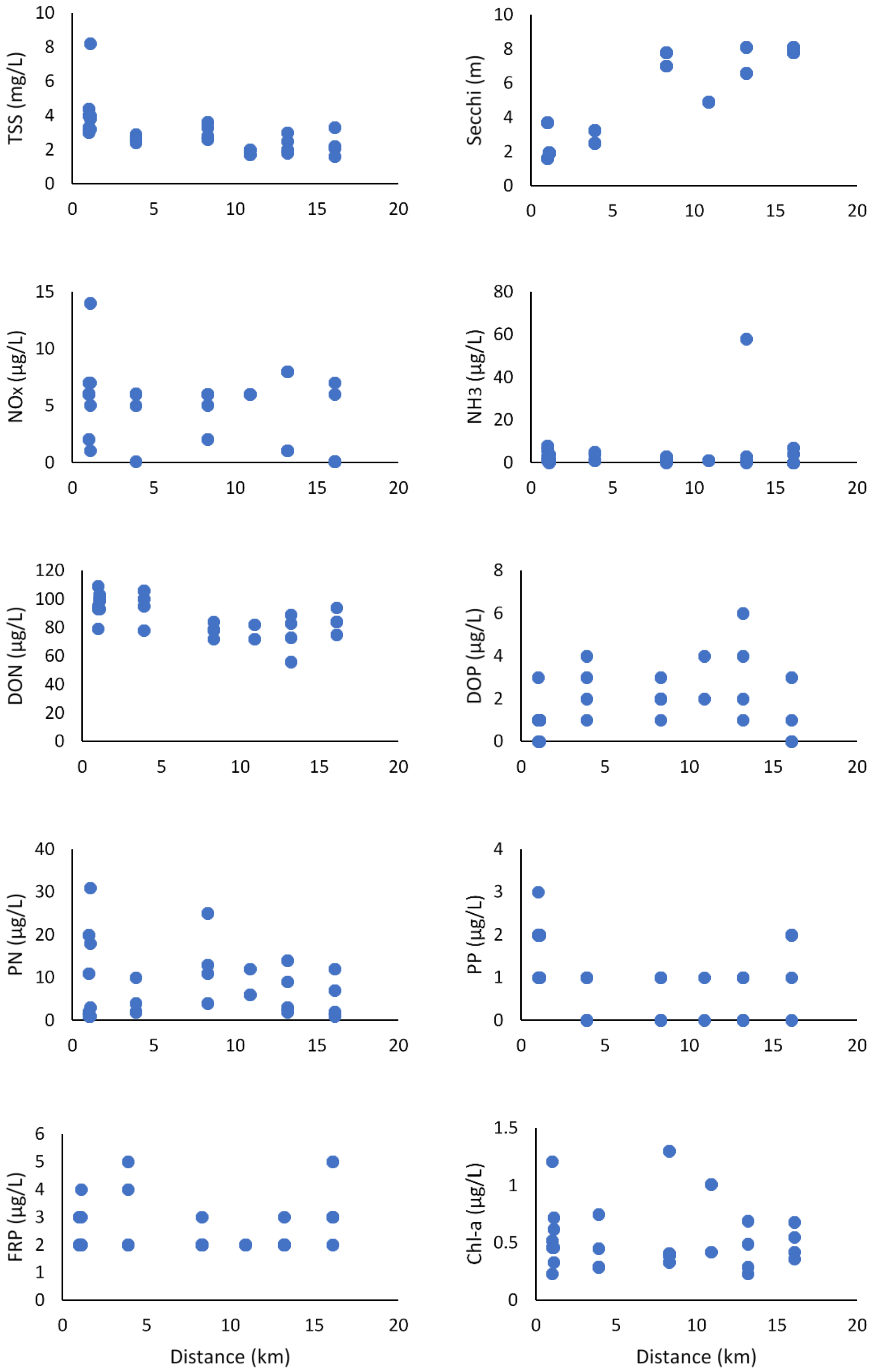


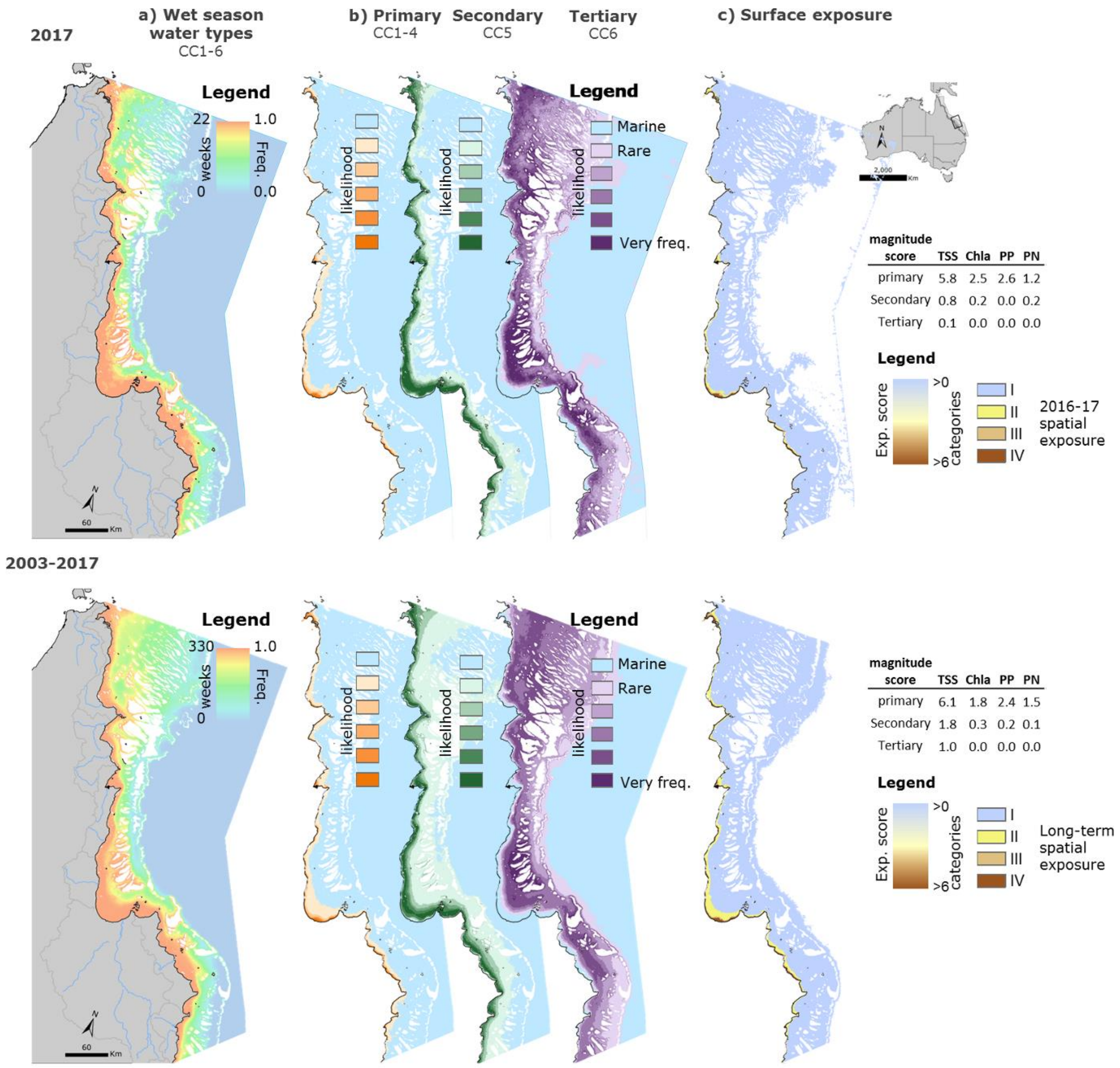
Figure 3-41: Water quality concentrations (surface and subsurface samples) and Secchi depth over distance (km) from river mouth for the Pascoe River sub-region. The Water Quality Index has not been calculated for Cape York due to lack of long-term data.

Cape York Region: Mapping wet season conditions

As described in Section 2.7, a number of mapping products are 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 3-42 and in a panel of weekly characteristics throughout the 22 week wet season period (Figure 3-43 and Figure 3-44). Details included 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; and the weekly wet season water type maps showing the six wet season colour classes.

Figure 3-42 (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 2016–17 wet season. Table 3-4 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 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 (2003–2017) in Figure 3-42 (bottom) with the areas and percentage of exposure summarised in Table 3-4 (numbers in brackets).



magnitude score	TSS	Chla	PP	PN
primary	5.8	2.5	2.6	1.2
Secondary	0.8	0.2	0.0	0.2
Tertiary	0.1	0.0	0.0	0.0

magnitude score	TSS	Chla	PP	PN
primary	6.1	1.8	2.4	1.5
Secondary	1.8	0.3	0.2	0.1
Tertiary	1.0	0.0	0.0	0.0

Figure 3-42: 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 2016–17 wet season (top).

In 2016–17, the Cape York region was most affected by the lowest exposure categories (categories I and II), in agreement with the long-term trends. Approximately 56% of the total area of the Cape York region was exposed to wet season water types (Primary, Secondary and Tertiary combined) during at least one week of the wet season. This area was similar to the long-term area (Table 3-4: 55% exposed to wet season water types). However, only 0.3% of the Cape York region was exposed to each of the higher exposure categories III and IV. These areas were similar to the long-term areas (0.4% exposed to category III and 0.4% to category IV).

In 2016–17, it was estimated that:

- A total of 97% of Cape York coral reefs were influenced by wet season water types (Primary, Secondary and Tertiary combined) during at least one week of the wet season. However, only 0.03% and 0.02% of corals were in the highest exposure categories III and IV.

- A total of 99% of the Cape York seagrasses were exposed to wet season water types, during at least one week of the wet season. Approximately 4% of seagrasses were in the highest exposure category IV and 3% were in exposure category III.
- These exposures indicate 'potential risk' but have not been yet validated against ecological health data to confirm the ecological consequences of the risk.
- In 2016–17, the areas of coral reefs and seagrasses exposed to the category III were slightly smaller than long-term (Table 3-4: 0.1% and 0.03% of reefs and 5% and 5% of seagrasses were exposed to categories III and IV, respectively). These results are logical with the characteristic of an average wet season for this region.

Table 3-4: Areas (km^2) and percentages (%) of the Cape York Marine NRM Region affected by different categories of exposure during the 2016–17 wet season (and *long-term values in brackets*).

Cape York Marine NRM region		**Total**	**Potential risk category** **Lowest ----------------------- highest**				**Total exposed**	**Total non-exposed**
			I	**II**	**III**	**IV**		
Surface area	Area (km^2)	96,316	52,348	624	255	277	53,505	42,811
			(50,746)	*(1,836)*	*(413)*	*(378)*	*(53,374)*	*(42,942)*
	Percentage (%)	100	54	1	0.3	0.3	56	44
			(53)	*(2)*	*(0.4)*	*(0.4)*	*(55)*	*(45)*
Coral reefs	Area (km^2)	10,375	10,006	21	3	2	10,032	342
			(9,998)	*(50)*	*(13)*	*(3)*	*(10,064)*	*(311)*
	Percentage (%)	100	96	0.2	0.03	0.02	97	3
			(96)	*(0)*	*(0.1)*	*(0.03)*	*(97)*	*(3)*
Surveyed seagrass	Area (km^2)	2,655	2,229	192	83	115	2,619	36
			(1,830)	*(525)*	*(130)*	*(145)*	*(26)*	*(262)9*
	Percentage (%)	100	84	7	3	4	99	1
			(69)	*(20)*	*(5)*	*(5)*	*(1)*	*(99)*

Figure 3-43 and Figure 3-44 illustrate the changes in water quality and environmental conditions in the Cape York region and focus on surface data collected by Howley Consulting between December 2016 and April 2017. The 2016–17 wet season was characterised by below average river discharges for the first quarter of the wet season (until 11 January 2017), then all weeks were characterised by above average weekly river discharges except for weeks 9, 20, 21 and 22.

The maximum wet season water quality surface concentrations were measured during week 10 (2–8 February: 200.0 mg L^{-1} for TSS, 81.0 µg L^{-1} for DIN and 1.3 µg L^{-1} for Chl-a). However, cloud cover prevented obtaining clear satellite image 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 measured during week 13 in colour class 1 for TSS (21.0 mg L^{-1}) and DIN (25.0 µg L^{-1}), corresponding to a weekly average Secchi depth of 0.2 m^{-1}, and in the colour class 2 for Chl-a (1.2 µg L^{-1}). No week had *in-situ* samples collected across all colour classes (1 to 6), which did not allow describing water quality changes across colour gradients. This is approximately 9 and 2 times the wet season TSS and Chl-a guidelines, respectively, for the open coastal and mid-shelf waters. The guideline, however, is a seasonal mean and the ecological effect of the acute concentration peak is not known.

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 7.8 and 4.2

mg L^{-1}, i.e., approximately 3 and 2 times the wet season TSS guidelines of 2.4 mg L^{-1}, respectively (Table E-7). The mean seasonal Chl-a concentrations in the Primary water type was 0.8 µg L^{-1}, i.e., approximately 1.3 times the wet season Chl-a guidelines of 0.63 µg L^{-1}. The mean seasonal PP concentration in the Primary water type was 6.1 µg L^{-1} (1.8 times the 3.3 µg L^{-1} guideline). Finally, the mean seasonal TSS concentrations in the Tertiary waters, Chl-a and PP concentration in the Secondary and Tertiary water types and the mean seasonal PN concentrations in all water types were all under their respective wet season guidelines (Table E-7).

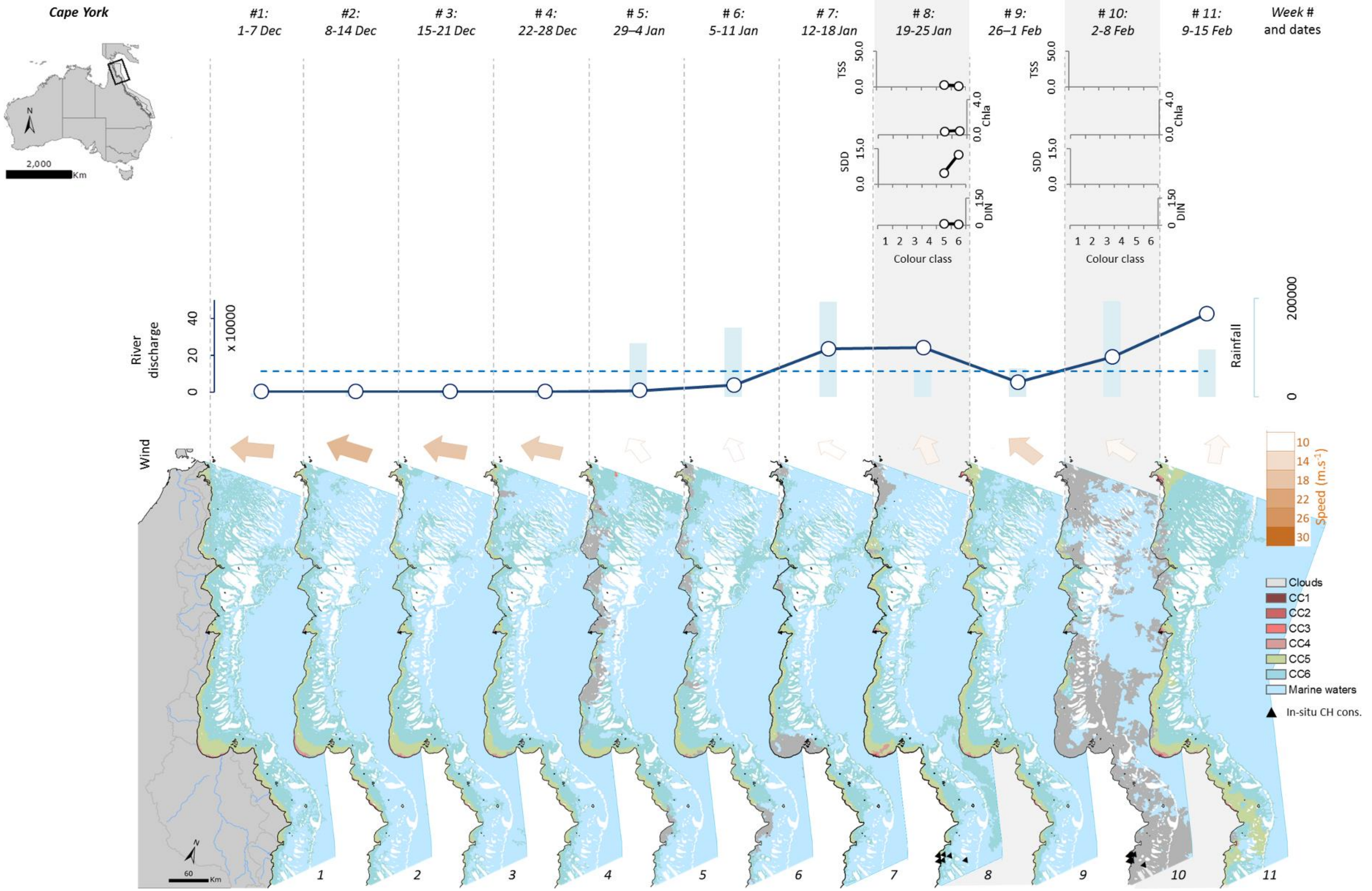


Figure 3-43: Panel of water quality and environmental characteristics in the Cape York region throughout the 2016–17 wet season period: weeks 1 to 11. Details included in the panels: mean TSS (mg L^{-1}), Secchi disc depth (SDD) (m), Chl-a (µg L^{-1}) and DIN (µg L^{-1}) within each colour class; weekly 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.

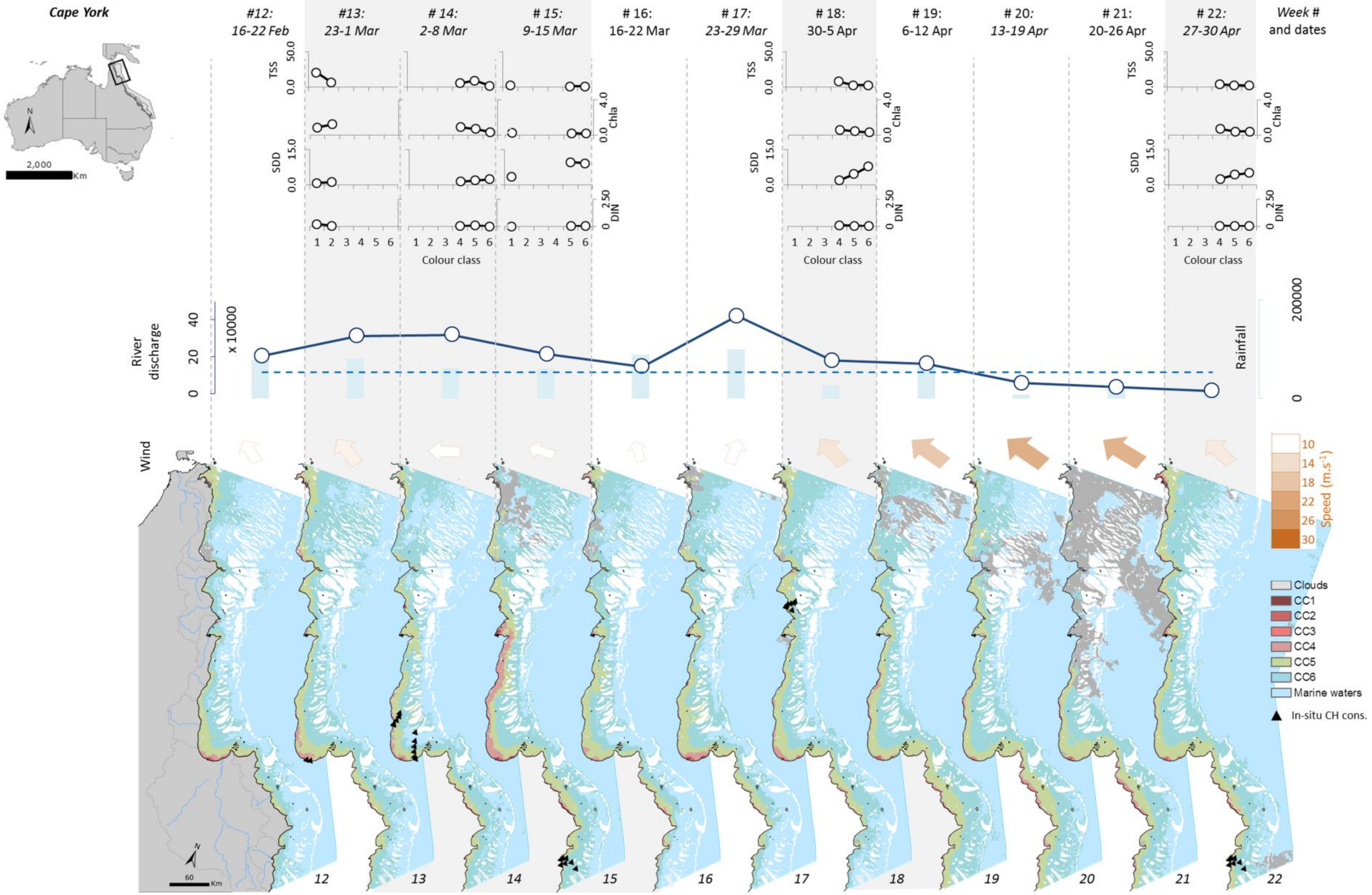


Figure 3-44: Panel of water quality and environmental characteristics in the Cape York region throughout the 2016–17 wet season period: weeks 12 to 22. Details included in the panels: mean TSS (mg L^{-1}), Secchi disc depth (SDD) (m), Chl-a (µg L^{-1}) and DIN (µg L^{-1}) within each colour class; weekly 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.

3.4.2 Wet Tropics Region: Barron Daintree focus area

Overview

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 2,107 km^2 and has a high proportion of protected areas (56% natural/minimise 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 2,189 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.

Until the end of 2014, seven stations were sampled three times per year to determine the regional water quality (Figure 3-45). Under the revised MMP water quality sampling design implemented in 2015, this sub-region now contains the six open water sites of the 'Cairns long-term water quality transect', which are sampled three times a year.

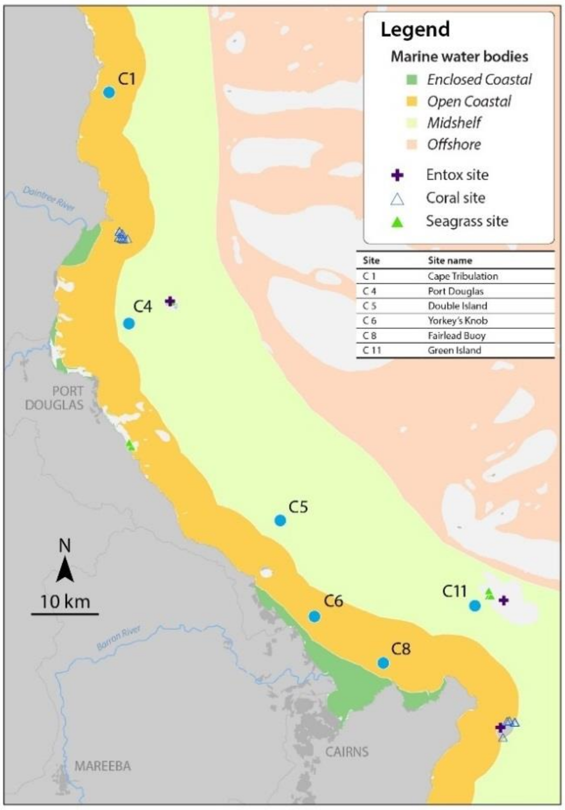


Figure 3-45: MMP water quality sampling sites in the Barron Daintree sub-region shown with water body boundaries.

Over the period from 2006 to 2017, annual discharge for both the Daintree and Barron Rivers has been close to, or slightly above, median levels in most years with major floods of the Barron River in 2008 and again in 2011 when the Daintree River also flooded (Figure 3-46, Table A2-1). The 2008 and 2011 floods were the highest flows recorded for the Barron over the last 14 years (at least three times the long-term median) (Table A2-1). The annual discharge of the Daintree River for the 2014 water year was three times the long-term median, the highest in the past 14 years, and was strongly influenced by Cyclone Ita (Figure 3-46,

Table A2-1). The total discharge during the 2016–17 water year was below the long-term median discharge with only one small flow event occurring in this year.

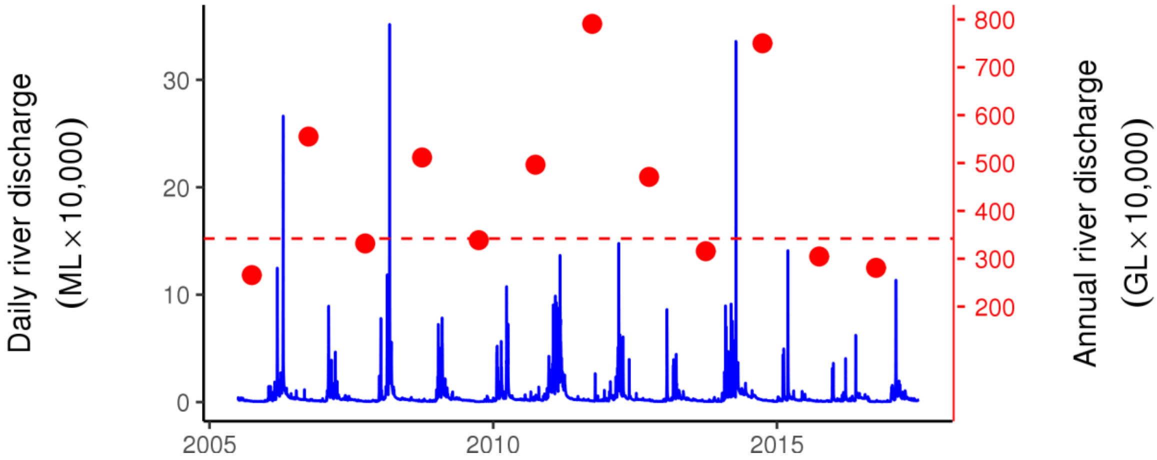


Figure 3-46: Combined discharge for the Barron (Myola gauge) and Daintree (Bairds gauge) Rivers. Daily (blue) and water year (October to September, red symbols) discharge volumes shown. Red dashed line represents long-term median of the combined annual discharge. Please note as this is the combined discharge, high flows in one river will not necessarily be visible in the graph.

Although the time coverage for the calculation of the accumulated exposure contemplates two months more than the period used in the previous reports, it can be observed that the area of influence of the Barron River was spatially restricted when compared to the period of 2010-2011 (Figure 3-47).

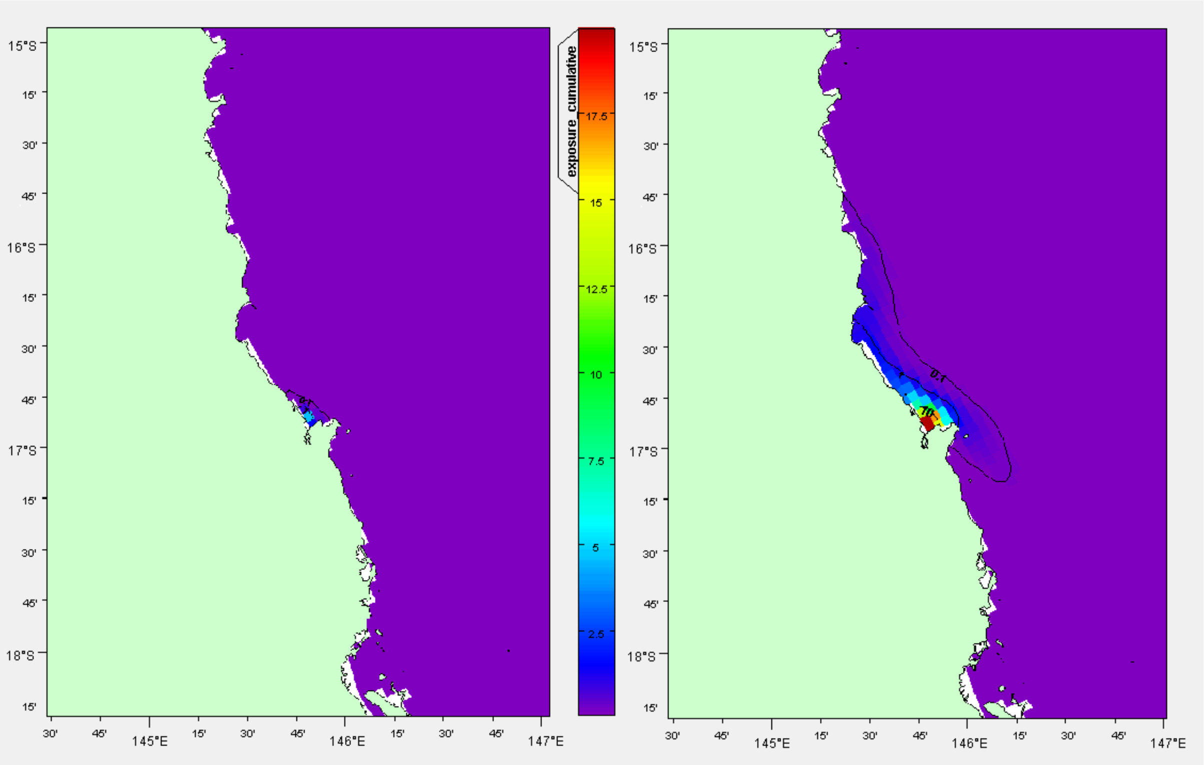


Figure 3-47: Cumulative exposure index for the Barron River at the end of June 2017 (left). Results for 2010–11 (right) are shown for context. The colour bar indicates the calculated cumulative exposure (concentration x days) above 1% of the incoming concentration. The colour bar is capped at 20 Conc.Days. Contours show 0.1, 1.0 and 10.0 Conc.Days exposure levels.

The combined discharge and loads calculated for the 2016–17 water year from the Barron, Daintree and Mossman Basins were in the lower range recorded over the past 10 years (Figure 3-48), although the discharge from the Daintree and Mossman Basins were near the long-term median. The discharge from the Barron Basin in 2016–17 was approximately half of the long-term median (Table 3-1). The past three water years all had very similar discharge and TSS, DIN and PN loads. Over the 11-year period from 2006, discharge has varied from 2,800,000 ML (2014–15) to 8,000,000 ML (2010–11), TSS loads have ranged from 180 kt (2015–16) to 720 kt (2010–11), DIN loads from 220 t (2014–15) to 560 t (2010–11) and PN loads from 540 t (2015–16) to 2,150 t (2010–11). 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 3.3 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 3-49 shows the estimated DIN and TSS contributions for the Wet Tropics region in 2010–11 and 2016–17. The panels show the important influence of the Burdekin River and northward movement of the river plume into the Wet Tropics NRM region in the flood events of 2010–11, accounting for almost half of the TSS loading and around 40% of the DIN loading. Figure 3-15 and Figure 3-18 also show that all of the Wet Tropics Rivers can influence the Cape York NRM region, and the Daintree and Mossman Rivers had a small contribution (~5%) in the low discharge year of 2016–17. The Herbert River also influences the Burdekin Region in most of the years modelled.

In 2016–17, the greatest DIN contributions to the marine NRM region were from the Johnstone (26%), Tully (23%) and Herbert Rivers (23%), whereas the TSS contributions were dominated by the Johnstone River (41%) and the Herbert (17%) River. 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 (5%, 2% and 1%, respectively) and TSS loading (~5% each); however, the Daintree and Mossman Rivers are predicted to contribute to the southern areas of the Cape York NRM region with the northward movement of the plume (see above in Cape York section).

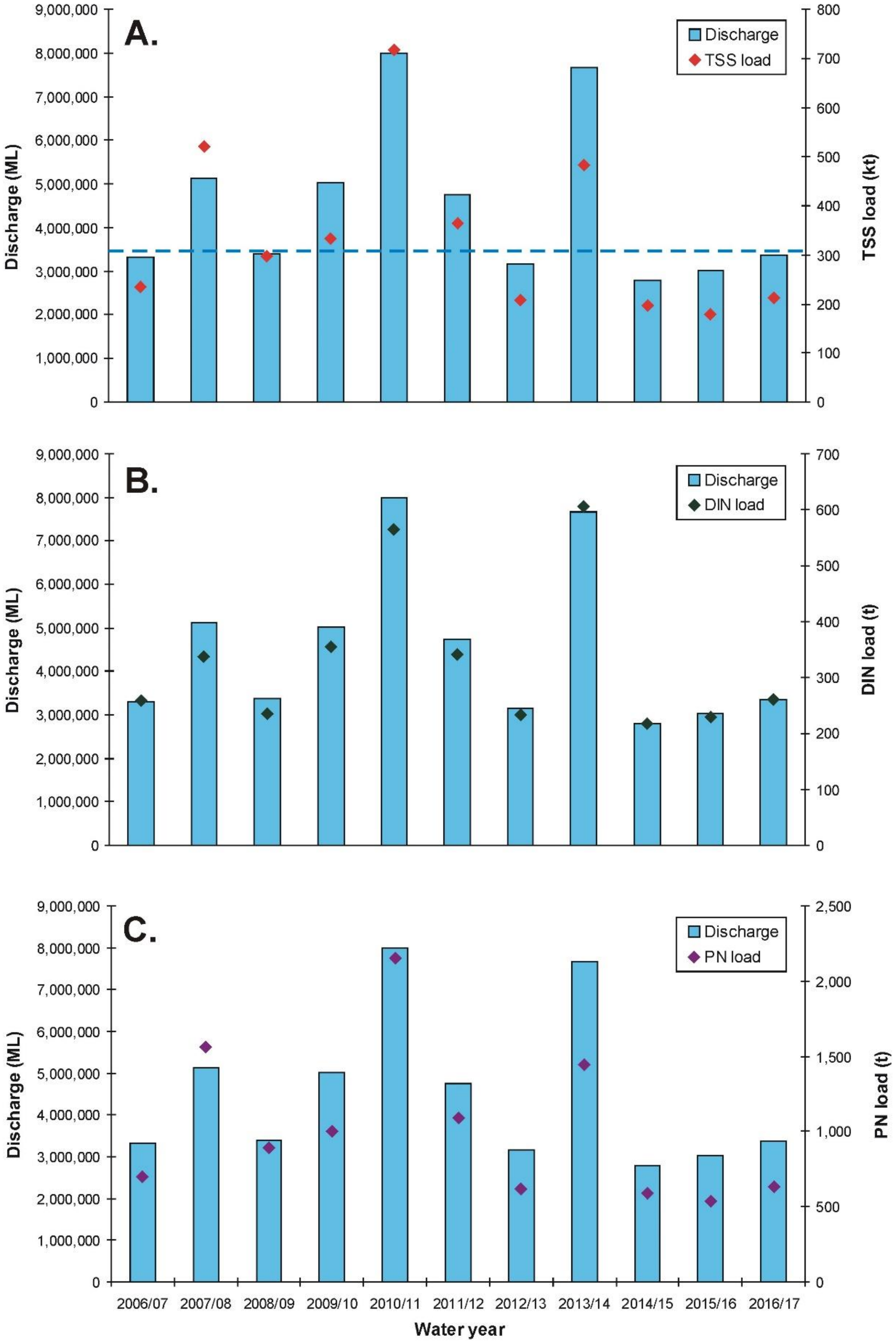


Figure 3-48. (A) Discharge and TSS, (B) DIN and (C) PN loads for the Barron, Daintree and Mossman Basins from 2006–07 to 2016–17. The loads reported here are a combination of 'best estimates' for each basin based on 'up-scaled discharge data from gauging stations, monitoring data (Barron River), the DIN model developed in Lewis et al. (2014) and annual mean concentrations and discharge from monitoring data or Source Catchments modelling data. Dotted line represents the long-term median for basin discharge.

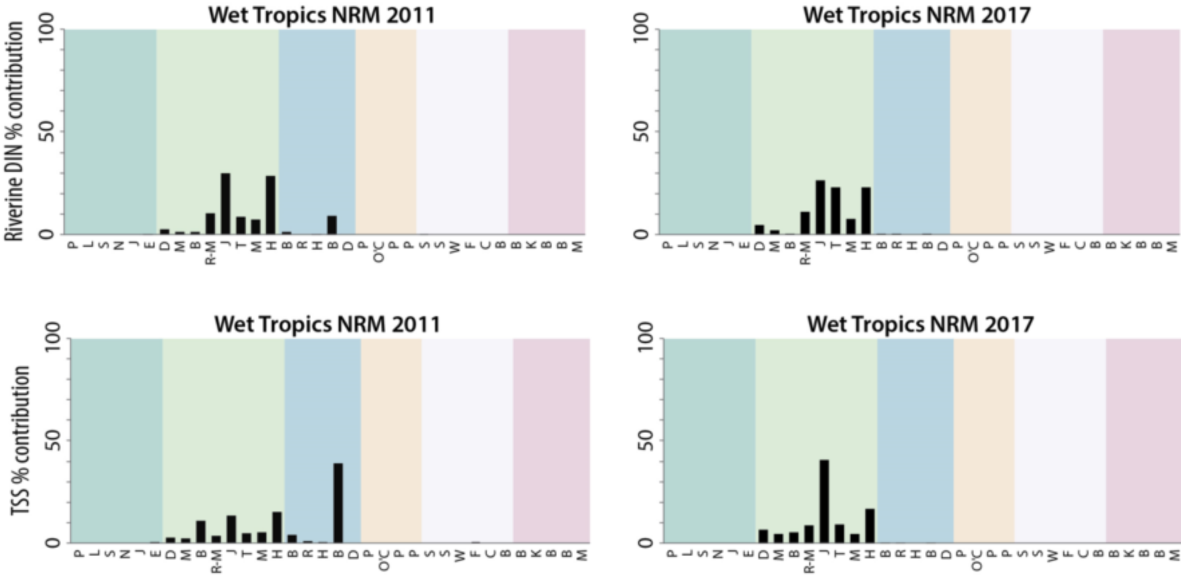


Figure 3-49. River contributions (x-axis, fully labelled in Figure 3-15) to the (top) DIN and (bottom) TSS mass to the Wet Tropics NRM region in 2010–11 (left column) and 2016–17 (right column). Shading groups rivers in the same NRM region: Cape York – dark green, Wet Tropics – light green, Burdekin - blue, Mackay Whitsunday – orange, Fitzroy – pink, Burnett Mary - red.

Ambient water quality

A brief description and definition of the water quality variables measured in this region can be found in Appendix D-1.

When analysing the water quality long-term trend in the Barron Daintree sub-region it should be noted that the Snapper Island site was discontinued in 2015. However, the data collected at this site in previous years are still included for consistency in the long-term analysis. It is also important to note that the below water quality trends accounts for the effect of wind, waves and tides; accordingly, the trends are independent of changes in local weather.

The Water Quality Index was calculated in two different ways. First, for continuity of the long-term trend an index score was calculated using the same approach as in previous years (see Appendix D-6 for details). Second, to include data collected under the revised sampling design and apply wet/dry guidelines, a separate score was calculated and shown as two separate points in Figure 3-50a. The long-term Water Quality Index showed that the score in this sub-region remained at ‘good‘, whereas the score calculated as part of the revised design declined to ‘moderate‘ in 2016–17 (Figure 3-50a).

Concentrations of Chl-a, PO_4, TSS, PN and PP showed some fluctuations over the monitoring period with no overall clear trend (Figure 3-50b, d, e, g, h). Generally, the highest concentrations of Chl-a, TSS, PN and PP were observed in 2014–15, with the trend lines for Chl-a, TSS and PP fluctuating around the Water Quality Guidelines (GBRMPA, 2010). Secchi depth showed a slight decline since the beginning of the monitoring program, reaching a stable level in 2017, with levels throughout the monitoring period being non-compliant with the guideline (Figure 3-50f).

The concentration of dissolved oxidised nitrogen (NO_x) increased slightly until 2014–15, approaching the Queensland 80th percentile guideline value, when concentrations started to decline reaching a seemingly stable level in 2016–17 (Figure 3-50c). The concentrations of POC have been constant over the monitoring period (Figure 3-50i), whereas the concentrations of DOC have generally increased over the whole period (Figure 3-50j).

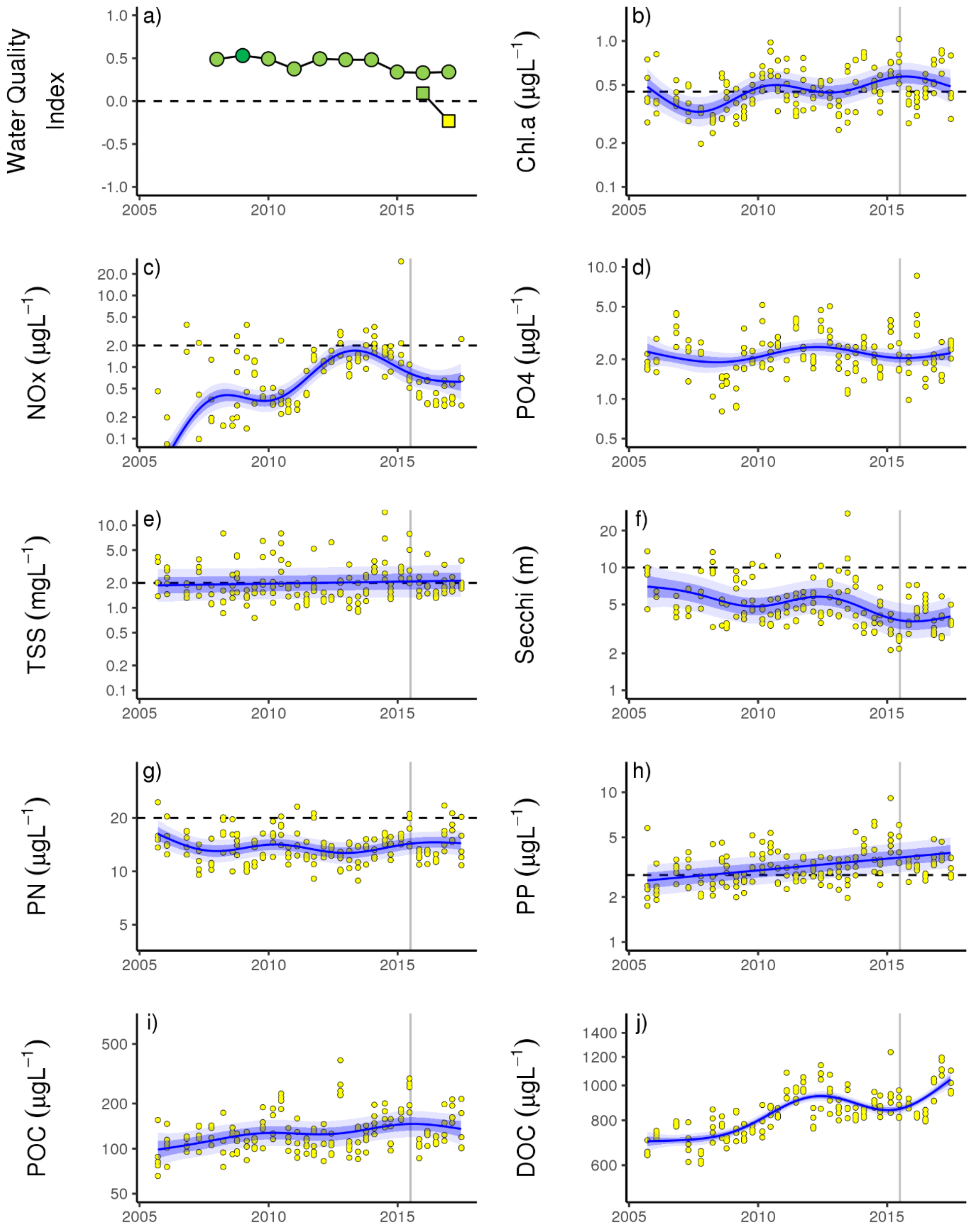


Figure 3-50: Temporal trends in water quality variables for the Barron Daintree sub-region. a) Water Quality Index, b) chlorophyll *a* (Chl-*a*), c) nitrate/nitrite (NO_x), d) phosphate (PO_4), e) total suspended solids (TSS), f) Secchi depth, g) particulate nitrogen (PN), h) particulate phosphorus (PP), i) particulate organic carbon (POC) and j) dissolved organic carbon (DOC). Water Quality Index colour coding: dark green– 'very good'; light green– 'good'; yellow – 'moderate; orange – 'poor'; red – 'very poor'. Note that from 2015 to 16 onwards a separate score was calculated using the wet/dry guidelines that are shown as two separate points in Figure 3-50a. The calculations are described in Appendix D-6. 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, yellow dots represent observed data. Dashed horizontal reference lines indicate yearly guideline values and the vertical dashed lines represent when the sampling design was changed (February 2015), both lines are only shown for reference.

Event water quality

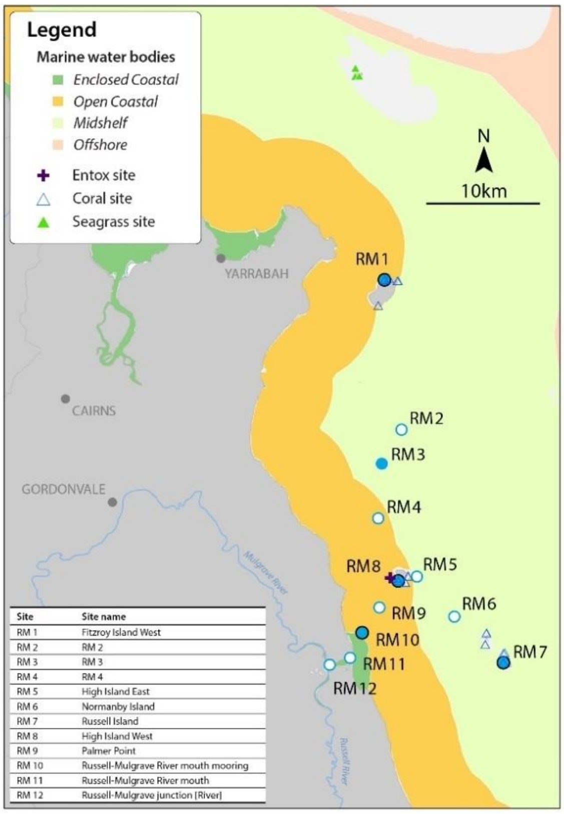
No event sampling was conducted in the Barron Daintree focus area in 2016–17.

3.4.3 Wet Tropics Region: Russell-Mulgrave focus area

Overview

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). 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 2,326 km^2 and has a relatively high proportion of natural/minimal use lands (55%). The remaining area contains 16% grazing, 12% sugarcane and smaller areas of dairy (in the upper catchment), bananas and other crops, and urban land uses (Terrain NRM, 2015).

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 6 stations during both the dry and wet season and 7 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 3-51).



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 3-51: MMP sampling sites in the Russell-Mulgrave focus area, shown with the water body boundaries.

Over the period 2006 to 2014, the annual discharge for both the Russell-Mulgrave and Johnstone Rivers was at, or slightly above, median levels in most years with major floods observed after the passing of tropical cyclones Larry in 2006, Tasha in late 2010 and Yasi in 2011 (Figure 3-52, Table A2-1). Discharge volumes in the 2016 and 2017 water years were comparable to the long-term median (Table A2-1).

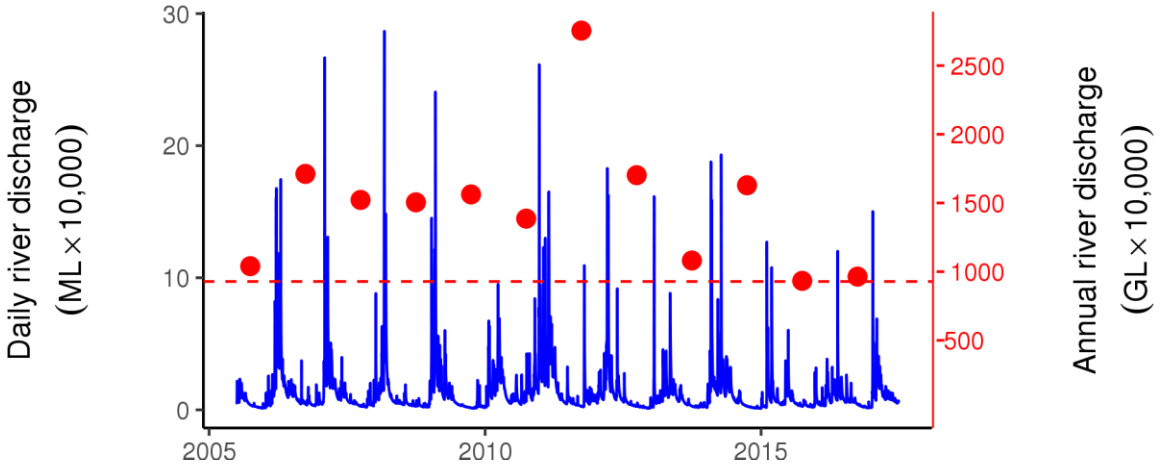


Figure 3-52: Combined discharge for the North and South Johnstone (Tung Oil and Central Mill gauges, respectively), Russell (Bucklands gauge) and Mulgrave (Peat's Bridge) Rivers. Daily (blue) and water year (October to September, red symbols) discharge is shown. Red dashed line represents the long-term 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 estimated areas of influence for the Russell-Mulgrave River are shown in Figure 3-53. The figure presents a much more constrained zone of influence in October 2016 to June 2017 compared to the large events of 2010–11.

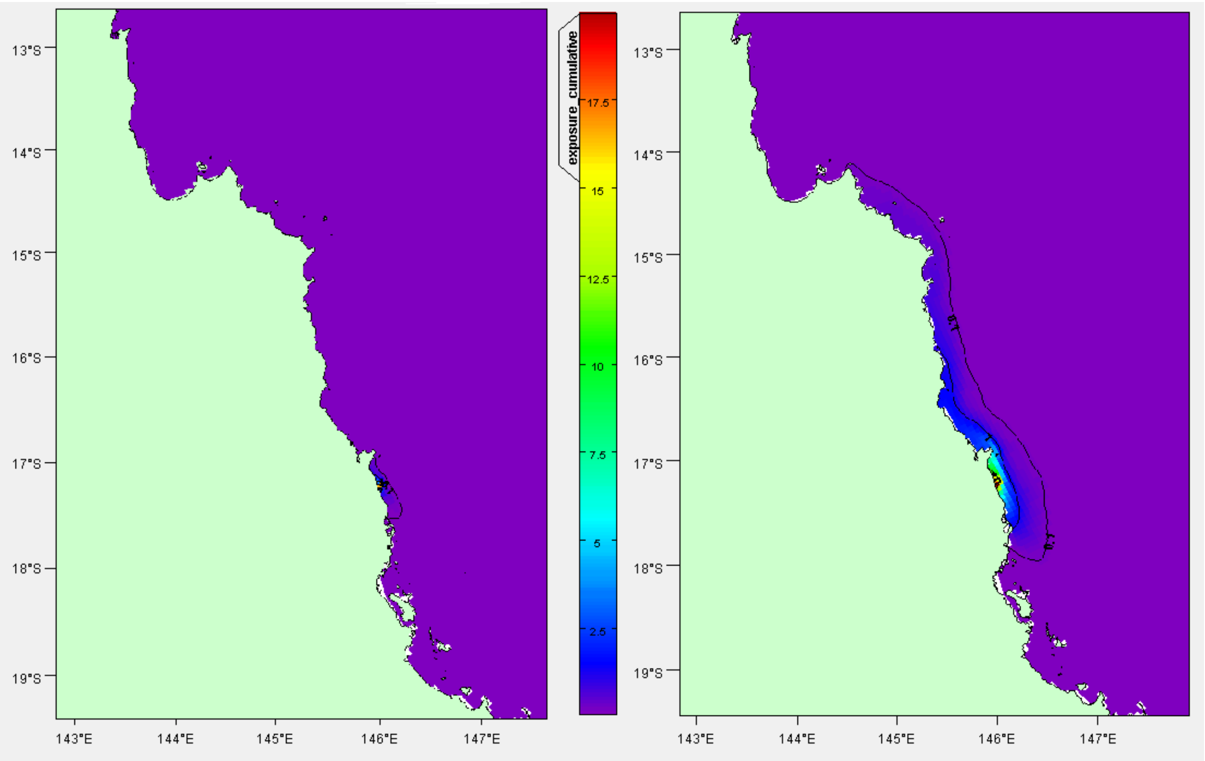


Figure 3-53: Cumulative exposure index for the Russell-Mulgrave River at the end of June 2017 (left). Results for 2010–11 (right) are shown for context. The colour bar indicates the calculated cumulative exposure (concentration x days) above 1% of the incoming concentration. The colour bar is capped at 20 Conc.Days. Contours show 0.1, 1.0 and 10.0 Conc.Days exposure levels.

Similar to the Barron Daintree sub-region, the combined discharge and loads calculated for the 2016–17 water year from the Russell-Mulgrave and Johnstone Basins were in the lower range recorded over the past 10 years (Figure 3-54). The past three water years had very similar discharge and TSS, DIN and PN loads with the lowest DIN load (981 t) recorded in 2016–17. Recently, the GBR Catchment Loads Monitoring Program established load monitoring sites at the Mulgrave River at Deeral, the Russell River at East Russell and the Johnstone River at Coquette Point. These sites are all located at the end of each respective basin and collectively provide a measured load for this sub-region as well as a comparison with the load calculation methods employed in the MMP reports (i.e., to upscale the loads to encompass the whole basin area).

In 2016–17, the total TSS, DIN and PN loads from these three sites were 240 kt, 970 t and 1000 t, respectively, compared to the modelling data of 492 kt, 981 t and 2059 t for TSS, DIN and PN, respectively. We note that while there appears to be a discrepancy in the TSS and PN loads, which are much higher in the model, the monitoring locations are all within the estuary and so considerable deposition of particulates would have occurred even before the sampling locations. Over the 11-year period, discharge has varied from 5,100,000 ML (2015–16) to 16,900,000 ML (2010–11), TSS loads have ranged from 320 kt (2014–15) to 1,200 kt (2010–11), DIN loads from 981 t (2016–17) to 5,000 t (2010–11) and PN loads from 1,400 t (2014–15) to 4,900 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 moderate rainfall/discharge years, although the latter basins contribute higher values during the high discharge years such as in 2008–09 and 2010–11 water years.

Figure 3-49 shows the estimated DIN and TSS contributions for the Wet Tropics region in 2010–11 and 2016–17, highlighting the dominant influence of the Johnstone River to river-derived DIN (27%) and TSS (41%) 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 10% for DIN and TSS.

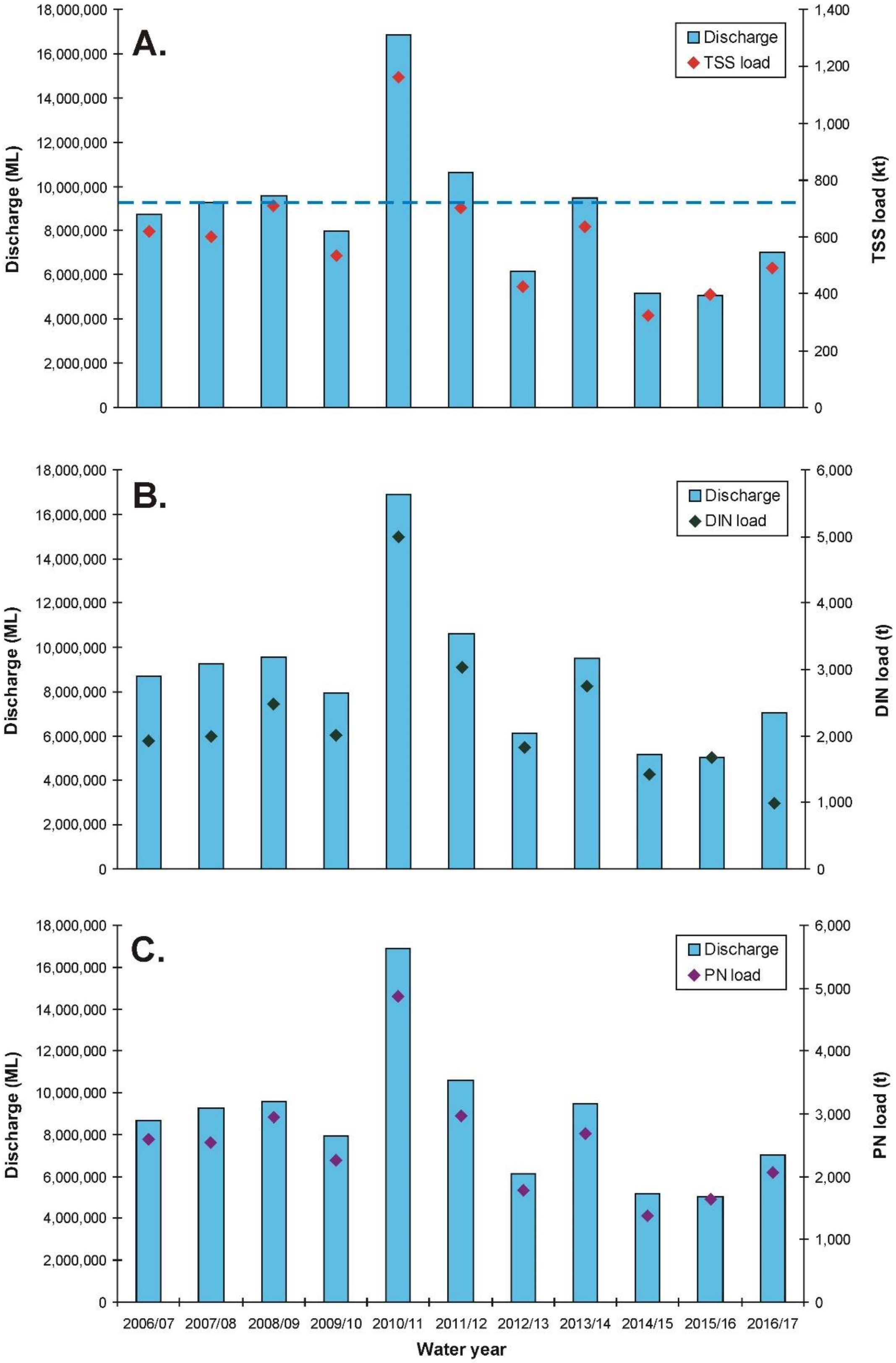


Figure 3-54: (A) Discharge and TSS, (B) DIN and (C) PN loads for the Russell, Mulgrave and Johnstone Basins from 2006–07 to 2016–17. The loads reported here are a combination of ‘best estimates’ for each basin based on ‘up-scaled discharge data from gauging stations, monitoring data (Johnstone River), 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

A brief description and definition of the water quality variables measured in this region can be found in Appendix D-1.

When analysing the long-term water quality trend in this region, it should be noted that one logger station has changed location, and that the number of water sampling sites and frequency of sampling has increased from 2015 onwards. Some of these sites are placed further inshore and they are therefore more likely to be affected by Primary and Secondary water types during the wet season, which may influence the results. It is also important to note that the below water quality trends accounts for the effect of wind, waves and tides; accordingly, the trends are independent of changes in local weather.

This year, the Water Quality Index was calculated in two different ways. First, for continuity of the long-term trend an index score was calculated using the same approach as in previous years (See Appendix D-6 for details). Second, to include data collected as part of the revised sampling design (AIMS and JCU data) and apply wet/dry guidelines, a separate score was calculated as two square points shown in Figure 3-55a. Both index scores showed that the water quality in this sub-region remained ‘good’, although the long-term trend has shown a slight decline since 2009 (Figure 3-55a). Reference graphs containing only AIMS data are shown in Appendix E, Figure E-3.

For all measured variables it is evident that when comparing Figure 3-55 and Figure E-3, the inclusion of the JCU and data collected under the changed sampling design (more stations and sampling) has resulted in a larger variability in concentrations of the measured variables. This has also changed the long-term trend lines especially for NO_x, TSS and PN (Figure 3-55 and Figure E-3). The overall predicted trend lines for Chl-a, PO_4, turbidity, TSS, Secchi depth, PN and PP showed only minor changes since the beginning of the monitoring program (Figure 3-55b, d, e, f, g, h, i). Instrumental Chl-a and turbidity records showed slightly more pronounced fluctuations than the trend line for the manual sampling data (Figure 3-55b, e). For all variables, except PN, where guidelines are available, concentrations were mostly fluctuating around the annual GVs over the entire sampling period (Figure 3-55).

The trend line for NO_x showed a pronounced increase since the implementation of the changed sampling design in 2015 (Figure 3-55c). The inclusion of the JCU data furthermore clearly skewed the trend line of NO_x as seen when comparing with AIMS only data (Figure 3-55c, Figure E-4c), showing that the overall long-term trends are biased by the change in sampling design and therefore do not represent a real overall change. Overall, the NO_x values increased slightly over the monitoring period fluctuating around the Queensland guideline since 2008 (Figure 3-55c). The PO_4 concentrations trend has remained constant over the monitoring period, but again with an increasing variability due to implementation of the changed sampling design in 2015 (Figure 3-55d). The concentrations of POC have increased since 2012–13(Figure 3-55j), whereas the DOC concentrations showed a continued increase over the whole monitoring period (Figure 3-55k).

Event water quality

Event sampling was conducted for the Russell-Mulgrave focus area on 13 January 2017 with a minor flood event. The results are presented in combination with the Tully focus area (Section 3.4.4 below).

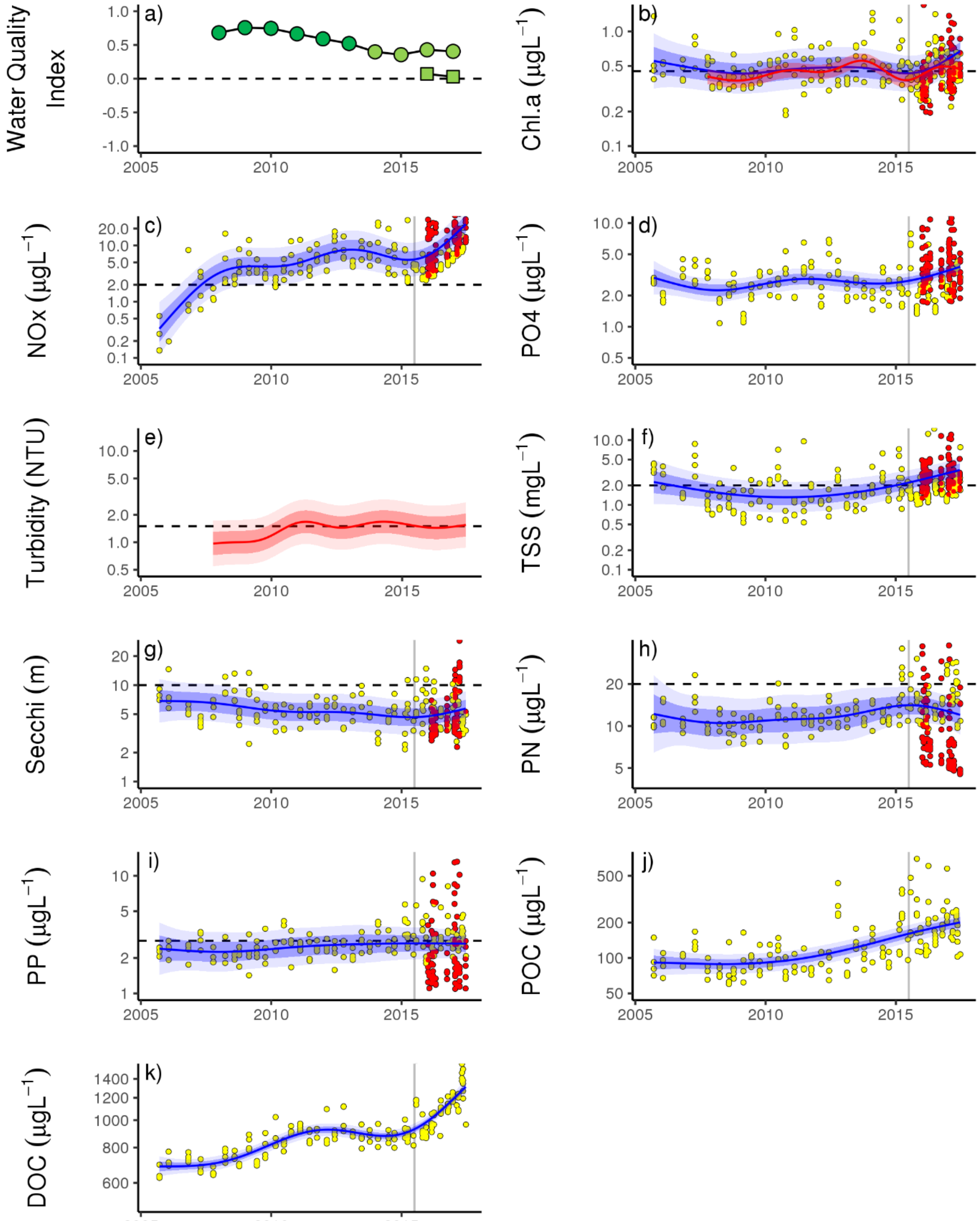


Figure 3-55: Temporal trends in water quality for the Russell-Mulgrave sub-region. a) Water Quality Index, b) chlorophyll a (Chl-a), c) nitrate/nitrite (NO_x), d) phosphate (PO4), e) turbidity, f) total suspended solids (TSS), g) Secchi depth, h) particulate nitrogen (PN), i) particulate phosphorus (PP), j) particulate organic carbon (POC) and k) dissolved organic carbon (DOC). Water Quality Index colour coding: dark green – 'very good'; light green – 'good'; yellow – 'moderate; orange – 'poor'; red – 'very poor. Note that from 2015–16 onwards both AIMS and JCU was included and a separate score was calculated using the wet/dry guidelines that are shown as two separate square points in Figure 3-55a. The calculations are described in Appendix D-6. 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. Yellow dots represent observed data collected by AIMS and red dots data collected by JCU. Trends of records from ECO FLNTUSB instruments are represented in red, individual records are not displayed. Dashed horizontal reference lines indicate yearly guideline values and the vertical dashed lines represent when the sampling design was changed (February 2015), both lines are only shown for reference.

3.4.4 Wet Tropics Region: Tully focus area

Overview

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). The Tully River Basin has an area of 1,685 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 1,115 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 9,842 km^2 and consists of 27% natural/minimal use lands, 56% grazing, 8% sugarcane and smaller areas of forestry.

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 6 stations during both the dry and wet seasons and 5 only during the wet season (Table 2-1). The sampling locations in this new design are located in a river mouth to open coastal water transect (Figure 3-56).

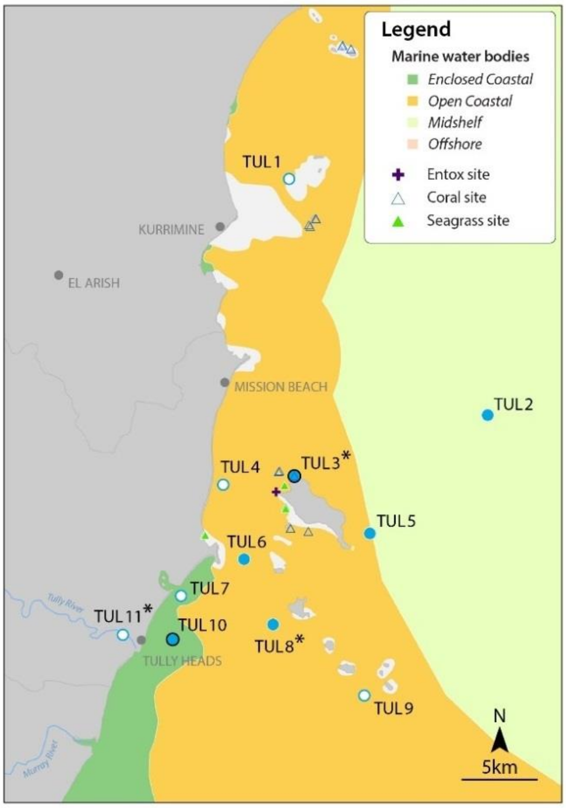


Figure 3-56: MMP sampling sites in the Tully focus area, shown with the water body boundaries.

Over the period 2006 to 2016, annual discharge for the Tully and Herbert Rivers (Figure 3-57) has been at, or slightly above, median levels except in two years due to the major floods of the Tully River in 2011 and of the Herbert River in 2009 and 2011 (Table A2-1). The discharge for 2016–17 was lower than the long-term median but higher than the very low levels measured in 2015–16 (Figure 3-57).

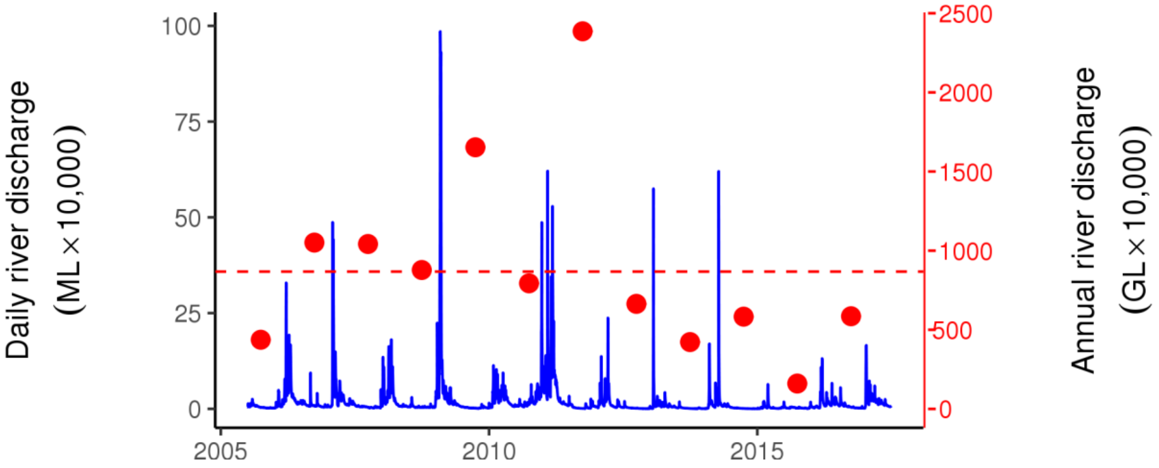


Figure 3-57: Combined discharge for Tully (Euramo gauge) and Herbert (Ingham gauge) Rivers. Daily (blue) and water year (October to September, red) discharge is shown. Red dashed line represents the long-term median of the combined annual discharge. Please note as this is the combined discharge, high flows in one river will not necessarily be visible in the graph.

The estimated area of influence for the Tully River is shown in Figure 3-58. It is important to emphasise that even though the use of a longer period (nine months) in the presentation of results for the current report (left panel), the Tully river influence region remains significantly lower than results related to the 2010–2011 wet season (right panel).

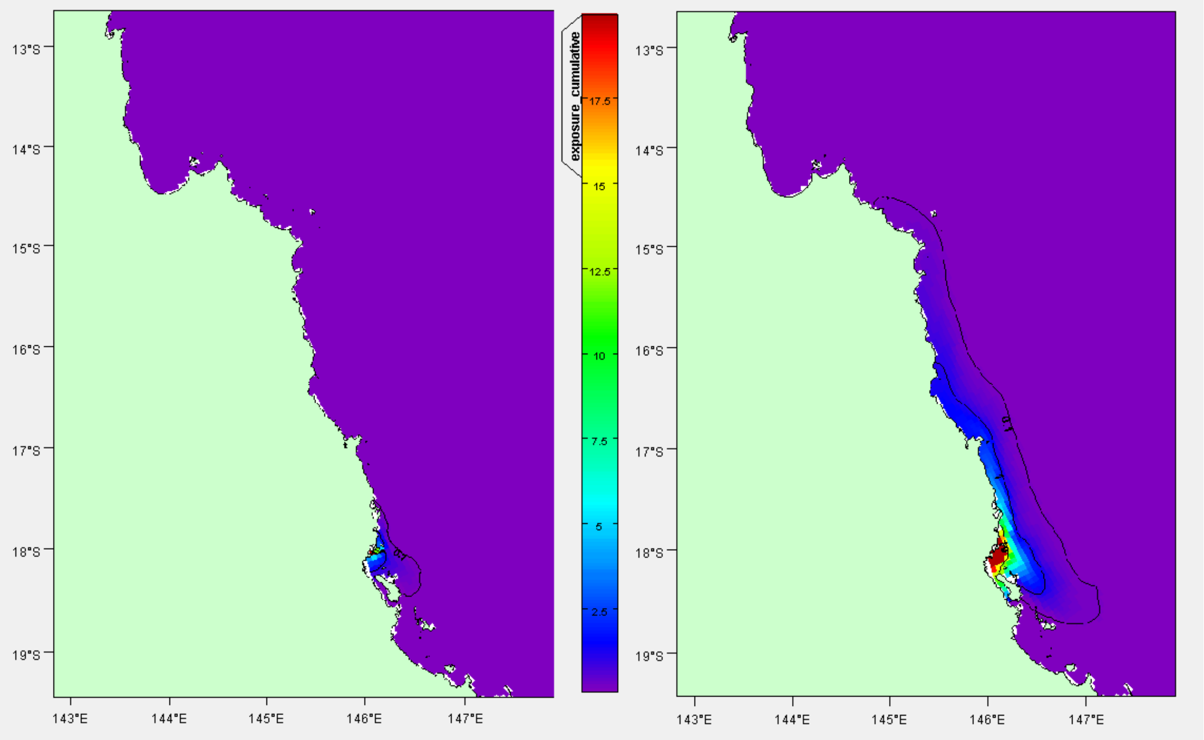


Figure 3-58: Cumulative exposure index for the Tully River at the end of June 2017 (left). Results for 2010–11 (right) are shown for context. The colour bar indicates the calculated cumulative exposure (concentration x days) above 1% of the incoming concentration. The colour bar is capped at 20 Conc.Days. Contours show 0.1, 1.0 and 10.0 Conc.Days exposure levels.

The combined discharge and loads calculated for the 2016–17 water year from the Tully, Murray and Herbert Basins were in the lower range recorded over the past decade (Figure 3-59). Over the 11-year period, discharge has varied from 4,100,000 ML (2014–15) to 24,800,000 ML (2010–11), TSS loads have ranged from 210 kt (2014–15) to 1,750 kt (2010–11), DIN loads from 750 t (2014–15) to 5,800 t (2010–11) and PN loads from 750 t (2014–15) to 5,200 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 loads to the Russell, Mulgrave and Johnstone Basins during low to moderate rainfall/discharge years, although the Tully, Murray and Herbert contribute higher values during the high discharge years such as in 2008–09 and 2010–11 water years.

Figure 3-49 shows the estimated DIN and TSS contributions for the Wet Tropics region in 2010–11 and 2016–17, 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%.

Ambient water quality

A brief description and definition of the water quality variables measured in this region can be found in Appendix D-1.

When analysing 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 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. It is also important to note that the trend analysis accounts for the effect of wind, waves and tides; accordingly, the trends are independent of changes in local weather.

The scores showed that the Water Quality Index in this sub-region remained ‘moderate to good’, with the long-term trend being fairly stable (Figure 3-60a). For all measured variables, it can be seen when comparing Figure 3-60 and Figure E-4 that the inclusion of the JCU and AIMS data collected under the changed sampling design (more stations and sampling) has led to a larger irregularity in the measured variables. Trend lines in concentrations of Chl-a, PN and PP showed only minor changes over the whole monitoring period (Figure 3-60b, h, i). Since the beginning of the monitoring program, the Chl-a trend line has exceeded or been near the guideline value (Figure 3-60b). The PN and PP trend lines generally fluctuated around the Water Quality Guidelines during the entire monitoring period (Figure 3-60h, i). The instrumental Chl-a records showed a general increase over the monitoring period (Figure 3-30b). The turbidity levels were around twice the guideline levels with fairly stable levels over the course of the monitoring period, and peak levels in 2011–12 and 2013–14 (Figure 3-60e). The trend lines for TSS were generally above guideline concentrations throughout the program (Figure 3-60f). Secchi depth remained relatively stable with a long-term average of approximately 5 m, which is non-compliant with the guideline (Figure 3-60g).

The concentrations of NO_x showed a pronounced increase after the implementation of the new sampling design in 2015, and therefore the trend suggested by the line does not represent a real change (Figure 3-60c, Figure E-5c). Generally, NO_x exceeded the Queensland guideline from 2011 onwards (Figure 3-60c). PO_4 concentrations remained relatively constant over the monitoring period; however, larger variability is seen since 2015 due to the implementation of the new sampling design (Figure 3-60d). The concentrations of POC have remained fairly stable since the beginning of the monitoring program (Figure 3-60j), whereas the DOC concentrations have shown a continued increase over the whole monitoring period (Figure 3-60k).

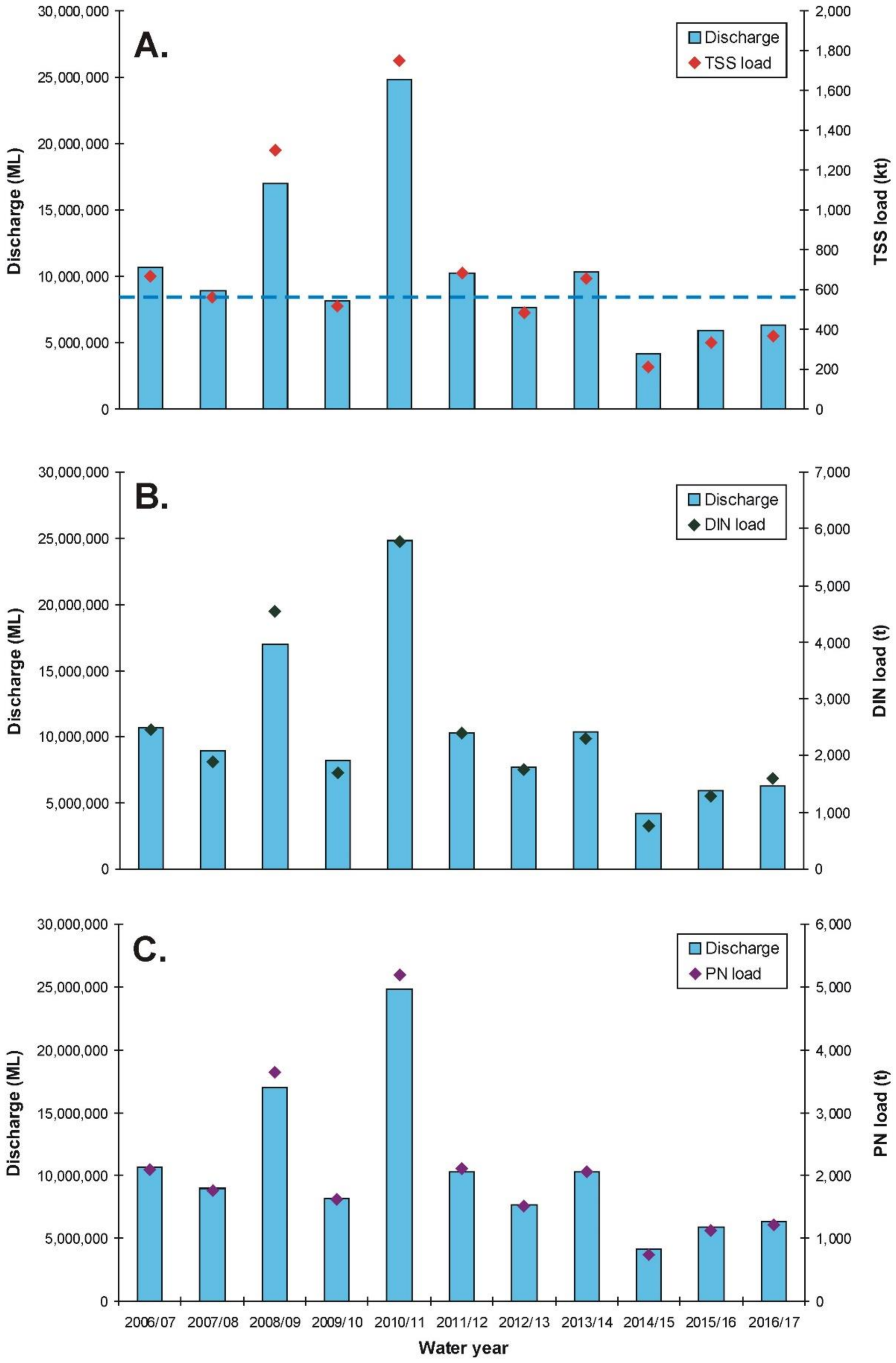


Figure 3-59: (A) Discharge and TSS, (B) DIN and (C) PN loads for the Tully, Murray and Herbert Basins from 2006–07 to 2016–17. The loads reported here are a combination of 'best estimates' for each basin based on 'up-scaled discharge data from gauging stations, monitoring data (Tully and Herbert Rivers), the DIN model developed in Lewis et al. (2014) and annual mean concentrations and discharge from monitoring data or Source Catchments modelling data. Dotted line represents the long-term median for basin discharge.

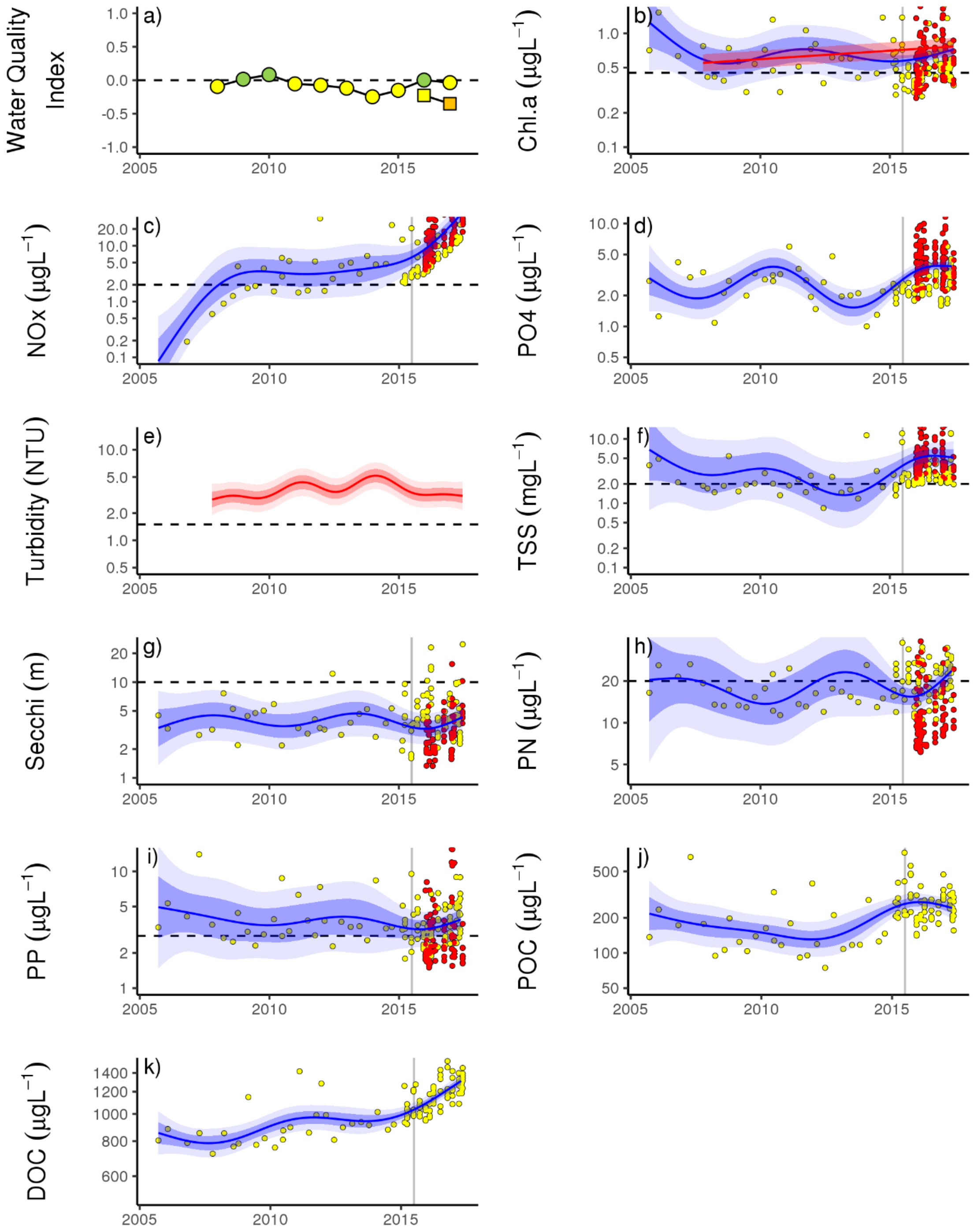


Figure 3-60: Temporal trends in water quality for the Tully sub-region. a) Water Quality Index, b) chlorophyll *a* (Chl-*a*), c) nitrate/nitrite (NO$_x$), d) phosphate (PO$_4$), e) turbidity, f) total suspended solids (TSS), g) Secchi depth, h) particulate nitrogen (PN), i) particulate phosphorus (PP), j) particulate organic carbon (POC) and k) dissolved organic carbon (DOC). Water Quality Index colour coding: dark green – 'very good'; light green – 'good'; yellow – 'moderate; orange – 'poor'; red – 'very poor'. Note that from 2015–16 onwards both AIMS and JCU was included and a separate score was calculated using the wet/dry guidelines that are shown as two separate points in Figure 3-60a. The calculations are described in Appendix D-6. 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. Yellow dots represent observed data collected by AIMS and red dots data collected by JCU. Trends of records from ECO FLNTUSB instruments are represented in red, individual records are not displayed. Dashed horizontal reference lines indicate yearly guideline values and the vertical dashed lines represent when the sampling design was changed (February 2015), both lines are only shown for reference.

Event water quality

Heavy rainfall occurred in the catchments of the Wet Tropics from 7 to 10 January 2017, which triggered a moderate flow event in the Tully River (Figure 3-61) and a sizable flood plume offshore. Cloud cover prevented obtaining a clear satellite image of the flood plumes from the Tully and Johnstone Rivers until the 12 January, which showed an area of influence along the inner and mid shelf (Figure 3-62).

Sampling within the freshwater reaches of the Tully River yielded a TSS concentration of 39 mg L^{-1} consisting of 18% organic material (i.e., volatile suspended solids of 7 mg L^{-1}). The TSS concentrations were higher in the initial mixing stages of the plume (64 and 97 mg L^{-1} in the 0.20 and 0.25 PSU reaches, respectively). It is likely these higher concentrations may be due to the influence of sediment resuspension as these samples were taken directly offshore from the Tully mouth in relatively shallow water (< 3 m) within choppy seas. The outer reaches of the plume near Bedarra Island had a TSS concentration of 18 ± 5 mg L^{-1} at 20.1 PSU, whereas outside the visible plume boundary yielded a TSS concentration of 6 mg L^{-1} at 33.8 PSU; hence even though it appeared that sampling was undertaken outside of the plume there was still a clear freshwater influence in the measured data.

Figure 3-63 shows the slow decline of the TSS concentrations over the salinity gradient for the Tully flood plume sampled over 2 days (11–12 January 2017). The TSS concentrations across the salinity gradient for the Russell-Mulgrave River plume were comparatively lower than the Tully River with concentrations <20 mg L^{-1} for all samples collected (Figure 3-64a). In contrast, Chl-a levels generally increased over the salinity gradient as TSS concentrations declined allowing a greater amount of light for primary production (Figure 3-64b). This is a commonly observed trend for flood plumes across the GBR (Devlin and Brodie, 2005).

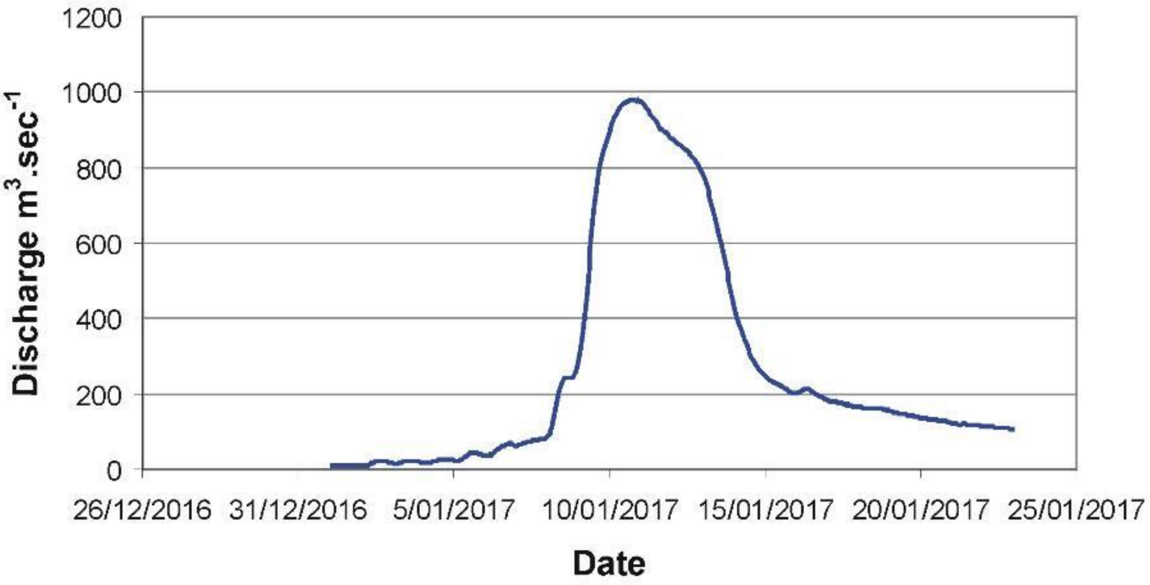


Figure 3-61: Discharge at Tully River at Euramo gauge for late December and January 2017.

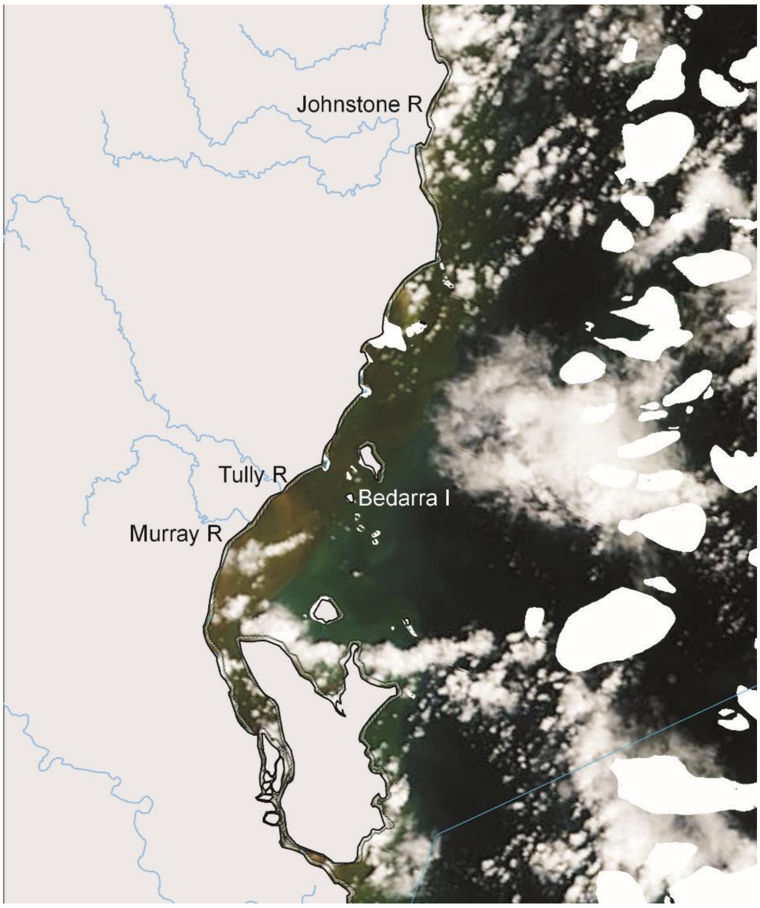


Figure 3-62: MODIS-Terra true colour satellite image showing the Tully and Johnstone River plumes taken on 12 January 2017. A transect of samples across the salinity gradient were collected on 11 January 2017 from the Tully River mouth to Bedarra Island with additional samples from Dunk Island and Sisters Island on 19 January 2017. Sampling of the Johnstone plume occurred on 15 January 2017. True colour images from the NASA's MODIS instrument are provided by the EOSDIS Worldview earthdata system. https://worldview.earthdata.nasa.gov/.

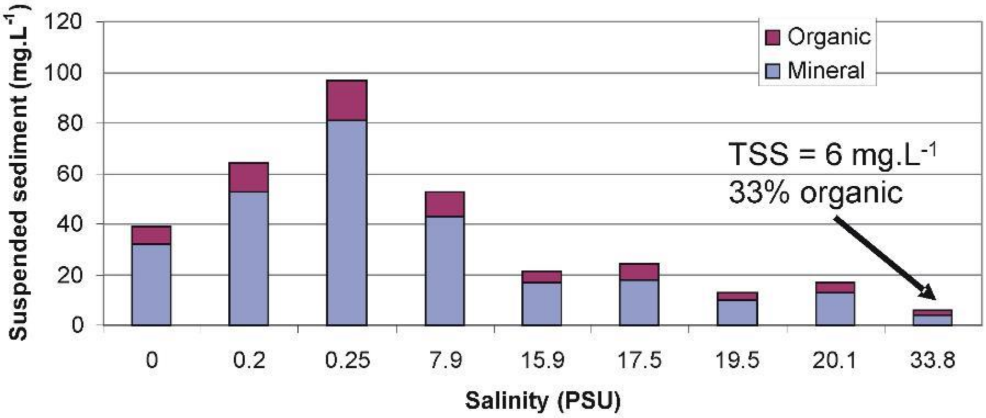


Figure 3-63: Suspended particle matter concentrations over the salinity gradient from the Tully River flood plume on 11 January 2017.

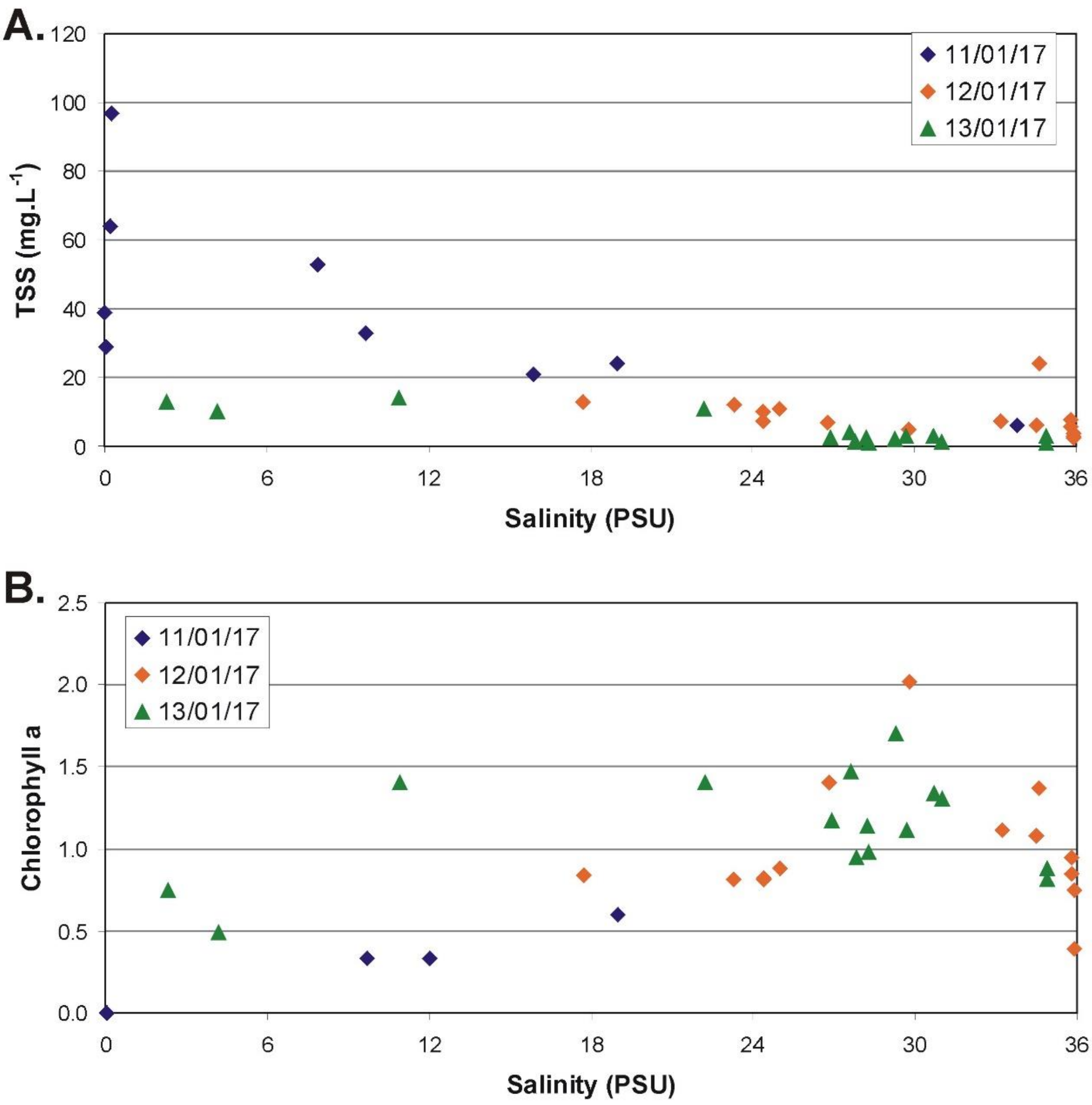
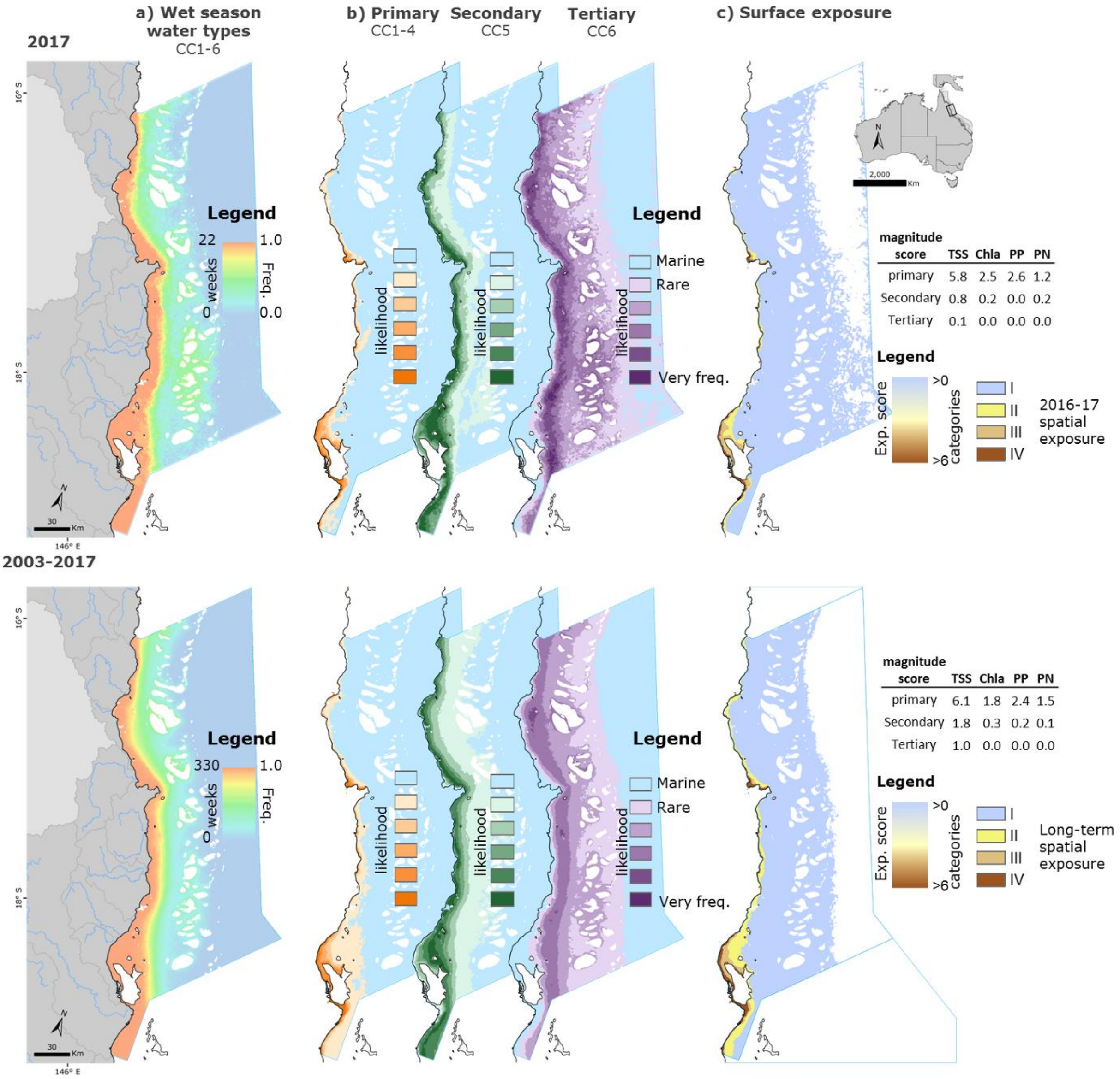


Figure 3-64: TSS concentrations (A) and Chl-a concentrations (B) from the flood plumes from the Tully (11–12/01/17) and Russell-Mulgrave (13/01/17) Rivers.

Wet Tropics Region: Mapping wet season conditions

As described in Section 2.7, mapping products were 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 3-65 and in a panel of weekly characteristics throughout the 22 week wet season period (Figure 3-66 and Figure 3-67). Details included 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; and the wet season water type maps showing the six colour wet season classes.



magnitude score	TSS	Chla	PP	PN
primary	5.8	2.5	2.6	1.2
Secondary	0.8	0.2	0.0	0.2
Tertiary	0.1	0.0	0.0	0.0

magnitude score	TSS	Chla	PP	PN
primary	6.1	1.8	2.4	1.5
Secondary	1.8	0.3	0.2	0.1
Tertiary	1.0	0.0	0.0	0.0

Figure 3-65: 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 2016–17 wet season (top).

Figure 3-65 (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 2016–17 wet season. Table 3-5 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 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 (2003–2016, Figure 3-65 (bottom) and Table 3-5 (numbers in brackets).

In 2016–17, the Wet Tropics region was most affected by the lower exposure category (category I), in agreement with the long-term trends. Approximately 72% of the total area of the Wet Tropics region was exposed to wet season water types (Primary, Secondary and Tertiary water types combined) during at least one week of the wet season. This area was greater than the long-term areas (Table 3-5: 64% exposed to wet season water types during at least one week of the wet season). However, only 3% of the Wet Tropics region was exposed to the higher exposure categories (categories III and IV). These areas were similar to the long-term areas (Table 3-5: 1% to category III and 2% to category IV). In 2016–17, it was estimated that:

- A total of 99% of the Wet Tropics coral reefs were exposed to wet season water types (Primary, Secondary and Tertiary waters combined), during at least one week of the wet season. However, only 0.4% of corals were in the highest exposure category (IV) and 3% were in the exposure category III.
- A total of 97% of the Wet Tropics seagrasses were exposed to wet season water types during at least one week of the wet season. Approximately 22% and 20% were in exposure categories III and IV, respectively.
- These exposures indicate potential risk only as exposure maps have not been yet validated against ecological health data to confirm the ecological consequences of the risk
- In 2016–17, the coral and seagrass areas in categories III and IV were slightly under the long-term areas (0.2% and 0.02% of reefs and 26% and 28% of seagrasses exposed to categories III and IV, respectively). These exposure characteristics are logical with the characteristic of a slightly under average wet season (Table 3-1).

Table 3-5: Areas (km^2) and percentages (%) of the Wet Tropics region affected by different categories of exposure during the 2016–17 wet season (*and long-term values in brackets*).

Wet Tropics Marine NRM Region		**Total**	**Potential risk category Lowest ----------------------- highest**				**Total exposed**	**Total non-exposed**
			I	**II**	**III**	**IV**		
Surface area	Area (km^2)	31,948	21,772	376	674	162	22,983	8,992
			(18,404)	*(1,044)*	*(734)*	*(261)*	*(20,443)*	*(11,533)*
	Percentage (%)	100	68	1	2	1	72	28
			(58)	*(3)*	*(2)*	*(1)*	*(64)*	*(36)*
Coral reefs	Area (km^2)	2,425	2,383	4	3	0.4	2,390	35
			(2,355)	*(26)*	*(4)*	*(0.5)*	*(2,386)*	*(39)*
	Percentage (%)	100	98	0.2	0.1	0.02	99	1
			(97)	*(1)*	*(0.2)*	*(0.02)*	*(98)*	*(2)*
Surveyed seagrass	Area (km^2)	232	76	52	50	47	225	7
			(15)	*(85)*	*(61)*	*(66)*	*(227)*	*(5)*
	Percentage (%)	100	33	22	22	20	97	3
			(6)	*(37)*	*(26)*	*(28)*	*(98)*	*(2)*

Figure 3-66 and Figure 3-67 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 2016 and April 2017. The 2016–17 wet season was characterised by below average rainfall in the Wet Tropics 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 in the 2016–17 sampling period were below the long-term mean weekly discharge value, except for weeks 6, 7 and 10 to 14, with a maximum weekly discharge value measured during week 10 (1,103,720 ML). The heavy rainfall occurring in the catchments of the Wet Tropics from 7 to 10 January 2017 resulted in a large flood plume from the Johnstone River (week 6), whereas the coastal region off the Tully River was cloudy.

An increase in water quality concentrations was observed following these weeks. The maximum TSS surface concentrations and minimum Secchi depth were measured during week 6 (5–11 January) (33.0 mg L^{-1}); however, cloud cover prevented obtaining clear satellite images of the flood plumes for this week. Using only sites with a colour class category (i.e., no cloud), the mean weekly TSS concentrations reached 12.5 mg L^{-1} (week 7) and 12.4 mg L^{-1} (week 12) in colour class 4. This is 5 times the wet season TSS guidelines for the open coastal and mid-shelf waters. The guideline however, is a seasonal mean and the ecological effect of the acute concentration peak is not known. The mean weekly Chl-a reached 1.8 µg L^{-1} during week 8 and up to 16.4 µg L^{-1} during week 17, when TSS were reduced due to sedimentation of the coarser particles (Bainbridge et al., 2012). The lower mean weekly Secchi depth was measured in colour class 4 during weeks 7 and 17 (Secchi depth = 0.8 and 0.5 m, respectively). The maximum highest mean weekly DIN values in colour class 4 were measured during week 8 (247.0 µg L^{-1}) and 12 (142.0 µg L^{-1}). No measurements were collected in colour classes 1, 2 and 3.

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 8.0 mg L^{-1} and 3.0 mg L^{-1}, i.e., approximately 3.3 and 1.3 the wet season TSS guidelines of 2.4 mg L^{-1}, respectively (Table E- 8). The mean seasonal Chl-a concentrations in the Primary and Secondary water types were 8.9 µg L^{-1} and 1.5 µg L^{-1}, i.e., approximately 14 and 2.3 times the wet season Chl-a guidelines of 0.63 µg L^{-1}, respectively. The mean seasonal PP concentration in the Primary water type was 17.56 µg L^{-1} (5.3 times the 3.3 µg L^{-1} guideline) and the mean seasonal PN concentrations in the Primary and Secondary water types were 83.9 and 50.2 (3.4 and 2 times the 25 µg L^{-1} guideline), respectively. Finally, the mean seasonal TSS, Chl-a, PP and PN concentrations in the Tertiary water type and the mean seasonal PP concentration in the Secondary water type were all under their respective wet season guidelines (Table E- 8).

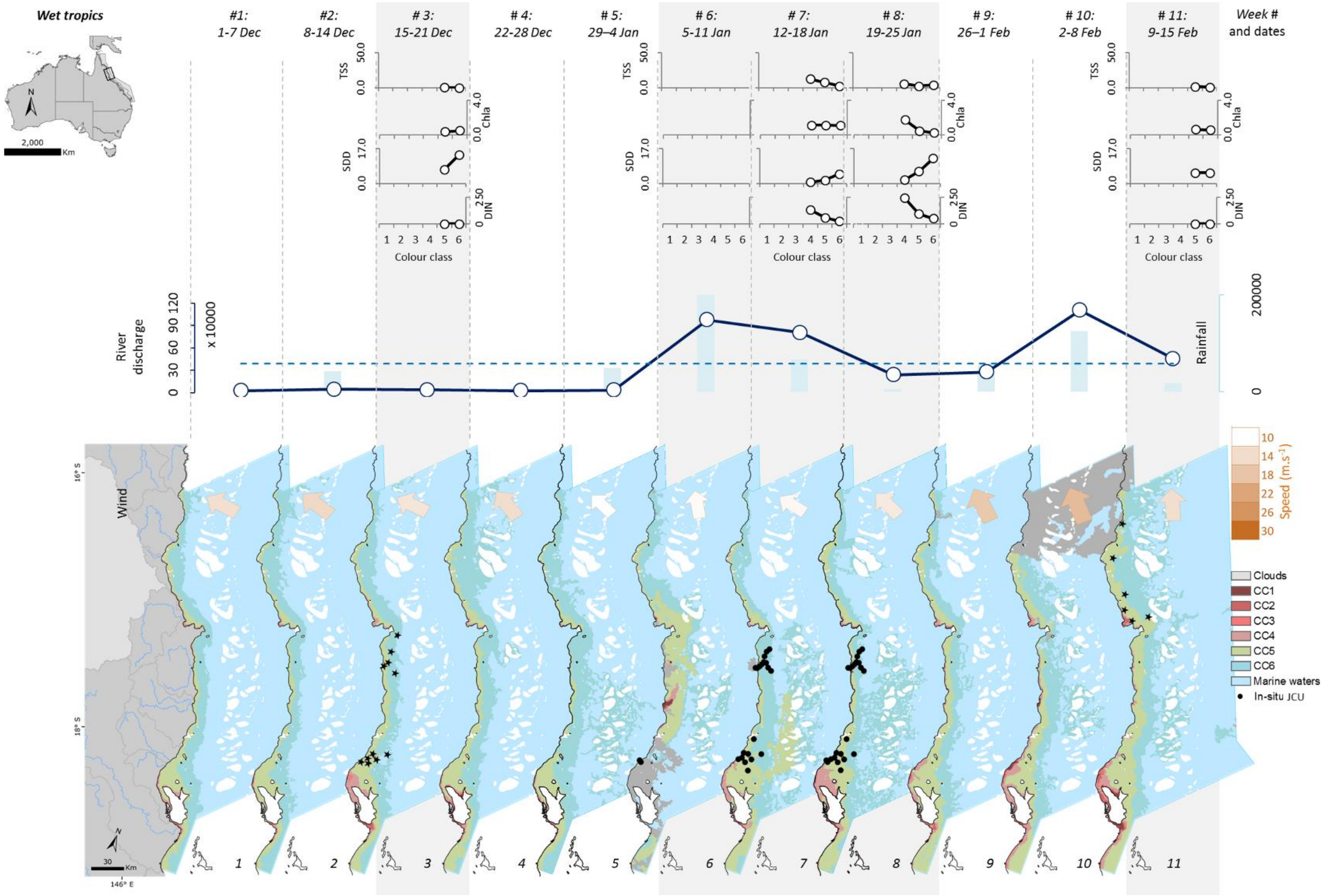


Figure 3-66: Panel of water quality and environmental characteristics in the Wet Tropics region throughout the 2015–16 wet season period: weeks 1 to 11. Details included in the panels: mean TSS (mg L^{-1}), Secchi disc depth (SDD) (m), Chl-a (µg L^{-1}) and DIN (µg L^{-1}) within each colour class; weekly 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.

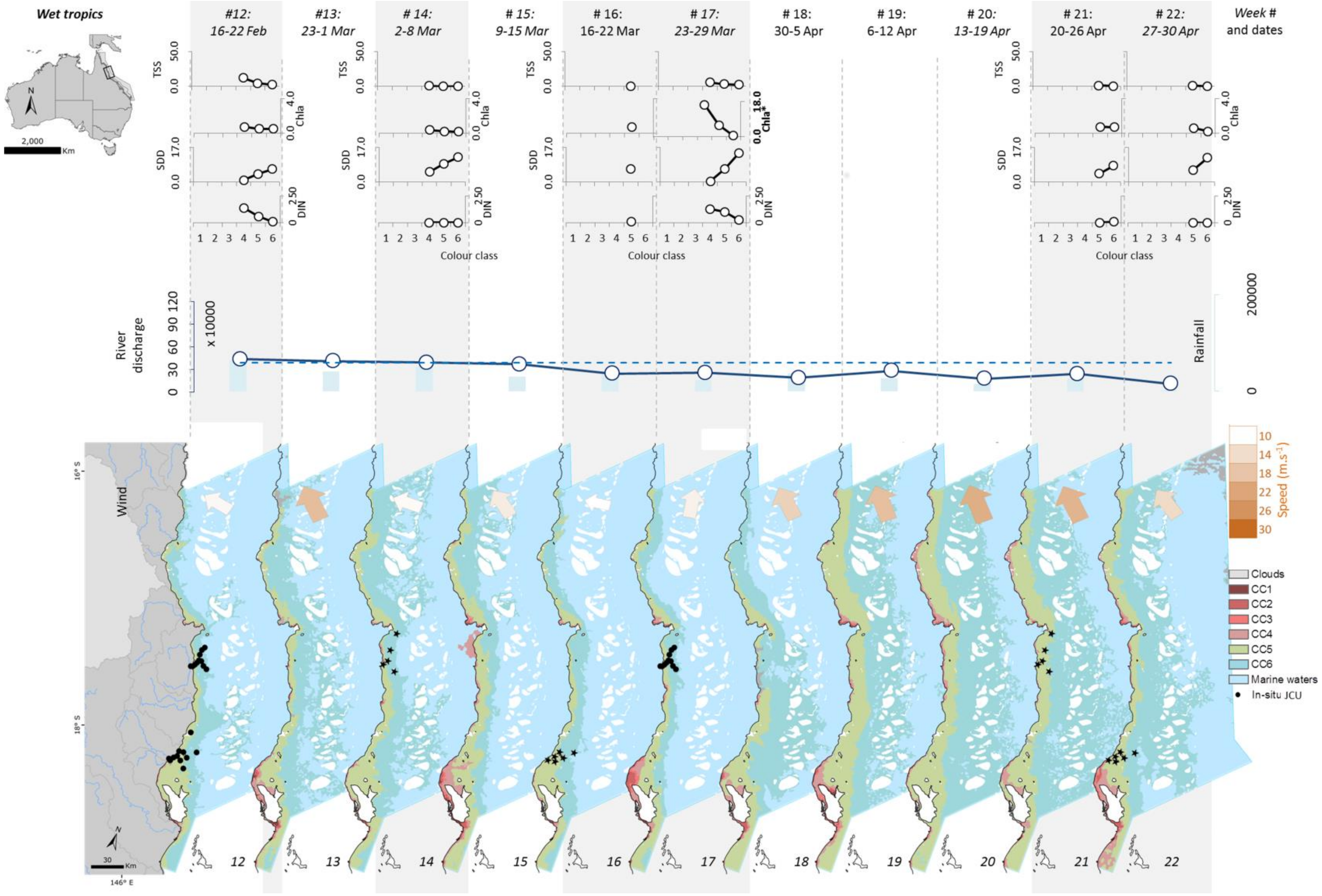


Figure 3-67: Panel of weekly water quality and environmental characteristics in the Wet Tropics region throughout the 2016–17 wet season period: weeks 12 to 22. Details included in the panels: mean TSS (mg L^{-1}), Secchi disc depth (SDD) (m), Chl-a (µg L^{-1}) and DIN (µg L^{-1}) within each colour 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.

3.4.5 Burdekin focus area

Overview

The Burdekin region is one of the two large dry tropical catchment regions adjacent to the GBR, with cattle grazing as the primary land use 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. 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 9 times per year, with 6 stations sampled during both the dry and wet season, and 9 only 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 3-68).

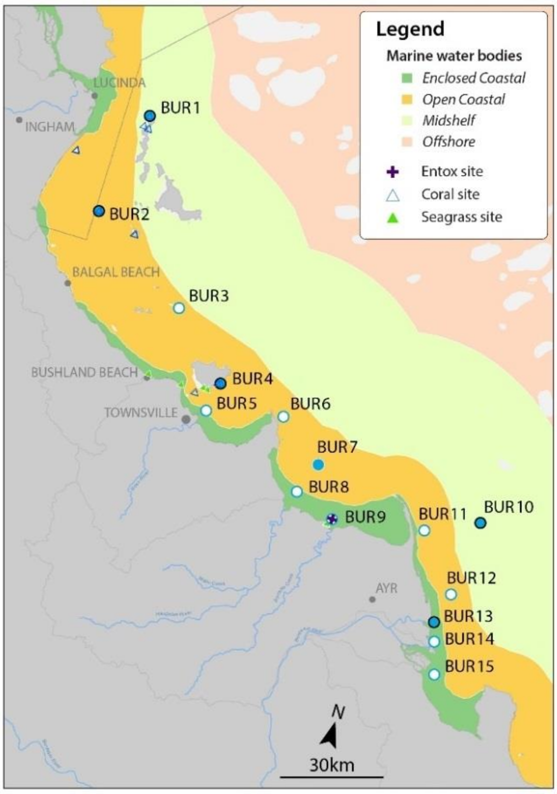


Figure 3-68: MMP sampling sites in the Burdekin focus area, shown with the water body boundaries.

Rainfall for the Burdekin Basin were generally low in 2016–17 and below the long-term average in all catchments, which is reflected in the lower flow than the long-term median flow in the Burdekin River (Figure 3-69). This contrasts substantively with the flow conditions between 2007 to 2012 (Table A2-1) when annual discharge from the Burdekin River was above median levels, followed by below the long-term median discharges in the later years (2013 to 2017) (Figure 3-69).

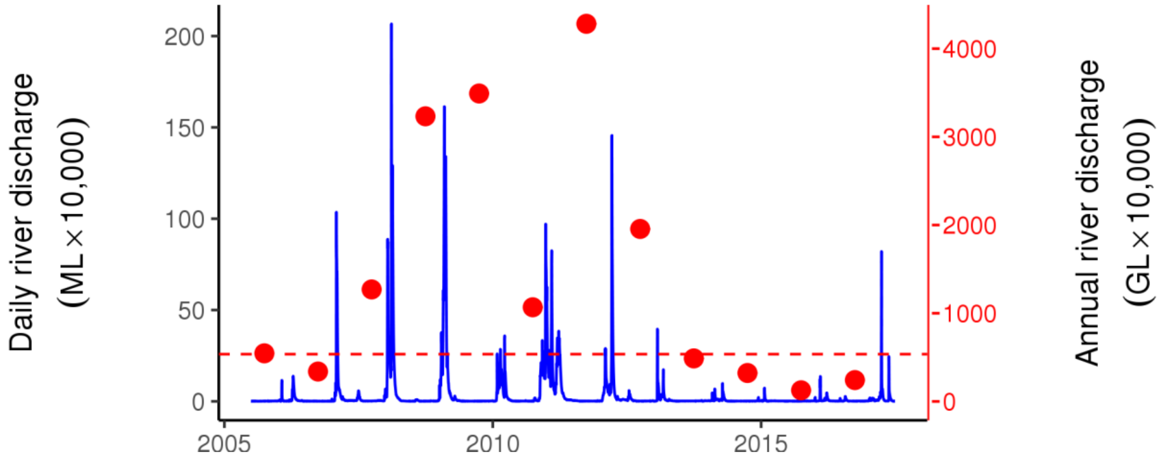


Figure 3-69: Discharge for the Burdekin River (Clare gauge). Daily (blue) and water year (October to September, red) discharge is shown. Red dashed line represents the long-term median annual discharge. Please note as this is the combined discharge, high flows in one river will not necessarily be visible in the graph.

The estimated zone of influence for the Burdekin River is presented in Figure 3-70, showing a substantially constrained zone of influence in 2016–17 compared to the large events of 2010–11, which was related with below long-term median discharge.

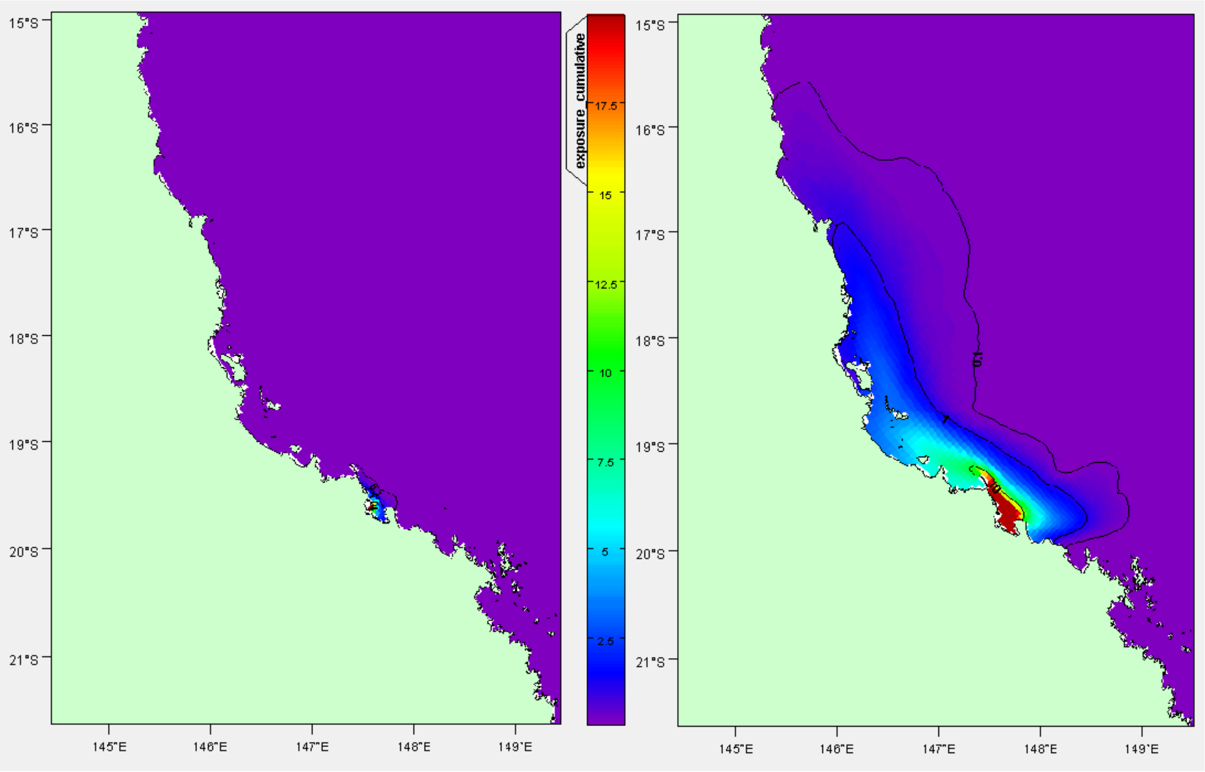


Figure 3-70: Cumulative exposure index for the Burdekin River at the end of June 2017 (left), results for 2010–11 (right) are shown for context. The colour bar indicates the calculated cumulative exposure (concentration x days) above 1% of the incoming concentration. The colour bar is capped at 20 Conc.Days. Contours show 0.1, 1.0 and 10.0 Conc.Days exposure levels.

The combined discharge and loads calculated for the 2016–17 water year from the Burdekin and Haughton Basins were in the lower range measured over the past decade, although the discharge was the highest since the 2011–12 water year and reflects a drier period in this region over the past 5 years (Figure 3-71). Indeed, the past 5 water years have had low discharge as well as lower TSS, DIN and PN loads compared to the previous wetter period. Over the 11-year period, discharge has varied from 930,000 ML (2014–15) to 37,300,000 ML

(2010–11), TSS loads have ranged from 300 kt (2013–14) to 15,100 kt (2007–08), DIN loads from 190 t (2014–15) to 3,600 t (2010–11) and PN loads 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.

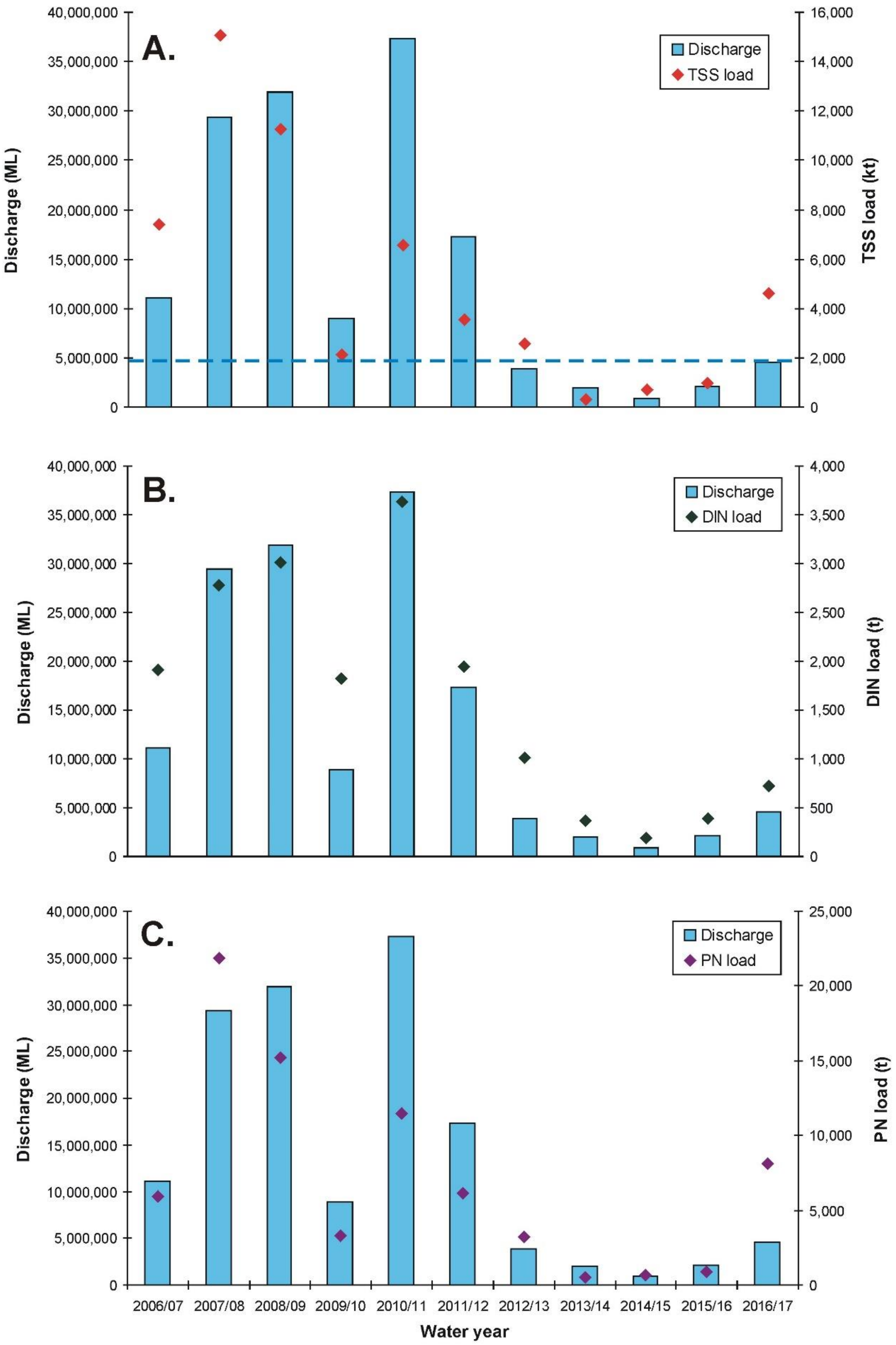


Figure 3-71: (A) Discharge and TSS, (B) DIN and (C) PN loads for the Burdekin and Haughton Basins from 2006–07 to 2016–17. The loads reported here are a combination of ‘best estimates’ for each basin based on ‘up-scaled discharge data from gauging stations, monitoring data (Burdekin River), the DIN model 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.

The loading maps presented in Section 3.3 can also be assessed to determine the relative contribution of loads from each river to the marine NRM region. Figure 3-72 shows the estimated DIN and TSS contributions for the Burdekin region in 2010–11 and 2016–17. 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 2016–17, with DIN loading contributions from the Proserpine and O'Connell Rivers (~13% and 11%, respectively) that are closer to the Burdekin NRM region boundary. Figure 3-15 also shows that the Burdekin River has an important influence on the Wet Tropics region during large discharge years, especially for TSS in 2010–11 (~40% of the contribution) and indicates that material can be transported as far north as the Cape York NRM region (estimated to contribute almost 20% of the regional loading). The Burdekin River had limited influence (<1%) in the Wet Tropics region in 2016–17 (Figure 3-15); however, the Herbert River influenced the Burdekin DIN loading (14%) in 2016–17; the Herbert River has influenced the Burdekin Region in most of the years modelled. In 2016–17, the highest river-derived DIN loading contributions to the Burdekin region were from the Burdekin (40%), Herbert (14%), Haughton (10%) and Don Rivers (11%), whereas the TSS contributions were dominated by the Burdekin River (86%).

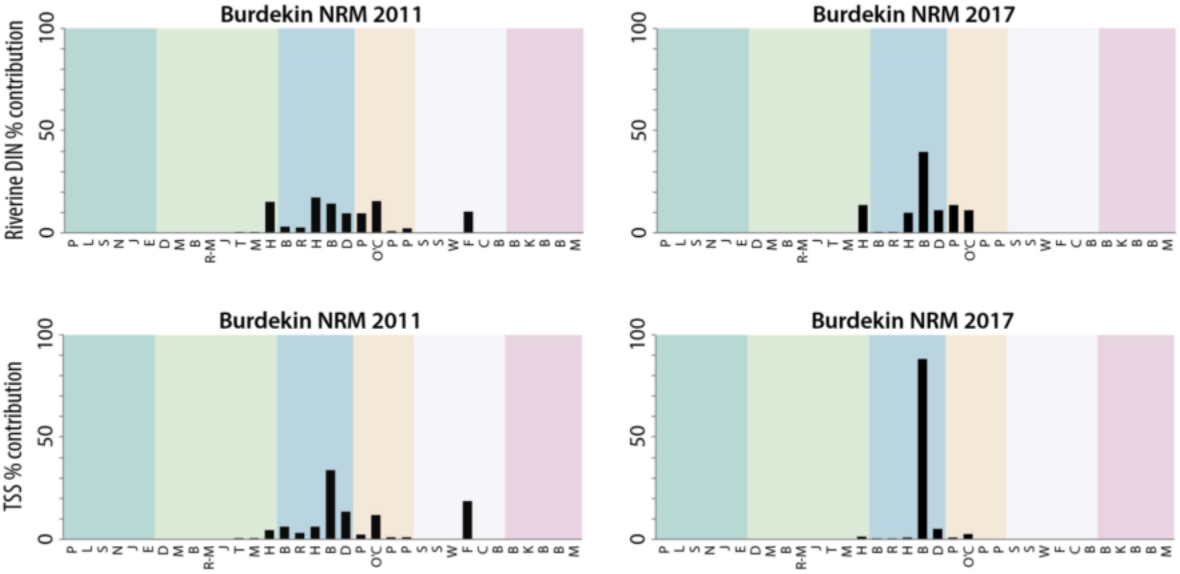


Figure 3-72. River contributions (x-axis, fully labelled in Figure 3-15) to the (top) DIN and (bottom) TSS loading to the Burdekin NRM region in 2010–11 (left column) and 2015–17 (right column). Shading groups rivers in the same NRM region: Cape York – dark green, Wet Tropics – light green, Burdekin – blue, Mackay Whitsunday – orange, Fitzroy – pink, Burnett Mary - red.

Ambient water quality

A brief description and definition of the water quality variables measured in this region can be found in Appendix D-1.

The location of some of the loggers have changed in this region (BUR13) and the number of water sampling sites and frequency of sampling increased during 2015. Some of the new sites are placed further inshore and they are therefore more likely to be affected by Primary and Secondary plume waters, which will influence assessment of longer term trends. It is also important to note that the trend lines accounts for the effect of wind, waves and tides; accordingly, the trends are independent of changes in local weather.

The long-term trend showed a 'good' rating, whereas the combined AIMS/JCU index showed a 'moderate' rating (Figure 3-73a). For all measured variables, as seen in Figure 3-73 and Figure-E5, it is evident that the inclusion of the JCU and data collected under the changed sampling design (more stations and sampling) has led to a larger variability in the water quality parameters and biased long-term trends in NO_x, PO_4, TSS and Secchi depth. These trends do not therefore represent a real change but are due to the changes in sampling design and inclusion of more wet season data.

Overall, the Chl-a trend line remained relatively stable over the monitoring period with a slight declining trend and concentrations near the guideline value (Figure 3-72b). The trend lines of the instrumental Chl-a showed distinct maxima above the guideline during the wet seasons of 2008–09 and 2013–14 (Figure 3-73b).

The TSS concentrations trend line shows a moderate increase over the last years, with levels above GBR Water Quality Guidelines in 2016–17 (GBRMPA, 2010). The PN and PP have been relatively stable over the entire monitoring period, with a minor decrease in PN in 2016–17 (Figure 3-73h, i). The overall trend lines for PN and PP were for the entire monitoring period around GBR Water Quality Guidelines (GBRMPA, 2010).

Secchi depth remained fairly stable and non-compliant with the GVs over the entire sampling period, with a slight decrease since 2014 (Figure 3-73g). The turbidity record showed relatively stable levels with most values since 2010 being above the guideline (Figure 3-73g).

The trend line for concentrations of NO_x has increased markedly after the implementation of the new sampling design in 2015, and therefore the trend line does not represent a real change (Figure E-73c). Generally, NO_x exceeded the Queensland guideline from 2011 onwards (Figure 3-73c). PO_4 concentrations have remained the same over the monitoring period (Figure 3-73d).

The concentrations of POC have remained relatively stable over the monitoring period, with a slight upward trend over the last two years (Figure 3-73j). The DOC concentrations have increased since the initiation of the sampling program and continued to increase during 2016–17 (Figure 3-73k).

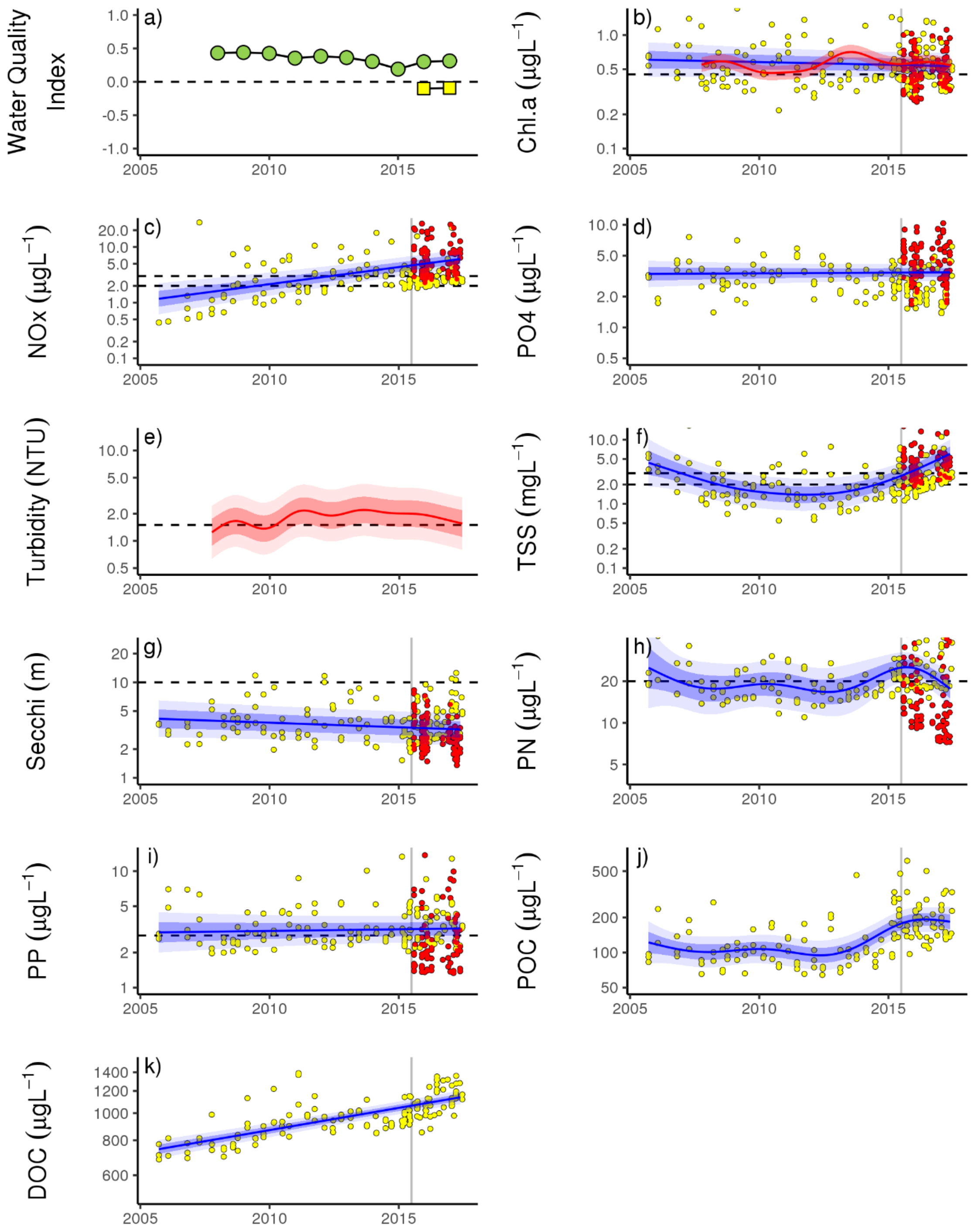


Figure 3-73: Temporal trends in water quality for the Burdekin focus area. a) Water Quality Index, b) chlorophyll *a* (Chl-a), c) nitrate/nitrite (NO_x), d) phosphate (PO_4), e) turbidity, f) total suspended solids (TSS), g) Secchi depth, h) particulate nitrogen (PN), i) particulate phosphorus (PP), j) particulate organic carbon (POC) and k) dissolved organic carbon (DOC). Water Quality Index colour coding: dark green- 'very good'; light green- 'good'; yellow – 'moderate; orange – 'poor'; red – 'very poor'. Note that from 2015-16 onwards both AIMS and JCU was included and a separate score was calculated using the wet/dry guidelines that are shown as two separate points in Figure 3-73(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. Yellow dots represent observed data collected by AIMS and red dots data collected by JCU. Trends of records from ECO FLNTUSB instruments are represented in red, individual records are not displayed. Dashed horizontal reference lines indicate yearly guideline values and the vertical dashed lines represent when the sampling design was changed (February 2015), both lines are only shown for reference.

Event water quality

Heavy rainfall associated with the crossing of tropical cyclone Debbie occurred in the Bowen-Broken-Bogie River sub-catchments of the Burdekin catchment in March 2017 and triggered very fast stream rises across these sub-catchments. The Burdekin River at Home Hill (Inkerman Bridge) peaked at a moderate flood level at ~ 2 am on 30 March 2017 (Figure 3-74) with discharge almost exclusively from the Bowen-Broken-Bogie River sub-catchments below the Burdekin Falls Dam; such an event from only this "below dam" source area is rare for the Burdekin. Seven samples were collected over the Burdekin flow hydrograph at the Inkerman Bridge with TSS concentrations reaching ~1,500 mg L^{-1} near the peak flow as well as additional samples from the mouth offshore into Bowling Green and Cleveland Bays (Figure 3-74). Using these data, a sediment load of 1.5 million tonnes was calculated over this six-day flow event. Bulk samples were collected near the peak flow for tracing purposes.

The Burdekin River flood plume was sampled on 31 March, 1 and 2 April 2017 over the salinity gradient with satellite images showing the plume moving in an easterly/south-easterly direction coinciding with the northerly winds at this time (Figure 3-75, Figure 3-76, Figure 3-77 and Figure 3-78). TSS concentrations rapidly decreased in the plume from 710 mg L^{-1} at 0 PSU to 250 mg L^{-1} at 6.4 PSU, 20 mg L^{-1} at 11.6 PSU and < 15 mg L^{-1} by 14.3 PSU and thereafter (Figure 3-79 and Figure 3-80). These measurements are consistent with previous studies on the Burdekin flood plume in previous years (Devlin and Brodie, 2005; Bainbridge et al., 2012). The proportion of organic matter (measured as volatile suspended solids) in the Burdekin plume increased from 13% (92 mg L^{-1}) at 0 PSU to 38% (4.2 mg L^{-1}) at 26.4 PSU (Figure 3-79). It is hoped the organic tracing work will help determine whether the organic material measured in the plume is terrestrial material that is being preferentially transported or the result of production of new organic material in the plume waters. Chl-a levels in the Burdekin plume were relatively lower than those in the plumes from other regions and were generally below 1 µg L^{-1} (Figure 3-80c).

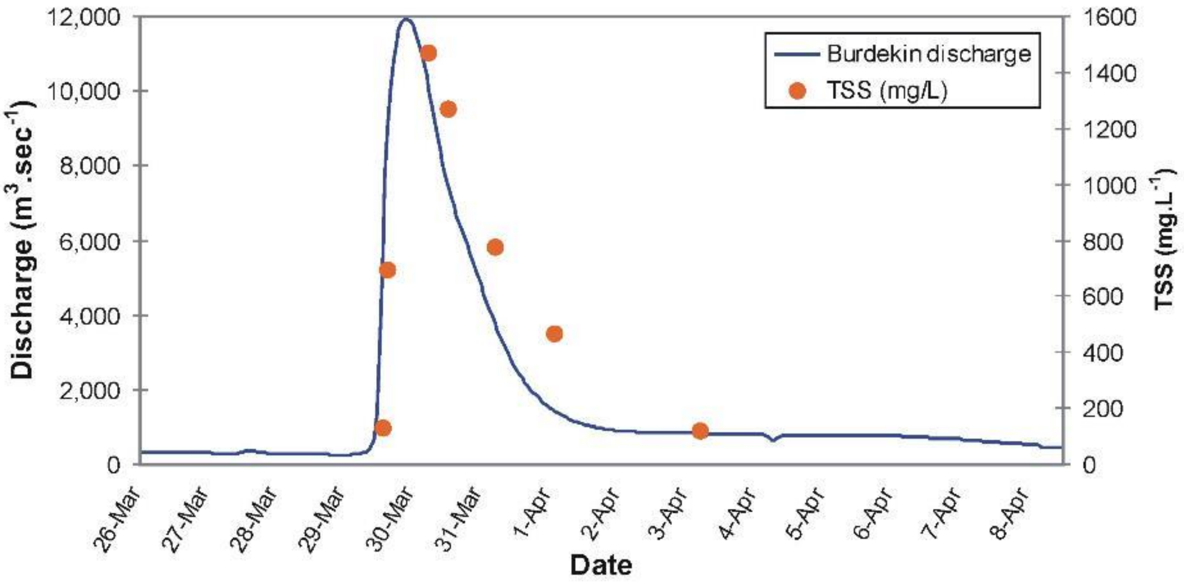


Figure 3-74: Burdekin River at Clare hydrograph along with TSS concentration in the discharge event associated with Tropical Cyclone Debbie.

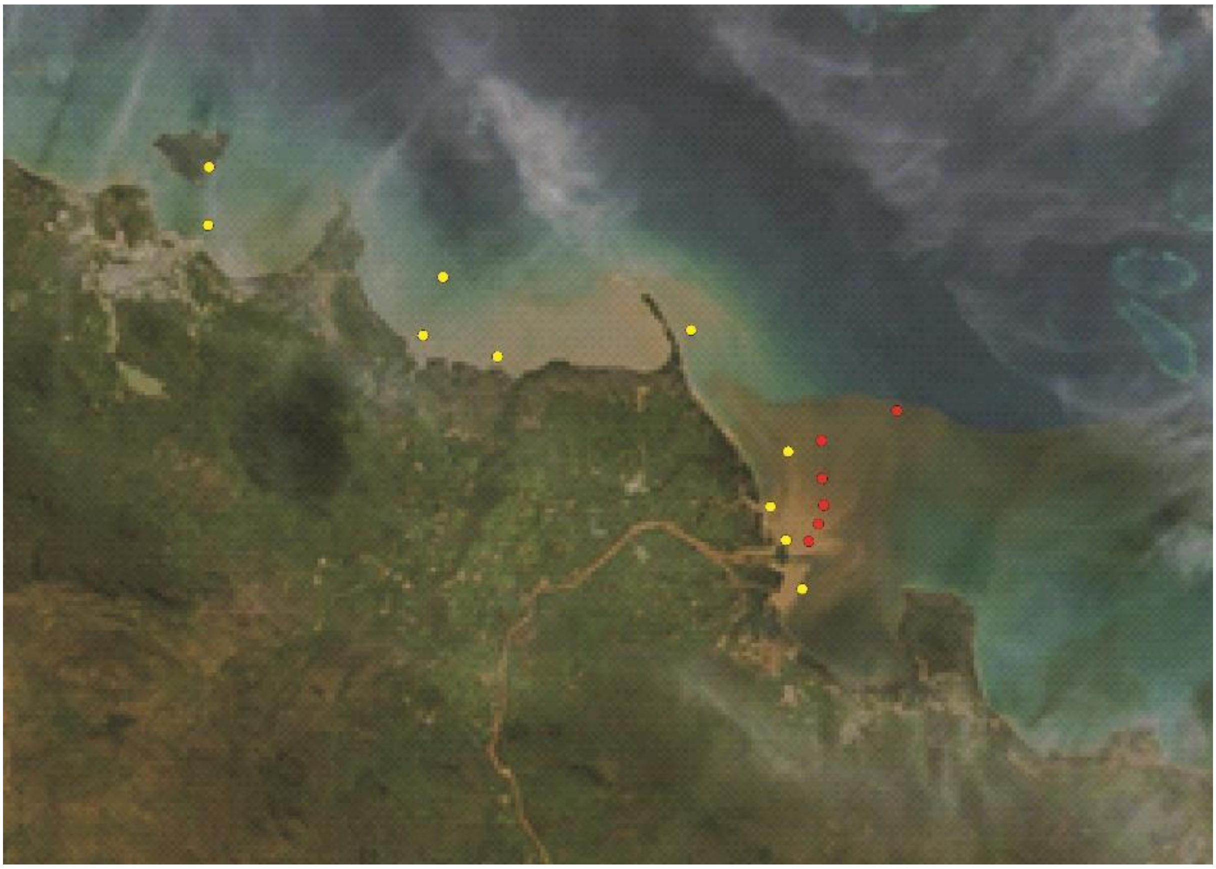


Figure 3-75: MODIS-Terra satellite image of the Burdekin River flood plume from 31 March 2017 showing the sampling sites (red dots = samples from 31 March 17; yellow dots = samples from 1 April 17). True colour Images from the NASA's MODIS instrument are provided by the EOSDIS Worldwiew earthdata system. https://worldview.earthdata.nasa.gov/.

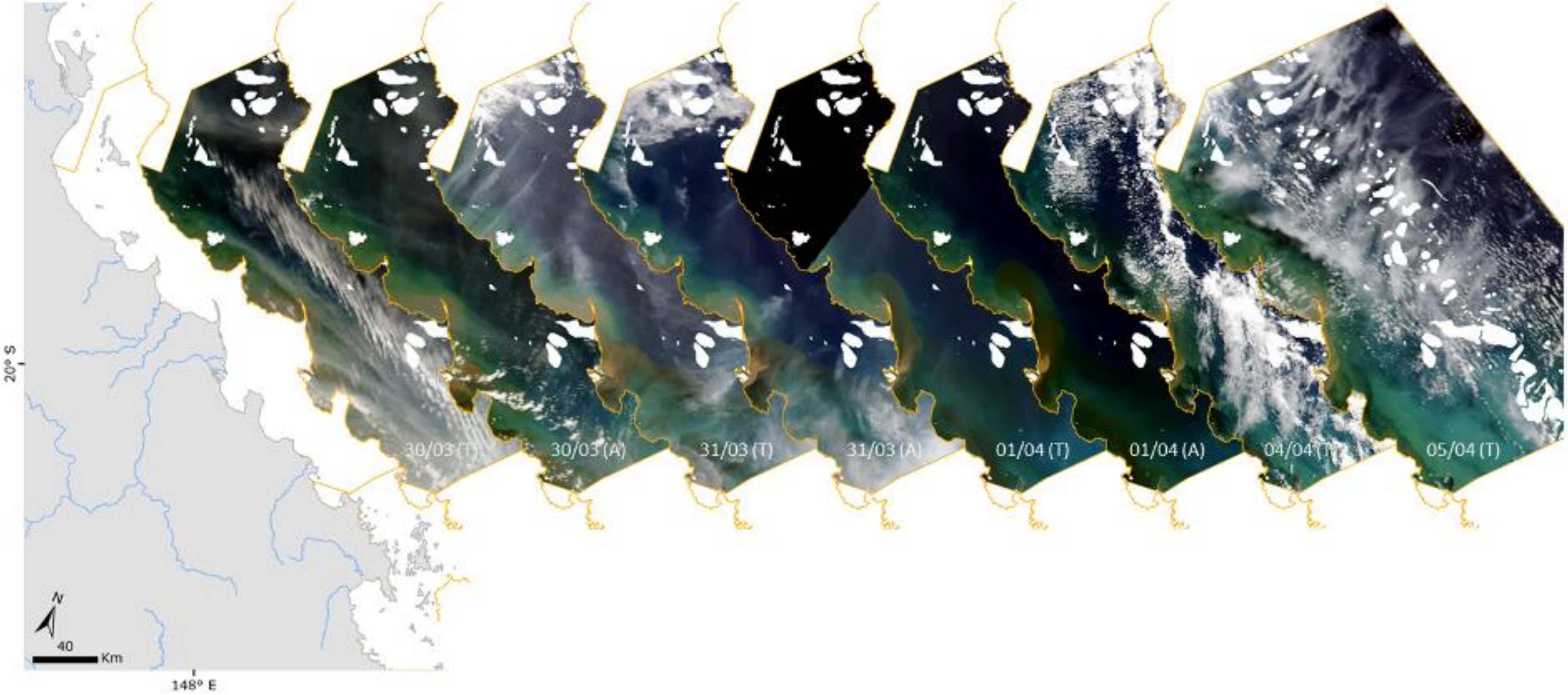


Figure 3-76: A collection of satellite images showing the evolution of the Burdekin River plume from 30 March to 5 April 2017. True colour images from the NASA's MODIS instrument are provided by the NASA EOSDIS Worldview earthdata system: (A) MODIS-Aqua, (T) MODIS-Terra. https://worldview.earthdata.nasa.gov/.

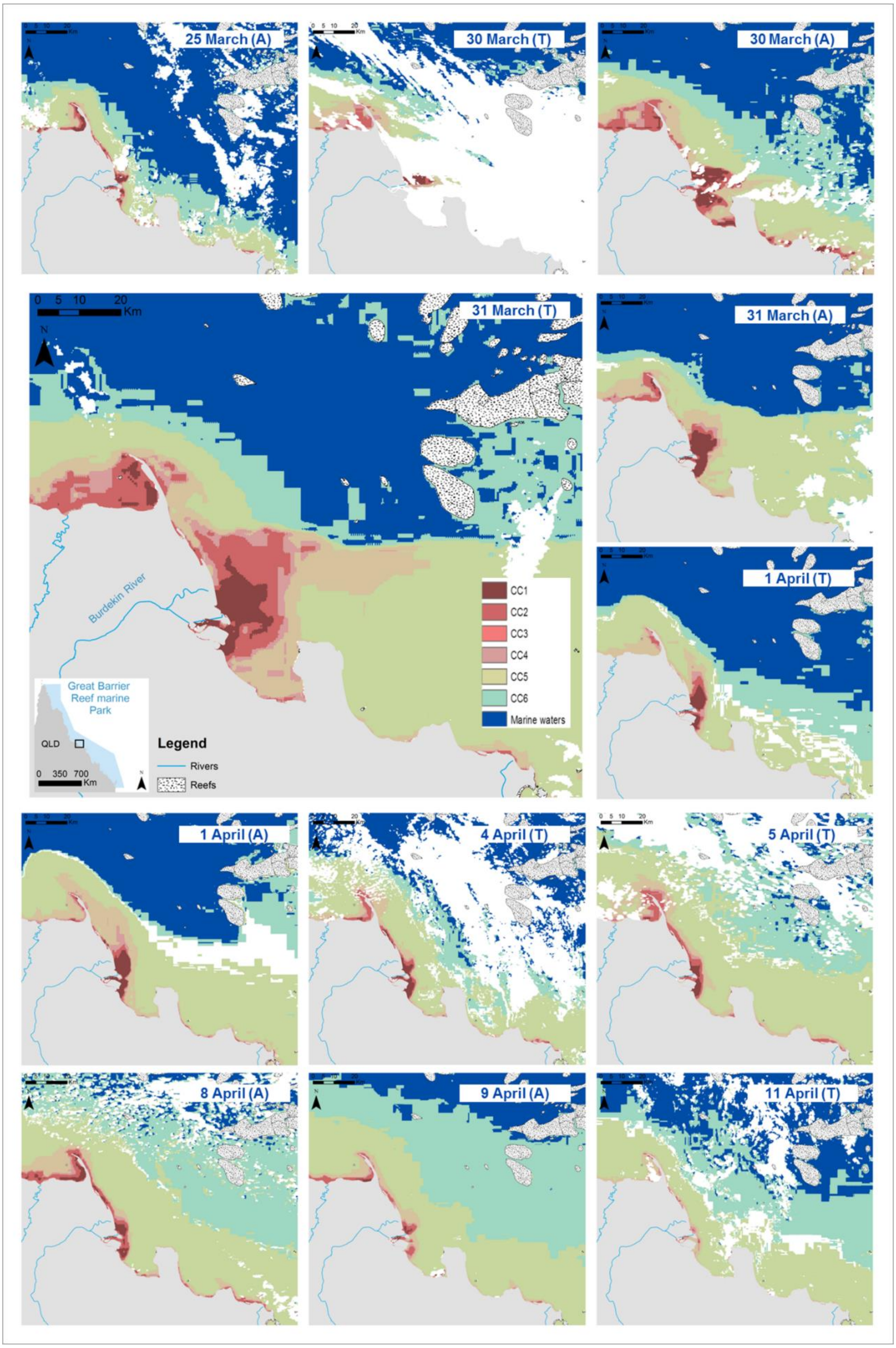


Figure 3-77: A collection of water type maps showing the evolution of the Burdekin River plume from 25 March to 11 April 2017: (A) MODIS-Aqua, (T) MODIS-Terra.

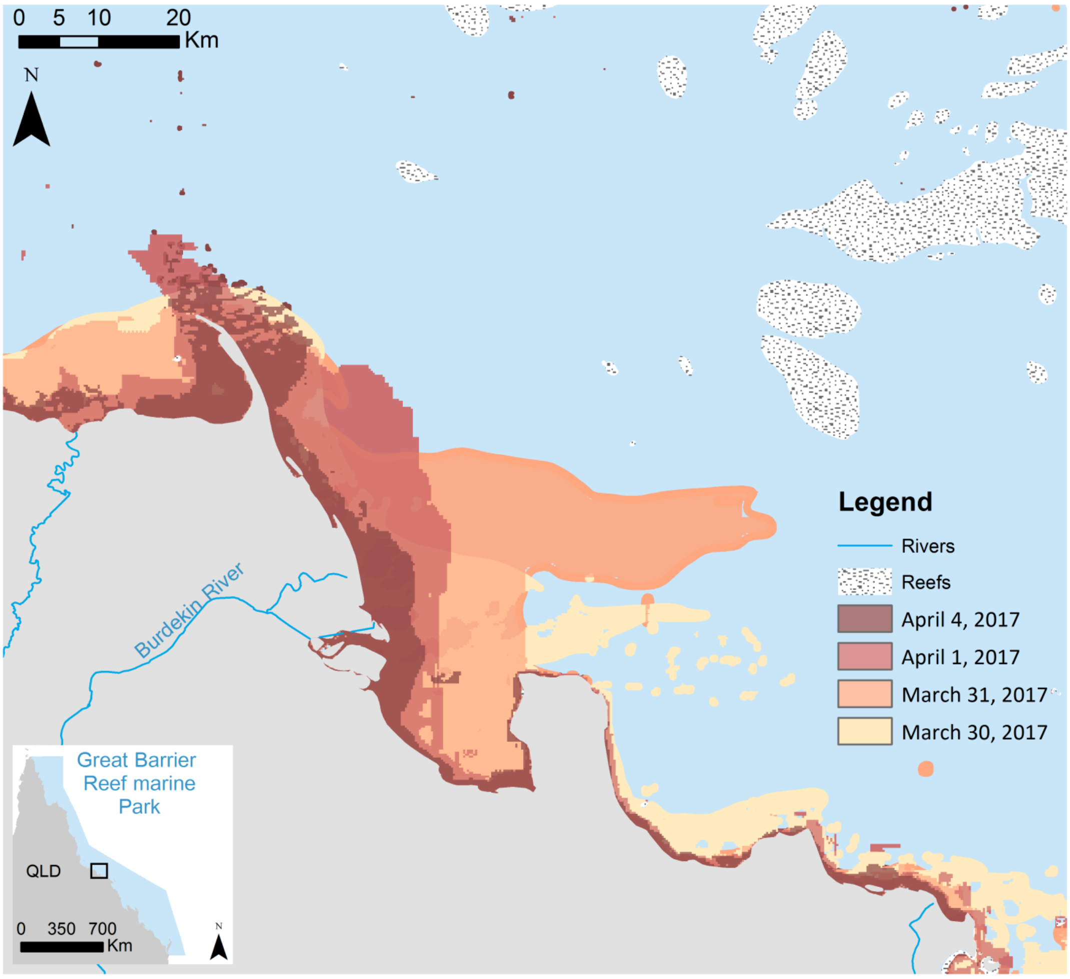


Figure 3-78: Burdekin River – Turbid river plume movements between 30 March and 4 April (Primary waters).

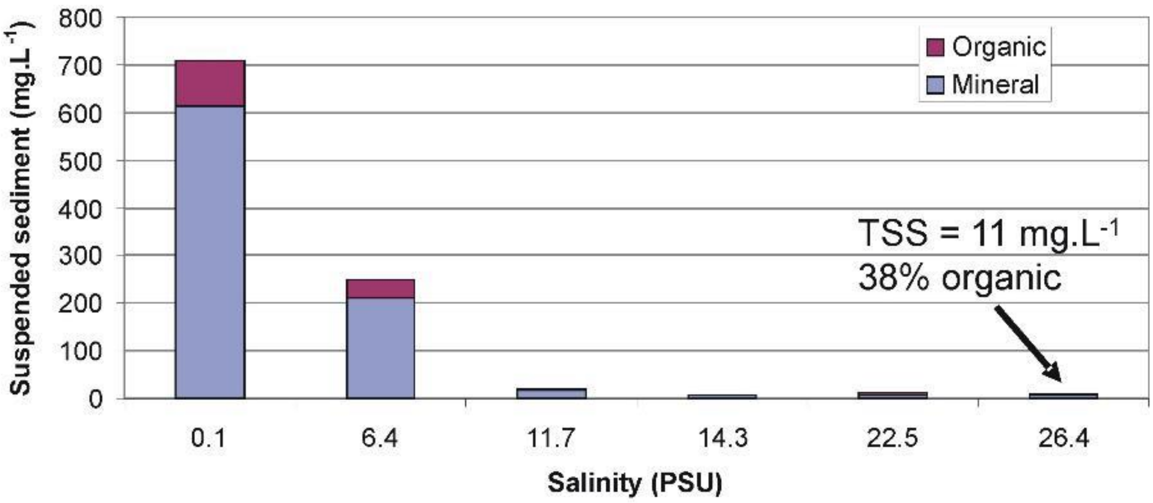


Figure 3-79: Suspended particle matter concentrations over the salinity gradient from the Burdekin River flood plume on 31 March 2017.

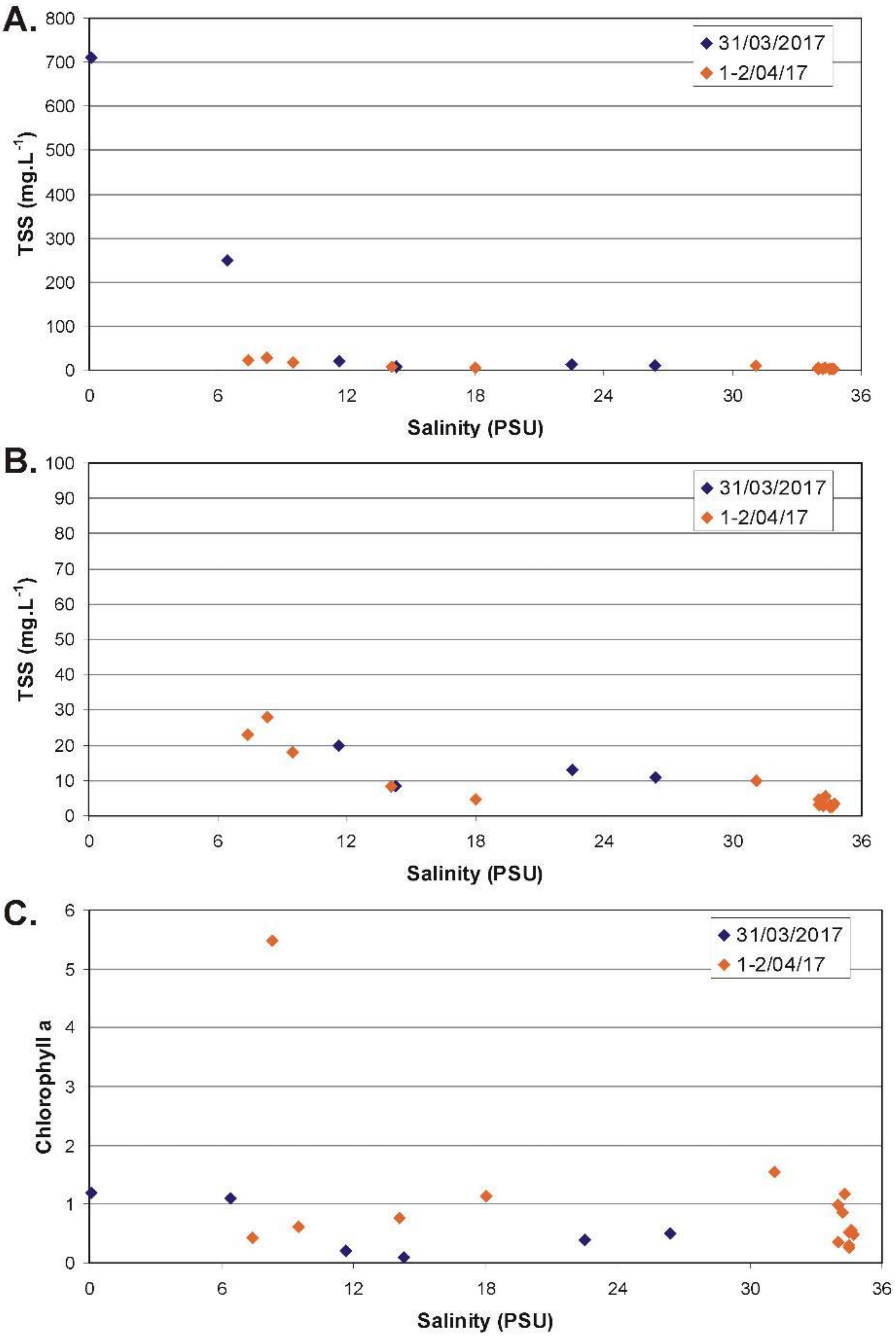


Figure 3-80: TSS concentrations from the Burdekin River flood plume over the salinity gradient (A) and an enlarged y axis to show the lower TSS values (B). Chl- a concentrations across the salinity gradient (C).

Burdekin Region: Mapping wet season conditions

As described in Section 2.7, a number of mapping products are 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. This data is presented in Figure 3-81 and in a panel of weekly characteristics throughout the 22-week wet season period (Figure 3-82 and Figure 3-83). Details included in the panels are *in-situ* water quality characteristics including TSS, Secchi depth, Chl-a and DIN within each colour class; weekly river discharge; wind speed and direction; and the wet season water type maps showing the six wet season colour classes.

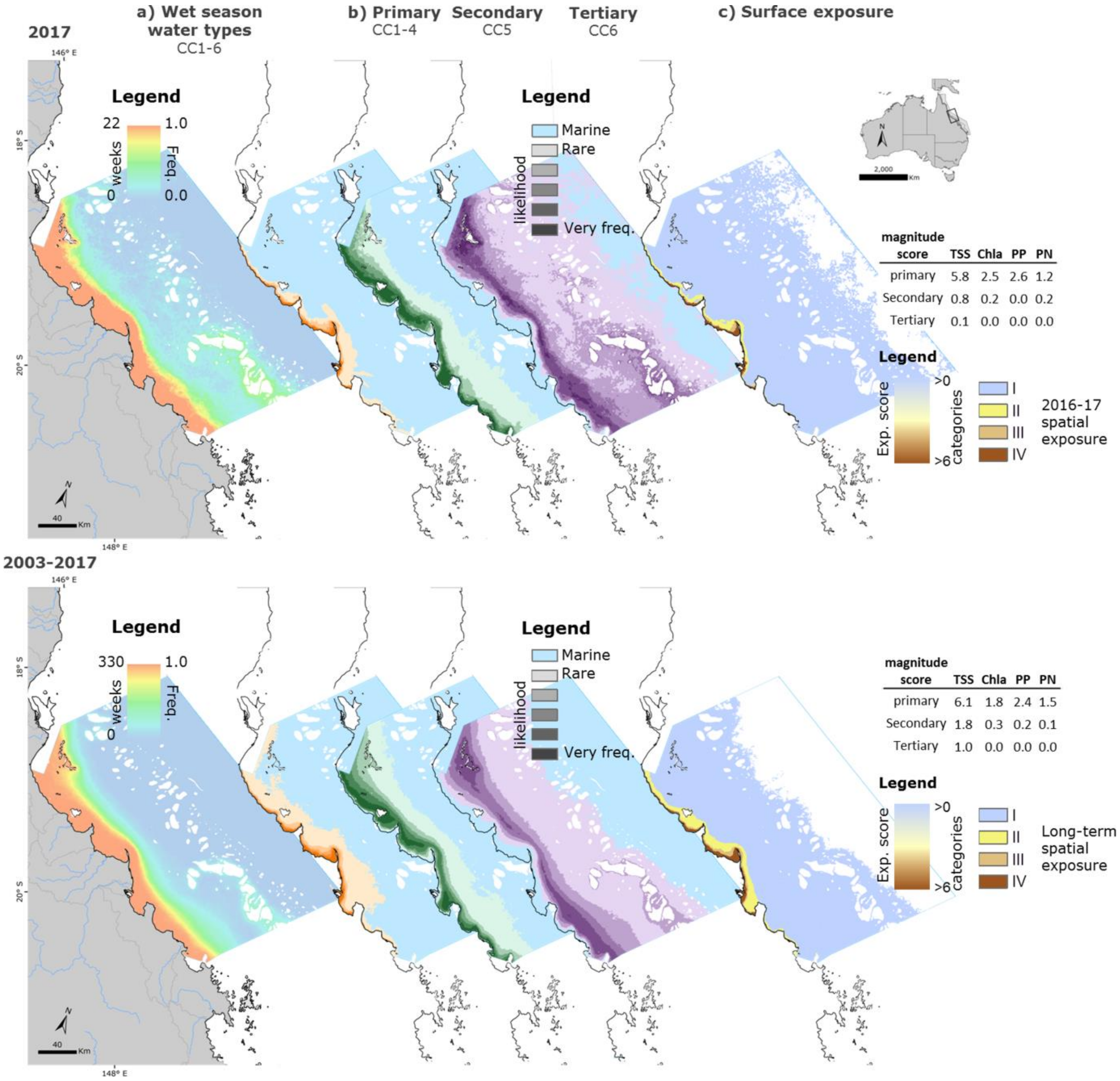


Figure 3-81: Maps showing the a) frequency of combined wet season water types waters (Primary, Secondary and Tertiary), b) the frequency of Primary, Secondary and Tertiary water types and c) the exposure maps for the Burdekin region in the long-term (bottom) and 2016–17 wet season (top).

Figure 3-81 (top) 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 2016–17 wet season. Table 3-6 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 Burdekin 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 results are presented in the context of the long-term exposure (2003–2017) shown in Figure 3-81 (bottom), with the area and percentage of exposure presented in Table 3-6 (long-term exposure in brackets).

In 2016–17, the Burdekin region was most affected by the lowest exposure categories (categories I and II) in agreement with long-term trends. Approximately 82% of the total area of the Burdekin Region was exposed to wet season water types (combined Primary, Secondary and Tertiary) during at least one week of the wet season. This area was greater than the long-term areas (Table 3-6: 62% exposed to wet season water types waters at least one day of the wet season). However, only 1% of the Burdekin Region was exposed to the highest exposure category (category IV) and only 0.4 % was exposed to category III. These areas were smaller than the long-term areas (Table 3-6: 1% to category III and 1% to category IV). In 2016–17, it was estimated that:

- A total of 99% of the Burdekin coral reefs were exposed to wet season water types (Primary, Secondary and Tertiary combined) during at least one week of the wet season. However, no corals were in the highest exposure category (IV) and very few (0.04%) were in the exposure category III.
- A total of 98% of the Burdekin seagrasses were exposed to wet season water types, during at least one week of the wet season. However, only 5% and 14% of seagrasses were in the highest exposure categories III and IV, respectively.
- These exposures indicate the potential risk as exposure maps have not been yet validated against ecological health data to confirm the ecological consequences of the risk.
- In 2016–17, the seagrass and coral areas in the categories III and IV of exposure were smaller than the long-term areas (Table 3-6: 1% and 1% of coral reefs and 8% and 19% of seagrass exposed to categories III and IV, respectively). Rainfall for the Burdekin Basin were generally low in 2016–17 and below the long-term average in all catchments and these results are coherent with the characteristic of a relatively dry wet season for this region.

Table 3-6: Areas (km^2) and percentages (%) of the Burdekin Region affected by different categories of exposure during the 2016–17 wet season (*and long-term values in brackets)*.

Burdekin Marine NRM Region		**Total**	**Potential risk category** **Lowest -------------------------------- highest**				**Total exposed**	**Total non-exposed**
			I	**II**	**III**	**IV**		
Surface area	Area (km^2)	47,009	37,527	544	185	331	38,588	8,421
			(26,781)	*(1,307)*	*(341)*	*(511)*	*(28,940)*	*(18,069)*
	Percentage (%)	*100*	80	1	0.4	1	8	18
			(57)	*(3)*	*(1)*	*(1)*	*(62)*	*(38)*
Coral reefs	Area (km^2)	2,966	2,946	3	1	-	17	2949
			2,590	*(17)*	*(2)*	*(0.3)*	*(2,608)*	*(358)*
	Percentage (%)	*100*	99	0.1	0.03	0	99	1
			(87)	*(1)*	*(0.1)*	*(0.01)*	*(88)*	*(12)*
Surveyed seagrass	Area (km^2)	708	444	115	34	102	694	14
			(270)	*(240)*	*(57)*	*(131)*	*(697)*	*11*
	Percentage (%)	*100*	63	16	5	14	98	2
			(38)	*(34)*	*(8)*	*(19)*	*(98)*	*(2)*

Figure 3-82 and Figure 3-83 illustrate the changes in water quality and environmental conditions in the Burdekin region and focus area with surface data collected by JCU and AIMS between December 2016 and April 2017. The 2016–17 wet season was in general characterised by low rainfall and consequent river discharge (below the long-term median), except for the influence of tropical cyclone Debbie in March 2017 (weeks 17 and 18). Weekly river discharges during the 2016–17 sampling period were below the long-term mean weekly discharge value, except for weeks 17 and 18 (23 March – 5 April) following the passage of tropical cyclone Debbie (see *Event water quality* section above).

An increase in water quality concentrations was observed following these 2 weeks, and highest weekly mean TSS, Chl-a and DIN values and minimum Secchi disc depth (SSD) were sampled during week 18, in the colour class 1 (23.0 mg L^{-1}, 2.2 µg L^{-1},122.3 µg L^{-1} and 0.4 m^{-1} respectively). This is approximately 10 and 3 times the wet season TSS and Chl-a guidelines, respectively, for the open coastal and mid-shelf waters. The guideline, however, is a seasonal mean and the ecological effect of the acute concentration peak is not known. Week 18 was the only week where *in-situ* samples were collected across all colour classes (1 to 6). This allowed observing the expected decrease in water quality concentration (and increase in Secchi depth) along the Burdekin transect.

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 12.0, 3.0 and 4.4 mg L^{-1}, i.e., approximately 5, 1.3 and 1.8 times the wet season TSS guidelines of 2.4 mg L^{-1}, respectively (Table E-9). The mean seasonal Chl-a concentrations in the Primary water type was 14 µg L^{-1}, i.e., approximately 22 times the wet season Chl-a guidelines of 0.63 µg L^{-1} and the mean seasonal PP concentration in the Primary water type was 14.6 µg L^{-1} (4.4 times the 3.3 µg L^{-1} guideline). Finally, the mean seasonal Chl-a and PP concentration in the Secondary and Tertiary water types and the mean seasonal PN concentrations in all water types were all under their respective wet season guidelines (Table E-9).

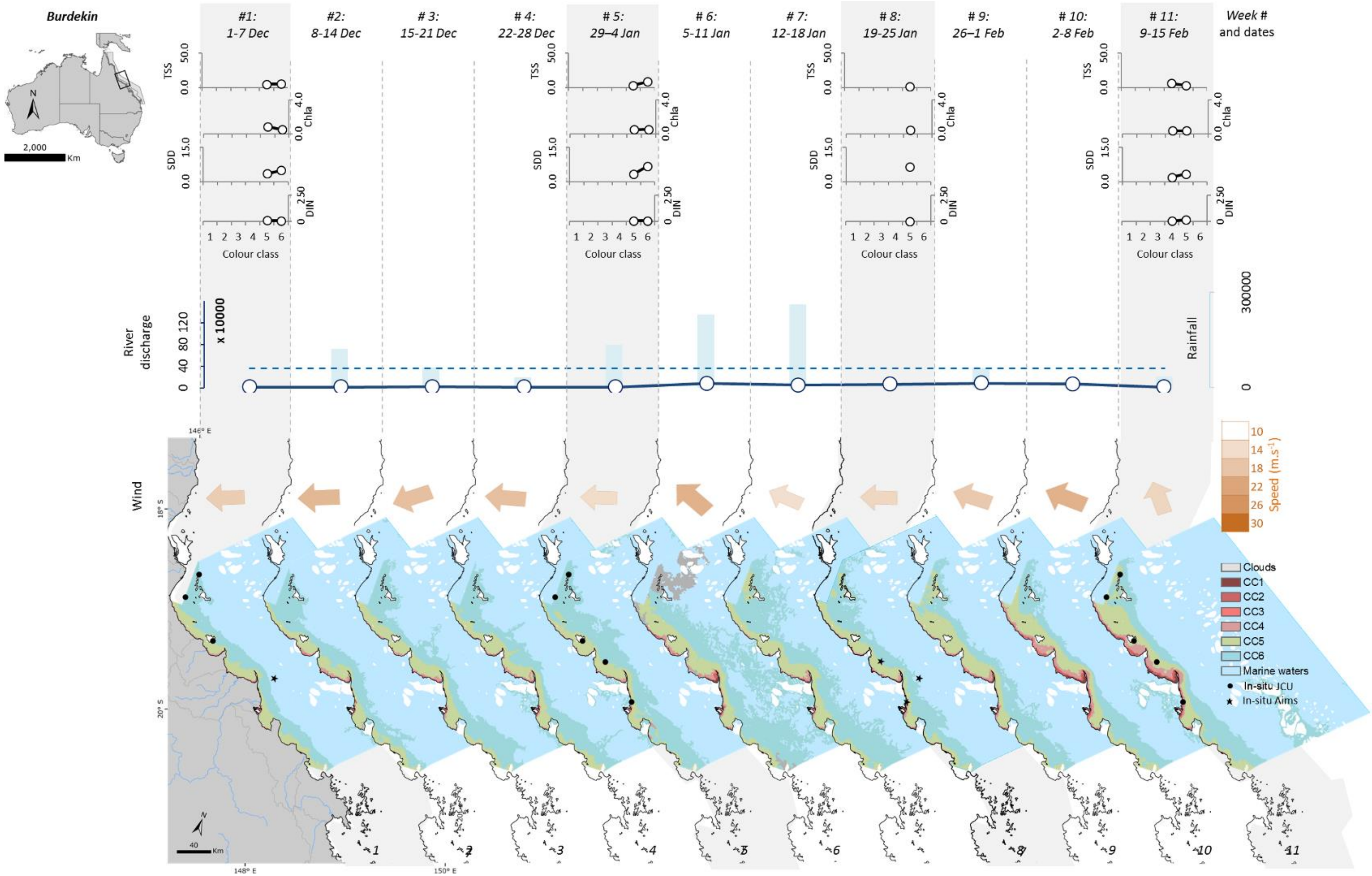


Figure 3-82: Panel of water quality and environmental characteristics in the Burdekin region throughout the 2016–17 wet season period: weeks 1 to 11. Details included in the panels include mean TSS (mg L^{-1}), Secchi disc depth (SDD) (m), Chl-a (µg L^{-1}) and DIN (µg L^{-1}) within each colour class; 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.

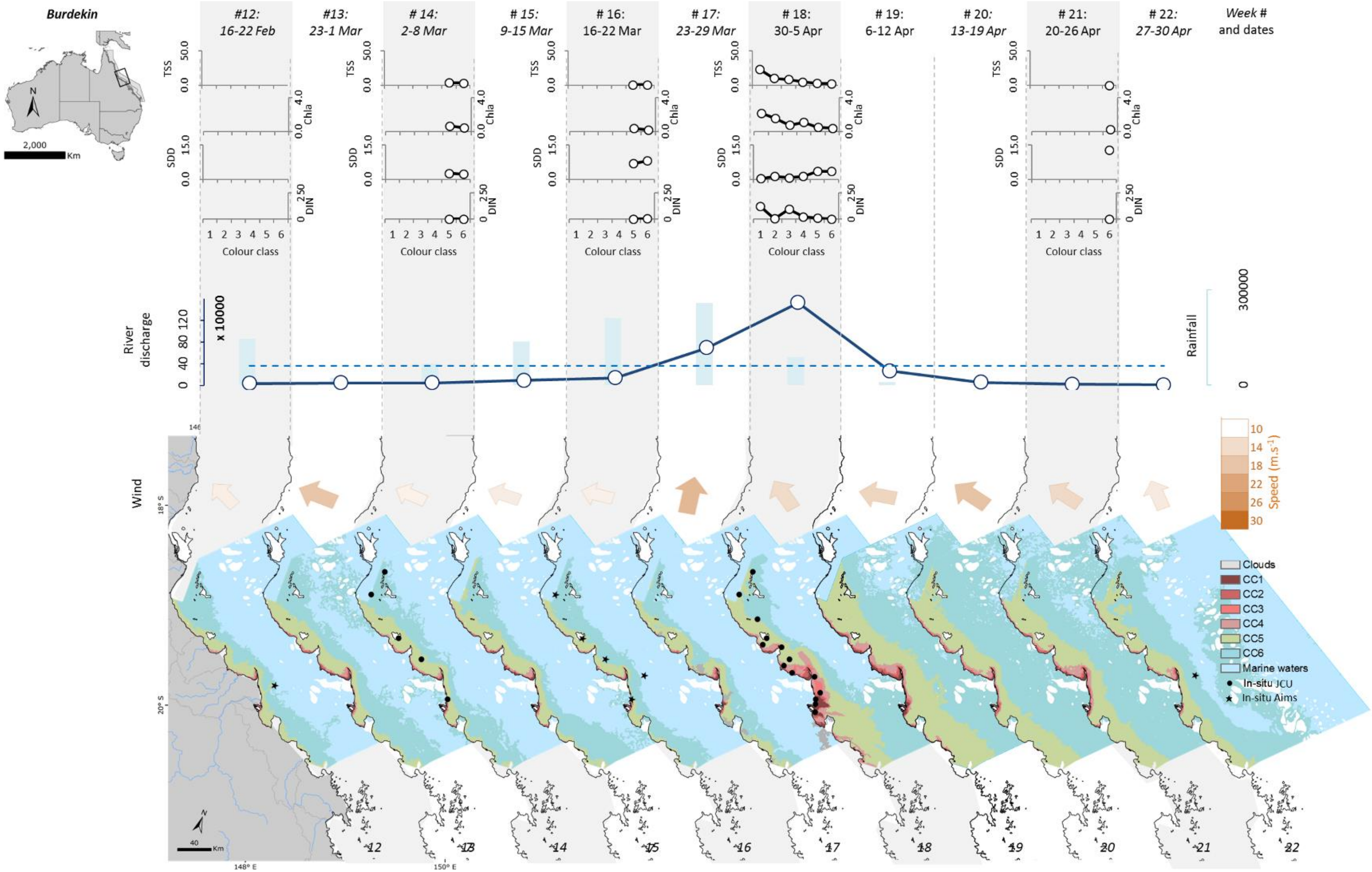


Figure 3-83: Panel of water quality and environmental characteristics in the Burdekin region throughout the 2016–17 wet season period: weeks 12 to 22. Details included in the panels include mean TSS (mg L^{-1}), Secchi disc depth (SDD) (m), Chl-a (µg L^{-1}) and DIN (µg L^{-1}) within each colour class; 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.

3.4.6 Mackay Whitsunday focus area

Overview

The Mackay Whitsunday Region is located in the central section of the GBR and comprises four major river basins, the Proserpine, O'Connell, Pioneer and Plane Basins. The region is also potentially influenced by run-off from the Burdekin and Fitzroy Rivers during extreme events or through longer-term transport and mixing. The climate in this 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.

Three stations were sampled three times per year in the Mackay Whitsunday region until the end of 2014. As part of the new MMP water quality sampling design in 2015, there are now eleven stations sampled up to five times per year, with eight stations sampled during both the dry and wet season and three only during the wet season (Table 2-1). The sampling locations in this new design are located in a river mouth to open coastal water transect (Figure 3-84).

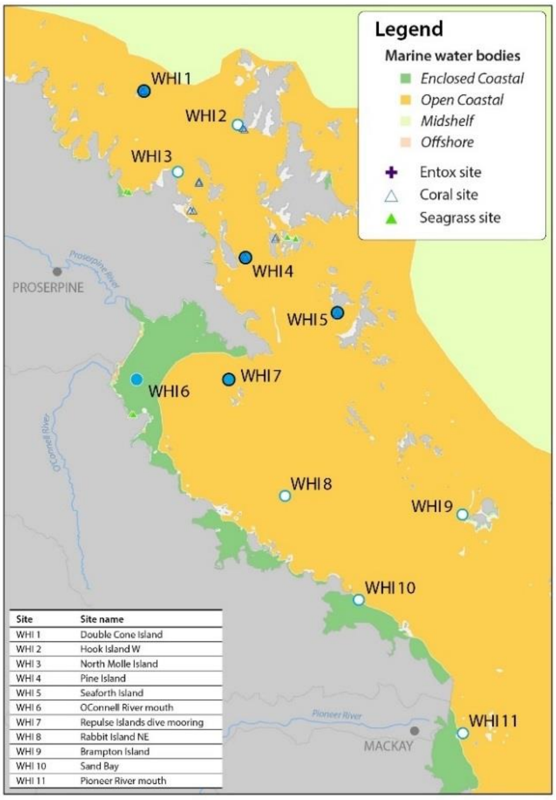


Figure 3-84: MMP sampling sites in the Mackay Whitsunday focus area, shown with the water body boundaries.

Over the period 2007 to 2013, annual discharge from the O'Connell and Pioneer Rivers was above median levels (Figure 3-85, Table D-1). Extreme floods (more than 3 times the long-term median) were recorded for the O'Connell River in 2011, and the Pioneer River in 2008 and 2010 to 2013 (Table A2-1). The 2011 flood was the third largest for the O'Connell River. Since 2011, annual discharge has generally declined, with values since 2014–15 being below the long-term median flows (Figure 3-85).

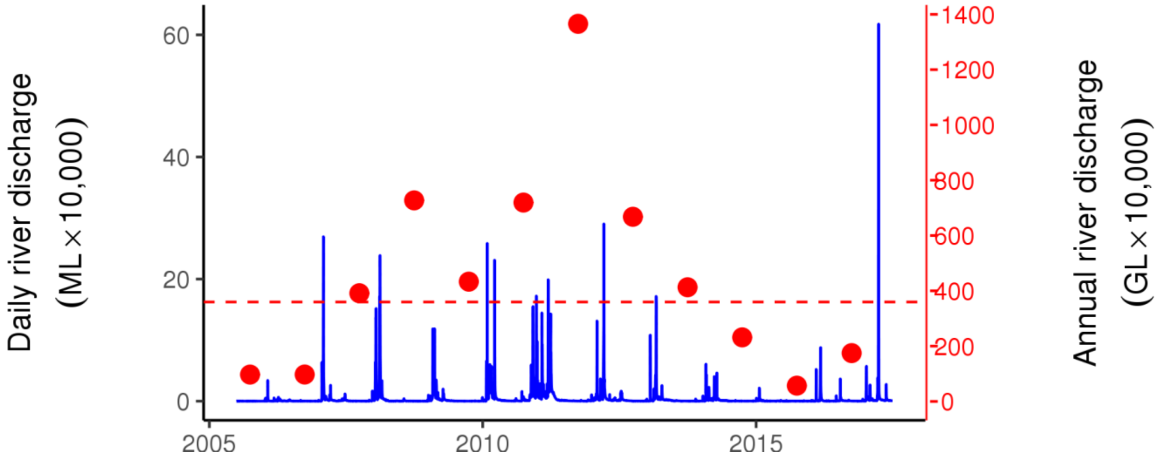


Figure 3-85: Combined discharge for the O'Connell (Stafford's Crossing gauge) and Pioneer (Dumbleton TW gauge) Rivers. Daily (blue) and water year (October to September, red) discharge is shown. Red dashed line represents the long-term median of the combined annual discharges. Please note as this is the combined discharge, high flows in one river will not necessarily be visible in the graph.

In the hydrodynamic model, the O'Connell River was the only river considered in the region. The cumulative exposure resulting from this hydrodynamic numerical model is presented in Figure 3-86. The result shows a limited zone of influence in 2016–17, which is unexpected and may be related to the period of the assessment being extended to cover the full year.

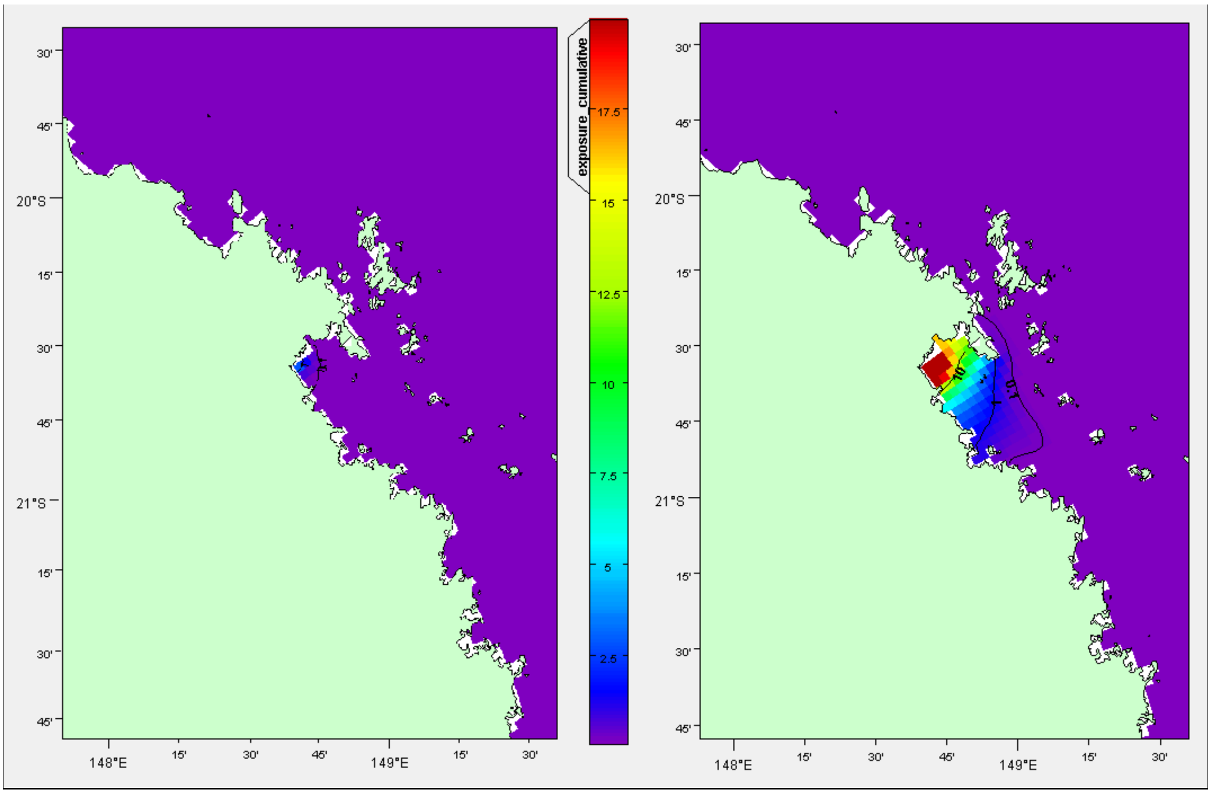


Figure 3-86: Cumulative exposure index for the O'Connell River at the end of June 2017 (left), results for 2010–11 (right) are shown for context. The colour bar indicates the calculated cumulative exposure (concentration x days) above 1% of the incoming concentration. The colour bar is capped at 20 Conc.Days. Contours show 0.1, 1.0 and 10.0 Conc.Days exposure levels.

Similar to the Burdekin-Haughton sub-region, the combined discharge and loads calculated for the 2016–17 water year from the Proserpine, O'Connell, Pioneer and Plane Basins were the highest since the 2011–12 water year and reflect the influence of tropical cyclone Debbie in this region. Over the 11-year period, discharge has varied from 730,000 ML (2014–15) to 17,400,000 ML (2010–11), TSS loads have ranged from 69 kt (2014–15) to 2,500 kt (2010–11), DIN loads from 190 t (2014–15) to 4,500 t (2010–11) and PN loads from 280 t (2014–15) to 8,600 t (2010–11). These four Basins of the Mackay Whitsunday show higher variability in discharge and loads compared to the Wet Tropics Basins, which produce more consistent loads and discharge each year. However, during moderate to large discharge years, the Proserpine, O'Connell, Pioneer and Plane Basins contribute similar (or slightly lower) discharge and loads to the southern Wet Tropics Basins (i.e., Russell, Mulgrave and Johnstone Basins and the Tully, Murray and Herbert Basins).

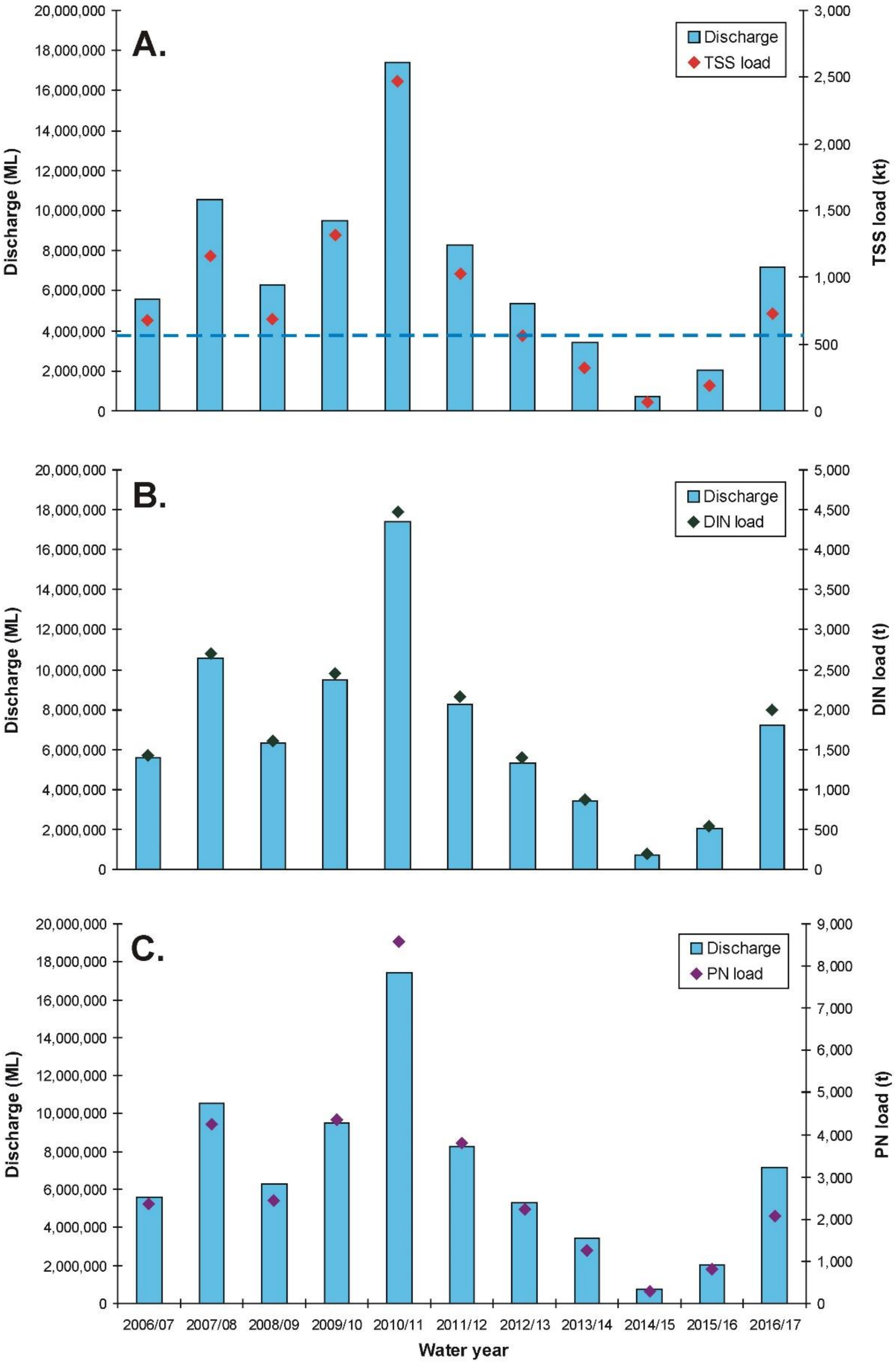


Figure 3-87: (A) Discharge and TSS, (B) DIN and (C) PN loads for the Proserpine, O'Connell, Pioneer and Plane Basins from 2006–07 to 2016–17. The loads reported here are a combination of 'best estimates' for each basin based on 'up-scaled discharge data from gauging stations, monitoring data (O'Connell 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.

The loading maps presented in Section 3.3 can also be assessed to determine the relative contribution of loads from each river to the marine NRM region. Figure 3-88 shows the estimated DIN and TSS contributions for the Mackay Whitsunday region in 2010–11 and 2016–17. The panels show that the DIN loading in the Mackay Whitsunday region was influenced by the Fitzroy River in the large event of 2010–11 in a minor way (~4%) but contributed almost 50% of the TSS loading. In 2016–17, the Fitzroy River also had a similar (~5%) contribution to the Mackay Whitsunday region river-derived DIN loading and 25% of the TSS loading. The model may be overestimating the influence of the Fitzroy River in the Mackay Whitsunday region in this year due to a deviation from the more typical south easterly wind conditions predicted in the model. As shown in Figure 3-102 and Figure 3-103 the Fitzroy River plume was more constrained to the Fitzroy region compared to 2010-11. Figure 3-15 also shows that the Mackay Whitsunday Rivers can influence the Burdekin Region.

In 2016–17, the river-derived DIN loadings in the Mackay Whitsunday region were dominated by Plane Creek (45%) and the Pioneer River (25%). Plane Creek also had the highest contribution to the TSS loadings (33%) in the region, followed by the O’Connell River (19%). While the loads from the O’Connell River in this year were larger than those from Plane Creek, the larger TSS loading from Plane Creek could be associated with the larger discharge volume from Plane Creek in 2016–17 (double the long-term median discharge) and therefore greater extent of influence.

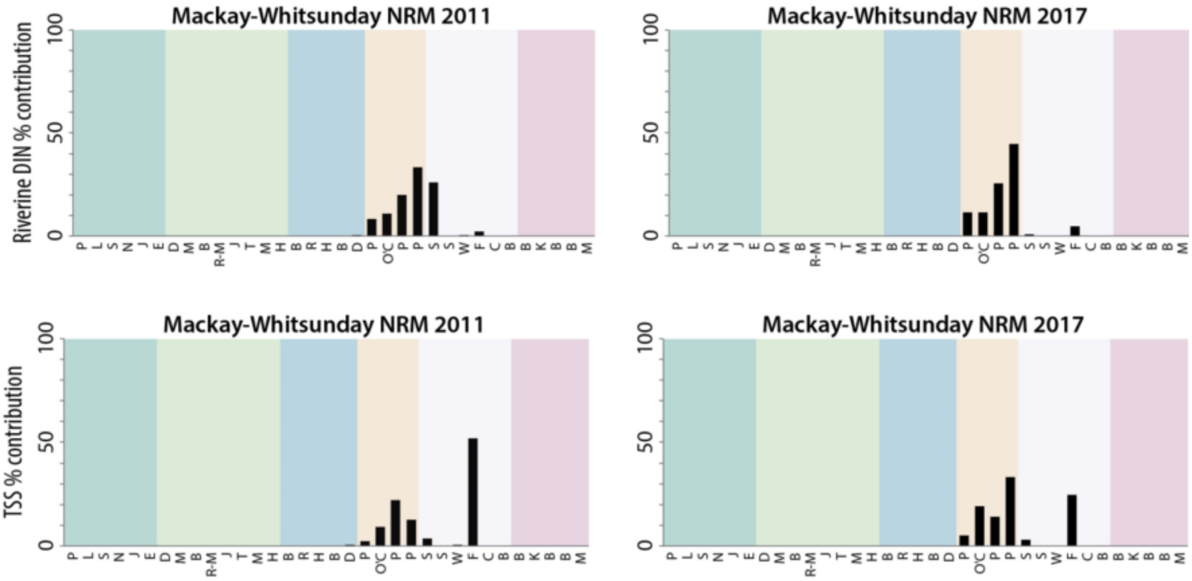


Figure 3-88: River contributions (x-axis, fully labelled in Figure 3-15) to the (top) DIN and (bottom) TSS mass to the Mackay Whitsunday NRM region. Shading groups rivers in the same NRM region: Cape York – dark green, Wet Tropics – light green, Burdekin – blue, Mackay Whitsunday – orange, Fitzroy – pink, Burnett Mary - red.

Ambient water quality

A brief description and definition of the water quality variables measured in this region can be found in Appendix D-1.

The number of water sampling sites and frequency of sampling increased during 2015. Some of these sites are placed further inshore and they are therefore more likely affected by Primary and Secondary wet season waters, which will influence assessment of longer term trends. It is also important to note that the water quality trend analysis accounts for the effect of wind, waves and tides; accordingly, the trends are independent of changes in local weather.

The long-term trend showed a decline since 2008 reaching ‘moderate’ rating in 2016–17, which was the same obtained by the new AIMS/JCU index (Figure 3-89a). For all measured variables it is clear, as seen in Figure 3-89 and Figure E-6, that the inclusion of the JCU and data collected under the changed sampling design (more stations and sampling) has led to a larger variability in the measured water quality variables.

The Chl-a trend line remained relatively stable over the monitoring period with concentrations remaining above the annual guideline (Figure 3-89b). Instrumental Chl-a records showed more pronounced fluctuations but generally followed the same trend as the manual sampling data (Figure 3-89b). Turbidity showed stable levels over the monitoring period, with values above the guideline (Figure 3-89e). The trend lines for both TSS and Secchi depth only showed minor changes, with slight increases in TSS and corresponding decreases in Secchi depth most likely due to the change of sampling design (Figure 3-89f, g). The trend line for TSS has remained at values around the guideline, whereas Secchi depth has been consistently non-compliant with the guideline (Figure 3-89f, g). Combined, the turbidity, TSS and Secchi depth data indicate that the water ‘clarity’ in the Mackay Whitsunday region has decreased. Concentrations of PN and PP have increased over the sampling period, with both being above GVs in 2016–17 (Figure 3-89h, i).

The trend line for NO_x has been clearly influenced by the difference in sampling design and inclusion of the JCU data in the analysis (compare Figure 3-89c and Figure E-6c). Over the monitoring period NO_x has shown a minor increase with the trend line maintaining above guide line values in 2016–17 (Figure 3-89c). PO_4 concentrations have decreased since the beginning of the monitoring period (Figure 3-89d).

The concentrations of POC have increased markedly since 2014, whereas the DOC concentrations have shown a continued increase over the whole monitoring period (Figure 3-89j, k).

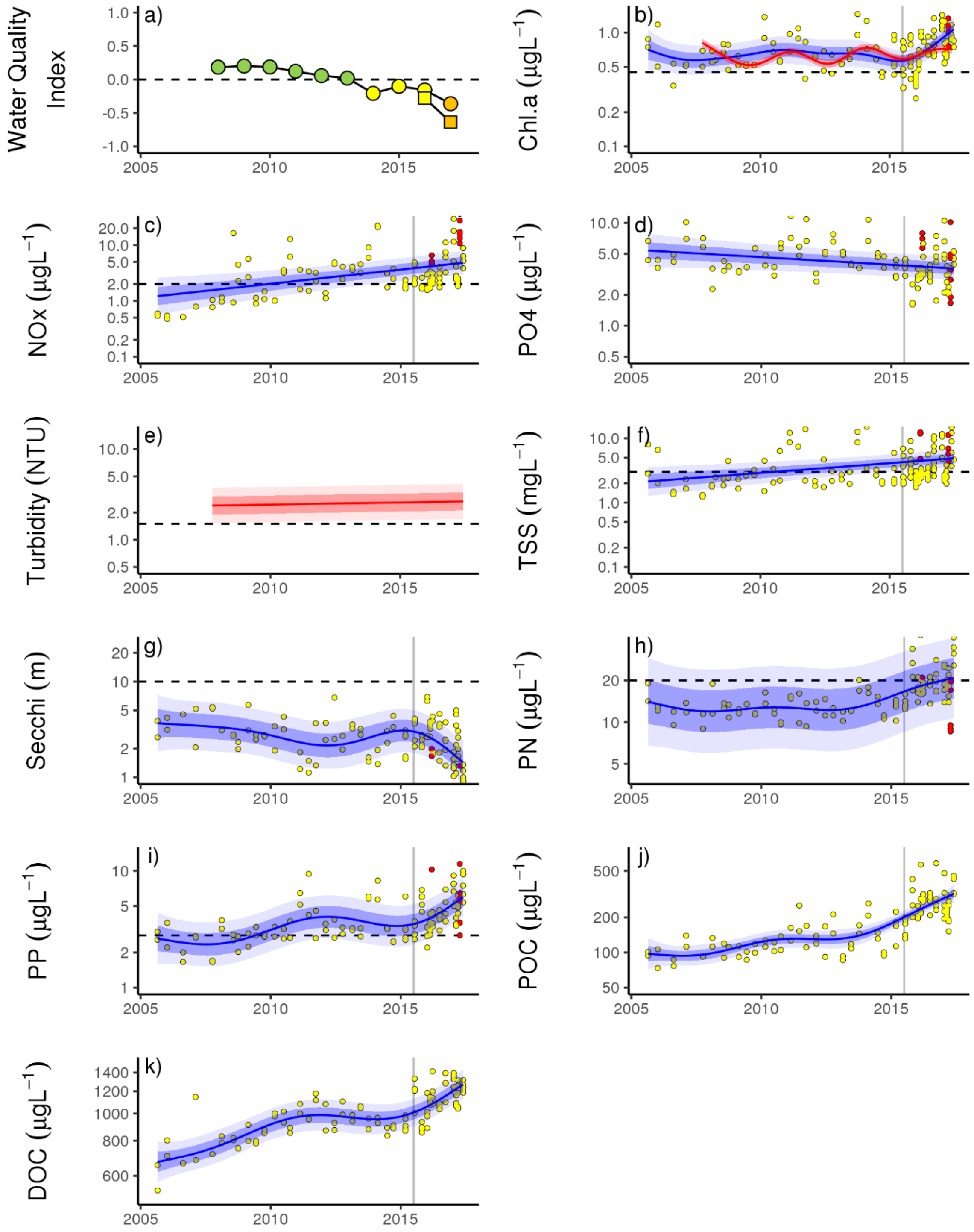


Figure 3-89: Temporal trends in water quality for the Mackay Whitsunday focus-region. a) Water Quality Index, b) chlorophyll *a* (Chl-*a*), c) nitrate/nitrite (NO_x), d) phosphate (PO_4), e) turbidity, f) total suspended solids (TSS), g) Secchi depth, h) particulate nitrogen (PN), i) particulate phosphorus (PP), j) particulate organic carbon (POC) and k) dissolved organic carbon (DOC). Water Quality Index colour coding: dark green – 'very good'; light green – 'good'; yellow – 'moderate; orange – 'poor'; red – 'very poor'. Note that from 2015–16 onwards both AIMS and JCU was included and a separate score was calculated using the wet/dry guidelines that are shown as two separate points in Figure 3-56a, 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. Yellow dots represent observed data collected by AIMS and red dots data collected by JCU. Trends of records from ECO FLNTUSB instruments are represented in red, individual records are not displayed. Dashed horizontal reference lines indicate yearly guideline values and the vertical dashed lines represent when the sampling design was changed (Feb-2015), both lines are only shown for reference.

Event water quality

Very heavy rainfall occurred in the catchments of the Mackay Whitsunday NRM region coinciding with the crossing of tropical cyclone Debbie in March 2017, which triggered large events in the Proserpine, O'Connell and Pioneer Rivers (Figure 3-90). Rough weather and logistical issues (i.e., road closures, cyclone damage and boat access) associated with tropical cyclone Debbie prevented flood plume sampling in the Proserpine/O'Connell and Pioneer Rivers until 9 and 10 April, respectively, ~10 days after peaks flows occurred (Figure 3-90). However, the flood plumes were still clearly evident in the region and were sampled across the prescribed flood plume response sites for both the Proserpine/O'Connell (Figure 3-91) and Pioneer (Figure 3-92) regions.

A series of true colour images showing the plume movement is shown in Figure 3-93, Figure 3-94 and Figure 3-95. Highly elevated TSS (> 20 mg L^{-1}: Figure 3-96a) and Chl-a (> 1 µg L^{-1}: Figure 3-96b) concentrations were observed over most of the salinity gradient up to at least 30 PSU across both the Proserpine/O'Connell and Pioneer Rivers plumes including key sites within the Whitsunday Islands. Initially, the higher TSS concentrations were thought to be related to relatively rough sea conditions that were persistent with tropical cyclone Debbie; however, AIMS reported very low Secchi depth (< 2 m) throughout the Whitsunday Islands at the end of May, so it appears this region experienced very low light levels for an extended period of time.

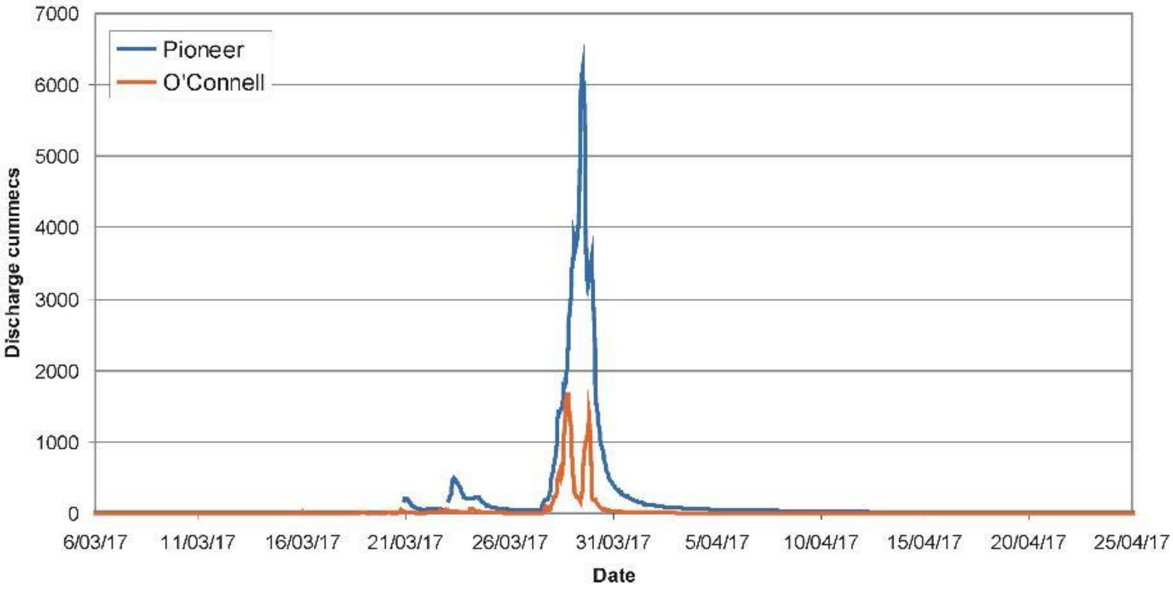


Figure 3-90: Hydrographs from the O'Connell (Stafford's Crossing gauge) and Pioneer (Dumbleton Weir tailwater gauge) Rivers highlighting the high flows associated with Tropical Cyclone Debbie. While the sampling of flood plumes did not occur until 9 and 10 April 2017when the river discharge had receded, the influence of the plumes was still evident offshore.

Figure 3-91: Sampling sites for the flood plumes from the Proserpine and O'Connell Rivers.

Figure 3-92: Sampling sites for the flood plume from the Pioneer River.

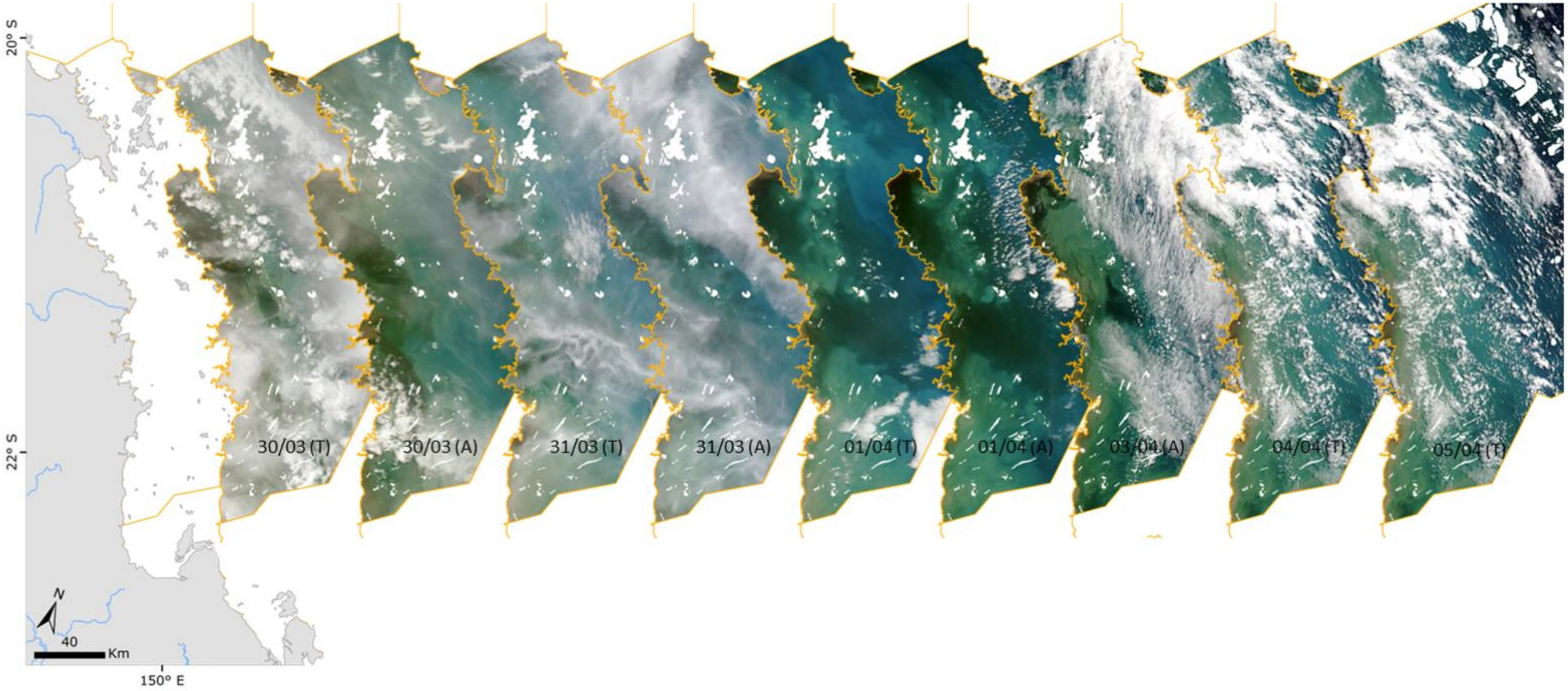


Figure 3-93: A collection of satellite images showing the evolution of the river plumes in the Mackay Whitsunday region from 30 March to 5 April. True colour images from the NASA's MODIS instrument are provided by the MODIS EOSDIS Worldview earthdata system: (A) MODIS-Aqua, (T) MODIS-Terra. https://worldview.earthdata.nasa.gov/.

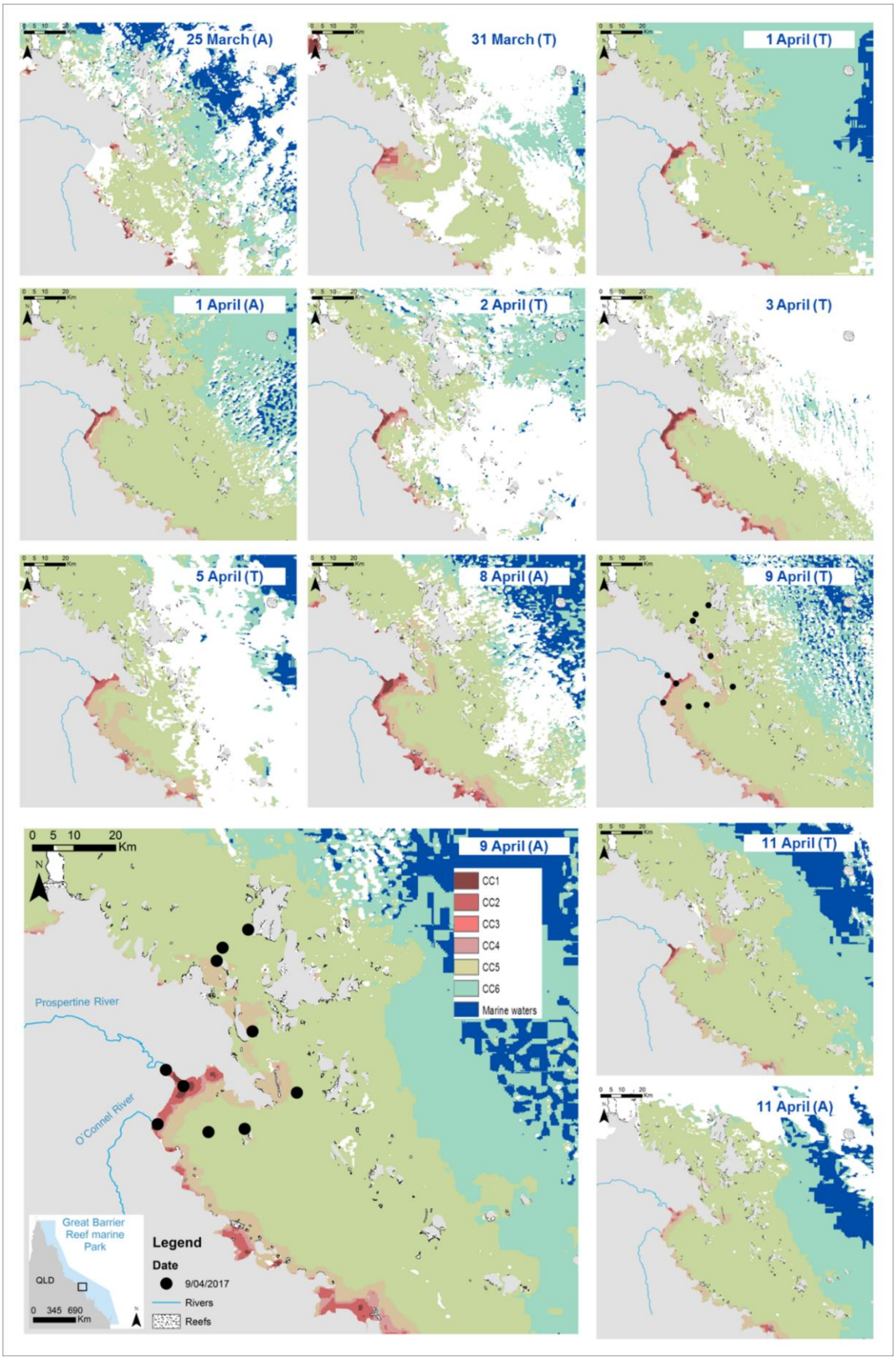


Figure 3-94: A collection of water type maps showing the evolution of the Proserpine River plume from 25 March to 11 April 2017 (A: MODIS-Aqua, T: MODIS-Terra).

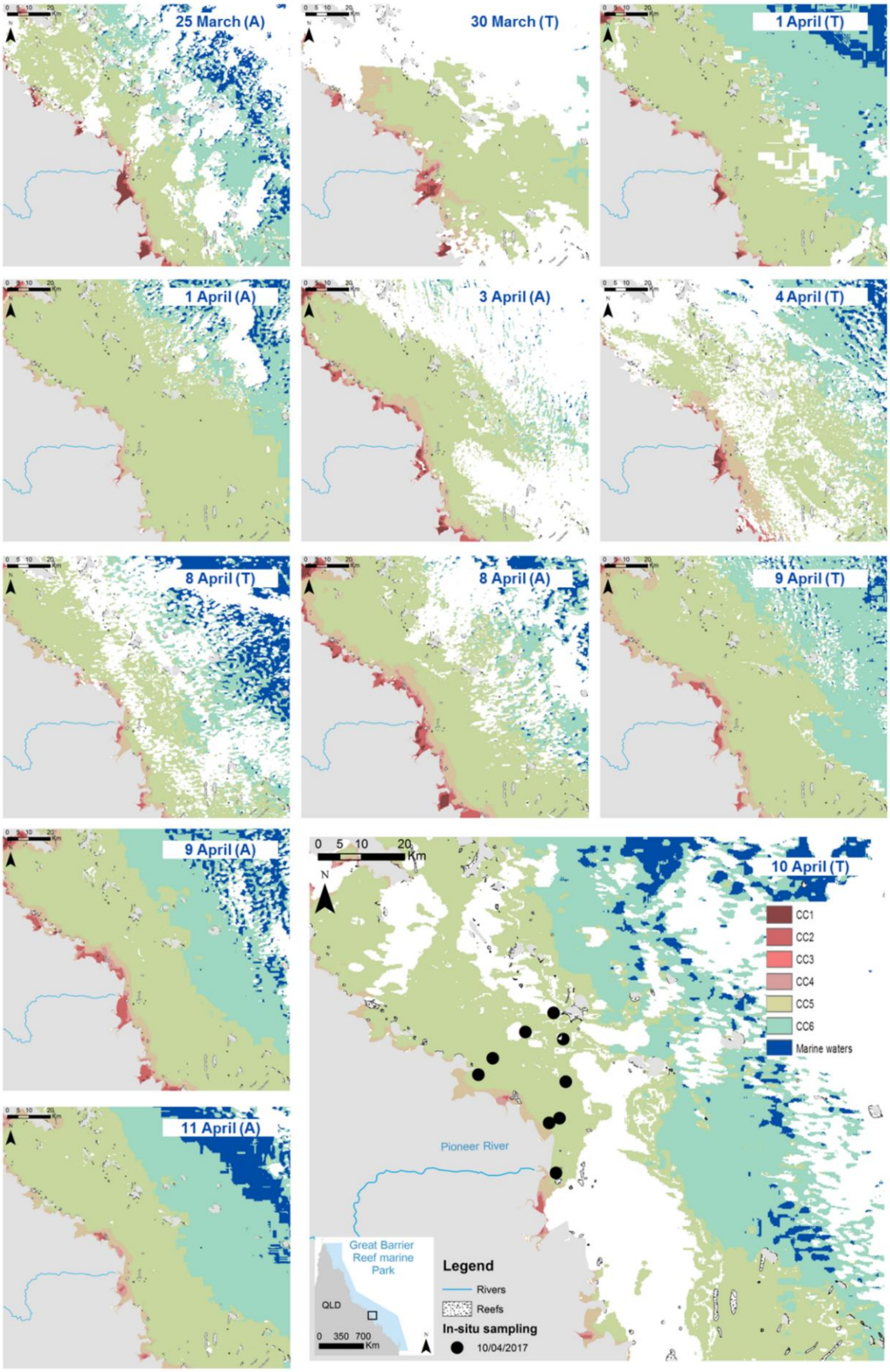


Figure 3-95: A collection of water type maps showing the evolution of the Pioneer River plume from 25 March to 11 April 2017 (A: MODIS-Aqua, T: MODIS-Terra).

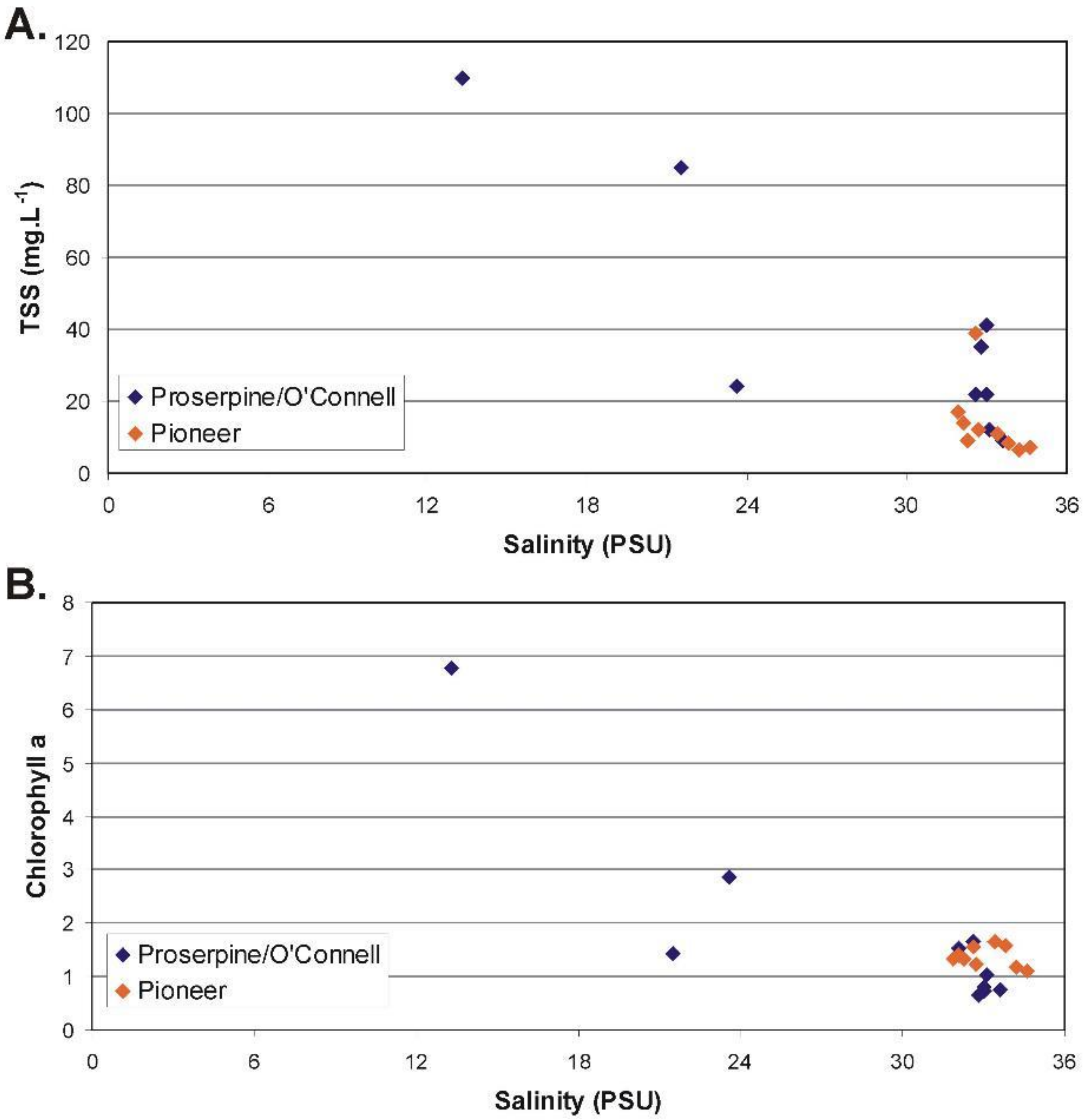


Figure 3-96: TSS concentrations (A) and Chl-a concentrations (B) from the flood plumes from the Proserpine/O'Connell and Pioneer Rivers.

Mackay Whitsunday Region: Mapping wet season conditions

As described in Section 2.7, a number of mapping products are 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 3-97 and in a panel of weekly characteristics throughout the 22 week wet season period (Figure 3-98 and Figure 3-99). Details included in the panels include *in-situ* water quality characteristics including TSS, Kd(PAR), Chl-a and DIN within each colour class; weekly river discharge; wind speed and direction; and the wet season water type maps showing the six wet season colour classes.

Figure 3-97 (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 2016–17 wet season. Table 3-7 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 as 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 (2003–2017), Figure 3-97 (bottom) and Table 3-7 (numbers in brackets).

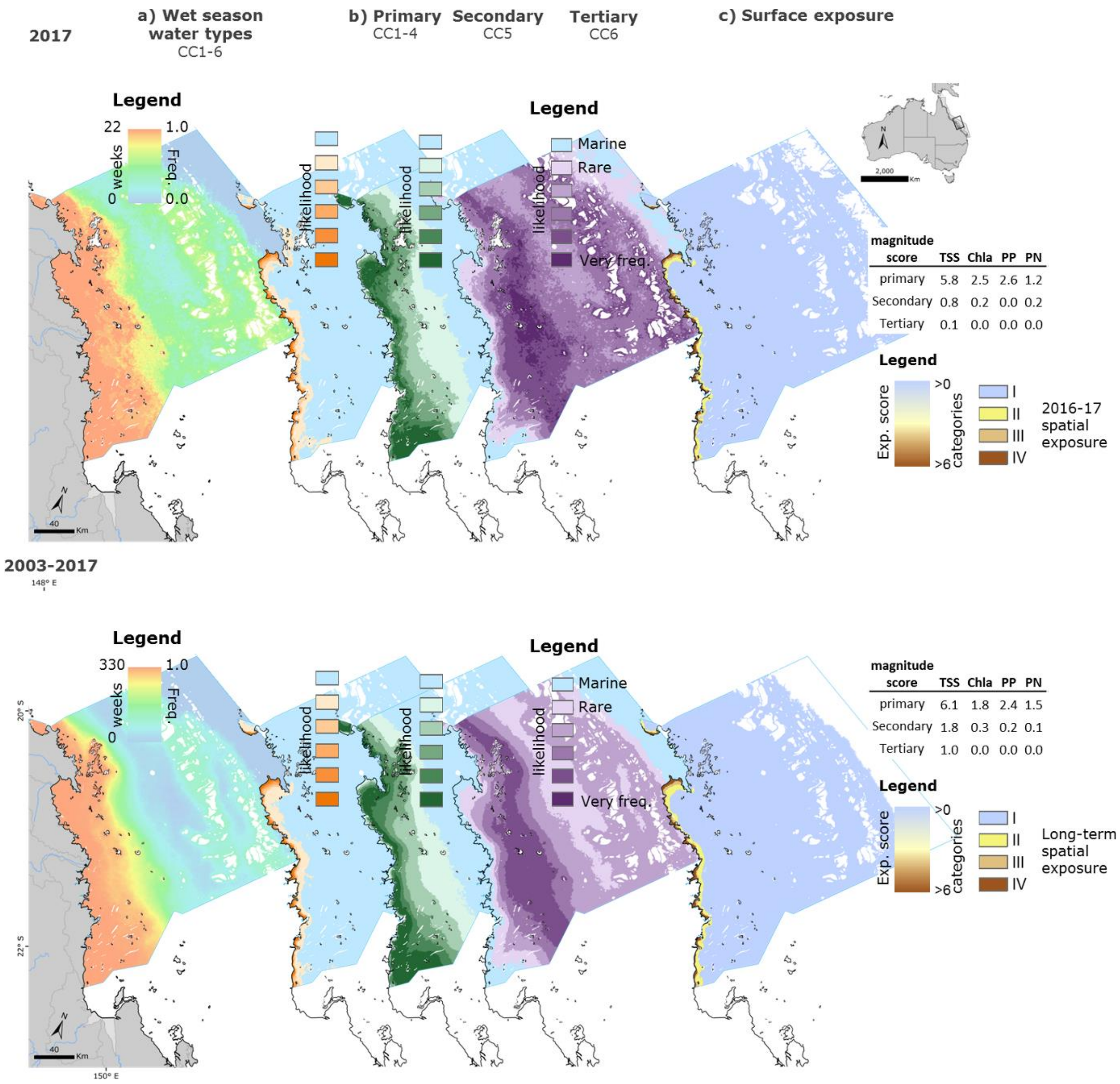


Figure 3-97: Maps showing the a) frequency of combined wet season water types (Primary, Secondary and Tertiary), b) the frequency of Primary, Secondary and Tertiary wet season water types and c) the exposure maps for the Mackay Whitsunday region in the long-term (bottom) and 2016–17 wet season (top).

In 2016–17, the Mackay Whitsunday region was most affected by the lowest exposure categories (categories I and II), in agreement with the long-term trends. Approximately 93% of the total area of the Mackay Whitsunday Region was exposed to wet season water types (Primary, Secondary and Tertiary water types combined) during at least one week of the wet season. This area was greater than the long-term area (Table 3-7: 85% exposed to wet season water types). However, only 1% and 0.5% of the Mackay Whitsunday region was exposed to the higher exposure categories III and IV, respectively. These areas were similar to the long-term areas (0.5% to category III and 1% to category IV).

In 2016–17, it was estimated that:

- A total of 99% of Mackay Whitsunday coral reefs were influenced by wet season water types (Primary, Secondary and Tertiary waters combined) during at least one week of the wet season. However, only 2% and 5% of corals were in the highest exposure categories III and IV, respectively.
- A total of 95% of the Mackay Whitsunday seagrasses were exposed to wet season water types, during at least one day of the wet season. A total of 15% of seagrasses were in the highest exposure category IV and only 12% were in exposure category III.
- These exposures indicate potential risk as the exposure maps have not been yet validated against ecological health data to confirm the ecological consequences of the risk.
- In 2015–16, the areas of coral reefs and seagrasses exposed to the exposure category III were similar to slightly smaller than long-term (Table 3-7: 0.5% and 1% of reefs and 10% and 20% of seagrasses exposed to categories III and IV, respectively). These results were logical with the characteristic of an average wet season for this region.

Table 3-7: Areas (km^2) and percentages (%) of the Mackay Whitsunday Region affected by different categories of exposure during the 2016–17 wet season (*and long-term values in brackets*).

Mackay Whitsunday Marine NRM Region		**Total**	**Potential risk category Lowest ------------------------ highest**				**Total exposed**	**Total non-exposed**
			I	**II**	**III**	**IV**		
Surface area	Area (km^2)	48,957	44,693	519	225	310	45,746	3,210
			(40,368)	*(776)*	*(233)*	*(352)*	*(41,729)*	*(7,228)*
	Percentage (%)	100	91	1	0.5	1	93	7
			(82)	*(2)*	*(0.5)*	*(1)*	*(85)*	*(15)*
Coral reefs	Area (km^2)	3,216	3,158	16	5	2	3,181	36
			(3,108)	*(24)*	*(5)*	*(2)*	*(3,138)*	*(78)*
	Percentage (%)	100	98	0.5	0.2	0.1	99	1
			(97)	*(1)*	*(0.2)*	*(0.1)*	*(9%)*	*(2)*
Surveyed seagrass	Area (km^2)	307	176	35	36	47	293	14
			(156)	*(46)*	*(31)*	*(61)*	*(294)*	*(13)*
	Percentage (%)	100	57	11	12	15	95	5
			(51)	*(15)*	*(10)*	*(20)*	*(96)*	*(4)*

Figure 3-98 and Figure 3-99 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 2016 and April 2017. The 2016–17 wet season was characterised by below average river discharges for the first half of the wet season, except for weeks 6 (191,475 ML) and 9 (72,761 ML) that were both well above the long-term mean weekly discharge value (39,448 ML). The second half of the wet season was characterised by very heavy rainfall coinciding with the crossing of tropical cyclone Debbie in March 2017. The weekly river discharges were above the long-term mean between 23 March and 5 April (week

17 and 18), which triggered large flood plumes in the Proserpine, O'Connell and Pioneer Rivers during these two weeks and week 19 (6–12 April).

Maximum TSS, Chl-a and DIN concentration and minimum SSD concentrations were measured during week 19 (110.0 mg L^{-1},6.8 µg L^{-1}, 80.0 µg L^{-1} and 0.5 m, respectively) in colour class 1. The highest weekly mean concentrations were also all measured during week 19 and were in colour class 1 (73.0 mg L^{-1}, 3.7 µg L^{-1}, 44.0 µg L^{-1} and 0.4 m, respectively). This is approximately 30 and 5.5 times the wet season TSS and Chl-a guidelines, respectively, for the open coastal and mid-shelf waters. The guideline, however, is a seasonal mean and the ecological effect of the acute concentration peak is not known. Week 19 was the only week where *in-situ* samples were collected across all colour classes (1 to 6). It allowed observing the expected decrease in water quality concentration (and increase in Secchi depth) along the colour class gradient.

The mean seasonal TSS concentrations measured across the Primary and Secondary water types were 34.6 and 9.4 mg L^{-1}, i.e., approximately 14 and 4 times the wet season TSS guidelines of 2.4 mg L^{-1}, respectively (Table E-10). The mean seasonal Chl-a concentrations in the Primary and Secondary water types were 2 and 1.2 µg L^{-1}, i.e., approximately 3 and 2 times the wet season Chl-a guidelines of 0.63 µg L^{-1}. The mean seasonal PP concentration in the Primary water type was 11.9 µg L^{-1} (3.6 times the 3.3 µg L^{-1} guideline). Finally, the mean seasonal Chl-a and TSS concentrations in the Tertiary waters, PP concentration in the Secondary and Tertiary water types and the mean seasonal PN concentrations in all water types were all below their respective wet season guidelines (Table E-10).

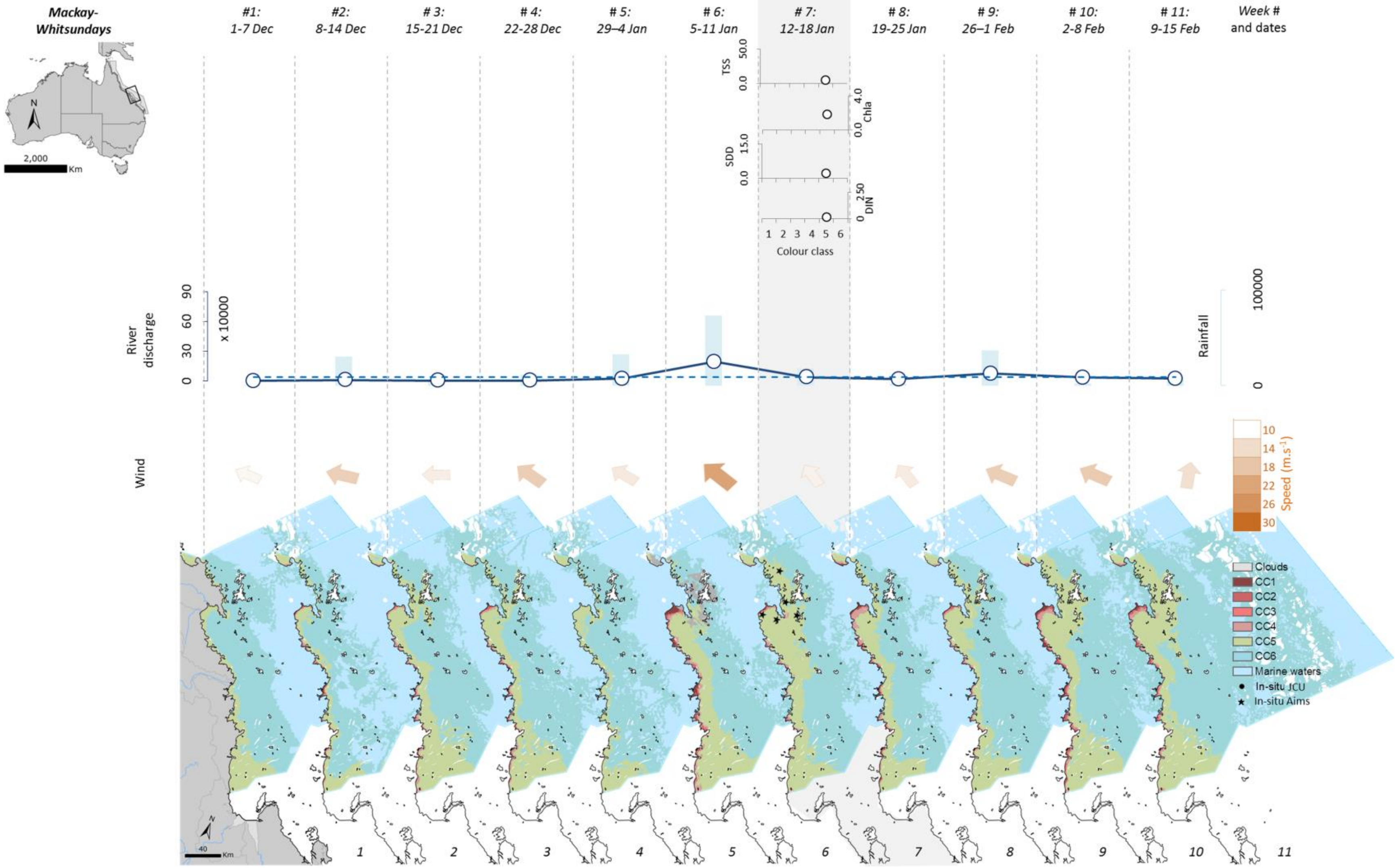


Figure 3-98: Panel of water quality and environmental characteristics in the Mackay Whitsunday region throughout the 2016–17 wet season period: weeks 1 to 11. Details included in the panels: mean TSS (mg L^{-1}), Secchi disc depth (SDD) (m), Chl-a (µg L^{-1}) and DIN (µg L^{-1}) within each colour class; 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.

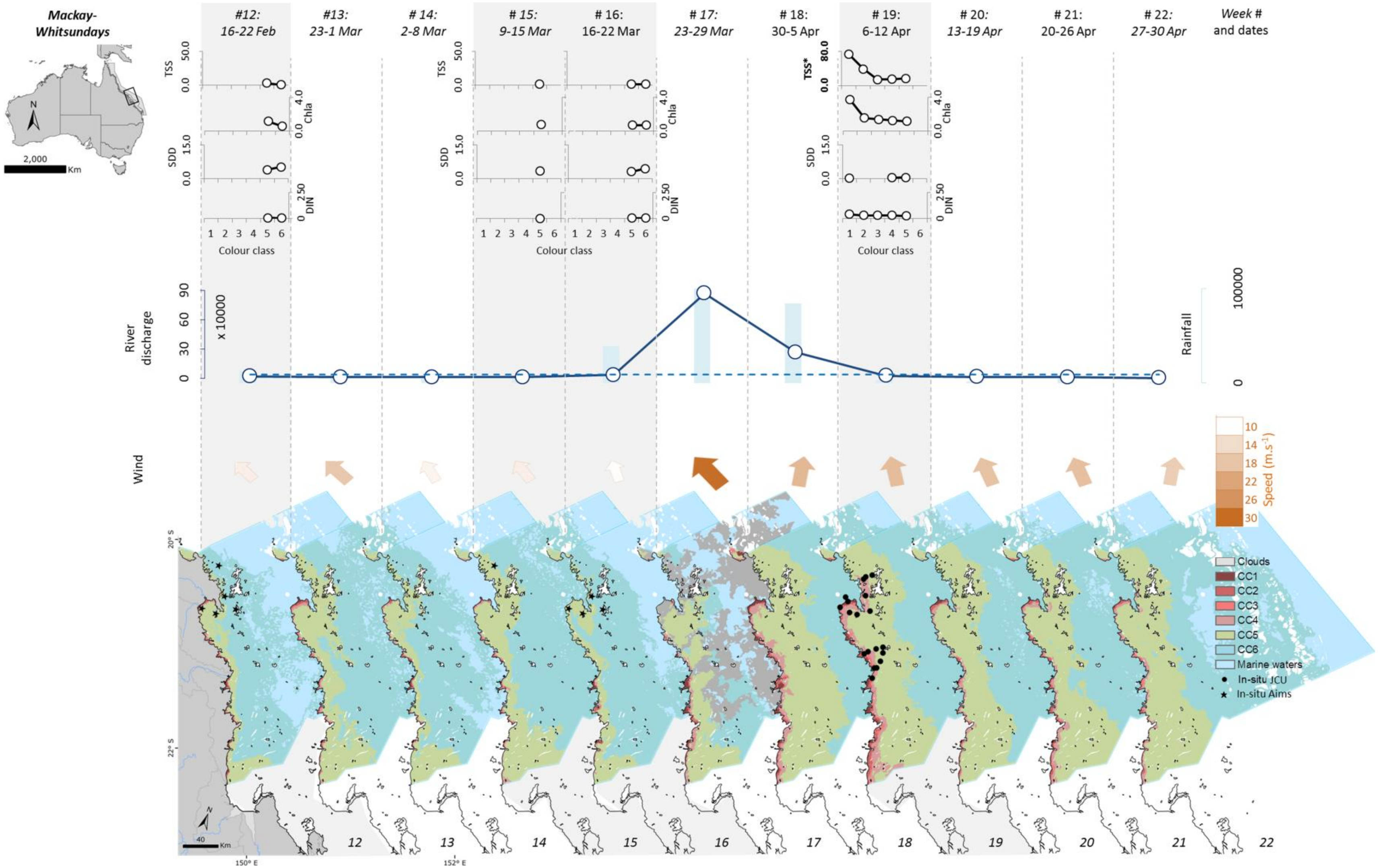


Figure 3-99: Panel of water quality and environmental characteristics in the Mackay Whitsunday region throughout the 2016–17 wet season period: weeks 12 to 22. Details included in the panels: mean TSS (mg L^{-1}), Secchi disc depth (SDD) (m), Chl-a (µg L^{-1}) and DIN (µg L^{-1}) within each colour class; 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.

3.4.7 Additional sampling in 2016–17

To continue long-term flood event monitoring datasets in the GBR, the Fitzroy River was also sampled in the flooding associated with heavy rainfall from tropical cyclone Debbie. The peak flow occurred on 6 April 2017 () and sampling of the flood plume occurred on 11 April 2017, 5 days after peak flow. The sampling sites followed a transect from the river mouth out through the Keppel Islands (Figure 3-101). A series of true colour images showing the plume movement is shown in Figure 3-102, with true colour and processed water type maps for 6 and 7 April shown in Figure 3-103 and Figure 3-104.

Salinity and TSS concentrations were lower than expected in the monitoring of the Fitzroy plume with salinity values mostly > 27 PSU and TSS concentrations mostly < 4 mg L^{-1} (Figure 3-105). These results are an encouraging sign for the ecosystems in Keppel Bay as previous studies have showed that during large Fitzroy River floods (e.g., 1990–91 and 2010–11) salinity levels in Keppel Bay can reduce to below 10 PSU for an extended period of time, which results in mortality of corals, oysters and barnacles (summarised in Lewis et al., 2015b). In that regard, the flooding in the Fitzroy River in 2017 only lasted ~10–14 days, which is on the shorter period compared to the 1991 and 2011 floods where elevated river flows lasted several weeks (40–50 days). Chl-a levels throughout the study area were elevated (> 1 µg L^{-1}) compared to previous recorded flood events and those recorded in other locations in 2016-17 (Figure 3-105B).

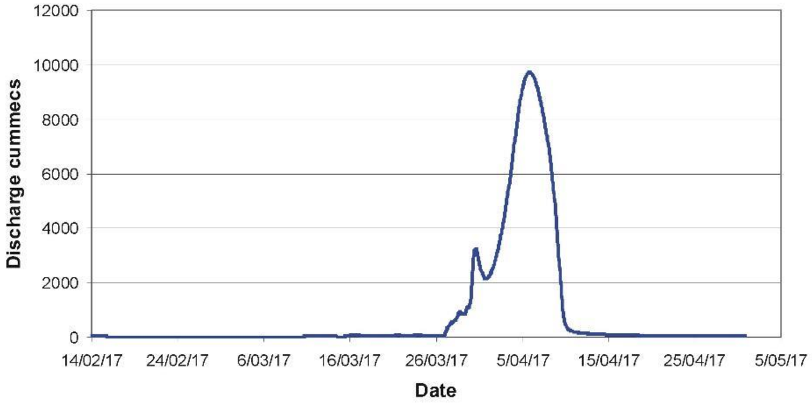


Figure 3-100: Hydrograph of the Fitzroy River (The Gap gauge) highlighting the high flows associated with Tropical Cyclone Debbie.

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Figure 3-101: Sampling sites for the flood plume from the Fitzroy River.

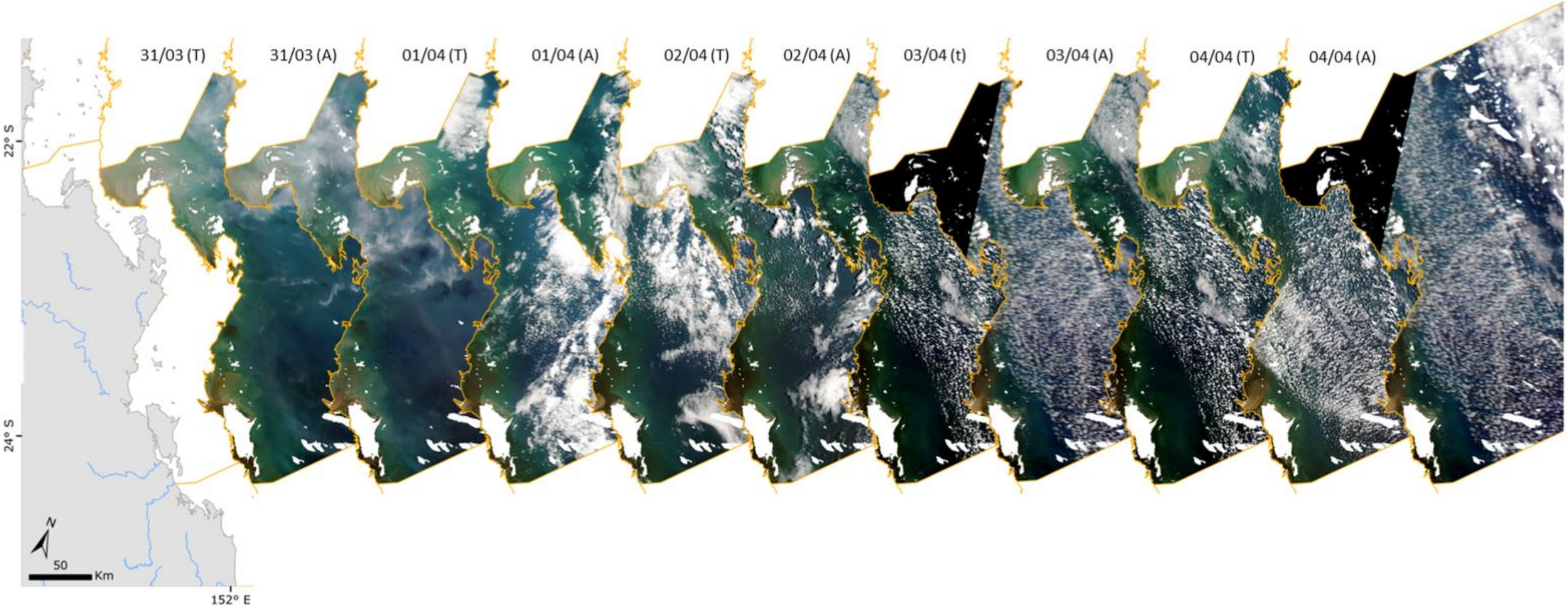

Figure 3-102: A collection of satellite images showing the evolution of the Fitzroy River plume from 31 March to 4 April 2017. True colour Images from the NASA's MODIS instrument are provided by the NASA EOSDIS Worldwiew earthdata system: (A) MODIS-Aqua, (T) MODIS-Terra. https://worldview.earthdata.nasa.gov/

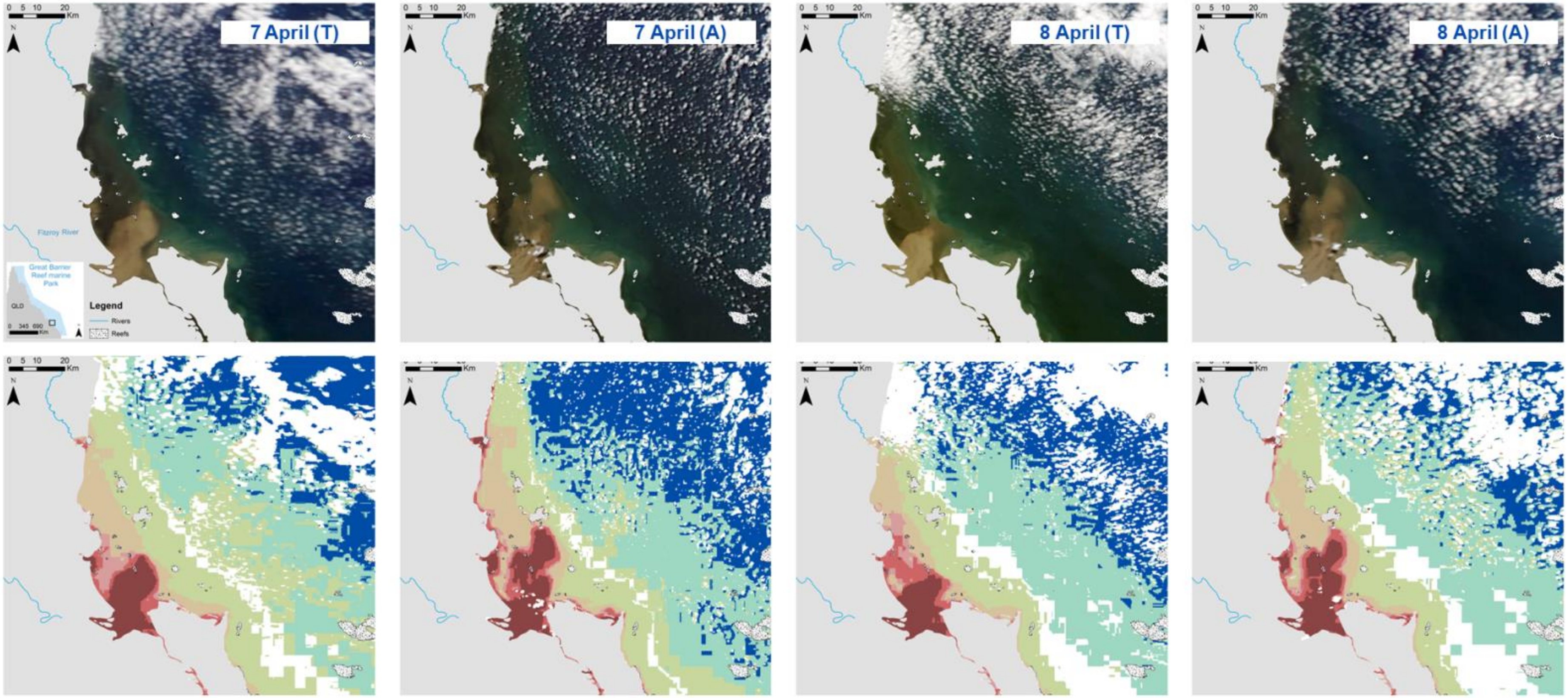

Figure 3-103: Fitzroy River – 6 and 7 April 2017. Fitzroy River mouth MODIS true colour (top) and processed water type maps (bottom): (A) MODIS-Aqua, (T) MODIS-Terra.

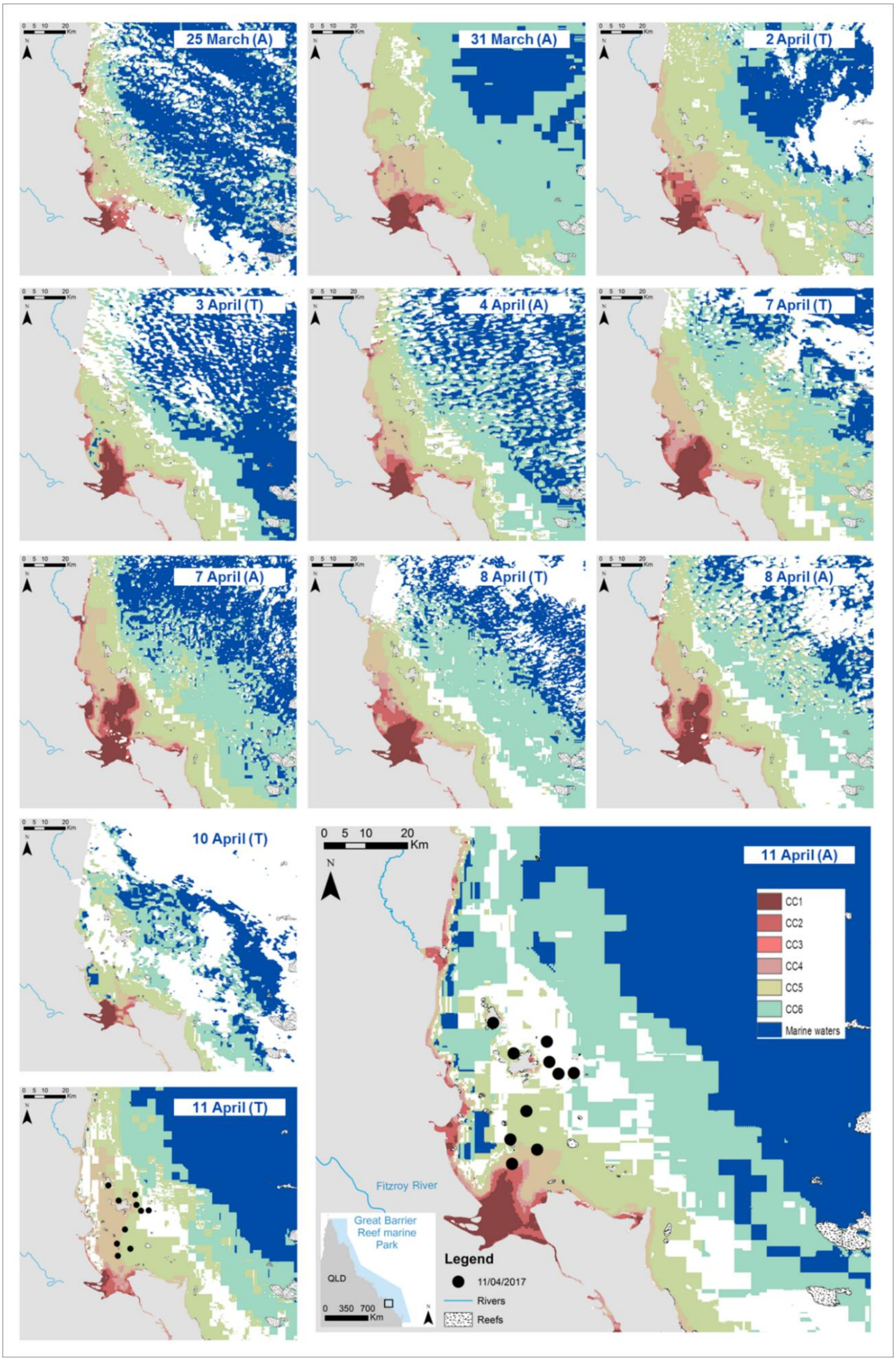

Figure 3-104. Processed water type maps for the Fitzroy River plume from 25 March to 11 April 2017. A) MODIS-Aqua, (T) MODIS-Terra.

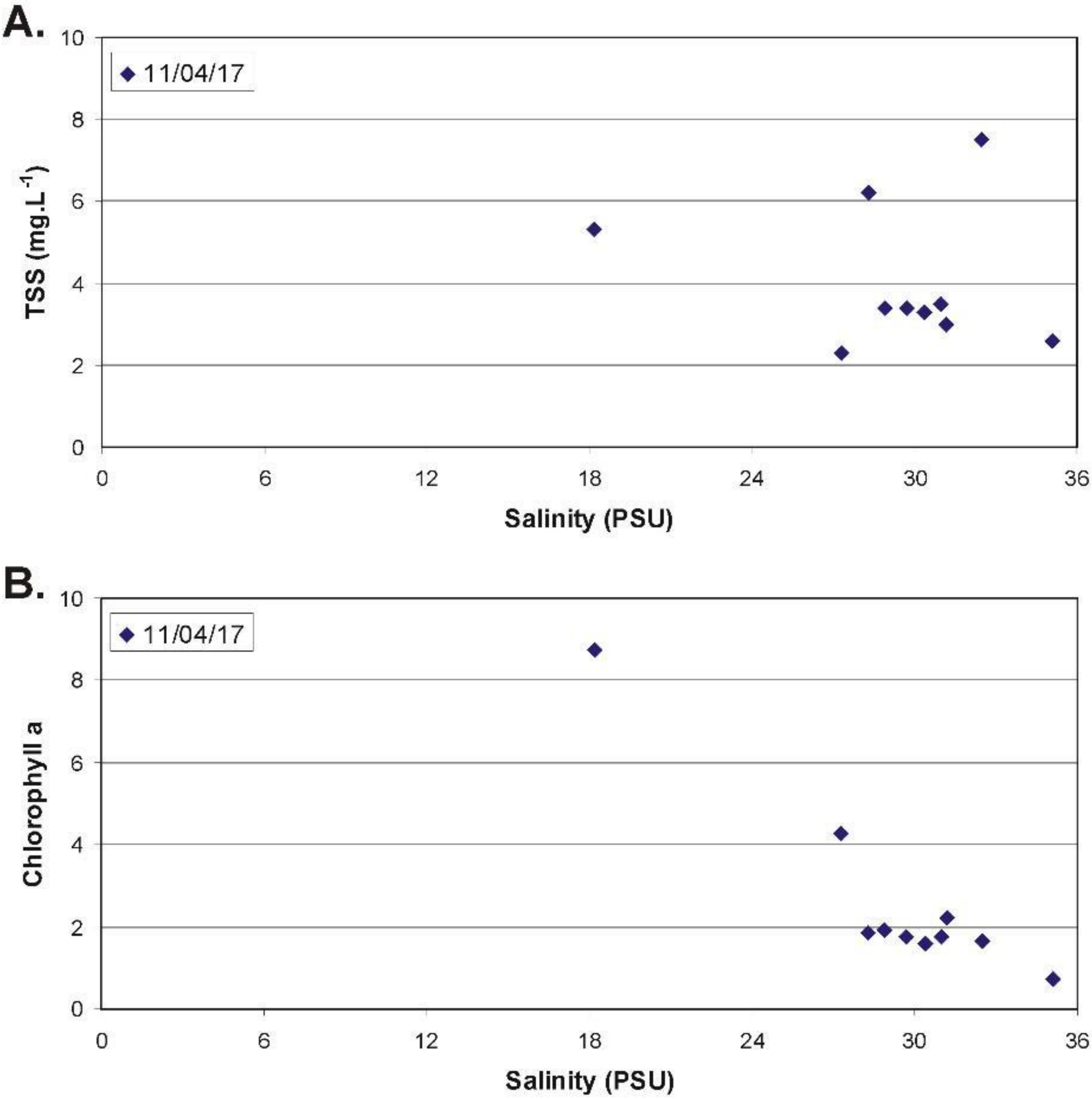

Figure 3-105: TSS concentrations (A) and Chl-a concentrations (B) from the flood plume from the Fitzroy River.

4. Discussion

Local environmental conditions, such as water quality, influence the benthic communities found on coastal and inshore reefs of the GBR. Collectively, these 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 pollutant loads delivered by rivers sufficiently alter the environmental conditions in inshore waters of the GBR to suppress ecological resilience.

In this report, spatial and temporal trends of water quality indicators in the GBR have been provided for four focus areas. The water quality changed in response to the magnitude of river flows, and end-of-catchment loads of sediments and nutrients. These are all important factors driving marine water quality.

4.1 Water quality characteristics during 2016–17

The rainfall and river flow across all basins of the GBR during the 2016–17 wet season was close to the long-term median. A number of southern rivers had wet season discharge above their long-term median flow including a majority of rivers in the Mackay Whitsunday, Fitzroy (coastal catchments) and Burnett Mary regions, largely associated with tropical cyclone Debbie. These influences are reflected in regional variability in the wet season conditions. The ambient conditions are more variable and difficult to correlate directly to the river influence. For most regions (except the Barron Daintree) the influence of the changing sampling design (i.e., more stations and sampling times) is now apparent, leading to larger variability in the measured variables. This, in turn, makes it difficult to determine trends across years versus changes due to changing sampling design.

The main findings for each NRM region are highlighted below.

Cape York

As this was the first 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 and Stewart River sub-regions were collected during the wet season between January and April 2017. Samples from the Pascoe River sub-region were collected during the 2017 wet season (April) and dry season (May).

During the 2016–17 wet season, discharge from the Cape York sub-regions sampled under the MMP was at (Stewart River) or slightly above (Endeavour Basin, Normanby Basin and Pascoe River) the long-term median discharge for these rivers.

TSS concentrations decreased with distance from the river mouth for all Cape York transects. Secchi depth increased or showed no difference with distance from river mouths. Nutrients and Chl-a concentrations generally decreased with distance from river mouths, with the exception of the Pascoe River transect, possibly because the Pascoe River transect was sampled late in the wet season and in the dry season, when there would be less freshwater influence.

Some concentrations of nutrients, Chl-a and TSS, plus Secchi depths exceeded the Draft Eastern Cape York Water Quality Guidelines. However, many of the guidelines (enclosed coastal zone and mid-shelf zone, and NH_3 and Secchi depth in the open coastal zone) are based on annual or baseflow concentrations, whereas the majority of Cape York samples were collected under wet season conditions and are therefore not representative of annual concentrations. Due to the limited number of samples collected to date under the MMP, it is recommended that this comparison be revisited in future years at which time the Draft Cape York Guidelines may be assessed and revised if necessary.

Wet season and event water quality

- The 2016–17 wet season was characterised by below average river discharges for the first quarter of the wet season (until 11 January 2017), then all weeks were characterised by above average weekly river discharges except for weeks 9 (26 January to 1 February), 20, 21 and 22 (13 to 30 April).
- The largest contributions to the river-derived DIN and TSS loadings in the Cape York region in 2016–17 were from the Normanby River (29% and 44%, respectively). The Pascoe and Endeavour Rivers also contributed 14% each to the regional TSS loading.
- Cape York had the lowest water quality concentrations of all regions across wet season water types.
- The maximum wet season (December–April) water quality surface concentrations were measured between 2 and 8 February (week 10); however, cloud cover prevented obtaining clear satellite image of the flood plumes for this week. Using only sites with a satellite colour class category (i.e., no cloud), the highest weekly mean concentrations were measured between 23 February and 1 March (week 13) in colour class 1 for TSS and DIN (corresponding to a minimum mean weekly SSD) and in colour class 2 for Chl-a. No week had *in-situ* samples collected across all colour classes (1 to 6), which did not allow describing water quality changes across colour gradients.
- The mean seasonal TSS concentrations measured across the Primary and Secondary water types exceeded the wet season TSS guidelines by 2–3 times. The mean seasonal Chl-a concentrations in the Primary water type was also above the wet season guideline, but below the guidelines in the Secondary and Tertiary water types.
- In 2016–17, the Cape York region was most affected by the lowest exposure categories (categories I and II), in agreement with the long-term trends. Approximately 56% of the total area of the Cape York region was exposed to wet season water types (Primary, Secondary and Tertiary water types combined) during at least one week of the wet season. This area was similar to the long-term area. Only 0.3% of the Cape York region was exposed to each of the higher exposure categories III and IV, which is similar to long-term areas.
- Additional flood samples were collected for the Endeavour transect over three days during the first and largest magnitude flood event of the wet season on 3, 6 and 8 February 2017. TSS concentrations declined over the salinity gradient for the flood plume sampled over 3 days. In contrast, Chl-a levels generally increased over the salinity gradient as TSS concentrations declined, which allowed a greater amount of light for primary production.

Wet Tropics

Ambient water quality

- The long-term Water Quality Index and combined AIMS/JCU score showed a ‘moderate’ to ‘good’ rating.
- Most parameters showed no clear trend over the monitoring period.
- The concentrations of NO_x have, in some sub-regions, remained stable while in others they have increased.
- DOC concentrations increased over the course of the monitoring period.
- Secchi depth was variable and showed a decline at most sites, generally with levels throughout the period continuing to not meet the guideline.

Wet season and event water quality

- The 2016–17 wet season was characterised by low rainfall and consequent river discharge, resulting in river plumes that were not well developed for most of the wet season, and therefore the sampling sites received a moderate river influence. Weekly river discharges in the 2016–17 sampling period were below the long-term mean weekly discharge value, except for weeks 6, 7 (5 to 18 January) and 10 to 14 (2 February to 8 March), with a maximum weekly discharge value measured during week 10 (2 to 8 February; 1,103,720 ML). The heavy rainfall occurring in the catchments of the Wet Tropics from 7 to 10 January 2017 resulted in a large flood plume from the Johnstone River (Week 6). Due to dense cloud cover, no satellite information was available in the coastal region off the Tully River.
- An increase in water quality concentrations was observed following these weeks. The maximum TSS surface concentrations and minimum Secchi depth were measured between 5 and 11 January (week 6); however, cloud cover prevented obtaining clear satellite image of the flood plumes for this week. Using only sites with a satellite colour class category (i.e., no cloud), the highest weekly mean concentrations were measured between 12 and 18 January (week 7) and 16 and 22 February (week 12) in colour class 4. The highest weekly mean Chl-a were measured between 23 and 29 March (week 17), when TSS was reduced due to sedimentation of the coarser particles (Bainbridge et al., 2012).
- The mean seasonal TSS and Chl-a concentrations measured across the Primary and Secondary water types exceeded the wet season guidelines.
- In 2016–17, the greatest DIN loading contributions to the marine NRM region were from the Johnstone (26%), Tully (23%) and Herbert Rivers (23%), whereas the TSS contributions were dominated by the Johnstone River (41%) and the Herbert (17%) Rivers. These results are comparable to the results of the relative risk assessment of DIN and TSS on coral reefs and seagrass completed as part of the 2017 Scientific Consensus Statement (Waterhouse et al., 2017b).
- The wet season exposure mapping showed that the Wet Tropics region was most affected by the lowest exposure categories (categories I and II), in agreement with the long-term trends and below average discharge. Approximately 72% of the total area of the region was exposed to wet season water types (Primary, Secondary and Tertiary water types combined) during at least one week of the wet season. This area was greater than the long-term areas (64%). However, only 3% of the Wet Tropics region was exposed to the higher exposure categories (categories III and IV). These areas were similar to the long-term areas.

Burdekin

Ambient water quality

- The long-term Water Quality Index calculated for the sites in the Burdekin region has remained fairly stable with a score of ‘good’ or ‘very good’. By contrast, the combined AIMS/JCU index shows a ‘moderate’ score for this region.
- Chl-a, TSS, PN and PP concentrations have been relatively stable over the entire monitoring period around GBR Water Quality Guidelines.
- The concentrations of NO_x have increased since the beginning of the monitoring program and have from 2015 onwards remained at levels above the Queensland guideline.
- DOC concentrations increased over the course of the monitoring period.

- Secchi depth remained stable and has not met the GVs over the entire sampling period.

Wet season and event water quality

- The 2016–17 wet season was generally characterised by low rainfall and consequent river discharge (below the long-term median), with the exception of the influence of tropical cyclone Debbie in March 2017 (weeks17 and 18, 23 March to 5 April).
- An increase in water quality concentrations was observed following these 2 weeks, and highest weekly mean TSS, Chl-a and DIN values and minimum SSD were sampled between 30 March and 5 April (week 18), in colour class 1.
- The mean seasonal TSS concentrations measured across the Primary, Secondary and Tertiary water types were all well above the wet season TSS guideline value. The mean Chl-a concentration also exceeded the wet season guideline in the Primary water type.
- In 2016–17, the highest river-derived DIN loading contributions to the Burdekin region were from the Burdekin (40%), Herbert (14%), Haughton (10%) and Don (11%) Rivers, whereas the TSS contributions were dominated by the Burdekin River (86%).
- In 2016–17, the Burdekin region was most affected by the lowest exposure categories (categories I and II), in agreement with the long-term trends. Approximately 82% of the total area of the Burdekin Region was exposed to wet season water types (Primary, Secondary and Tertiary water types combined) during at least one week of the wet season. This area was greater than the long-term areas. However, only 1% of the Burdekin Region was exposed to the highest exposure category (category IV) and only 0.4% was exposed to category III. These areas were smaller than the long-term areas.
- Heavy rainfall associated with the crossing of tropical cyclone Debbie occurred in the Bowen-Broken-Bogie River sub-catchments of the Burdekin catchment in March 2017 and triggered very fast stream rises across these sub-catchments. The Burdekin River flood plume was sampled on 31 March, 1 and 2 April 2017 over the salinity gradient with satellite images showing the plume moving in an easterly/south-easterly direction coinciding with the northerly winds at this time. The TSS concentrations were consistent with previous studies on the Burdekin flood plume in previous years.

Mackay Whitsunday

Ambient water quality

- Long-term Water Quality Index scores in the Mackay Whitsunday region have steadily declined over the course of the MMP to a ‘poor’ index score this year. A similar score was found for the combined AIMS/JCU index.
- Chl-a have general concentrations remaining above the annual guideline.
- Combined, the turbidity, TSS and Secchi depth data indicate that the water clarity in the Mackay Whitsunday region has decreased.
- Concentrations of PN and PP have increased over the sampling period, with both being above GVs in 2015–16.
- The concentrations of NO_x increased slightly over the monitoring period, with the trend line above Queensland GVs.
- POC and DOC concentrations showed a continued increase over the monitoring period.

Wet season and event water quality

- The 2016–17 wet season was characterised by below average river discharges for the first half of the wet season, except between 5 to 11 January (week 6) and 26 January to 1 February (week 9) that were both well above the long-term mean weekly discharge value. The second half of the wet season was characterised by very heavy rainfall coinciding with the crossing of tropical cyclone Debbie in March 2017. The weekly river discharges were above the long-term mean between 23 March and 5 April (weeks 17 and 18), which triggered large flood plumes in the Proserpine, O'Connell and Pioneer Rivers during these two weeks and week 19 (6–12 April).
- Maximum and highest weekly mean TSS, Chl-a and DIN concentrations and minimum SSD were measured between 6 and 12 April (week 19) in colour class 1.
- The mean seasonal TSS and Chl-a concentrations measured across the Primary and Secondary water types were above the mean wet season guidelines, but slightly below the guidelines in the Tertiary water type.
- In 2016–17, the river-derived DIN loadings in the Mackay Whitsunday region were dominated by Plane Creek (45%) and the Pioneer River (25%). Plane Creek also had the highest contribution to the TSS loadings (33%) in the region, followed by the O'Connell River (19%). In 2016–17, the Fitzroy River had a minor (~5%) contribution to the Mackay Whitsunday region river-derived DIN loading but was predicted to contribute 25% of the TSS loading.
- In 2016–17, the Mackay Whitsunday region was most affected by the lowest exposure categories (categories I and II), in agreement with the long-term trends. Approximately 93% of the total area of the Mackay Whitsunday Region was exposed to wet season water types (Primary, Secondary and Tertiary water types combined) during at least one week of the wet season. This area was greater than the long-term area. However, only 1% and 0.5% of the Mackay Whitsunday region was exposed to the higher exposure categories III and IV. These areas were similar to the long-term areas.
- Event sampling was undertaken in the Proserpine/O'Connell and Pioneer Rivers with the floods associated with tropical cyclone Debbie. Due to poor weather conditions, sampling was not conducted until 9 and 10 April,~10 days after peaks flows occurred. Highly elevated TSS (> 20 mg L^{-1}) and Chl-a (> 1 µg L^{-1}) concentrations were observed over most of the salinity gradient up to at least 30 PSU across both the Proserpine/O'Connell and Pioneer River plumes including key sites within the Whitsunday Islands.

4.2 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 no evidence for an overall change in the water quality of the GBR lagoon, although inter-annual differences, likely related to wet season characteristics and river discharge specifically, are evident. In addition, changes in coral reef and seagrass condition as reported in Thompson et al. (2017) and McKenzie et al. (2017) are influenced by the variability in river discharge and exposure to wet season water types during the wet season, which is demonstrated in the exposure assessments within this report and supported by other literature (Petus et al., 2014a, b, 2016), but are also confounded by other influences such as the sensitivity and resilience of particular seagrass or coral communities. For example, different seagrass species assemblages will respond differently to the same exposure to pollutants or wet season water types (Collier et al., 2016). These complexities result in continued uncertainty about the controlling factors in the cycling of key water quality variables (e.g., nitrogen) in the GBR.

To advance our ability to manage and understand whether better land management has improved marine water quality, knowledge of biogeochemical processes is required on the carbon, nitrogen and phosphorus cycling on land, in rivers/wetlands and in the marine system. One recent study has shown that the GBR organic nutrients contain approximately 94% and 75% of the bioavailable nitrogen and phosphorus, respectively, delivering enough nutrients to sustain phytoplankton productivity in the GBR (Lønborg et al., 2017). This demonstrates that using NO_x as a proxy for nitrogen availability in the calculations of the Water Quality Index is insufficient. Therefore, obtaining further knowledge of the GBR biogeochemistry will be pivotal for effective support of policy development and to provide greater confidence that a management policy has delivered sufficient improvement in the water quality.

The results for 2016–17 followed typical patterns of water quality in the inshore GBR, which generally shows minor gradients away from river mouths, with elevated levels of most indicators closest to the coast. During the wet season conditions, the water quality concentrations were typically well above GBR water quality GVs in Primary waters (typically enclosed and open coastal waters). These gradients are influenced over short time periods by flood events and sediment resuspension, and over longer time periods by a complex interplay of physical forcing and biogeochemical processes (see Schaffelke et al., 2017 and references therein). Such gradients and processes are a part of the natural GBR ecosystem, albeit under lower levels of input of runoff-derived pollutants than at present. A statistical analysis of five years of MMP water quality data showed significant variability (Schaffelke et al., 2012) between years and locations. Most variation was explained by temporal factors (e.g., seasons, years and river flow), highlighting the variable climate 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 continuous sampling from coastal waters of the GBR point to a notable long-term stability in most key water quality properties, with only DOC showing clear change in all regions over the last decade. These findings suggest that the system is able to assimilate the nutrients currently transported into the system, which could be through nutrient sinks in sediments for example.

An increase in the DOC concentrations was found in all regions. DOC constitutes the major carbon source for heterotrophic microbial growth in marine pelagic systems (e.g., Lønborg et al., 2011) and increases in DOC have previously been shown to promote microbial activity and coral diseases (Kline et al., 2006; Kuntz et al., 2005). Increases in DOC as found here could have several probable, although not necessarily mutually exclusive, explanations as follows: 1) the coral and plankton community have increased primary production, 2) primary producers are directing more of their production towards DOC release or 3) there is an enhanced export of DOC from the catchment, e.g., from eroded soils and mangroves.

A predominant part of DOC present in the GBR is derived from marine primary producers and any increases in plankton community production would result in elevated DOC concentrations. As time series measurements of primary production are not available for the GBR, it is not possible to assess if changes in the productivity could explain the increased DOC concentrations. Plankton communities have been shown to increase their DOC production in response to environmental stress (e.g., changing light and nutrient conditions) and changes in the plankton community structure (e.g., Church et al., 2002; Thornton, 2014). Previous studies have also found that increased DOC levels could be associated with changes in the plankton community driven by climate variability (e.g., increased temperature) (Church et al., 2002). Unfortunately, there are no data available on these processes in the GBR.

Globally, it has been recognised that DOC loads from catchments to coastal waters have increased over the last decades, which has been linked with changing land use (e.g., land clearing), precipitation patterns/chemistry and increased temperature (Lennon et al., 2013; Reader et al., 2014). Unfortunately, there are no data available on the DOC loads from GBR rivers. However, there has been little large-scale changes in land use in the catchments coinciding with the 10-year monitoring period, and while some load reductions have been modelled in Source Catchments due to improved management practices, the measured loads have shown little long-term change outside of the variability in intra-annual flow. Indeed, catchment lags in improvements and end-of-river loads have been acknowledged (e.g., Darnell et al., 2012) and lags between river loads and marine improvements are also expected.

In this report, the Water Quality Index was calculated in two different ways, showing slightly different scores in most regions. These differences are most likely driven by the inclusion of higher frequency wet season sampling. In addition, increased variability was detected in some of the ambient water quality variables over the last 3 years. This is most likely linked with a different sampling design, more frequent sampling during the wet season and more sites further inshore.

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 GBR lagoon provide important insights on water quality in the GBR. For example, the remote sensing research highlights the spatial and temporal influence of river plumes during the wet season within the GBR lagoon and help 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 GBR 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). The sediment resuspension influence is not captured by the ambient grab sample monitoring. Hence, three possible scenarios may explain the limited trends in the ambient monitoring program despite the high inter-annual variability in the river discharge over the monitoring period. First, the flood plume nutrients delivered over a period of weeks are rapidly removed from the water column via biological uptake and are no longer available to influence water quality once hydrodynamic flushing removes the influences of the plankton. Second, the influence of the previous plume may only become evident in sediment resuspension events where newly delivered sediment (and associated nutrients) are more easily resuspended and result in increased turbidity in the inshore and mid-shelf areas of the GBR lagoon as shown by Fabricius et al. (2016). Third, river nutrients entering the system could be rapidly diluted by the flushing with nutrient poor ocean and/or lost from the system due to denitrification in inshore areas for example, leading to an overall minor impact of river nutrients.

The case study (Appendix A) of the link between phytoplankton pigment composition and environmental conditions conducted by AIMS showed that the phytoplankton community in the inshore GBR is primarily influenced by environmental factors including temperature, irradiance and resuspension events. Monitoring of marine ecosystem status and health requires indicators of community structure and function. Previous studies have suggested that the phytoplankton community composition potentially can be used as a reliable indicator of change and system health in temperate coastal waters (Tett et al. 2008). In accordance with these findings, the case study analysis suggests that a similar approach based on pigment analysis could potentially be used in the GBR and should be a consideration for future monitoring design.

5. Conclusions

After more than a decade of continuous sampling, it is not clear whether there has been measurable change in the water quality of the GBR lagoon or not.

This report has presented the combined results of the ambient and flood response inshore water quality monitoring program, including refined methods for the remote sensing products. In 2016–17 it has also become apparent that the change in sampling design (e.g., more stations and sampling times) has led to much larger variability in the measured variables. This, in turn, makes it difficult to determine long-term trends versus changes due to changing sampling design. However, the increased frequency provides substantial benefits for the statistical rigour of the program. It is difficult to fully assess the value of the revised design in the last two low discharge years (since the commencement of the revised design); however, the design is still considered to be statistically sound. Further discussion on this aspect will be required in any further review of the MMP design.

The results of the program varied between the focus areas, with variable responses to the relatively low river discharges and end-of-catchment pollutant loads in 2016–17. Overall, the frequency and extent of river plumes were constrained compared to long-term trends, except in the Mackay Whitsunday region. Based on the *in-situ* monitoring results, the Wet Tropics region had a ‘moderate’ to ‘very good’ rating for the site-specific Water Quality Index. For the Burdekin region, the site-specific Water Quality Index showed a relatively stable overall rating of ‘good’ to ‘very good’, not reflecting the increasing levels of NO_x and DOC. In the Mackay Whitsunday region, the site-specific Water Quality Index has currently a ‘moderate’ rating, which contrary to the other regions, generally replicates the changes in NO_x and DOC, but is also driven by reduced water clarity.

The addition of the Cape York focus area had been identified as a high priority for inclusion in the MMP for many years. This first year of monitoring provides a strong foundation for continuation as part of the MMP. It is still strongly recommended that routine and event monitoring is resumed in the Fitzroy region and commenced in the Burnett Mary region to provide greater data coverage across the GBR.

The incorporation of the river-derived DIN and TSS loading contribution maps, and the new assessment of the relative contribution from each river to the NRM regions, provided further 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. This highlights the need to assess and define management priorities at a basin scale, and the importance of recognising cross-regional influences, outside of the administrative marine NRM boundaries. The basin scale approach was used for most assessments in the 2017 Scientific Consensus Statement (Waterhouse et al., 2017b, c) and should be adopted for MMP reporting where possible. This is likely to require further application of the eReefs modelling platform.

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. It has also highlighted 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 in 2018 to establish a metric specific to river plumes, distinct from overall wet season conditions.

Recent discussions on the Report Card metric highlight the need to review the methods for developing an overall metric that represents water quality conditions in the GBR through this sampling program and is sensitive enough to reflect changes in annual river discharge characteristics (for example, possibly using percentiles rather than means). In addition, there are still significant uncertainties in the knowledge of factors and process that control the processing and transformation of key water quality variables (e.g., nitrogen) in the GBR. It is therefore pivotal that more in-depth understanding of which biogeochemical processes control the changes in water quality is progressed. Improved understanding of these aspects will also assist in the revision of a representative water quality metric.

Sustained improvements in the marine water quality of the inshore GBR have not yet been observed in the MMP water quality program, even though there has been reported progress in improving land management practices, and river discharge at or below the long-term median in the last two years. This highlights the complexity of the relationship between river inputs and ambient water quality, and the expected slow response timeframe. Continued water quality monitoring and modelling of the GBR lagoon will be fundamental to determine and track long-term changes in response to management actions and interventions, for example, those under *Reef Plan* and the *Reef 2050 Plan*.

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Appendix A. Case study: Phytoplankton pigment composition and environmental conditions – is there a link in the Great Barrier Reef?

Authors: Jason Doyle, Christian Lønborg & Britta Schaffelke, AIMS

A-1 Scope

Phytoplankton communities play fundamental roles in the food web of coral reef ecosystems. Despite this role few studies have investigated the temporal and spatial variability in the community composition of phytoplankton in the Great Barrier Reef. Therefore, in this case study we studied the variability in phytoplankton pigment signatures and how these are related to environmental factors (e.g., temperature, nutrients). This analysis will help us understand how changes in the environment will impact the basis of the Great Barrier Reef food web (phytoplankton).

A-2 Introduction

In the Great Barrier Reef (GBR), phytoplankton contribute approximately 40% of the net primary production and have therefore a large impact on the food web structure and function. The earliest published work on phytoplankton community dynamics in the GBR was by Marshall (1933) who noted that diatom abundances were related to the amounts of suspended solids and wind strength. Around 50 years later, Revelante and Gilmartin (1982) reported that diatom abundances in the central GBR lagoon were correlated to rainfall and riverine run-off, and are inversely related to the abundance of diazotrophic *Trichodesmium.* Although small phytoplankton organisms (< 20 µm) account for most of the chlorophyll a biomass and primary production in the GBR, changes in the biomass amounts and composition of these communities are difficult to detect (Furnas and Mitchell, 1986; Revelante and Gilmartin, 1982), most likely due to low growth rates (Crosbie and Furnas 2001b) and a close coupling between production and grazing.

Many phytoplankton groups harbor signature pigments, and pigment analysis via high performance liquid chromatography (HPLC) can provide a measure of the phytoplankton community composition (Paerl et al., 2003; Wright and Jeffrey, 2006). As no study until now has used this tool for detailed analysis of phytoplankton community composition in the GBR, we used data from the AIMS database to describe the spatial and temporal patterns in phytoplankton pigment structure and how this varies with environmental conditions.

A-3 Materials and methods

Sample collection – Surface water samples were collected in winter (June–August, 2008 and 2009), spring (October, 2008 and 2009) and summer (February–March, 2009 and 2010) from 20 sites as part of the Marine Monitoring Program (MMP). Full-depth continuous conductivity-temperature-depth (CTD) profiles were recorded at each sampling site before sample collection. Following the CTD cast, surface Niskin bottle samples were collected for the analysis of phytoplankton pigments and environmental variables.

Sample measurements – All environmental data used in this case study were obtained from the routine MMP sampling, so these measurements are not described here (see Appendix D of this report for more details). Pigment samples (1,000 mL) were filtered through 25 mm GF/F filters. Filters were thereafter placed in cryotubes and frozen in liquid nitrogen until analysis. The collected filters were extracted and internal tests showed that we recovered > 95% of all pigments (data not shown). Phytoplankton pigments were separated based on a modified version of the method described by Van Heukelem and Thomas (2001) using a Shimadzu HPLC system. Pigments were identified via retention time and diode array spectral confirmation against certified reference pigments. Quality control of the pigment quantification was performed based on the method described by Aiken et al. (2009). The phytoplankton community composition was thereafter estimated using the CHEMTAX algorithm (Mackey et al., 1996), with the output matrices averaged to produce the final phytoplankton community composition (Wright and Jeffrey, 2006)

Statistical analyses – All phytoplankton community and environmental data were standardised (Wisconsin procedure) prior to analysis. Regional, seasonal and annual differences between the phytoplankton community as well as environmental data were examined by a three-way, fixed-factor, multivariate analysis of variance, employing the permutation method based on the Bray Curtis association measure. Post hoc analysis of highly significant factors employed either a Spearman rank order correlation or a Kruskal-Wallis one-way analysis of variance for parametric and non-parametric data.

A-4 Results and discussion

In this study, the potential of phytoplankton pigment analysis to be used as a tool to further our understanding of the phytoplankton community over space and time within the GBR lagoon was investigated. Concentrations of total chlorophyll a (TChla) were typically less than 1 mg m^{-3} in all regions, which is consistent with previous work in the GBR (e.g., Revelante and Gilmartin, 1982; Furnas et al., 2005; Thompson et al., 2011). The signature pigments identified are shown in Table A-1 and eight phytoplankton major groups were estimated using the CHEMTAX algorithm (accounting for approx. 80% of TChla) with the dominating groups being *Synechococcus*, diatoms, haptophytes and prasinophytes. The cyanobacterium, *Prochlorococcus* was not a dominant phytoplankton group; however, it did reveal the most distinct distribution pattern of all groups with a decreasing relative abundance from north to south (Figure A-1).

Table A-1: The major signature pigments identified in this study, abbreviations and the phytoplankton groups containing these pigments are shown.

Pigment group	Abbreviation	Phytoplankton group
Alloxanthin	Allo	Cryptophytes
19-Butanoyloxyfucoxathin	But	Pelagophytes
Chlorophyll b	Chlb	Chlorophytes and prasinophytes
Divinyl chlorophyll a	DVChla	*Prochlorococcus*
Fucoxanthin	Fuc	Diatoms, haptophytes and dinophytes

19-Hexanoyloxyfucoxanthin	Hex	Haptophytes
Peridinin	Per	Dinophytes
Prasinoxanthin	Pras	Prasinophytes
Zeaxanthin	Zea	*Synechococcus* and *Prochlorococcus*

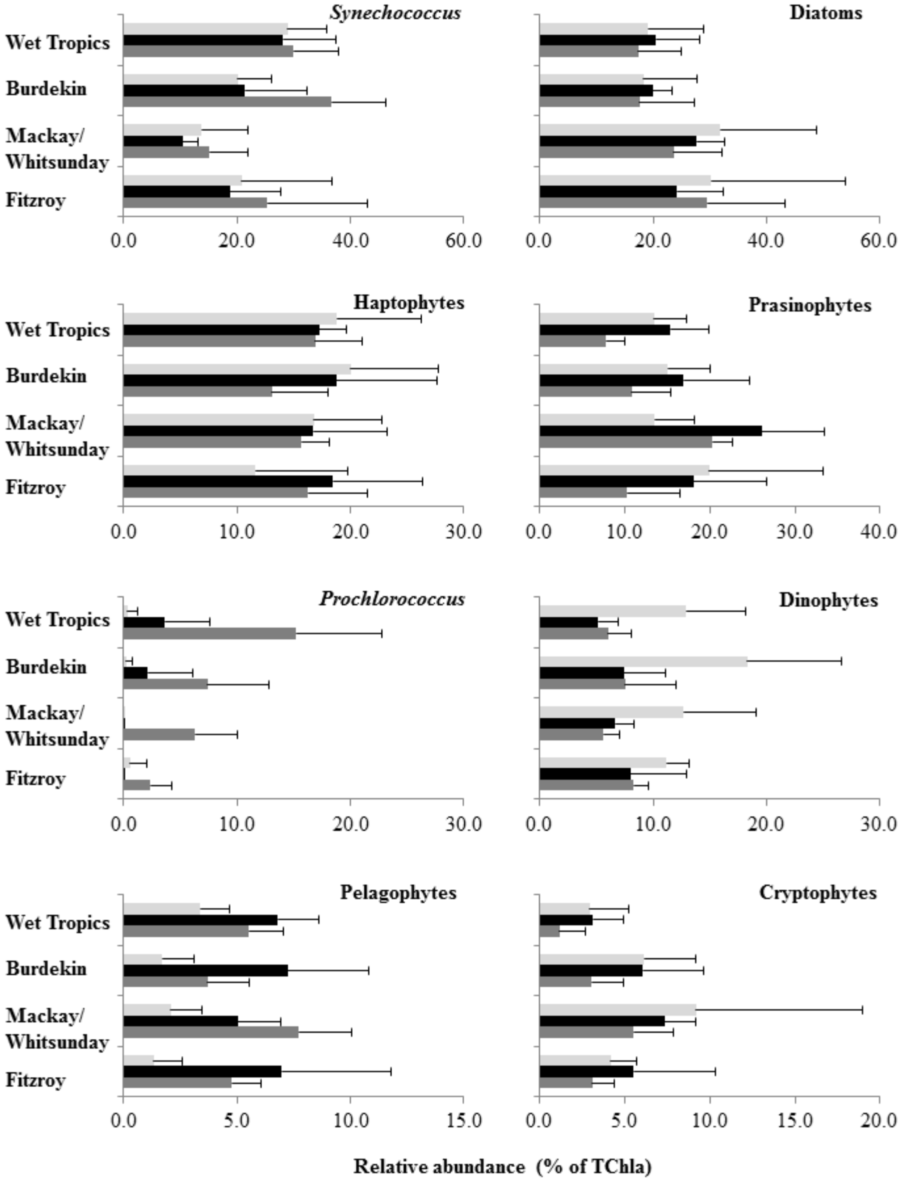

Figure A-1: Regional and seasonal mean relative abundance (percentage of total chlorophyll a [TChla]) of phytoplankton in inshore Great Barrier Reef estimated via CHEMTAX (░ = summer, ■ = winter, ▒ = spring).

Multivariate analysis revealed a strong difference between regions and seasons, along with higher level interactions between region, season and year (Table A-2). Further post hoc analysis (Table A-3) showed consistent results with the few previous studies that *Synechococcus and Prochlorococcus* have higher abundance in the north, whereas diatoms are more abundant in the southern regions (e.g. Furnas and Mitchell, 1986; Furnas and Mitchell, 1988; Revelante and Gilmartin, 1982; Thompson et al., 2011). This dominance of *Synechococcus and Prochlorococcus* has previously been shown to be related to higher temperatures and irradiance, lower nutrient levels and grazing pressure in the northern GBR (Crosbie and Furnas, 2001b).

Table A-2: Multivariate analysis of regional, seasonal and annual differences in the phytoplankton community on the Great Barrier Reef. df, degrees of freedom.

	df	**Sum of Squares**	**Mean Squares**	**Psuedo F**	**R^2**	**P (perm)**
Region	**3**	**0.8321**	**0.27736**	**12.090**	**0.14356**	**<0.001**
Season	**2**	**1.5051**	**0.75255**	**32.803**	**0.25967**	**<0.001**
Year	**1**	**0.0780**	**0.07801**	**3.400**	**0.01346**	**0.023**
Region x Season	**6**	**0.2586**	**0.04309**	**1.878**	**0.04461**	**0.011**
Region x Year	**3**	**0.3429**	**0.11431**	**4.983**	**0.05917**	**<0.001**
Season x Year	**2**	**0.4054**	**0.20268**	**8.835**	**0.06994**	**<0.001**
Region x Season x Year	**6**	**0.3094**	**0.05156**	**2.247**	**0.05337**	**0.004**
Residuals	**90**	**2.0648**	**0.02294**		**0.35623**	
Total	**113**	**5.7962**			**1**	

Ordination of environmental variables with the phytoplankton community revealed several significant relationships (Figure A-2), with the major factors determining the phytoplankton distribution being latitude and season (both associated with irradiance and temperature; Figure A-2); however, these correlations require more investigation to enable further interpretation. Diatom abundance was positively correlated with suspended solids but showed only a minor association with decreased water clarity (Secchi disc depth). Both *Synechococcus* and dinophytes were linked with increased dissolved organic phosphorus (DOP), higher temperatures and river flow, indicating that hotter, wetter months of the year (i.e., summer) favour the growth of these phytoplankton groups (Figure A-2). The abundances of *Synechococcus* and diatoms were further inversely related. Dinophytes are also weakly associated with sites closer to river mouths (as indicated by ‘Proximity’). The relative abundance of *Prochlorococcus* and, to a lesser extent, pelagophytes, also increased with water clarity and lower nutrient concentrations. All nutrient parameters included in the ordination, except DOP, were directly related to decreased water clarity (lower Secchi depth) and strongly associated with prasinophytes and cryptophytes. Prasinophyte abundances were also positively correlated with dissolved and particulate matter whereas haptophytes were present throughout the year but showed no significant correlations to the environmental data (Figure A-2).

Table A-3: Latitudinal and seasonal differences in phytoplankton distribution in inshore Great Barrier Reef waters. Spr, Spring; Sum, Summer; Win, Winter; NS, not significant; *, P < 0.05; **, P < 0.01; ***, P < 0.001.

Phytoplankton group	**Latitude**			**Season**
	Summer	**Winter**	**Spring**	
Synechococcus	**-0.744*****	**-0.806*****	**NS**	**NS**
Diatoms	**0.602****	**0.565****	**NS**	**NS**
Haptophytes	**NS**	**NS**	**NS**	**NS**
Prasinophytes	**NS**	**NS**	**0.593****	**Spr / (Sum, Win)*****
Prochlorococcus	**NS**	**NS**	**-0.747*****	**Sum / Win / Spr*****
Dinophytes	**NS**	**0.587****	**NS**	**Sum / (Win, Spr)*****
Pelagophytes	**-0.705*****	**NS**	**NS**	**Sum / (Win, Spr)*****
Cryptophytes	**0.592****	**0.498***	**0.469***	**Spr / (Sum, Win)****

These findings demonstrate that phytoplankton pigments are a useful tool for evaluating the phytoplankton community composition within the GBR, providing valuable insight into how the community responds to changes in the environment. However, it should be noted that some of the pigments are found in more than one phytoplankton group; for example, haptophytes and diatoms both contain fucoxanthin, confounding the interpretation of fucoxanthin relationships with environmental variables. Therefore, in future studies our findings need an initial verification using microscopic or genetic tools.

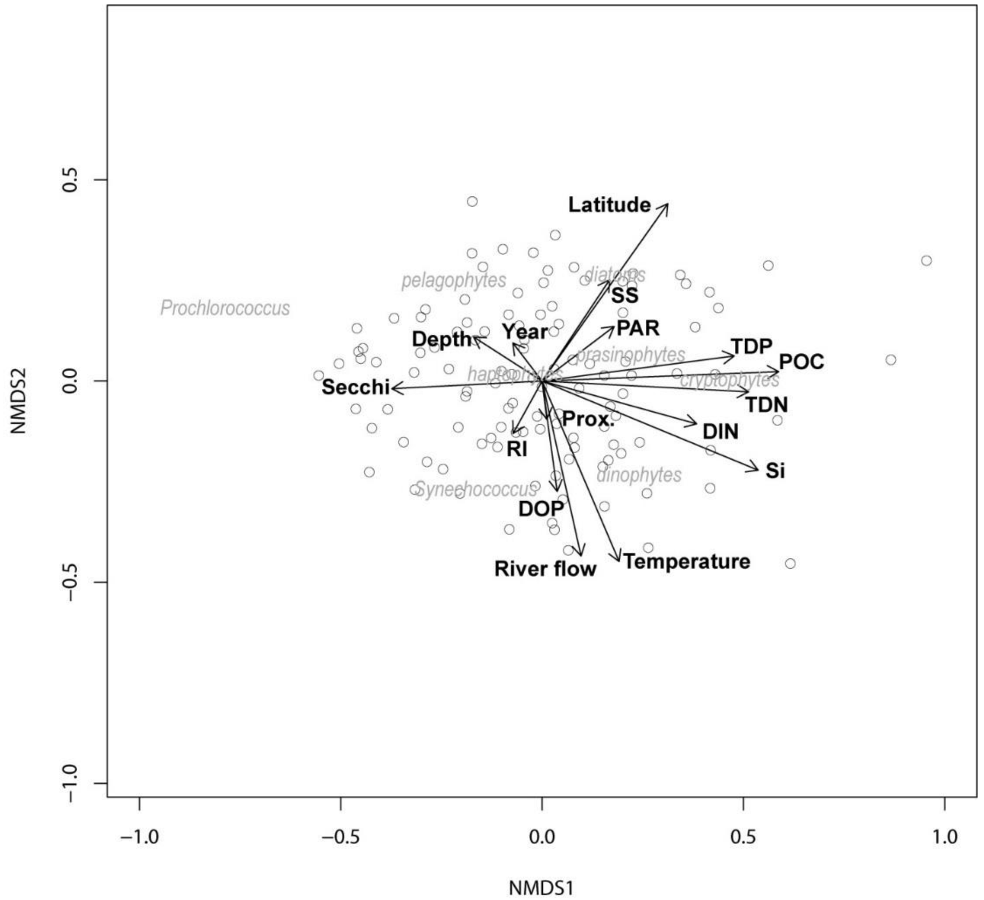

Figure A-2: Associations of the phytoplankton community as estimated by CHEMTAX with the measured environmental variables. SS, suspended solids; PAR, photosynthetically active radiation; TDP, total dissolved phosphorus; POC, particulate organic carbon; TDN, total dissolved nitrogen; DIN, dissolved inorganic nitrogen; Si, dissolved silicate; Prox., proximity to closest river mouth; DOP, dissolved organic phosphorus; RI, resuspension.

A-5 Conclusion

- The phytoplankton community in the inshore GBR is primarily influenced by environmental factors including temperature, irradiance and resuspension events.
- Some pigment classes show clear seasonal-spatial pattern (especially *Synechococcus* and *Prochlorococcus*).
- Phytoplankton pigment analysis could enable a more detailed analysis of the phytoplankton community structure and dynamics in the GBR.

Why is this relevant for the management of the Great Barrier Reef?

- Monitoring marine ecosystem status and health requires indicators of community structure and function. Previous studies have suggested that the phytoplankton community composition can potentially be used as a reliable indicator of change and system health in temperate coastal waters (Tett et al., 2008). Our analysis suggests that a similar approach based on pigment analysis coupled with other quantitative methods could potentially be used in the GBR to monitor the pelagic ecosystem status and health.

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

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B-1 Introduction

For the 2016–2017 Marine Monitoring Program (MMP) reporting, satellite-derived water type maps were produced using Moderate Resolution Imaging Spectroradiometer (MODIS-Aqua) quasi-true colour data (hereafter, true colour) produced by the Australian Government Bureau of Meteorology (BOM). MODIS-Aqua data are operationally used in the MMP as the radiometric quality of the MODIS-Terra ocean colour bands is significantly worse and crosscalibrated to MODIS-Aqua (Kwiatkowska et al., 2008). To complement this dataset, MODIS-Terra true colour images are also occasionally downloaded from NASA's EOSDIS worldview website and processed to water type maps. MODIS-Terra are only used when MODIS-Aqua data are too cloudy or unavailable, and when satellite information are needed in near real time (rapid response maping of flood events). The MODIS-Terra data are used only for informative purposes and are not included in the processing of the weekly, frequency and exposure composite maps. The MODIS-Aqua imagery is hereafter and in the main body of the report named as "MODIS" and MODIS-Terra as "MODIS-Terra".

BOM used the latest version of the SeaDAS software (SeaDAS 7.4) as well as the latest version of the MODIS calibration and look-up (LUT) tables (hereafter ***'BOM processing methods'***). SeaDAS is a comprehensive software package for the processing, display, analysis and quality control of ocean colour data. Originally developed to support the SeaWiFS mission, it now supports most U.S. and international ocean colour missions, including MODIS. The LUT and calibration files provide calibration parameters determined from pre-launch and on-orbit calibration and characterisation. These files are inputs to process the MODIS true colour data through SeaDAS and are updated on a regular basis (Table B-1).

In the previous MMP reports (2012–13 to 2015–16), MODIS true colour data were produced using version 6.4 of SeaDAS and the former version of the cross-calibration and LUT tables (Great Barrier Reef Marine Park Authority [GBRMPA], 2014) (hereafter ***'past processing methods'***). This case study aims to (1) present the new methods used by BOM to produce the MODIS true colour data and (2) compare satellite-derived data produced using the past **(reference dataset)** and BOM processing methods as well as two different cloud masks.

B-2 Methods

BOM processing methods of MODIS true colour data

Modis-Aqua L0 (and associated ancillary fields) were obtained by BOM from the NASA Ocean Biology Processing Group (OBPG) webpage and the Ocean Colour Web (https://oceancolor.gsfc.nasa.gov/) and were processed using The SeaWiFS Data Analysis System (SeaDAS, version 7.4, https://seadas.gsfc.nasa.gov/) following several steps:

1. L0 data (raw radiance counts – digital numbers) are processed using the SeaDAS modis_L0_to_L1A.py tool to obtain L1A data at native resolution (250, 500 and 1000m). Where multiple granules are required to cover the region of interest, the SeaDAS pdsmerge tool is used to merge the adjacent granules before being processed to ensure that there are no gaps between granules.
2. The L1A file is then used to calculate the geometry (GEO file) using the SeaDAS modis_GEO.py tool.

3. The GEO and L1A files are used to compute the calibrated top of atmosphere radiances (L1B data) using the SeaDAS modis_L1B.py tool at native resolution (250, 500, and 1000m).
4. The SeaDAS l1mapgen tool is then used to compute the Rayleigh corrected reflectance for MODIS bands 1 (645 nm at 250m resolution), 4 (555 nm at 500m resolution) and 3 (469 nm at 500m resolution).

The output of the SEADAS l1mapgen tool is a true colour image in GeoTIFF format. Where multiple granules are required to cover the region of interest, the true colour GeoTIFF images are combined using the imagemagick convert tool. In this process the GeoTIFF location tags are removed. They are added back to the GeoTIFF image through the use of the GDAL gdalcopyproj.py script. The argument and keywords used are described in Table B-1:.

Table B-1: Keywords and justification used in SeaDAS 7.4 to process MODIS true colour images of the Great Barrier Reef (GBR).

Step 2: modis_GEO.py	terrain correction	Given the area of interest is the ocean, terrain correction is not used (in modis_GEO.py the --enable-dem flag is not used)
Step 3: modis_L1B.py	look up table (LUT)	The arguments "-l 6.1.33.4_OC -d /short/er8/packages/seadas/7.0/ocssw/run/var/modisa/cal/EVAL/" are passed to use the 6.1.33.4_OC L1B look up table.
Step 4: l1mapgen	Calibration table	The msl12_defaults.par was updated to use the xcal_modisa_axc39d cross-calibration files.
	Atmospheric correction	The atmocor keyword was set to "on" to ensure Rayleigh correction was applied.
	resolution	The resolution keyword was set to "250" to use band 1 as input.

Comparison of new against past water type products

MODIS true colour data produced using the BOM and past processing methods (hereafter, ***'new'*** and **'past'** true colour datasets, respectively) were used as input to produce wet season water type maps (daily, weekly, annual and multi-annual composites) of the 2015–16 and 2016–17 wet seasons. Methods described in GBRMPA (2014), Appendix D-7 and summarised below were used.

- **Colour classification**

The method developed in Alvarez-Romero et al. (2013) and subsequently used in Devlin et al. (2015), Petus et al. (2014, 2016) and previous MMP reports was used to produce weekly and annual wet season water type maps of the 2015–16 and 2016–17 wet seasons. The 2015–16 wet season water type maps were derived from MODIS true colour data processed using (i) the past and (ii) BOM processing methods. The 2016–17 wet season water type maps were derived from MODIS true colour data processed using the BOM processing methods.

The method used, described in detail in Álvarez-Romero et al. (2013) and Appendix D-7, uses the apparent surface colour of the ocean and MODIS true colour data to cluster GBR coastal and river plumes into six colour classes or water bodies, typical of colour and water quality gradients existing across coastal waters of the GBR during the wet season (Alvarez-Romero et al., 2013). The clustering is done through a supervised classification using typical apparent surface colour signatures (red green blue, RGB, values transformed into intensity hue saturation, HIS, values) of river plumes in the GBR (Alvarez-Romero et al., 2013). This method assumes that the RGB and IHS signal recorded over turbid, sediment dominated, plume waters such as the GBR plume waters mainly results from the water contribution and that accurate atmospheric corrections is not crucial for this type of waters (Doxaran et al., 2009).

The brownish to brownish-green turbid waters (colour classes 1 to 4 or Primary water type) are typical for inshore regions of GBR river plumes or nearshore marine areas with high concentrations of resuspended sediments found 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 waters (colour class 5 or Secondary water type) is typical of coastal waters rich in algae (Chlorophyll a) and also containing dissolved matter and fine sediment. This water body is found in the GBR 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. Discrimination of colour classes has been based on the GBR river plume typology as defined in Johnson et al. (2011) and Devlin et al. (2011, 2012) and in the MMP (Devlin et al., 2011, 2012) and has been calibrated and validated with satellite and *in-situ* water quality data (e.g., Alvarez-Romero et al., 2013; Devlin et al., 2013, 2015, Petus et al. 2016).

- **Production of weekly and annual wet season water type maps**

Daily GBR true-colour images were processed using Rayleigh corrected reflectance of MODIS bands 1 (645 nm at 250m resolution), 4 (555 nm at 500m resolution) and 3 (469 nm at 500m resolution) with a spatial resolution of 500 m × 500 m. True-colour images of the 2015–16 wet season were produced using both the past and BOM processing methods. True-colour images of the 2016–17 wet season were produced using only the BOM processing methods (the version 6.4 of SeaDAS was no more available in 2016).

The cloud mask presented in Alvarez-Romero et al. (2013) (hereafter ***‘v1’***, Waterhouse et al., 2017) was used with MODIS true colour data processed using the past processing methods (hereafter ***‘past**$_{v1}$**’*** dataset). Both the cloud mask v1 and a slightly modified version of the cloud mask[4] (hereafter, ***‘v2’***) were used with MODIS data processed using the BOM processing methods (hereafter **‘*new*$_{v1}$** and ***new*$_{v2}$’**datasets, respectively), former cloud mask was masking some coastal turbid areas on the new (BOM) true colour dataset. This resulted in five daily MODIS true colour datasets available for this case study: the 2015–16 *past$_{v1}$ (used as reference dataset),* the: 2015–16 new$_{v1}$, 2015–16 new$_{v2}$, 2016–17 new$_{v1}$ and 2016–17 new$_{v2}$ datasets.

Weekly GBR colour class maps for the 2015–16 and 2016–17 wet seasons were created using the five datasets and 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 (Álvarez-Romero et al. (2013)). The minimum colour-class value of each cell/week was 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).

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[4] The semi-automated classification technique developed in Alvarez-Romero et al. (2013) spectrally enhance (Red-Green-Blue, RGB to Intensity-Hue-Saturation, IHS) MODIS true colour imagery and cluster the MODIS pixels into “cloud” (from the RGB image), “ambiant water” and six WSC classes (from the HIS image) through a supervised classification using typical apparent surface colour signatures of clouds (RGB values) and flood waters ((HIS values) in the GBR. In the original method (‘v1’, Alvarez-Romero et al., 2013,) the RGB images were clustered into 32 colour (rgb) class, 3 classes being “clouds”, 29 being water (marine waters + wet season colour classe). We changed one of the “cloud" colour signature into a “water” signature in the method (cloud mask ‘v2’). Please refer to Alvarez-Romero et al. (2013), section 2.2.1 for a full description of the methods.

Weekly composites derived from the five datasets were thus overlaid (i.e., presence/absence of Primary, Secondary, Tertiary water type) and normalised, to compute annual GBR normalised frequency maps of occurrence of Primary, Secondary and Tertiary water types.

- **Extraction of summary statistics**

All *in-situ* samples collected by the Tropwater team during the wet seasons 2015–16 and 2016–17 were assigned a satellite-derived surface water colour category (1 to 7), derived from the five weekly true colour datasets (2015–16 $past_{v1}$, 2015–16 new_{v1}, 2015–16 new_{v2}, 2016–17 new_{v1} and 2016–17 new_{v2} datasets). The colour class category corresponding to the location and week of acquisition of each *in-situ* sample was extracted using the raster package (Hijmans et al., 2015) with the bilinear method in R 3.1 (R Development Core Team, 2015). Zonal average frequency statistics were finally calculated on the annual frequency maps derived from the 2015–16 $past_{v1}$, 2015–16 new_{v1} and 2015–16 new_{v2} datasets. The zones used were the latest marine waterbodies from the Great Barrier Reef Marine Park Authority broken down by natural resource management (NRM) region (Table B-2:). Summary statistics were produced and compared across datasets.

Table B-2: GBR zones used to calculate the zonal average frequency statistics.

NRM	Waterbody	Zone Code
Cape York	Enclosed Coastal	12
Cape York	Open Coastal	13
Cape York	Midshelf	14
Cape York	Offshore	15
Wet Tropics	Enclosed Coastal	22
Wet Tropics	Open Coastal	23
Wet Tropics	Midshelf	24
Wet Tropics	Offshore	25
Burdekin	Enclosed Coastal	32
Burdekin	Open Coastal	33
Burdekin	Midshelf	34
Burdekin	Offshore	35
Mackay Whitsunday	Macro Tidal Enclosed Coastal	40
Mackay Whitsunday	Macro Tidal Open Coastal	41
Mackay Whitsunday	Enclosed Coastal	42
Mackay Whitsunday	Open Coastal	43
Mackay Whitsunday	Midshelf	44
Mackay Whitsunday	Offshore	45
Fitzroy	Macro Tidal Enclosed Coastal	50
Fitzroy	Macro Tidal Open Coastal	51
Fitzroy	Enclosed Coastal	52
Fitzroy	Open Coastal	53
Fitzroy	Midshelf	54
Fitzroy	Offshore	55
Burnett Mary	Enclosed Coastal	62
Burnett Mary	Open Coastal	63

Burnett Mary	Midshelf	64
Burnett Mary	Offshore	65

B-3 Results and discussion

Comparison of colour class categories extracted at the TropWATER site locations

- **2015–16 wet season**

The mean colour class values extracted from the 2015–16 past$_{v1}$, new$_{v1}$ and new$_{v2}$ datasets at the Tropwater sample locations were similar and ranged from 4.94 ± 1.02 to 5.02 ± 1.16 (Table B-3:). The weekly data processed using the new$_{v2}$ dataset had the closest mean value to the 2015–16 past$_{v1}$ (reference dataset*)* as well as the closest number of data classified as plume or marine waters (163 values vs. 169 for the past $_{v1}$ reference dataset).

Table B-3: Comparison of summary statistics derived from the colour class categories extracted from the weekly water type maps produced using the 2015–16 past$_{v1}$, new$_{v1}$ and new$_{v2}$ MODIS true colour datasets. Count is the number of JCU samples classified as plume or marine waters and the mean; Standard Deviation (SD) and median colour class category are also indicated.

2015–16 wet season	MODIS true colour dataset			Difference	
	past	new$_{v1}$	new$_{v2}$	new$_{v1}$-past	new$_{v2}$-past
count	169	155	163	-14	-6
mean	4.94	5.02	4.99	0.08	0.05
SD	1.02	1.16	1.14	0.14	0.12
median	5.0	5.0	5.0	0.0	0.0

The distribution of the number of values extracted across colour class categories (1–7) and the Primary, Secondary and Tertiary water types was similar for the three datasets, with a greater number of samples classified as Secondary (colour class 5), then Tertiary, then Primary waters (colour class 6) (

Figure B-1:a). However, the 2015–16 new$_{v1}$ dataset had a largest number of *in-situ* samples classified as “No Data” (i.e., corresponding to clouds or no satellite information) and less samples classified as Primary (colour class 1–4) and Secondary (colour class 5) water types than the reference 2015–16 past$_{v1}$ dataset. The number of data classified as Primary was 40 in the 2015–16 new$_{v1}$ vs. 28 in the 2015–16 past$_{v1}$ and the number of data classified as Secondary was 82 in the 2015–16 new$_{v1}$ dataset vs. 74 in the 2015–16 past$_{v1}$ dataset.

The main differences between the 2015–16 new$_{v1}$ and new$_{v2}$ datasets was in the number of samples classified as colour classes 4 and 5 (Figure B-1a and d). The number of data classified as Primary, Secondary and No Data in the 2015–16 past$_{v1}$ dataset was 32, 79 and 18, respectively. Trends in the variability of the colour class values extracted at each Tropwater sites for the 2015–16 new$_{v1}$ (Figure B-1b) and 2015-16 new$_{v2}$ (Figure B-1c) datasets against the 2015-16 past $_{v1}$ dataset were similar, but the 2015-16 new$_{v2}$ had a closest distribution to the reference 2015-16 past$_{v1}$ dataset (Figure B-1a and b). Using the new cloud mask (2015–16 new$_{v2}$ dataset), the number of data correctly classified (in comparison to the reference dataset past$_{v1}$) as colour classes 1, 2, 3, 4, 5, 6 and 7 was 100%, 40%, 25%, 66%, 82%, 80% and 100%, respectively (Figure B-2b). When data were reclassified into Primary, Secondary and Tertiary water types the number of samples correctly classified was P = 78%, S = 82%, T = 80 % and Marine waters = 100% (Figure B-2d).

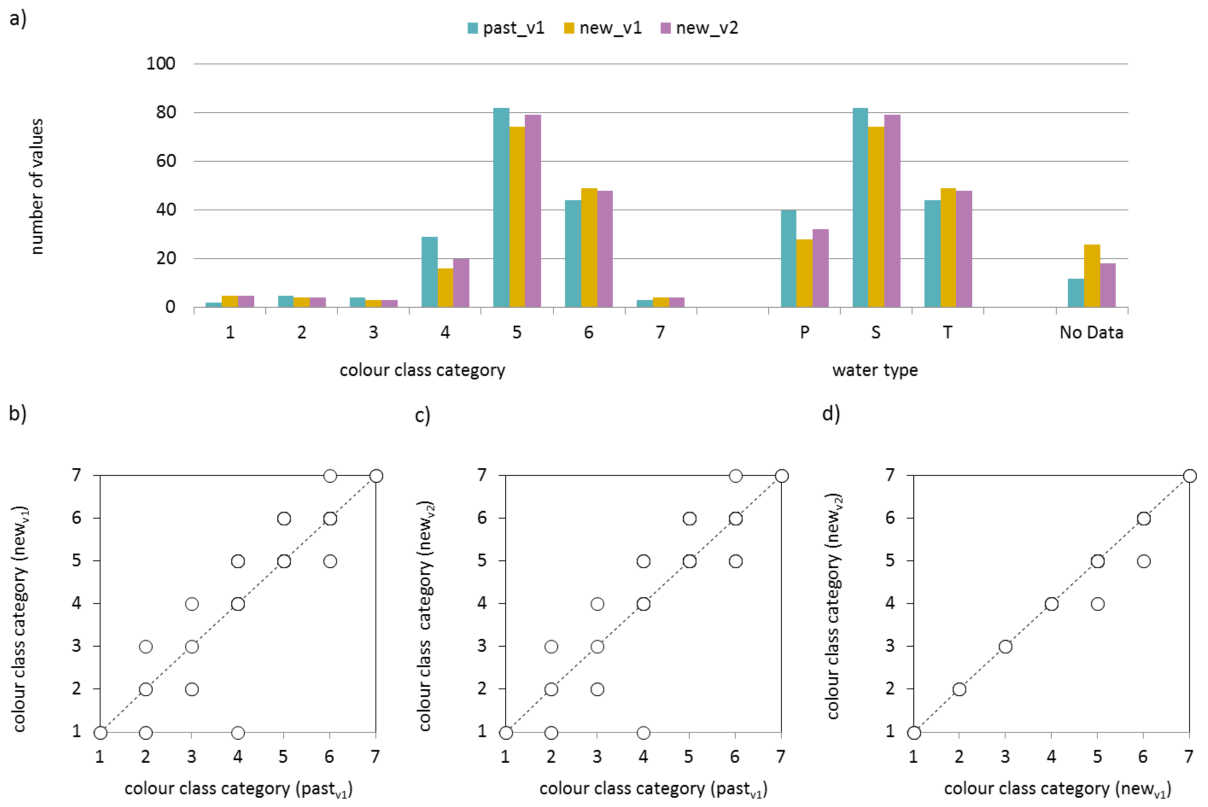
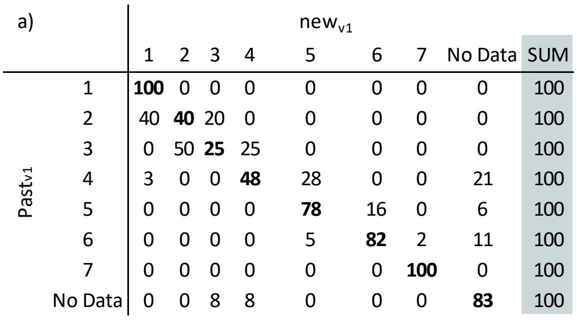
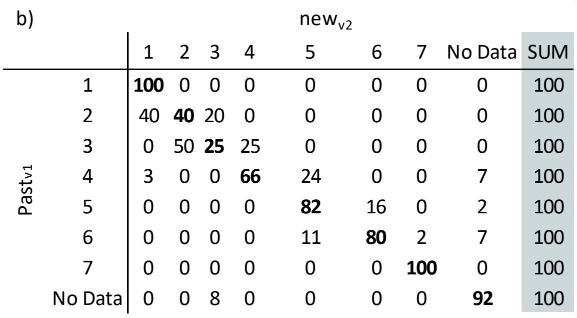


Figure B-1: Comparison of 2015-16 weekly water type maps derived from true colour data processed using the reference 'past' dataset and BOM processing methods ('new' dataset). newv1 and newv2 correspond to new datasets processed using the v1 and v2 versions of the cloud mask, respectively. Colour class categories 1 to 4, 5 and 6 correspond to the Primary (P), Secondary (S) and Tertiary (T) water types, respectively, and the colour class category 7 to the ambient marine waters. The colour class categories were extracted from weekly wet season water type maps at the Tropwater sites location and figures show the distribution of the a) number of samples classified as colour class categories 1 to 7 and PST water types, and (b-d) comparisons between the values of the colour class categories extracted at each Tropwater site location, derived using all 3 datasets (past, newv1 and newv2). 1:1 lines are indicated with dashed lines.



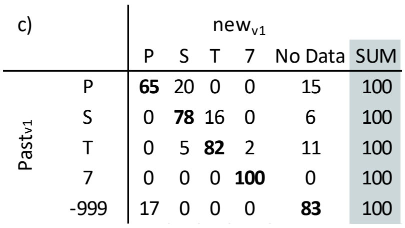
a)

		new$_{v1}$								
		1	2	3	4	5	6	7	No Data	SUM
Past$_{v1}$	1	**100**	0	0	0	0	0	0	0	100
	2	40	**40**	20	0	0	0	0	0	100
	3	0	50	**25**	25	0	0	0	0	100
	4	3	0	0	**48**	28	0	0	21	100
	5	0	0	0	0	**78**	16	0	6	100
	6	0	0	0	0	5	**82**	2	11	100
	7	0	0	0	0	0	0	**100**	0	100
	No Data	0	0	8	8	0	0	0	**83**	100



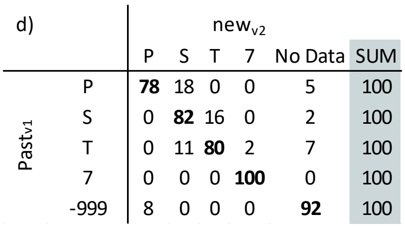
b)

		new$_{v2}$								
		1	2	3	4	5	6	7	No Data	SUM
Past$_{v1}$	1	**100**	0	0	0	0	0	0	0	100
	2	40	**40**	20	0	0	0	0	0	100
	3	0	50	**25**	25	0	0	0	0	100
	4	3	0	0	**66**	24	0	0	7	100
	5	0	0	0	0	**82**	16	0	2	100
	6	0	0	0	0	11	**80**	2	7	100
	7	0	0	0	0	0	0	**100**	0	100
	No Data	0	0	8	0	0	0	0	**92**	100



c)

		new$_{v1}$					
		P	S	T	7	No Data	SUM
Past$_{v1}$	P	**65**	20	0	0	15	100
	S	0	**78**	16	0	6	100
	T	0	5	**82**	2	11	100
	7	0	0	0	**100**	0	100
	-999	17	0	0	0	**83**	100



d)

		new$_{v2}$					
		P	S	T	7	No Data	SUM
Past$_{v1}$	P	**78**	18	0	0	5	100
	S	0	**82**	16	0	2	100
	T	0	11	**80**	2	7	100
	7	0	0	0	**100**	0	100
	-999	8	0	0	0	**92**	100

Figure B-2: Contingency matrices (in %) showing the distribution of the number of samples classified as colour class categories 1 to 7 in the a) 2015-16 new$_{v1}$ and b) 2015-16 new$_{v2}$ datasets in comparison to the reference past$_{v1}$ dataset.

- **2016–17 wet season**

The mean colour class value extracted from the 2016–17 new$_{v1}$ and new$_{v2}$ datasets at the Tropwater sample locations were similar and ranged from 4.97 ± 1.23 to 5.09 ± 1.17 (Table B-4). The 2016–17 new$_{v2}$ dataset had a greater number of samples classified as colour classes 2 and 4 (2 samples vs. 0 and 18 samples vs. 10, respectively), less samples classified as colour classes 3, 5 and 6 (2 samples vs. 3, 56 samples vs. 59 and 42 samples vs. 46, respectively) and less samples classified as No Data (60 samples vs. 62) in comparison to the 2016–17 new$_{v1}$ datasets (Figure B-3). When data were reclassified into Primary, Secondary and Tertiary water types, the 2016–17 new$_{v2}$ dataset had a greater number of samples classified as Primary waters and less samples classified as Secondary and Tertiary (28 samples vs. 19, 56 samples vs. 59 and 42 samples vs. 46).

Table B-4: Comparison of summary statistics derived from the colour class categories extracted from the weekly water type maps produced using the 2016–17 new$_{v}$1 and new$_{v2}$ MODIS true colour datasets. Count is the number of JCU samples classified as plume or marine waters and the mean; Standard Deviation (SD) and median colour class category are also indicated.

2017 data	new$_{v1}$	new$_{v2}$	Difference new $_{v1}$ -new $_{v2}$
count	127	129	-2.00
mean	5.09	4.97	0.13
SD	1.17	1.23	-0.05
median	5.00	5.00	0.00

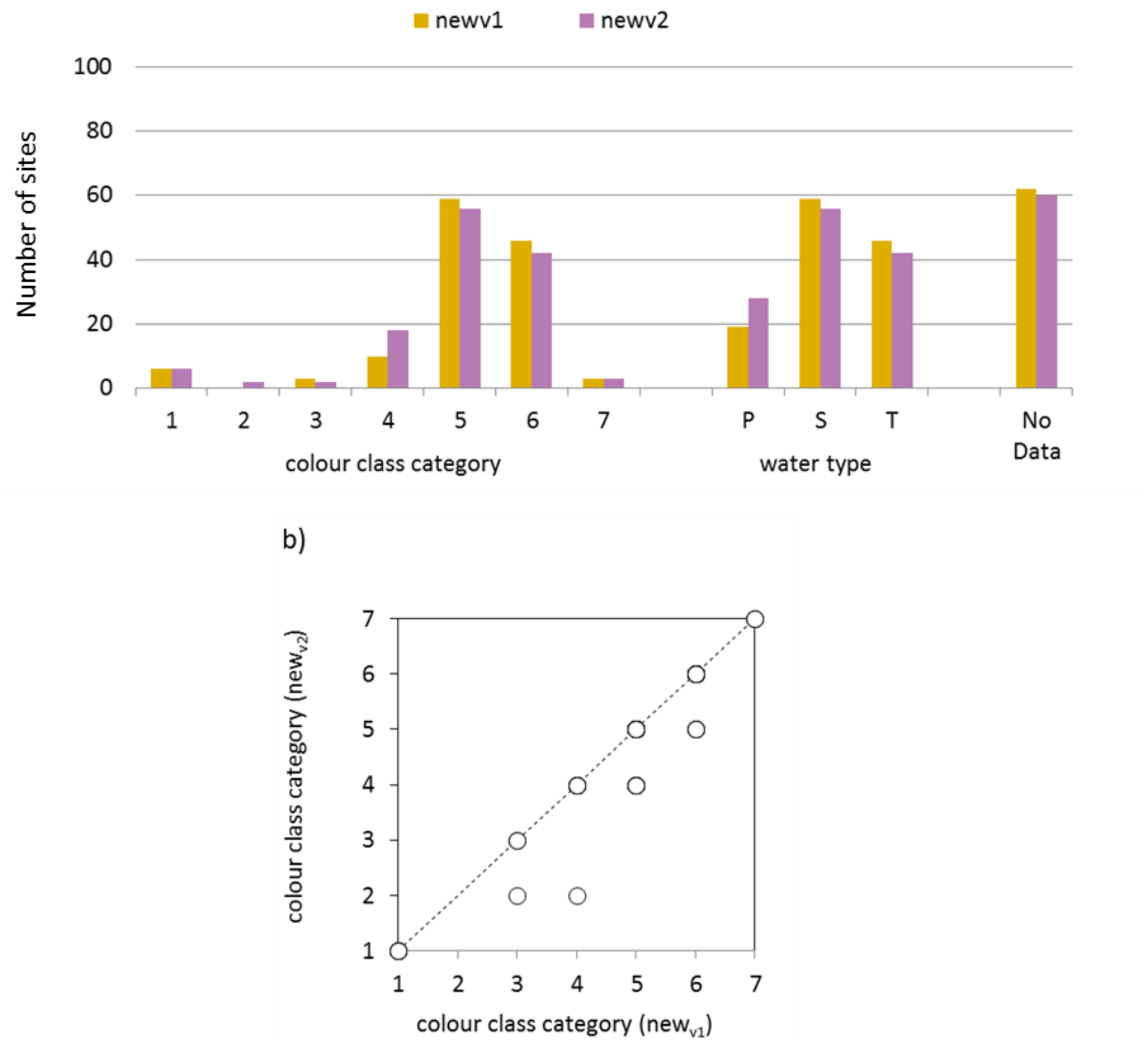


Figure B-3: Comparison of 2016–17 weekly water type maps derived from true colour maps processed using BOM processing methods (‘new’ dataset). new$_{v1}$ and new$_{v2}$ correspond to new datasets processed using the v1 and v2 versions of the cloud mask, respectively. Colour class categories 1 to 4, 5 and 6 correspond to the Primary (P), Secondary (S) and Tertiary (T) water types, respectively, and the colour class category 7 to the ambient marine waters. The colour class categories were extracted from weekly wet season water type maps at the JCU site locations and figures show the distribution of the a) as colour class categories 1 to 7 and Primary, Secondary and Tertiary water types, and (b) comparisons between the values of the colour class categories extracted at each Tropwater site location, derived using the 2016–17 new$_{v1}$ and new$_{v2}$ datasets. 1:1 lines are indicated with dashed lines.

Comparison of zonal summary statistics (2015–16)

Coefficients of determination (R^2) of zonal averaged frequencies derived from the new$_{v1}$ and new$_{v2}$ datasets (Fnew$_{v1}$ and Fnew$_{v2}$) against zonal averaged frequencies derived from the past$_{v1}$ dataset (Fpast$_{v1}$) varied from 0.82 to 0.99 (Figure B-4). The largest difference between Fnew$_{v1}$ and Fpast$_{v1}$ were observed for the Macro Tidal Enclosed Coastal waters (Figure B-4a, c and Table B-2, C40 and C50) as the previous cloud mask (v1) masked these waters as ‘cloud’ in the new true colour (2015 new$_{v1}$) dataset. The use of the new cloud mask (2015 new$_{v2}$ dataset) resulted in a significant improvement in the coefficient of determination for the Primary (R^2: 82% to 99%, Figure B-4a and b) and Secondary waters (R^2: 82% to 96%, Figure B-4c and d). Zonal statistics calculated for the Tertiary waters using all three datasets were similar (Figure B-4e and f, R^2 = 0.95–0.97).

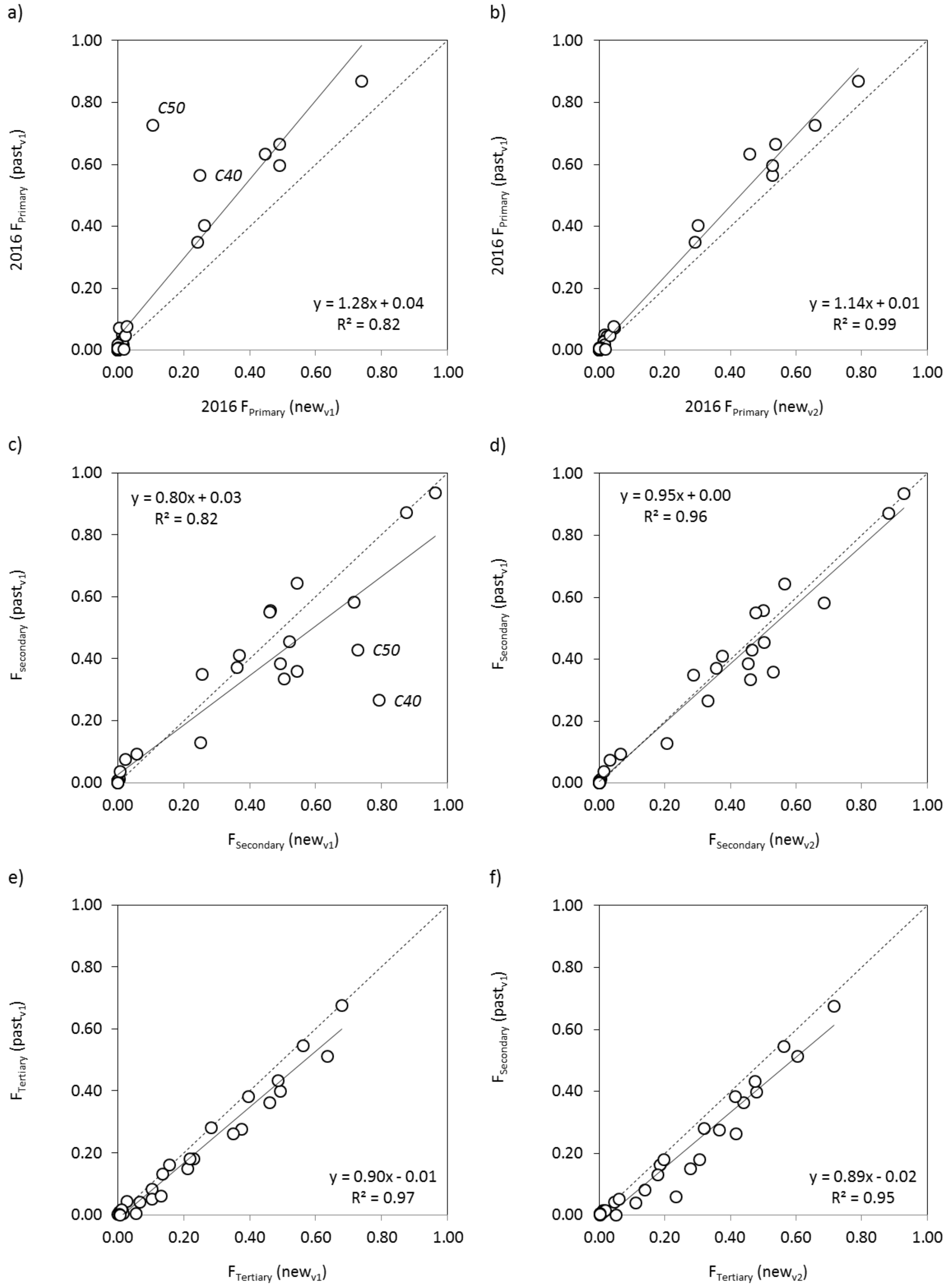


Figure B-4: Comparison of zonal averaged (a and b) Primary, (c and d) Secondary and (e and f) Tertiary 2015-16 frequency values derived from true colour data processed BOM processing methods ('new' dataset) against reference 'past' dataset. new$_{v1}$ and new$_{v2}$ correspond to new datasets processed using the v1 and v2 versions of the cloud mask, respectively. Across zones of the GBR Marine Park. The zones used were the latest marine waterbodies from GBRMPA (Macro Tidal Enclosed Coastal, Macro Tidal Open Coastal, Enclosed Coastal, Open Coastal, Midshelf, Offshore waterbodies) broken down by NRM region (cape York, Wet Tropics, Burdekin, Mackay Whitsunday, Fitzroy, Burnett Mary). Cxx indicates the zone code (Table B-1).

B-4 Summary and conclusions

For this wet season (2016–17), satellite-derived water type maps were derived using MODIS true colour data produced by BOM. BOM used different (up-to-date) versions of the SeaDAS software, LUT and calibration files than previously and the present case study aimed to assess continuity between satellite-derived products presented in this and the previous MMP reports.

A modified version of the cloud mask (v2) was implemented, and data showed that this new version of the cloud mask was efficient at (i) increasing similarity of local statistics between the past and new satellite-derived products and (ii) decreasing the number of data classified as No Data (i.e., cloud or no satellite information). Using this new cloud mask, the number of Tropwater samples correctly classified (in comparison to the reference dataset) as Primary, Secondary, Tertiary and marine waters were 78%, 82%, 80% and 100% in the 2015–16 wet season, respectively. The annual frequency of occurrence of Primary, Secondary and Tertiary water types across GBR NRMs and water types were also similar (r2 = 0.99, 0.96 and 0.95). This case study validated the use of the 2016–17 true colour data processed by BOM to produce the 2016–17 wet season water type maps.

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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 GBRMPA), 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 2016–17. Stations in bold font were part of the ambient monitoring design from 2005–2015. 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 2 depths) (1)	
Kennedy inshore				4 (Sampling 2 depths) (0)	
Cliff Islands				4 (Sampling 2 depths) (0)	
Bizant River mouth				4 (Sampling 2 depths) (1)	
Normanby River mouth				4 (Sampling 2 depths) (1)	
Normanby inshore				4 (Sampling 2 depths) (1)	
NR-03				4 (Sampling 2 depths) (1)	
NR-04				4 (Sampling 2 depths) (1)	
NR-05				4 (Sampling 2 depths) (1)	
Corbett Reef				4 (Sampling 2 depths) (1)	
Pascoe transect					* (specific sites TBD)
Pascoe mouth north				6 (Sampling 2 depths) (2)	
Pascoe mouth south				6 (Sampling 2 depths) (2)	
PR-02				6 (Sampling 2 depths) (2)	
PR-03				6 (Sampling 2 depths) (2)	
PR-04				6 (Sampling 2 depths) (2)	
PR-05				6 (Sampling 2 depths) (2)	
Middle Reef				6 (Sampling 2 depths) (1)	
Annan and Endeavour transect					* (specific sites TBD)
Annan mouth				6 (Sampling 2 depths) (3)	(3)
Walker Bay				6 (Sampling 2 depths) (3)	(3)
Dawson Reef				6 (Sampling 2 depths) (3)	(3)
Endeavour mouth				6 (Sampling 2 depths) (3)	(3)
Endeavour north shore				6 (Sampling 2 depths) (3)	(3)
Endeavour offshore				6 (Sampling 2 depths) (3)	
Egret and Boulder Reef				6 (Sampling 2 depths) (3)	
Big Unchartered Reef				6 (Sampling 2 depths) (1)	
Stewart transect					* (specific sites TBD)
Stewart mouth				6 (Sampling 2 depths) (1)	
SR-02				6 (Sampling 2 depths) (1)	
SR-03				6 (Sampling 2 depths) (1)	
SR-04				6 (Sampling 2 depths) (1)	
Hannah Island				6 (Sampling 2 depths) (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**
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) (1)
RM3			6 (Sampling 2 depths) (5)	6 (Sampling 2 depths) (6)	
RM4					** (Surface sampling only) (1)
High Island East					** (Surface sampling only) (1)
Normanby Island					** (Surface sampling only) (1)
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) (1)
Russell-Mulgrave River mouth mooring	√	√	6 (Sampling 2 depths) (5)	6 (Sampling 2 depths) (6)	
Russell-Mulgrave River mouth					** (Surface sampling only) (1)
Russell-Mulgrave junction [River]					** (Surface sampling only) (1)
Tully Focus Area			6 (Sampling 2 depths) (5)		
King Reef				1	** (Surface sampling only) (2)
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) (2)
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) (2)
Bedarra Island			6 (Sampling 2 depths) (5)	6 (Sampling 2 depths) (6)	
Triplets					** (Surface sampling only) (2)
Tully River mouth mooring	√	√	6 (Sampling 2 depths) (5)	6 (Sampling 2 depths) (6)	
Tully River					** (Surface sampling only) (2)2
Burdekin					
Burdekin Focus Area			2+ (Sampling 2 depths) (4+)		
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) (1)
Magnetic Island (Geoffrey Bay)	√		3 (Sampling 2 depths) (4)	5 (Sampling 2 depths) (5)	
Inner Cleveland Bay					** (Surface sampling only) (1)
Cape Cleveland					** (Surface sampling only) (1)
Haughton 2			2 (Sampling 2 depths) (4)	5 (Sampling 2 depths) (5)	
Haughton River mouth					** (Surface sampling only) (1)
Barratta Creek					** (Surface sampling only) (1)
Yongala IMOS NRS	√	√	11 (Sampling 2 depths) (12)		
Cape Bowling Green					** (Surface sampling only) (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**
Plantation Creek					** (Surface sampling only) (1)
Burdekin River mouth mooring	√	√	2 (Sampling 2 depths) (5)	5 (Sampling 2 depths) (5)	
Burdekin Mouth 2					** (Surface sampling only) (1)
Burdekin Mouth 3					** (Surface sampling only) (1)
Mackay Whitsunday					
Whitsunday focus area					
Double Cone Island	√		5 (Sampling 2 depths) (5)		
Hook Island W					** (Surface sampling only) (1)
North Molle Island					** (Surface sampling only) (1)
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) (1)
Brampton Island					** (Surface sampling only) (1)
Sand Bay					** (Surface sampling only) (1)
Pioneer River mouth					** (Surface sampling only) (1)

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Appendix D: Water quality monitoring methods

D-1 Direct water sample collection, preparation and analyses

At all the Australian Institute of Marine Science (AIMS) water quality monitoring locations (Figure 2-1, in main report text), vertical profiles of water temperature and salinity were measured with a Conductivity Temperature Depth profiler (CTD) (Sea-Bird Electronics SBE25 or SBE19) to characterise the water column, e.g., to identify and record any stratification. The CTD was fitted with a fluorometer (WET Labs) and a beam transmissometer (SeaTech, 25 cm, 660 nm) for concurrent chlorophyll a and turbidity measurements (derived from fluorescence and beam attenuation coefficients readings respectively). CTD data are not reported here but were used for the interpretation of water sample results.

Immediately following the CTD cast, discrete water samples were collected from two depths through the water column with Niskin bottles. Sub-samples taken from the Niskin bottles were analysed for the following water quality variables:

- Chlorophyll a = Chl-a
- total suspended solids = TSS
- ammonium = NH_4
- nitrite = NO_2
- nitrate = NO_3
- phosphate/filterable reactive phosphorus = PO_4
- silicate/filterable reactive silicon = $Si(OH)_4$
- dissolved organic carbon = DOC
- dissolved organic nitrogen = DON
- dissolved organic phosphorus = DOP
- coloured dissolved organic matter = CDOM
- particulate organic carbon = POC
- particulate nitrogen = PN
- particulate phosphorus = PP

(note that +/- signs identifying the charge of the nutrient ions were omitted for brevity).

Subsamples were also taken for laboratory salinity measurements using a Portasal Model 8410A Salinometer. Temperatures were measured with reversing thermometers from 2 depths.

In addition to the ship-based sampling, water samples for Chl-a and TSS were collected by diver-operated Niskin bottle sampling close to the autonomous water quality instruments (see below). These water samples were processed in the same way as the ship-based samples.

The sub-samples for dissolved nutrients were immediately hand-filtered through a 0.45-µm filter cartridge (Sartorius Minisart N) into acid-washed (10% HCl) screw-cap plastic test tubes and stored frozen (-18ºC) until subsequent analysis ashore. Separate samples for DOC analysis were filtered, acidified with 100 µL of AR-grade HCl and stored at 4ºC until analysis. Separate sub-samples for $Si(OH)_4$ were filtered and stored at 10°C until analysis.

Dissolved Inorganic nutrients (NH_4, NO_2, NO_3, PO_4 and $Si(OH)_4$) concentrations were determined by standard wet chemical methods (Ryle et al., 1981) implemented on a segmented flow analyser (Anon., 1997) after return to the AIMS laboratories. NO_2 + NO_3, is reported as NO_x (oxidised nitrogen). Analyses of total dissolved nutrients (TDN and TDP) were carried out using persulphate digestion of water samples (Valderrama, 1981), which were then analysed for inorganic nutrients, as above.

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

DOC concentrations were measured by high temperature combustion (720ºC) using a Shimadzu TOC-L carbon analyser. Prior to analysis, CO_2 remaining in the acidified sample water was removed by sparging with O_2 carrier gas.

The sub-samples for Chl-a and particulate matter determinations were collected by vacuum filtration on pre-combusted glass-fibre filters (Whatman GF/F). Filters were wrapped in pre-combusted aluminium foil envelopes and stored at -18ºC until analyses

Chl-a concentrations were measured fluorometrically using a Turner Designs 10AU fluorometer after grinding the filters in 90% acetone (Parsons et al., 1984). The fluorometer was calibrated against Chl-a extracts from log-phase diatom cultures. The Chl-a concentration of the standards prepared from the culture were determined spectrophotometrically using the wavelengths and equation specified by Jeffrey and Humphrey (1975). The solutions were then diluted by orders of magnitude and used to produce a standard curve matching the sample concentration range and of suitable concentration for use in the fluorometer.

The POC and PN contents of material collected on filters was determined by high temperature combustion (950ºC) using a Shimadzu TOC-L carbon analyser fitted with a TNM-L Total Nitrogen unit and a SSM-5000A solid sample module. Filters containing sampled material were placed in pre-combusted (950ºC) ceramic sample boats. Inorganic C on the filters (e.g., $CaCO_3$) was removed by acidification of the sample with 2M hydrochloric acid and warming to near dryness. The filter was then introduced into the sample oven (950ºC), purged of atmospheric CO_2 and the remaining organic matter was then combusted in stream of “Zero Air”. Total Organic Carbon (as CO_2) was then quantified by infrared gas analysis and total bound Nitrogen (TNb, as nitrogen oxides) was quantified by chemiluminescence. The analyses were standardised using certified reference materials.

PP was determined spectrophotometrically as inorganic P (PO_4: Parsons et al., 1984) after digesting the particulate matter in 5% potassium persulphate (Furnas et al., 1995). The method was standardised using orthophosphoric acid and dissolved sugar phosphates as the primary standards.

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

Details about method performance and QA/QC procedures are given in Appendix F.

Below is a brief description of each of the main water quality variables measured as part of the monitoring program. These definitions are not all-embracing and are meant to provide a short description of what they measure and what processes impacts the variables:

- **Turbidity** is a measure of light scattering caused by fine suspended particles, such as clay and silt, detritus, microbes and phyto- 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.

- **Chlorophyll-a** concentration is a measure of phytoplankton biomass in a water body and in coastal waters can reflect changes in river nutrient loads.
- **Dissolved inorganic nutrients (NH_4, NO_X, PO_4, $Si(OH)_4$)** measure the amount of readily available nutrients for primiairly plankton growth in a water samples. The inorganic nitrogen (NH_4, NO_X) and phosphate (PO_4) contain around 1% of the nutrient pools in the Great Barrier Reef (GBR). 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 lad use) ones.
- **Particulate matter (POC, PN and PP)** is in this report a measure of the material retained on a filter with a pore size of approximately 0.7 µm. This material can be both suspended and sink to the sediments and it 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 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.

D-2 Autonomous water quality loggers

In-situ autonomous water quality monitoring (Figure 2-1, Table 2-1 in main report text) was undertaken using WET Labs ECO FLNTUSB Combination Fluorometer and Turbidity Sensors. These were deployed at 5 m below the water surface. The ECO FLNTUSB Combination instruments were deployed all year and perform simultaneous *in-situ* measurements of chlorophyll fluorescence, turbidity and temperature.

The fluorometer monitors chlorophyll concentration by directly measuring the amount of chlorophyll fluorescence emission, using LEDs (centred at 455 nm and modulated at 1 kHz) as the excitation source. The fluorometer measures fluorescence from a number of chlorophyll pigments and their degradation products that are collectively referred to as “chlorophyll”, in contrast to data from the direct water sampling which specifically measures “chlorophyll a”. Optical interference, and hence an overestimation of the true “chlorophyll” concentration, can occur if fluorescent compounds in dissolved organic matter are abundant (Wright and Jeffrey, 2006), for example in waters affected by flood plumes (see also Appendix E). Throughout this report the instrument data are referred to as “chlorophyll”, in contrast to data from the direct water sampling which measures specifically “chlorophyll a”. A blue interference filter is used to reject the small amount of red light emitted by the LEDs. The light from the sources enters the water at an angle of approximately 55–60 degrees with respect to the end face of the unit. The red fluorescence emitted (683 nm) is detected by a silicon photodiode positioned where the acceptance angle forms a 140-degree intersection with the source beam. A red interference filter discriminates against the scattered excitation light.

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

Pre- and post-deployment checks of each instrument included measurements of the maximum fluorescence response, the dark count (instrument response with no external fluorescence, essentially the ‘zero’ point). After retrieval from the field locations, the instruments were cleaned, and data downloaded and converted from raw instrumental records into actual measurement units (µg L^{-1} for chlorophyll fluorescence, NTU for turbidity, ºC for temperature) according to standard procedures by the manufacturer. Deployment information and all raw and converted instrumental records were stored in an Oracle-based data management system developed by AIMS. Records are quality-checked using a time series data editing software (WISKI©-TV, Kisters). Instrumental data were validated by comparison with chlorophyll and suspended solid concentration obtained by analyses of water samples collected close to the instruments, which was carried out at each change-over (see Appendix E).

D-3 Salinity and temperature profilers

The CTD profilers measure salinity and temperature in a vertical profile through the water column at each sample site in parallel with the discrete water sample grabs. AIMS uses several Sea-Bird Electronics (SBE) CTD profilers, which are also fitted with additional sensors such as fluorometers, transmissometers or Photosynthetically Available Radiation (PAR) sensors. Annual calibrations of the profiler instrumentation are carried out by specialised laboratories, such as CSIRO CMAR in Hobart, or Sea-Bird Electronics in the USA. These calibration values are included within the SBE configuration files.

Pre-trip CTD checks are carried out at AIMS. These include checking the physical status of the sensors and cables. The C-T (Conductivity-Temperature) cell is also kept ‘soaked’ in de-ionised water for at least 1 h prior to use. The optical sensors are washed down at the commencement of each transect and the CTD is equilibrated just under the water’s surface for 3 minutes prior to each cast. The CTD is connected to the SBE program SeaTerm, where communications are checked and the ‘display status’ command provides a battery power check and memory available. Batteries are replaced once voltage drops below 11.2 V and the CTD memory is cleared prior to each field trip.

Pre-deployment of the CTD profiler on board the boat, the CTD is secured to the hydrographic wire. Tygon tubing is removed from the CTD to allow flush water to drain from the C-T cell and protective caps are removed from the other sensors. To activate logging, the magnetic switch is moved to the on position and the CTD cage is lowered into the water sitting at the surface below the surface. A three minute ‘soak’ of the CTD begins, to allow sensors to equilibrate and air bubbles to be flushed by the pump.

The profile is commenced at a rate no greater than 0.5 m s^{-1} to achieve a minimum sensor scan rate of 8 scans m^{-1} vertically. The CTD is sent to near bottom, ensuring it does not impact with the seabed, and retrieved to the surface where the switch is turned off. After completion of casts, the Tygon tubing is fitted back on and the C-T cell is filled with water.

Post-deployment, when on board the RV Cape Ferguson, the CTD is reconnected to the laptop and the SBE SeaTerm program is run to upload the data, or upon returning to shore when deployed on the RV Aquarius. The SBE configuration file is used to plot the CTD profile using SeasaveV7, to ensure the CTD is functioning and data capture was successful. The CTD output as hex files or xml are stored in a folder labelled by cruise number and containing the configuration file.

Upon return to AIMS, the CTD files for each cruise are loaded onto the *Reef Plan* Marine Monitoring Program (MMP) central data storage area, where they are batch processed using the program SBEDataProcessing-Win32. Processing includes data conversion (from hex or xml to ascii output and using the configuration file) and processing modules including Wild Edit, Loop Edit and Bin Averaging using the downcast.

D-4 Comparison with GBR Water Quality Guideline values

The Water Quality Guidelines for the Great Barrier Reef Marine Park (Great Barrier reef Marine park Authority [GBRMPA], 2010) provides a useful framework to interpret the water quality values obtained at the sampling locations and to identify areas/locations with potential water quality issues. Table D-1 gives a summary of the guidelines values (GVs) for seven water quality variables in four cross-shelf water bodies. The MMP inshore monitoring locations are mostly located in the Open coastal water body, with four sites (Franklands West, Palms West, Pandora and Barren) located in the Midshelf water body, which has the same GVs. The specific GVs applied at each site can be found in Table E-12.

The relevant GVs from Queensland Water Quality Guidelines (Department of Environment and Resource Management [DERM], 2009) are used in the GBR Guidelines for the enclosed coastal water body (Table D-1). The Queensland guidelines also identify GVs for dissolved inorganic nutrients in marine waters. At present, GVs for dissolved inorganic nutrients are not defined for the GBR lagoon as in the GBR lagoon dissolved inorganic nutrients are rapidly cycled through uptake and release by biota and are variable on very 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 integrate nutrient availability over time (De'ath and Fabricius, 2010).

Table D-1: Guidelines values from the Water Quality Guidelines for the Great Barrier Reef Marine Park (GBRMPA, 2010) and the Queensland Water Quality Guidelines (DERM, 2009).
Please note that the guideline values provided by DERM are the 80th percentile guidelines.

		Enclosed coastal^{Qld}		**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}	n/a	15.0	2.0	2.0	2.0	2.0	0.7	0.7
Turbidity	NTU	10.0	6.0	1.5*	1.5*	1.5*	1.5*	<1^{Qld}	<1^{Qld}
Secchi	m	1.0	1.5	10.0	10.0	10.0	10.0	17.0	17.0
NO$_x^{Qld}$	µg L^{-1}	10.0	3.0	2.0	3.0	2.0	2.0	2.0	2.0
PO$_4^{Qld}$	µg L^{-1}	5.0	6.0	4.0	6.0	4.0	6.0	4.0	5.0

** 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-5 Summary statistics and data presentation

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. This included the samples collected by divers directly above the reef surface and the depth-profile station collected from the research vessel. Summary statistics for each of the 20 locations over all sampling years of these depth-weighted mean values are presented as tables in Appendix E. Concentrations were compared to Guideline trigger values (guideline, DERM, 2009; GBRMPA, 2010,) for the following water quality constituents: Chl-a, PN, PP, TSS, Secchi depth, NO_x and PO_4.

Daily averages of the chlorophyll and turbidity levels, derived from fluorescence and beam attenuation coefficient measurements collected by the ECO FLNTUSB instruments at each of 14 core locations, are presented as line 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.

In the main report, temporal trends are reported for selected key water quality variables (Chla, TSS, Secchi depth, turbidity, NO_x, PN and PP) on a region or sub-region level. The Wet Tropics natural resource management (NRM) region was subdivided 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 GBRMPA).

Generalised additive mixed effects models (GAMMs; Wood, 2006) were used to decompose the irregularly spaced time series into its trend cycles (long-term) and periodic (seasonal) components. 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), in which 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 indicator within each (sub-) region, the indicator 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 physical conditions at the time of sampling. For water parameters 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-6 Interim site-specific water quality index

In the Great Barrier Reef Reef Report Cards 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 20 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 GBR 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 that connects the instrumental measurements to the broader suite of variables (e.g., nutrients, dissolved and suspended organic matter, suspended particulates) that influence the health, productivity and resilience of coral reefs. The application of remote sensing data will remain useful to assess the broader water quality in the inshore GBR lagoon.

We have previously developed a simple Water Quality Index to generate an overall assessment of water quality at each of the water quality sampling locations. The index is based on all available data using four-year running means as a compromise between having sufficient data for the assessment and the ability to show trends. The index is different to that reported by Schaffelke et al. (2012) as we now include a scaling step that moves beyond a simple binary compliance vs non-compliance assessment. The index aggregates scores given to seven indicators, in comparison with the GBR Water Quality Guidelines (GBRMPA, 2010) and Queensland Water Quality Guidelines (DERM, 2009). The seven indicators, comprising five indicator groups were:

1. TSS concentration in water samples, Secchi depth and turbidity measurements by FLNTUSB instruments, where available.
2. Chl-a concentration in water samples.
3. PN concentrations in water samples.
4. PP concentrations in water samples.
5. Dissolved NO_x concentrations in water samples; for this variable only Queensland guideline were available.

The seven individual 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 Guideline trigger values (guideline, GBRMPA, 2010) are available for these measures and they can be considered as relatively robust indicators, integrating a number of bio-physical processes. TSS, turbidity and Secchi depth are indicators of the clarity of the water, which is influenced by a number of oceanographic factors, such as wind, waves and tides as well as by TSS carried into the coastal zone by rivers. 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 a useful indicator for nutrient stocks in the water column (predominantly bound in phytoplankton and detritus 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). We have also included NO_x in our index calculation even though only Queensland guidelines are available. The Queensland guideline values used here are the 80th percentiles, which are considered to be high compared to the values normally found in the GBR lagoon hence, a score based on the compliance with the Queensland guideline does not properly reflect changes in the NO_x concentrations. Despite these significant limitations we believe it to be more valuable to include these measurements than not at all considering the increased NO_x concentrations. It has to be emphasised that it is pivotal for the reliability of the index to establish a Great Barrier Reef Marine Park Authority guideline for NO_x (amongst others) specifically developed for coral reefs. The current index has obvious limitations and a future version could therefore potentially apply shorter average steps (e.g., two instead of four-year running means) and include other variables such as total nitrogen and phosphorus.

Steps in the calculation of the index:

1. Calculate four 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 guideline 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 guideline, ratios < 0 signify running means that exceeded the guideline and ratios > 0 means running means that complied with the guideline.

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

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

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

6. In accordance with other Great Barrier Reef Report Card indicators, the Water Quality 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.

Recent alterations to the Great Barrier Reef Marine Park Authority guidelines (guidelines values are now site-specific and pertain to a more complex assortment of seasonal and annual means and median) as well as modifications to sampling design and the addition of JCU observations. Consequently, in addition to the above procedure (used with the previous guidelines and water body boundaries to provide backward continuity), a new index formulation has been generated:

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

2. GBRMPA guidelines are consulted to select the appropriate aggregation and statistic for each Site/Measure.

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

Ratio = log_2V - log_2 guideline.

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

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

6. The Water Quality Index for each site per four-year period was calculated by averaging the ratios of PP, PN, NO_x, Chla and the combined turbidity ratio.

7. In accordance with other GBR Report Card indicators (see Anon, 2011), the Water Quality 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 (sub-)region were averaged and converted into the colour scheme as above.

The above formulation was only calculated for the current reporting year (2016–17), as many of the design changes make comparisons to previous years difficult to interpret.

The WQ Guideline values used for each sampling site are shown in Appendix E, Table E-11.

D-7 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 GBR. 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 GBR ecosystems. Ocean colour imagery provides synoptic-scale information regarding the movement and composition of turbid waters. Thus, in the past eight 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 GBR 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) (see Appendix B). 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 (Figure 3-9).

The brownish to brownish-green turbid waters (colour classes 1 to 4 or Primary water type) are typical for inshore regions of GBR river plumes or nearshore marine areas with high concentrations of resuspended sediments found 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 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 the GBR 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.

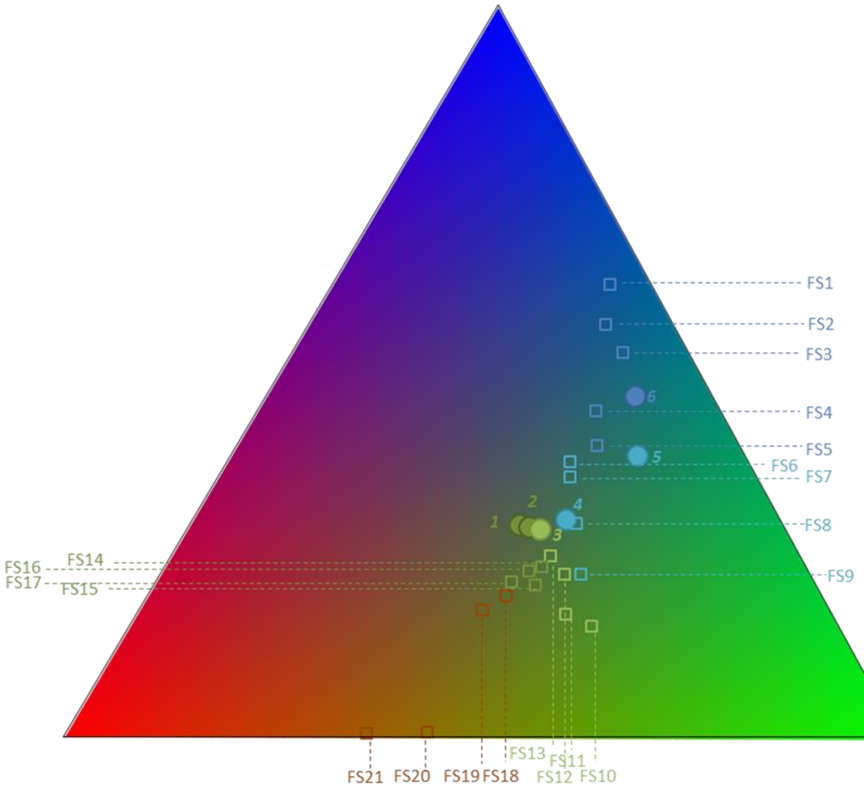

Figure D-1: Triangular colour plot showing the characteristic colour signatures of the GBR river plume waters (1 to 6) in the Red-Green-Blue (RGB or true colour) space, compared to approximate RGB colour of the Forel-Ule scale, a colour comparator used to estimate the colour of natural waters since the 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) (see Appendix B) 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 GBR. 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 (2003-2017) 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, DIP, PP, PN, TSS, Chl-a, CDOM and Kd(PAR) or Secchi depth and the mean, standard deviation, minimum, maximum values for each pollutant across colour classes and water types are calculated

D-8 Estimating the level of exposure of GBR 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 2.7) can be overlaid with information on the presence or distribution of ‘contamination receptors’, i.e., GBR 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, GBR) 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 GBR. 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 GBR 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

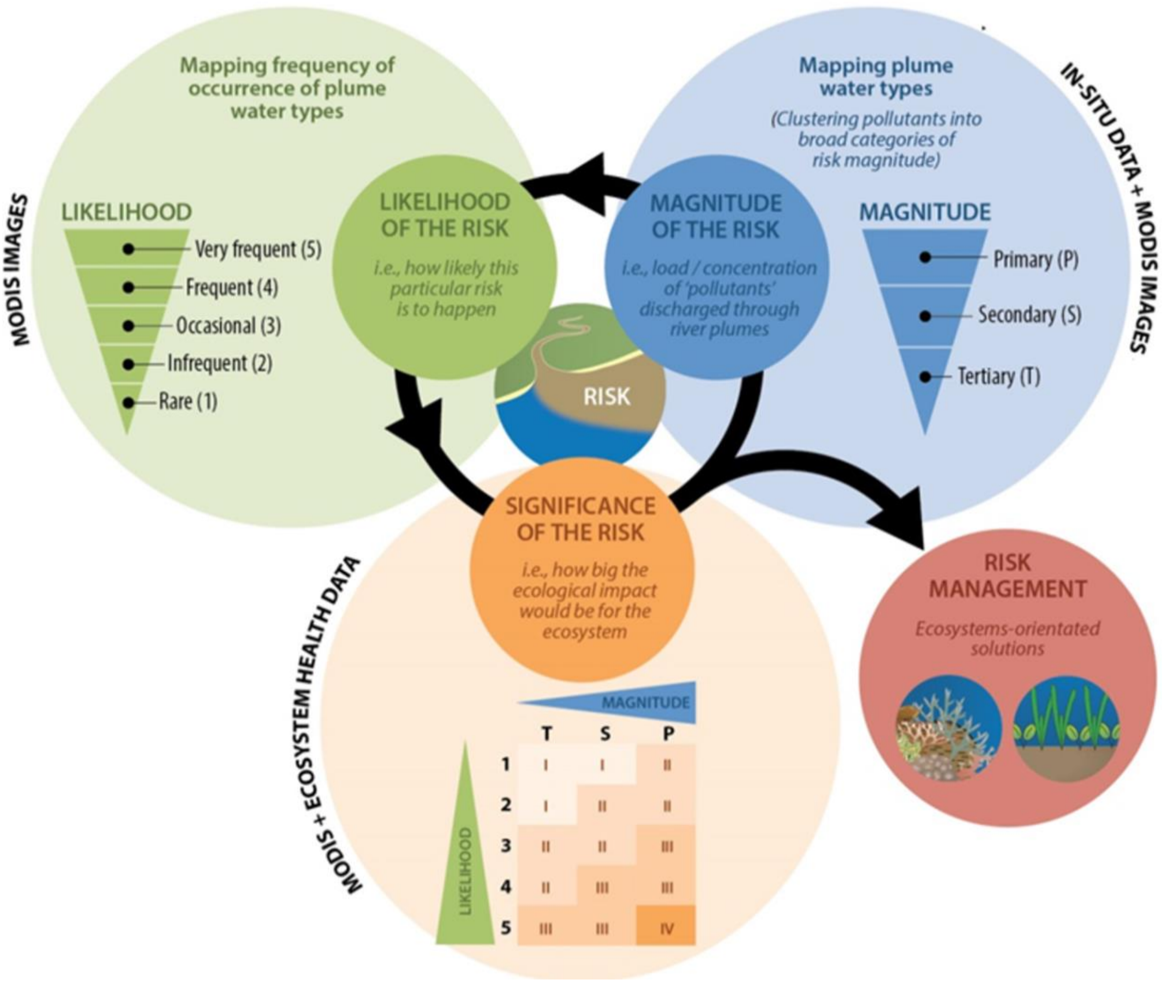

Figure D-2: Conceptual scheme of the risk framework proposed in Petus et al. (2014a).

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 GBR 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).

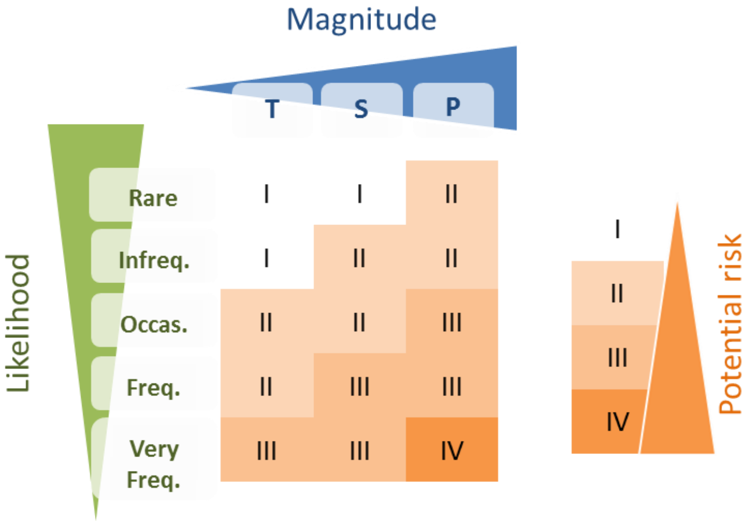

Figure D-3: Potential risk matrix in function of the magnitude and the likelihood of the river plume risk. Potential risk categories I, II, III, IV (modified from Petus et al., 2014b).

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) of the GBR:

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

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

$$magnitude_{water\ type} = \frac{[Poll.]_{water\ type} - guideline}{guideline}$$

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

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 GBR 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; GBRMPA, 2010).

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 (Figure 3-9):

$$Chla\_exp_{Primary} = \frac{1.8-0.63}{0.63} \times frequency_{water\,type\ (0-1, cell-specific)}$$

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

$Chla\_exp_{Tertiary}$ = 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 GBR 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 GBR 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 GBR 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 GBR 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.

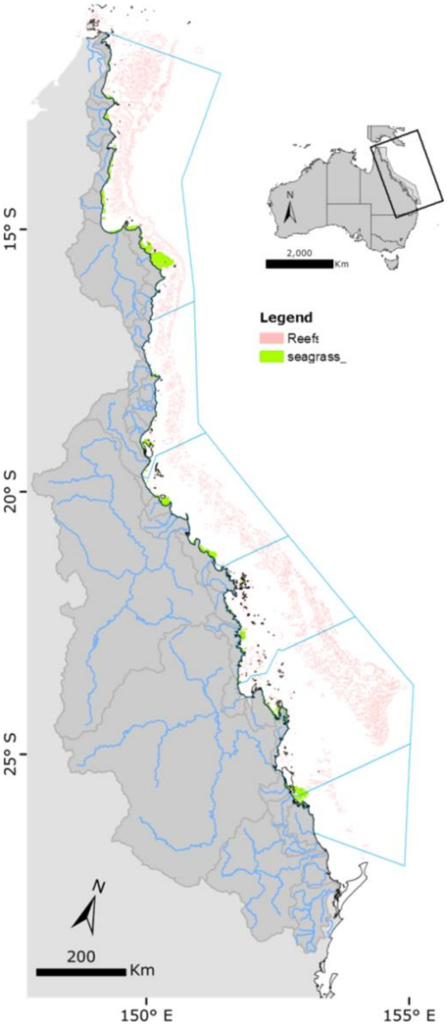

Figure D-4: Marine boundaries used for the GBR Marine Park, each NRM region and the coral reefs and seagrass ecosystems. Coral reef and NRM layers derived from GBRMPA, supplied 2013. Seagrass layer is a composite of surveys conducted by DAF.

D-9 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 GBR 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 GBR (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 GBR. 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 GBR 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 GBR watersheds. In the model, loads provide the amount of DIN delivered along the GBR, 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 GBR lagoon. This model produces annual maps of average DIN concentration in the GBR 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 (Environmental Systems Research Institute (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 GBR 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 GBR 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 GBR lagoon discharged by the rivers. In the following these four major steps are presented, starting with the generation of individual river plumes.

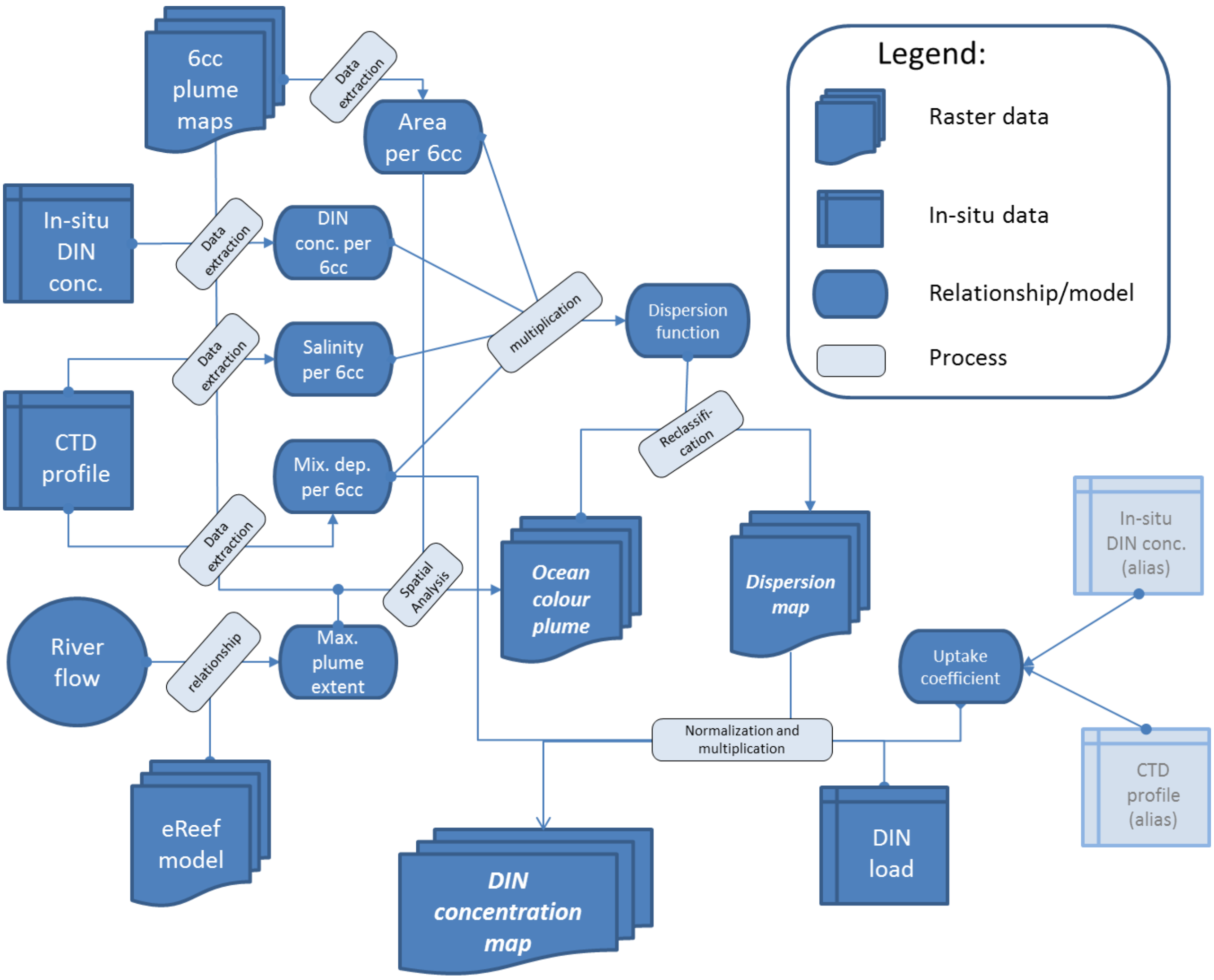

Figure D-5: Conceptual model for DIN concentration load mapping. See text for explanation.

(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 GBR.

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, in prep.), 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):

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

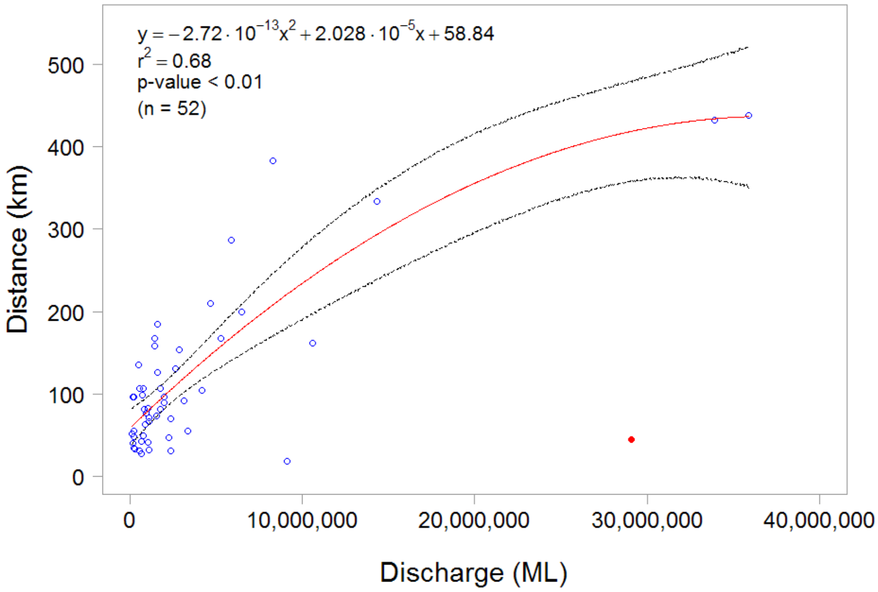

Figure D-6: Relationship between river discharge (million litres, ML) and distance (km) between river mouth and the outer edge of tracer plume as obtained from the eReefs hydrodynamic model for the GBR. Dashed lines stand for CI 95%. Red dot stands for point excluded from the regression model.

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 a *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 GBR lagoon as part of the water quality flood plume program under the Reef Rescue MMP (Figure D-7).

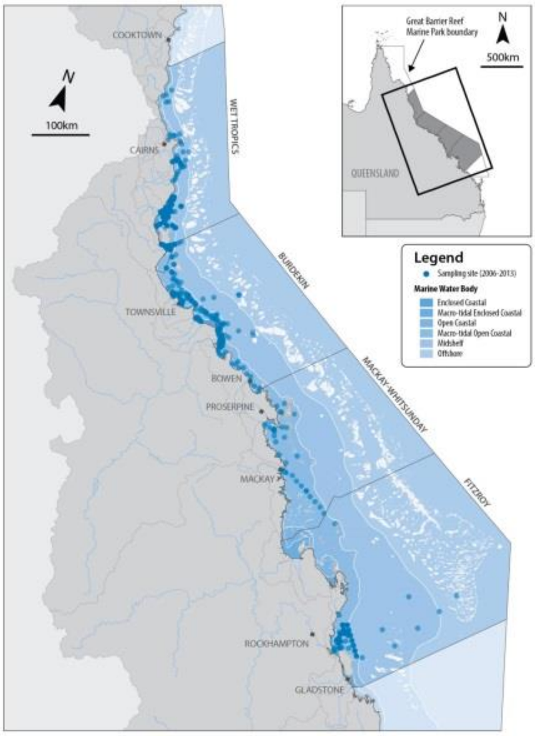

Figure D-7: The GBRMP (Queensland, Australia), boundaries of the NRM regions, and the sampling sites (colour density indicates recurrent sampling) included for validation.

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-8: presents 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 GBR 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.

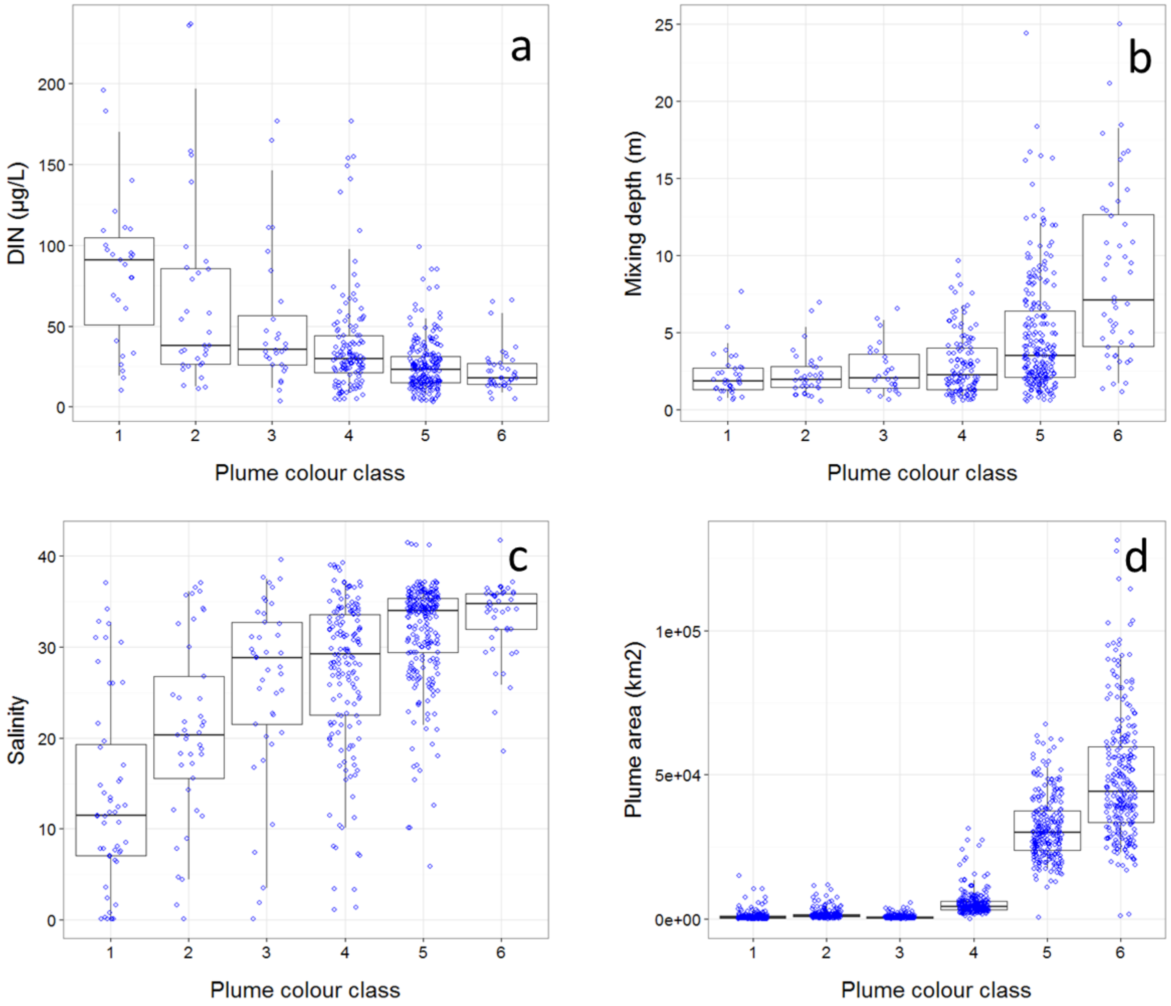

Figure D-8: *In-situ* DIN concentration (a), depth of the mixing layer (b), superficial salinity (c) and plume area (d) per colour class, measured over 13 wet seasons (December to April inclusive) from 2002-03 to 2014-15. Boxplot presents the median (dark black line), 25th and 75th percentile values (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.

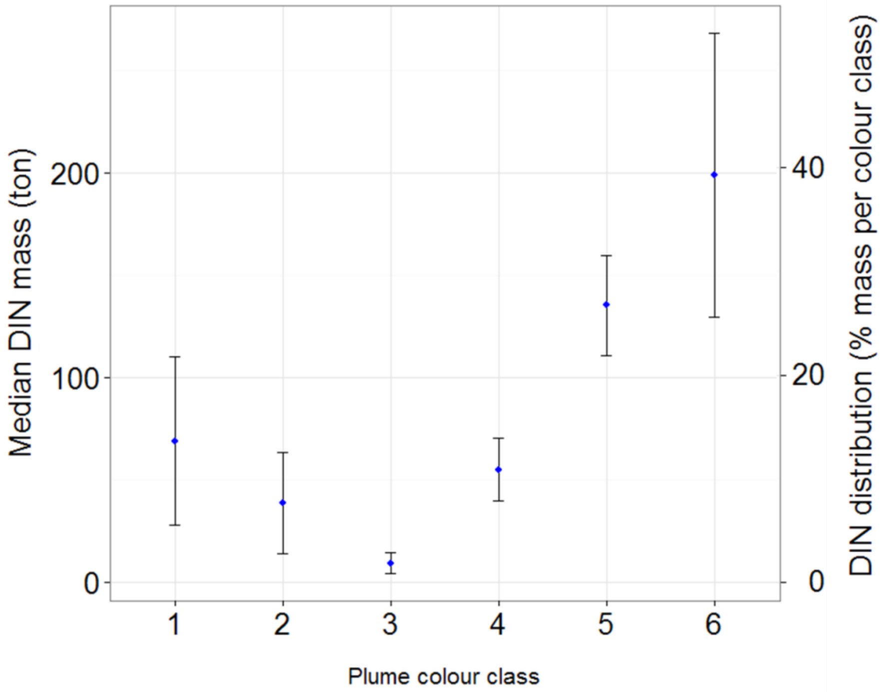

Figure D-9: Median DIN mass and percent contribution across the six-colour class. Error bars represent 95%CI (see text for explanation).

Therefore, the values of 1 to 6 in the ocean colour plumes (raster file) are converted into DIN mass, as per Figure D-9: The 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 GBR 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.

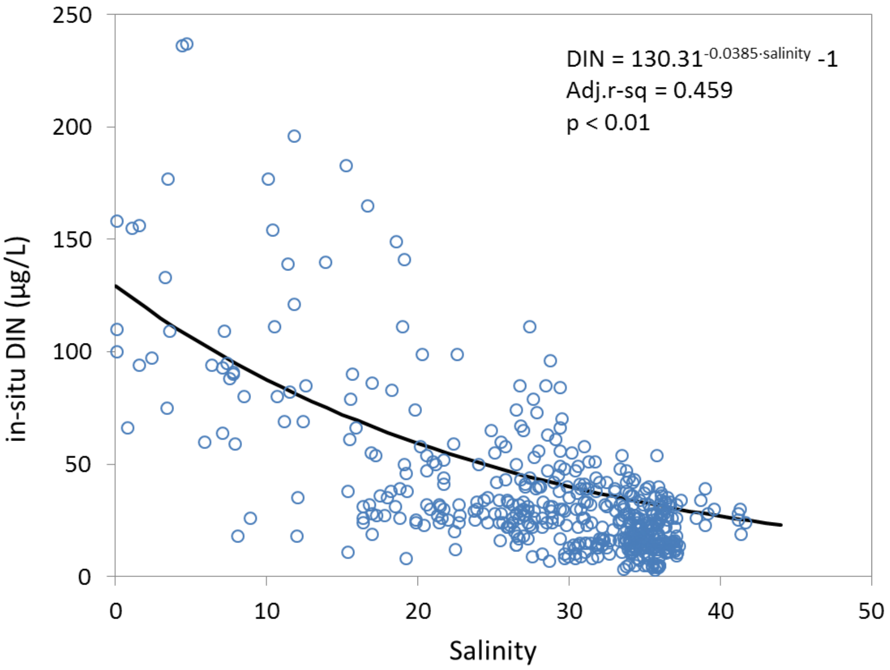

Figure D-10: Relationship between *in-situ* DIN concentration (µg/L) and salinity opportunistically measured at the surface in river plume waters over the GBR lagoon (2002–2003 to 2014–2015 wet season) under river discharge > 75th percentile (see text for explanation).

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: DIN_m) and at the river mouth (salinity 0 ppt: 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 ppt) 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 over the GBR as a multiplicative coefficient, ca *1 - Potential DIN uptake*.

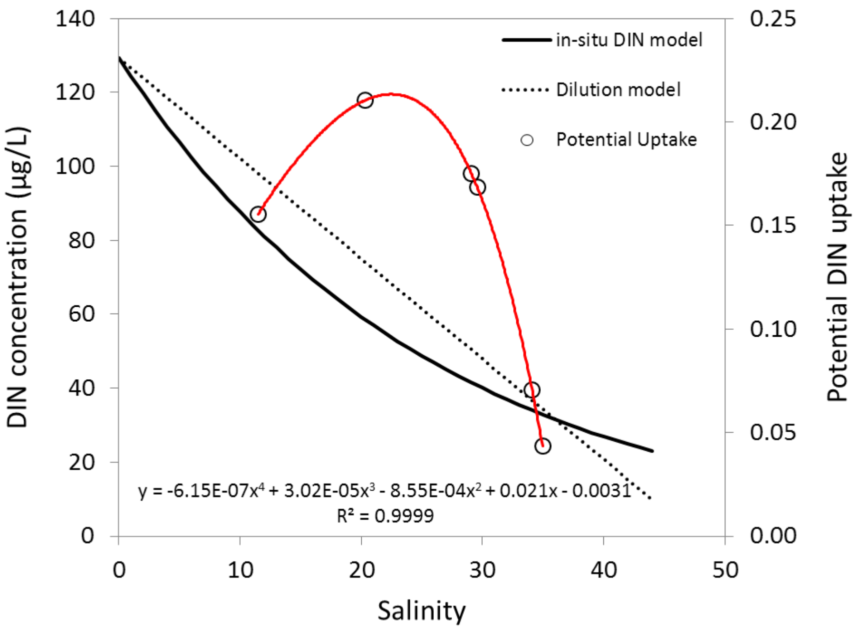

Figure D-11: Potential DIN uptake (red line) derived from the ratio between *in-situ* DIN concentration x salinity (black solid line, as in Figure D-11) and the theoretical dilution model (black dashed line, derived from Eq. 4).

(d) Mapping of DIN concentration over the GBR 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 along the GBR. 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 GBR 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 GBR 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 GBR (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 GBR waters.

Table D-4: End-of-catchment DIN loads (t/year) from 2003 to 2016 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**
Jacky Jacky Creek	69	127	116	354	76	79	76	184	237	91	99	190	75	32	119
Olive Pascoe River	87	159	144	443	95	99	95	230	296	114	124	237	94	39	149
Lockhart River	55	101	91	280	60	63	60	146	187	72	79	150	59	25	94
Stewart River	22	68	29	141	50	29	33	55	109	31	26	66	15	16	34
Normanby River	18	492	67	489	216	411	266	386	648	112	227	399	170	180	199
Jeannie River	1	61	12	89	22	47	29	64	75	28	19	50	38	42	87
Endeavour River	1	75	15	109	26	58	35	79	92	34	23	61	47	51	57
Daintree River	20	221	75	193	120	150	120	232	361	220	153	470	170	149	177
Mossman River	82	182	119	204	118	108	77	99	111	85	66	106	32	69	64
Barron River	6	48	19	38	21	79	38	24	92	37	14	29	17	12	19
Russell-Mulgrave	280	970	434	760	597	707	549	534	1,199	822	437	711	443	242	291
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
Tully River	165	393	264	441	471	361	413	328	710	434	341	432	211	333	598
Murray River	124	293	197	329	352	270	308	245	530	324	255	323	158	273	199
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
Black River	8	35	21	41	107	139	230	115	267	140	35	79	3	24	7
Ross River	5	39	15	29	93	110	159	100	167	106	22	94	0	2	1
Haughton River	87	190	264	312	610	776	1,210	524	1,030	749	209	235	42	114	144
Burdekin River	477	353	1,312	350	1,296	2,006	1,798	1,303	2,600	1,200	800	130	150	280	580
Don River	22	31	58	27	108	287	171	99	560	143	103	58	31	18	164
Proserpine River	49	64	152	168	394	930	503	483	880	317	310	304	46	76	404
O'Connell River	52	54	170	201	411	573	427	732	1,312	622	236	199	42	68	363
Pioneer River	22	5	43	16	226	347	230	363	836	361	268	146	30	140	450
Plane Creek	112	24	167	15	391	854	443	878	1,441	855	584	221	71	250	784
Styx River	83	30	6	3	1	54	24	89	171	59	266	48	82	25	51
Shoalwater Creek	95	35	7	3	1	61	27	101	194	67	303	55	93	29	58
Water Park Creek	55	7	24	13	29	140	55	160	272	83	290	163	113	103	152
Fitzroy River	674	382	363	135	176	1,580	367	2,060	3,900	950	920	150	470	680	910
Calliope River	98	36	7	3	1	63	28	104	200	69	312	57	96	30	81
Boyne River	24	9	1	1	0	19	5	31	53	26	29	4	10	4	21
Baffle Creek	112	41	7	6	1	91	23	149	256	124	142	19	50	18	58
Kolan River	100	15	0	0	0	31	1	87	234	92	243	14	64	33	44
Burrum River	37	70	6	12	2	17	10	19	34	35	27	19	45	100	107
Burnett River	114	49	30	15	7	4	5	225	1,884	129	1,516	44	171	76	137
Mary River	167	153	61	56	87	300	209	378	1,221	608	1,072	83	231	67	82

Table D-5: Total wet season river discharge (ML) from 2003 to 2016 water years (from October 2002 to September 2017).

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
Jacky Jacky Creek	1,387,023	2,541,227	2,311,225	7,081,701	1,523,413	1,587,651	1,527,240	3,683,267	4,735,197	1,820,422	1,986,825	3,790,832	1,498,138	630,787	2,383,057
Olive Pascoe River	1,733,779	3,176,534	2,889,031	8,852,126	1,904,267	1,984,563	1,909,050	4,604,083	5,918,996	2,275,527	2,483,531	4,738,541	1,872,672	788,484	2,978,821
Lockhart River	1,098,060	2,011,805	1,829,720	5,606,347	1,206,036	1,256,890	1,209,065	2,915,920	3,748,697	1,441,167	1,572,903	3,001,076	1,186,026	499,373	1,886,587
Stewart River	449,620	1,359,261	589,205	2,820,925	1,002,841	576,106	655,502	1,093,462	2,180,850	616,070	523,353	1,311,775	298,816	311,901	685,263
Normanby River	153,135	9,649,679	1,131,307	9,572,119	4,117,333	8,028,853	5,128,931	7,526,667	12,758,816	2,049,656	4,337,847	7,785,509	3,200,982	3,407,359	3,780,651
Jeannie River	11,330	1,223,719	249,916	1,786,090	430,938	946,246	582,148	1,289,182	1,505,627	558,727	370,539	996,700	764,560	842,681	1,746,929
Endeavour River	13,818	1,492,340	304,776	2,178,159	525,534	1,153,959	709,936	1,572,174	1,836,131	681,375	451,877	1,215,488	932,391	1,027,660	1,135,504
Daintree River	318,095	3,438,846	1,178,834	3,014,833	1,720,850	2,102,458	1,542,348	2,926,666	3,946,553	2,403,043	1,673,100	5,138,200	1,854,603	1,627,636	1,931,878
Mossman River	737,652	1,568,165	1,036,555	1,769,793	1,138,429	1,261,422	997,653	1,541,396	1,937,769	1,485,942	1,160,305	1,860,659	564,018	1,216,558	1,142,698
Barron River	124,804	1,043,517	421,095	819,015	453,916	1,764,706	848,609	549,357	2,116,333	850,666	327,714	662,880	380,321	182,700	287,790
Russell-Mulgrave	1,601,311	5,442,839	2,529,841	4,502,355	3,549,473	4,655,023	3,551,126	3,714,999	7,498,666	5,137,518	2,733,778	4,447,386	2,767,706	1,514,627	3,015,734
Johnstone River	1,812,122	2,508,367	3,155,228	5,898,095	5,153,857	4,619,246	6,025,819	4,235,139	9,370,837	5,475,276	3,420,023	5,040,240	2,406,113	3,531,069	4,017,617
Tully River	1,730,453	3,940,728	2,640,847	4,349,147	4,738,947	3,834,178	4,308,192	3,581,372	7,442,768	3,425,096	3,341,887	4,322,496	2,659,775	2,942,770	3,098,701
Murray River	264,003	1,239,487	423,481	1,770,631	1,353,402	1,271,771	1,893,451	961,533	4,267,125	2,062,103	1,006,286	1,531,172	366,212	974,244	947,985
Herbert River	789,567	3,787,241	1,539,837	4,577,377	4,571,896	3,828,527	10,771,362	3,627,443	13,132,558	4,781,507	3,334,467	4,480,455	1,116,610	1,976,635	2,248,436
Black River	72,784	317,714	194,155	375,454	974,687	1,264,706	2,093,840	1,045,240	2,431,703	1,275,927	321,774	715,861	30,141	221,581	64,873
Ross River	67,536	481,735	186,633	368,090	1,158,781	1,380,736	1,985,663	1,248,524	2,092,684	1,324,707	276,584	1,177,255	3,229	23,741	11,867
Haughton River	183,955	393,404	565,909	654,617	1,334,351	1,838,469	2,540,549	1,139,341	2,395,672	1,741,085	486,268	545,739	98,003	265,758	338,245
Burdekin River	2,096,476	1,518,832	4,275,406	2,203,510	9,785,645	27,550,436	29,403,288	7,800,795	34,894,227	15,543,509	3,399,760	1,440,976	827,223	1,810,248	4,165,129
Don River	161,646	201,956	360,394	152,351	610,112	1,707,903	907,810	534,581	3,136,184	802,738	578,391	324,120	171,305	101,562	920,610
Proserpine River	205,759	266,342	632,572	701,708	1,643,247	3,876,001	2,096,676	2,012,078	3,665,811	1,321,608	1,289,762	1,268,222	192,200	316,648	1,683,894
O'Connell River	216,260	223,120	707,247	835,484	1,713,083	2,388,072	1,779,341	3,049,315	5,468,241	2,590,858	982,905	830,888	176,263	284,171	1,511,187
Pioneer River	90,527	20,194	178,699	67,040	940,748	1,445,928	956,405	1,511,171	3,482,259	1,503,686	1,115,412	609,388	126,367	597,117	1,388,687
Plane Creek	371,955	78,736	557,278	49,269	1,304,018	2,848,322	1,476,538	2,927,662	4,802,051	2,849,950	1,946,017	737,019	238,199	832,508	2,613,261
Styx River	833,952	304,835	63,737	28,139	7,981	537,429	235,078	887,953	1,705,937	589,729	2,658,413	484,113	818,599	253,404	507,927
Shoalwater Creek	948,980	346,881	72,529	32,020	9,082	611,557	267,503	1,010,429	1,941,239	671,071	3,025,091	550,887	931,509	288,356	577,985
Water Park Creek	549,481	68,589	241,729	127,047	294,909	1,397,756	550,135	1,595,833	2,718,432	825,657	2,904,319	1,632,466	1,128,027	1,031,630	1,523,780
Fitzroy River	1,710,000	970,000	930,000	700,000	830,000	12,063,000	2,192,993	11,666,996	38,537,012	7,993,273	8,530,440	1,576,378	2,673,890	3,589,342	6,170,044
Calliope River	488,868	178,696	37,363	16,495	4,679	315,044	137,805	520,524	1,000,032	345,703	1,558,380	283,790	479,868	148,547	406,321
Boyne River	121,397	42,710	7,018	5,788	747	93,962	23,585	154,456	264,317	128,589	147,039	19,951	51,439	18,617	102,775
Baffle Creek	1,600,236	589,801	96,913	79,923	10,310	1,297,575	325,702	2,132,966	3,650,093	1,775,749	2,030,545	275,517	710,352	257,093	829,460
Kolan River	332,442	50,429	434	23	0	102,198	4,090	289,107	779,168	307,837	810,411	45,304	213,857	111,172	146,154
Burrum River	568,581	243,401	150,670	76,457	32,868	18,369	27,012	1,125,102	9,421,517	643,137	7,581,543	218,087	853,349	381,054	536,242
Burnett River	122,721	233,064	21,034	40,309	6,942	55,997	32,348	62,897	114,492	117,762	90,921	62,188	150,113	334,681	456,549
Mary River	1,193,617	1,095,811	433,746	402,045	621,459	2,146,131	1,493,129	2,696,672	8,719,106	4,340,275	7,654,320	594,612	1,651,901	480,854	582,510

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: .

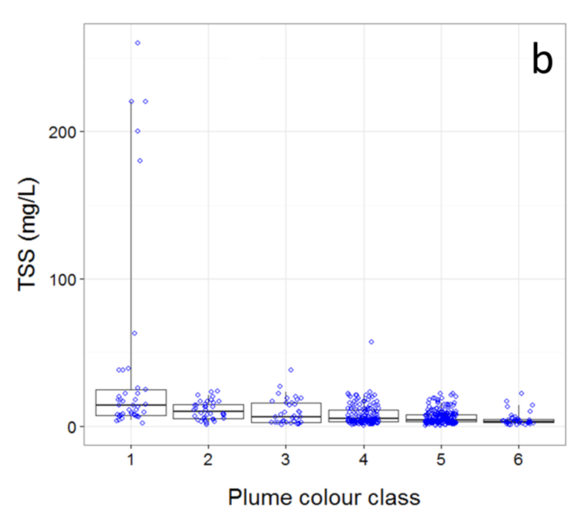

Figure D-12: *In-situ* TSS per colour class, measured over 13 wet seasons (c.a., December to April inclusive) from 2002/03 to 2014/15 wet season. Boxplot presents the median (dark black line), 25th and 75th percentile values (rectangle) and 5th and 95th percentile values (vertical lines). Nudge was applied 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 GBR 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 along the GBR 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
Jacky Jacky Creek	28	51	46	142	30	32	31	74	95	36	40	76	30	13	48
Olive Pascoe River	35	64	58	177	38	40	38	92	118	46	50	95	37	16	60
Lockhart River	22	40	37	112	24	25	24	58	75	29	31	60	24	10	38
Stewart River	9	27	12	56	20	12	13	22	44	12	10	26	6	6	14
Normanby River	8	482	57	479	206	401	256	376	638	102	217	389	160	170	189
Jeannie River	0	24	5	36	9	19	12	26	30	11	7	20	15	17	35
Endeavour River	1	75	15	109	26	58	35	79	92	34	23	61	47	51	57
Daintree River	16	172	59	151	86	105	77	146	197	120	84	257	93	81	97
Mossman River	37	78	52	88	57	63	50	77	97	74	58	93	28	61	57
Barron River	25	209	84	164	91	353	170	110	423	170	66	133	76	37	58
Russell-Mulgrave	48	163	76	135	106	140	107	111	225	154	82	133	83	45	90
Johnstone River	181	251	316	590	515	462	603	424	937	548	342	504	241	353	402
Tully River	52	118	79	130	142	115	129	107	223	103	100	130	80	88	93
Murray River	13	62	21	89	68	64	95	48	213	103	50	77	18	49	47
Herbert River	79	379	154	458	457	383	1,077	363	1,313	478	333	448	112	198	225
Black River	15	64	39	75	195	253	419	209	486	255	64	143	6	44	13
Ross River	7	48	19	37	116	138	199	125	209	132	28	118	0	2	1
Haughton River	28	59	85	98	200	276	381	171	359	261	73	82	15	272	51
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
Don River	40	50	90	38	153	427	227	134	784	201	145	81	43	25	230
Proserpine River	10	13	32	35	82	194	105	101	183	66	64	63	10	16	84
O'Connell River	39	40	127	150	308	430	320	549	984	466	177	150	32	51	272
Pioneer River	16	4	32	12	156	255	112	374	820	210	130	35	4	44	110
Plane Creek	37	8	56	5	130	285	148	293	480	285	195	74	24	83	261
Styx River	108	40	8	4	1	70	31	115	222	77	346	63	106	33	66
Shoalwater Creek	57	21	4	2	1	37	16	61	116	40	182	33	56	17	35
Water Park Creek	33	4	15	8	18	84	33	96	163	50	174	98	68	62	91
Fitzroy River	1,800	600	250	140	425	4,530	404	3,564	7,000	1,300	2,500	52	900	670	2,200
Calliope River	88	32	7	3	1	57	25	94	180	62	281	51	86	27	73
Boyne River	8	3	0	0	0	7	2	11	19	9	10	1	4	1	7
Baffle Creek	256	94	16	13	2	208	52	341	584	284	325	44	114	41	133
Kolan River	43	7	0	0	0	13	1	38	101	40	105	6	28	14	19
Burrum River	80	34	21	11	5	3	4	158	1,319	90	1,061	31	119	53	75
Burnett River	12	23	2	4	1	6	3	6	11	12	9	6	15	33	46
Mary River	286	263	104	96	149	515	358	647	2,093	1,042	1,837	143	396	115	140

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 GBR waters up to a salinity of 20–25 ppt commonly displays conservative mixing behaviour (i.e., dilution) (Devlin and Brodie, 2005). However, salinity in colour class 2 is 21.0 ± 9.9 ppt 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 run-off is the largest source of new nutrients to the inshore GBR, especially during monsoonal flood events (Furnas et al., 2011). Moreover, upwelling intrusions are spatially restricted to the Central GBR 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-8: a), 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-8: d). 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 GBR 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 GBR 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.

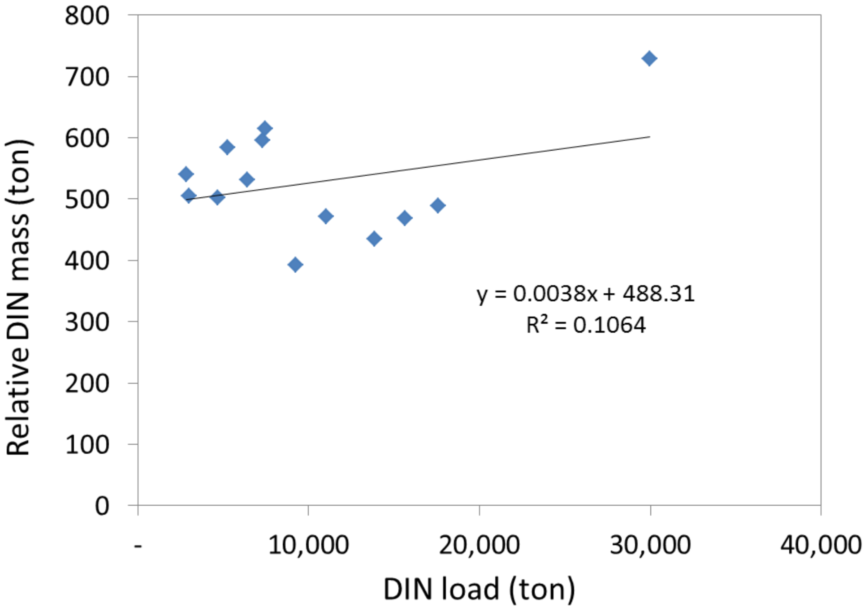

Figure D-13: Relationship between DIN load (tonnes) against the relative DIN mass (tonnes) in plume waters (see text for explanation).

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 GBR 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 mg/L to 140 mg/L 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).

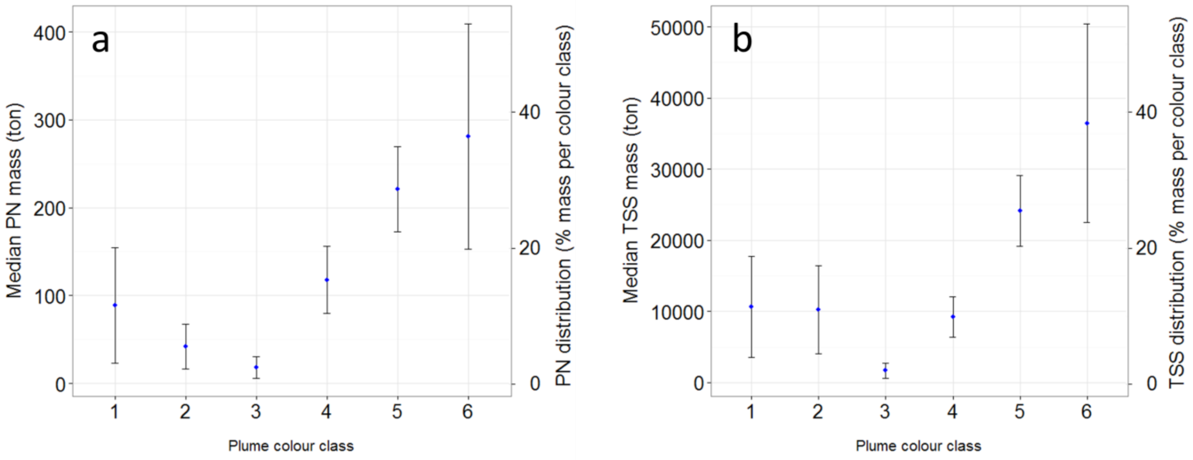

Figure D-14: Median mass of particulate nitrogen (a) and TSS (b), and percent contribution across the six-colour class. Error bars stand for 95%CI (see text for explanation).

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 ppt 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 ppt. 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 GBR 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-10 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 GBR 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 GBR 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 GBR. 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 2014 until 31 March 2015 of the following year. River-tagged passive tracers were released from each of the major gauged rivers between discharging in to the GBR. The influence of the Baron, Russell-Mulgrave, Tully, Burdekin and O'Connell 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 GBR 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,

$$\text{Conc}_{exceedance} = \begin{cases} \text{Conc(t) - Conc}_{threshold}, \text{ where Conc(t)} > \text{Conc}_{threshold} \\ 0, \quad \text{where Conc(t)} \leq \text{Conc}_{threshold} \end{cases}$$

and $Conc_{threshold}$ 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 GBR 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

Table E-1: Relative annual freshwater discharge (fraction of long-term median) for the major GBR catchment rivers influencing the sampling sites of the MMP Inshore Water Quality Monitoring Program. Shaded cells highlight years for which river flow exceeded the median annual flow 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 2017 water year are incomplete (to August 2017). Discharge data were supplied by the Queensland Department of Natural Resources and Mines (gauging station codes given after river names). *** Indicates years for which >15% of daily flow estimates were not available, ** similarly indicate 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, whereas an * indicates that between 5% and 15% of daily observations were missing.

Region	River	Median discharge (ML)	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
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
	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
	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
	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	0.9
	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
	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
	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
	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
	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
	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
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
	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	0.9
	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	2.7
	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
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
	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
	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
	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
	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
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
	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

Table E-2: Water quality results for Cape York sampling sites within the Enclosed Coastal, Open Coastal and Mid-shelf zones, compared against the Draft Eastern Cape York Water Quality Guidelines for each zone. The tables present wet season sampling results (Endeavour Basin, Normanby Basin, Stewart River and Pascoe River transects), dry season (Pascoe transect only) and wet and dry season combined (Pascoe transect only). Guidelines vary for each zone and sub-region based on available data: baseflow (wet and dry season) guidelines have been designated for Endeavour and Normanby Basin Enclosed Coastal zones, Open Coastal zone guidelines (all sub-regions) include wet season and dry season guidelines except for NH3 and Secchi depth (annual), and the Mid-Shelf guidelines (all sub-regions) are based on annual (wet and dry season) concentrations. Stewart & Pascoe enclosed coastal zone results are compared with Endeavour River HEV Water Quality Guidelines due to lack of guidelines for these sub-regions.

WET SEASON 2016-17																
								Quantiles				Guidelines				
Region/ Water Body	Site	Measure	N	Min	Max	Mean	Median	Q5	Q20	Q80	Q95	DirectionOf Failure	Statistic	Base Flow/ Annual	Dry	Wet
Cape York Enclosed Coastal Zone	Endeavour Basin	DIN (μgL^{-1})	12	2.05	35.05	11.70	8.08	3.12	4.25	19.01	27.87					
		NH_3 (μgL^{-1})	12	1.00	12.00	4.92	4.50	1.55	2.20	6.80	9.80		20th-50th-80th	1-4-10		
		DON (μgL^{-1})	12	62.95	200.00	102.63	97.95	64.05	74.15	120.19	160.40					
		DOP (μgL^{-1})	12	0.00	7.00	2.00	1.50	0.55	1.00	2.00	5.35					
		Chla (μgL^{-1})	12	0.24	1.17	0.64	0.67	0.25	0.26	0.91	1.14		20th-50th-80th	0.5-1.0-1.5		
		NOx (μgL^{-1})	12	0.10	31.05	6.79	2.03	0.62	1.05	9.84	22.22		20th-50th-80th	1-2-10		
		PN (μgL^{-1})	12	0.00	64.00	22.83	15.00	1.65	4.80	44.80	62.35					
		FRP (μgL^{-1})	12	1.00	4.00	2.58	2.00	1.55	2.00	3.80	4.00		20th-50th-80th	1-1-3		
		PP (μgL^{-1})	12	0.00	5.00	1.92	2.00	0.00	1.00	3.00	3.90					
		Secchi (m)	8	2.60	10.00	5.45	4.60	2.60	3.00	8.24	10.00					
		TSS (mgL^{-1})	12	2.00	11.00	4.64	3.85	2.28	2.80	5.30	10.07					
	Normanby Basin	DIN (μgL^{-1})	8	0.15	34.05	14.41	7.03	1.85	5.02	29.20	33.33					
		NH_3 (μgL^{-1})	8	0.05	29.00	9.51	4.50	0.38	1.00	18.00	25.15		20th-50th-80th (IMP)	2-8-14		
		DON (μgL^{-1})	8	80.00	297.00	156.59	129.40	84.18	98.37	211.18	270.75					
		DOP (μgL^{-1})	8	1.00	5.00	3.25	4.00	1.35	2.00	4.00	4.65					
		Chla (μgL^{-1})	8	0.85	1.95	1.28	1.17	0.85	0.95	1.64	1.94		Median IMP	1.9		
		NOx (μgL^{-1})	8	0.10	14.00	4.91	4.50	0.43	1.85	6.22	11.55		20th-50th-80th (IMP)	5-13-23		
		PN (μgL^{-1})	8	1.00	51.00	26.25	23.50	6.95	18.80	37.80	48.20					
		FRP (μgL^{-1})	8	2.00	8.00	4.13	3.50	2.00	2.00	6.40	8.00		20th-50th-80th (IMP)	1-1-3		
		PP (μgL^{-1})	8	1.00	27.00	8.75	6.00	1.00	1.40	13.80	22.80					

WET SEASON 2016-17																	
								Quantiles				Guidelines					
Region/ Water Body	Site	Measure	N	Min	Max	Mean	Median	Q5	Q20	Q80	Q95	DirectionOf Failure	Statistic	Base Flow/ Annual	Dry	Wet
Cape York Enclosed Coastal Zone		Secchi (m)	8	0.21	1.73	0.91	0.84	0.21	0.32	1.52	1.73					
		TSS (mgL^{-1})	8	6.50	40.00	17.08	14.80	6.71	8.02	22.20	34.05					
	Stewart River	DIN (µgL^{-1})	4	3.05	5.05	4.04	4.03	3.05	3.05	5.02	5.04					
		NH_3 (µgL^{-1})	4	1.00	2.00	1.50	1.50	1.00	1.00	2.00	2.00		20th-50th-80th	1-4-10		
		DON (µgL^{-1})	4	105.95	170.95	136.21	133.98	106.55	108.35	163.18	169.01					
		DOP (µgL^{-1})	4	3.00	4.00	3.50	3.50	3.00	3.00	4.00	4.00					
		Chla (µgL^{-1})	4	0.78	1.00	0.87	0.85	0.78	0.79	0.95	0.99		20th-50th-80th	0.5-1.0-1.5		
		NOx (µgL^{-1})	4	2.05	3.05	2.54	2.53	2.05	2.05	3.02	3.04		20th-50th-80th	1-2-10		
		PN (µgL^{-1})	4	8.00	34.00	21.00	21.00	9.80	15.20	26.80	32.20					
		FRP (µgL^{-1})	4	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00		20th-50th-80th	1-1-3		
		PP (µgL^{-1})	4	2.00	5.00	3.00	2.50	2.00	2.00	3.80	4.70					
		Secchi (m)	4	1.43	1.60	1.52	1.52	1.43	1.43	1.60	1.60					
		TSS (mgL^{-1})	4	4.90	6.00	5.33	5.20	4.92	4.96	5.64	5.91					
	Pascoe River	DIN (µgL^{-1})	4	8.00	14.05	9.76	8.50	8.00	8.00	11.02	13.29					
		NH_3 (µgL^{-1})	4	0.05	3.00	1.26	1.00	0.19	0.62	1.80	2.70		20th-50th-80th	1-4-10		
		DON (µgL^{-1})	4	79.00	98.95	90.99	93.00	81.10	87.40	95.38	98.06					
		DOP (µgL^{-1})	4	0.00	1.00	0.75	1.00	0.15	0.60	1.00	1.00					
		Chla (µgL^{-1})	4	0.23	1.21	0.70	0.67	0.29	0.46	0.92	1.14		20th-50th-80th	0.5-1.0-1.5		
		NOx (µgL^{-1})	4	6.00	14.00	8.50	7.00	6.15	6.60	9.80	12.95		20th-50th-80th	1-2-10		
		PN (µgL^{-1})	4	2.00	31.00	15.50	14.50	3.35	7.40	23.20	29.05					
		FRP (µgL^{-1})	4	2.00	4.00	3.00	3.00	2.15	2.60	3.40	3.85		20th-50th-80th	1-1-3		
		PP (µgL^{-1})	4	1.00	3.00	2.00	2.00	1.15	1.60	2.40	2.85					
		Secchi (m)	4	1.60	1.96	1.78	1.78	1.60	1.60	1.96	1.96					
		TSS (mgL^{-1})	4	3.80	8.20	5.10	4.20	3.83	3.92	5.92	7.63					

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								Quantiles				Guidelines				
Region/ Water Body	Site	Measure	N	Min	Max	Mean	Median	Q5	Q20	Q80	Q95	DirectionOf Failure	Statistic	Base Flow/ Annual	Dry	Wet
Cape York Open Coastal Zone	Endeavour Basin	DIN (µgL^{-1})	24	2.05	13.05	5.97	6.03	3.24	4.08	7.05	10.70					
		NH_3 (µgL^{-1})	24	0.05	7.00	3.50	4.00	0.19	2.00	5.00	5.85		Annual 20th-50th-80th	0-1-3		
		DON (µgL^{-1})	24	68.95	158.00	89.49	85.45	71.69	78.58	95.35	105.46					
		DOP (µgL^{-1})	24	0.00	6.00	1.83	1.00	0.00	1.00	3.40	4.00					
		Chla (µgL^{-1})	24	0.10	1.05	0.41	0.36	0.10	0.24	0.55	0.81		20th-50th-80th			0.30-0.46-0.78
		NOx (µgL^{-1})	24	0.10	8.00	2.46	2.05	0.10	1.05	3.45	6.89		20th-50th-80th			0-0-1
		PN (µgL^{-1})	24	0.00	49.00	12.21	9.50	1.00	2.00	19.60	26.55		20th-50th-80th			14-20-26
		FRP (µgL^{-1})	24	1.00	4.00	2.71	3.00	2.00	2.00	3.40	4.00		20th-50th-80th			0-1-2
		PP (µgL^{-1})	24	0.00	4.00	1.04	1.00	0.00	0.00	1.40	3.70		20th-50th-80th			2.2-3.0-3.9
		Secchi (m)	22	2.60	10.90	7.26	7.50	2.65	4.30	10.00	10.87		Annual Mean	≥10		
		TSS (mgL^{-1})	24	1.00	5.60	2.71	2.60	1.13	1.72	3.48	5.01		20th-50th-80th			1.1-1.7-2.2
	Normanby Basin	DIN (µgL^{-1})	6	4.05	7.05	5.20	5.03	4.29	5.00	5.05	6.55					
		NH_3 (µgL^{-1})	6	0.05	3.00	1.18	1.00	0.29	1.00	1.00	2.50		Annual 20th-50th-80th	0-1-3		
		DON (µgL^{-1})	6	70.95	81.95	76.47	75.98	72.20	75.95	78.00	80.96					
		DOP (µgL^{-1})	6	0.00	4.00	2.33	2.50	0.25	1.00	4.00	4.00					
		Chla (µgL^{-1})	6	0.30	0.78	0.53	0.51	0.34	0.44	0.62	0.74		20th-50th-80th			0.30-0.46-0.78
		NOx (µgL^{-1})	6	4.00	4.05	4.03	4.03	4.00	4.00	4.05	4.05		20th-50th-80th			0-0-1
		PN (µgL^{-1})	6	2.00	35.00	10.33	6.00	2.50	4.00	9.00	28.50		20th-50th-80th			14-20-26
		FRP (µgL^{-1})	6	2.00	5.00	3.33	3.50	2.00	2.00	4.00	4.75		20th-50th-80th			0-1-2
		PP (µgL^{-1})	6	2.00	8.00	4.83	4.50	2.25	3.00	7.00	7.75		20th-50th-80th			2.2-3.0-3.9
		Secchi (m)	6	2.19	3.20	2.70	2.70	2.19	2.19	3.20	3.20		Annual Mean	≥10		
		TSS (mgL^{-1})	6	1.30	14.00	5.47	4.30	1.88	3.60	5.30	11.83		20th-50th-80th			1.1-1.7-2.2
	Stewart River	DIN (µgL^{-1})	3	4.05	5.05	4.38	4.05	4.05	4.05	4.65	4.95					
		NH_3 (µgL^{-1})	3	1.00	2.00	1.33	1.00	1.00	1.00	1.60	1.90		Annual 20th-50th-80th	0-1-3		
		DON (µgL^{-1})	3	81.95	121.95	96.62	85.95	82.35	83.55	107.55	118.35					

WET SEASON 2016-17

								Quantiles				Guidelines				
Region/ Water Body	Site	Measure	N	Min	Max	Mean	Median	Q5	Q20	Q80	Q95	DirectionOf Failure	Statistic	Base Flow/ Annual	Dry	Wet
Cape York Open Coastal Zone		DOP (µgL^{-1})	3	2.00	5.00	3.67	4.00	2.20	2.80	4.60	4.90					
		Chla (µgL^{-1})	3	0.29	0.67	0.43	0.33	0.29	0.31	0.53	0.64		20th-50th-80th			0.30-0.46-0.78
		NOx (µgL^{-1})	3	2.05	4.05	3.05	3.05	2.15	2.45	3.65	3.95		20th-50th-80th			0-0-1
		PN (µgL^{-1})	3	0.00	28.00	11.33	6.00	0.60	2.40	19.20	25.80		20th-50th-80th			14-20-26
		FRP (µgL^{-1})	3	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00		20th-50th-80th			0-1-2
		PP (µgL^{-1})	3	1.00	2.00	1.67	2.00	1.10	1.40	2.00	2.00		20th-50th-80th			2.2-3.0-3.9
		Secchi (m)	2	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60		Annual Mean	≥10		
		TSS (mgL^{-1})	3	2.10	3.90	3.07	3.20	2.21	2.54	3.62	3.83		20th-50th-80th			1.1-1.7-2.2
	Pascoe River	DIN (µgL^{-1})	4	6.00	7.00	6.51	6.53	6.01	6.03	7.00	7.00					
		NH$_3$ (µgL^{-1})	4	0.05	1.00	0.76	1.00	0.19	0.62	1.00	1.00		Annual 20th-50th-80th	0-1-3		
		DON (µgL^{-1})	4	78.00	100.00	83.74	78.48	78.00	78.00	87.37	96.84					
		DOP (µgL^{-1})	4	1.00	3.00	1.75	1.50	1.00	1.00	2.40	2.85					
		Chla (µgL^{-1})	4	0.33	0.75	0.49	0.43	0.34	0.38	0.57	0.71		20th-50th-80th			0.30-0.46-0.78
		NOx (µgL^{-1})	4	5.00	6.00	5.75	6.00	5.15	5.60	6.00	6.00		20th-50th-80th			0-0-1
		PN (µgL^{-1})	4	2.00	11.00	6.75	7.00	2.30	3.20	10.40	10.85		20th-50th-80th			14-20-26
		FRP (µgL^{-1})	4	2.00	4.00	2.75	2.50	2.00	2.00	3.40	3.85		20th-50th-80th			0-1-2
		PP (µgL^{-1})	4	0.00	1.00	0.75	1.00	0.15	0.60	1.00	1.00		20th-50th-80th			2.2-3.0-3.9
		Secchi (m)	4	2.50	7.80	5.15	5.15	2.50	2.50	7.80	7.80		Annual Mean	≥10		
		TSS (mgL^{-1})	4	2.60	2.90	2.75	2.75	2.62	2.66	2.84	2.89		20th-50th-80th			1.1-1.7-2.2
Cape York Mid Shelf Zone	Endeavour Basin	DIN (µgL^{-1})	8	3.10	14.00	6.79	5.05	3.77	5.00	8.85	12.62					
		NH$_3$ (µgL^{-1})	8	1.00	7.00	3.63	3.50	1.35	2.40	4.60	6.30		20th-50th-80th	0-1-3		
		DON (µgL^{-1})	8	51.00	106.90	80.34	76.98	56.60	70.58	94.15	102.72					
		DOP (µgL^{-1})	8	0.00	4.00	1.38	0.50	0.00	0.00	3.00	3.65					

WET SEASON 2016-17

								Quantiles				Guidelines				
Region/ Water Body	Site	Measure	N	Min	Max	Mean	Median	Q5	Q20	Q80	Q95	DirectionOf Failure	Statistic	Base Flow/ Annual	Dry	Wet
Cape York Mid Shelf Zone		Chla (µgL^{-1})	8	0.10	0.43	0.25	0.28	0.10	0.10	0.35	0.41		20th-50th-80th	0.18-0.27-0.45		
		NOx (µgL^{-1})	8	0.10	12.00	3.16	2.03	0.43	1.05	3.62	9.20		20th-50th-80th	0-0-1		
		PN (µgL^{-1})	8	4.00	36.00	14.25	10.00	5.05	7.40	19.80	30.75		20th-50th-80th	14-18-22		
		FRP (µgL^{-1})	8	1.00	4.00	3.25	3.50	1.70	3.00	4.00	4.00		20th-50th-80th	0-1-2		
		PP (µgL^{-1})	8	0.00	1.00	0.25	0.00	0.00	0.00	0.60	1.00		20th-50th-80th	1.5-2.0-2.8		
		Secchi (m)	6	7.60	19.40	13.60	13.70	7.60	7.60	18.60	19.40		Mean	≥10		
		TSS (mgL^{-1})	8	1.30	4.50	2.11	1.85	1.30	1.38	2.30	3.73		20th-50th-80th	0.9-1.5-2.3		
	Normanby Basin	DIN (µgL^{-1})	2	2.10	3.05	2.58	2.58	2.15	2.29	2.86	3.00					
		NH_3 (µgL^{-1})	2	0.05	1.00	0.53	0.53	0.10	0.24	0.81	0.95		20th-50th-80th	0-1-3		
		DON (µgL^{-1})	2	79.95	88.90	84.43	84.43	80.40	81.74	87.11	88.45					
		DOP (µgL^{-1})	2	2.00	3.00	2.50	2.50	2.05	2.20	2.80	2.95					
		Chla (µgL^{-1})	2	0.24	0.36	0.30	0.30	0.25	0.26	0.34	0.35		20th-50th-80th	0.18-0.27-0.45		
		NOx (µgL^{-1})	2	2.05	2.05	2.05	2.05	2.05	2.05	2.05	2.05		20th-50th-80th	0-0-1		
		PN (µgL^{-1})	2	7.00	12.00	9.50	9.50	7.25	8.00	11.00	11.75		20th-50th-80th	14-18-22		
		FRP (µgL^{-1})	2	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00		20th-50th-80th	0-1-2		
		PP (µgL^{-1})	2	2.00	6.00	4.00	4.00	2.20	2.80	5.20	5.80		20th-50th-80th	1.5-2.0-2.8		
		Secchi (m)	2	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50		Mean	≥10		
		TSS (mgL^{-1})	2	2.10	2.50	2.30	2.30	2.12	2.18	2.42	2.48		20th-50th-80th	0.9-1.5-2.3		
	Stewart River	DIN (µgL^{-1})	2	3.05	4.10	3.58	3.58	3.10	3.26	3.89	4.05					
		NH_3 (µgL^{-1})	2	0.05	1.00	0.53	0.53	0.10	0.24	0.81	0.95		20th-50th-80th	0-1-3		
		DON (µgL^{-1})	2	78.95	84.90	81.93	81.93	79.25	80.14	83.71	84.60					
		DOP (µgL^{-1})	2	1.00	8.00	4.50	4.50	1.35	2.40	6.60	7.65					
		Chla (µgL^{-1})	2	0.35	0.39	0.37	0.37	0.35	0.36	0.38	0.39		20th-50th-80th	0.18-0.27-0.45		
		NOx (µgL^{-1})	2	2.05	4.05	3.05	3.05	2.15	2.45	3.65	3.95		20th-50th-80th	0-0-1		
		PN (µgL^{-1})	2	5.00	8.00	6.50	6.50	5.15	5.60	7.40	7.85		20th-50th-80th	14-18-22		

WET SEASON 2016-17

								Quantiles				Guidelines				
Region/ Water Body	Site	Measure	N	Min	Max	Mean	Median	Q5	Q20	Q80	Q95	DirectionOf Failure	Statistic	Base Flow/ Annual	Dry	Wet
Cape York Mid Shelf Zone		FRP (μgL^{-1})	2	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00		20th-50th-80th	0-1-2		
		PP (μgL^{-1})	2	0.00	3.00	1.50	1.50	0.15	0.60	2.40	2.85		20th-50th-80th	1.5-2.0-2.8		
		Secchi (m)	0										Mean	≥10		
		TSS (mgL⁻¹)	2	2.2	3.6	2.9	2.9	2.27	2.48	3.32	3.53		20th-50th-80th	0.9-1.5-2.3		
	Pascoe River Not compared against guidelines	DIN (μgL^{-1})	10	6.05	9.00	7.36	7.03	6.29	7.00	8.05	8.76					
		NH_3 (μgL^{-1})	10	0.05	1.00	0.53	0.53	0.05	0.05	1.00	1.00		20th-50th-80th	0-1-3		
		DON (μgL^{-1})	10	72.00	83.95	79.64	82.50	72.24	72.95	83.95	83.95					
		DOP (μgL^{-1})	10	0.00	4.00	1.67	1.50	0.25	1.00	2.00	3.50					
		Chla (μgL^{-1})	10	0.23	1.01	0.60	0.62	0.28	0.42	0.69	0.93		20th-50th-80th	0.18-0.27-0.45		
		NOx (μgL^{-1})	10	6.00	8.00	6.83	6.50	6.00	6.00	8.00	8.00		20th-50th-80th	0-0-1		
		PN (μgL^{-1})	10	1.00	12.00	6.33	6.50	1.50	3.00	9.00	11.25		20th-50th-80th	14-18-22		
		FRP (μgL^{-1})	10	2.00	3.00	2.33	2.00	2.00	2.00	3.00	3.00		20th-50th-80th	0-1-2		
		PP (μgL^{-1})	10	0.00	2.00	1.00	1.00	0.00	0.00	2.00	2.00		20th-50th-80th	1.5-2.0-2.8		
		Secchi (m)	10	4.90	7.80	6.43	6.60	4.90	4.90	7.80	7.80		Mean	≥10		
		TSS (mgL⁻¹)	10	1.70	2.50	2.05	2.05	1.73	1.80	2.20	2.43		20th-50th-80th	0.9-1.5-2.3		

DRY SEASON 2016-17

								Quantiles				Guidelines				
Region/ Water Body	Site	Measure	N	Min	Max	Mean	Median	Q5	Q20	Q80	Q95	DirectionOf Failure	Location	Base Flow/ Annual	Dry	Wet
Cape York Enclosed Coastal Zone	Pascoe River	DIN (μgL^{-1})	4	3.05	12.05	8.55	9.55	3.95	6.65	10.85	11.75					
		NH_3 (μgL^{-1})	4	2.00	8.00	5.00	5.00	2.30	3.20	6.80	7.70		20th-50th-80th	1-4-10		
		DON (μgL^{-1})	4	94.95	108.95	101.70	101.45	95.70	97.95	105.35	108.05					
		DOP (μgL^{-1})	4	0.00	3.00	1.25	1.00	0.15	0.60	1.80	2.70					
		Chla (μgL^{-1})	4	0.33	0.52	0.44	0.46	0.35	0.41	0.48	0.51		20th-50th-80th	0.5-1.0-1.5		
		NOx (μgL^{-1})	4	1.05	6.05	3.55	3.55	1.20	1.65	5.45	5.90		20th-50th-80th	1-2-10		

DRY SEASON 2016-17																
								Quantiles				Guidelines				
Region/ Water Body	Site	Measure	N	Min	Max	Mean	Median	Q5	Q20	Q80	Q95	DirectionOf Failure	Location	Base Flow/ Annual	Dry	Wet
		PN (µgL^{-1})	4	1.00	20.00	6.25	2.00	1.00	1.00	9.80	17.45					
		FRP (µgL^{-1})	4	2.00	3.00	2.25	2.00	2.00	2.00	2.40	2.85		20th-50th-80th	1-1-3		
		PP (µgL^{-1})	4	1.00	2.00	1.50	1.50	1.00	1.00	2.00	2.00					
		Secchi (m)	4	1.90	3.70	2.80	2.80	1.90	1.90	3.70	3.70					
		TSS (mgL^{-1})	4	3.00	4.00	3.38	3.25	3.03	3.12	3.58	3.90					
Cape York Open Coastal Zone	Pascoe River	DIN (µgL^{-1})	4	4.05	10.05	6.81	6.58	4.21	4.68	8.85	9.75					
		NH_3 (µgL^{-1})	4	2.00	5.00	3.50	3.50	2.15	2.60	4.40	4.85		20th-50th-80th annual	0-1-3		
		DON (µgL^{-1})	4	71.95	105.95	89.19	89.43	73.75	79.15	99.32	104.29					
		DOP (µgL^{-1})	4	2.00	4.00	2.75	2.50	2.00	2.00	3.40	3.85					
		Chla (µgL^{-1})	4	0.29	1.30	0.57	0.34	0.29	0.29	0.75	1.16		20th-50th-80th		0.16-0.25-0.46	
		NOx (µgL^{-1})	4	0.10	6.05	3.31	3.55	0.39	1.27	5.45	5.90		20th-50th-80th		0-0-1	
		PN (µgL^{-1})	4	2.00	25.00	11.00	8.50	2.30	3.20	17.80	23.20		Mean		≤ 16	
		FRP (µgL^{-1})	4	2.00	5.00	2.75	2.00	2.00	2.00	3.20	4.55		20th-50th-80th		0-2-3	
		PP (µgL^{-1})	4	0.00	1.00	0.25	0.00	0.00	0.00	0.40	0.85		Mean		≤ 2.3	
		Secchi (m)	4	3.25	7.00	5.13	5.13	3.25	3.25	7.00	7.00		Annual Mean	≥ 10		
		TSS (mgL^{-1})	4	2.40	3.60	2.98	2.95	2.43	2.52	3.42	3.56		Mean		≤ 1.6	
Cape York Mid Shelf Zone	Pascoe River	DIN (µgL^{-1})	4	4.05	59.05	18.58	5.60	4.06	4.08	27.88	51.26			0-1-3		
		NH_3 (µgL^{-1})	4	3.00	58.00	18.00	5.50	3.15	3.60	27.40	50.35					
		DON (µgL^{-1})	4	55.95	93.90	78.43	81.93	58.79	67.32	90.93	93.16					
		DOP (µgL^{-1})	4	0.00	6.00	3.25	3.50	0.45	1.80	4.80	5.70			0.18-0.27-0.45		
		Chla (µgL^{-1})	4	0.29	0.49	0.39	0.39	0.30	0.33	0.45	0.48			0-0-1		
		NOx (µgL^{-1})	4	0.10	1.05	0.58	0.58	0.10	0.10	1.05	1.05			14-18-22		
		PN (µgL^{-1})	4	2.00	14.00	7.50	7.00	2.00	2.00	12.80	13.70			0-1-2		
		FRP (µgL^{-1})	4	2.00	5.00	3.00	2.50	2.00	2.00	3.80	4.70			1.5-2.0-2.8		
		PP (µgL^{-1})	4	0.00	1.00	0.50	0.50	0.00	0.00	1.00	1.00			≥10		

DRY SEASON 2016-17

								Quantiles				Guidelines				
Region/ Water Body	Site	Measure	N	Min	Max	Mean	Median	Q5	Q20	Q80	Q95	DirectionOf Failure	Location	Base Flow/ Annual	Dry	Wet
		Secchi (m)	4	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10			0.9-1.5-2.3		
		TSS (mgL^{-1})	4	1.60	3.30	2.48	2.50	1.66	1.84	3.12	3.26					

WET and DRY SEASON COMBINED 2016-17

								Quantiles				Guidelines				
Region/ Water body	Site	Measure	N	Min	Max	Mean	Median	Q5	Q20	Q80	Q95	DirectionOf Failure	Statistic	Base Flow/ Annual	Dry	Wet
Cape York Enclosed Coastal Zone	Pascoe River	DIN (μgL^{-1})	4	3.05	14.05	9.16	9.03	4.78	8.00	11.25	13.35					
		NH$_3$ (μgL^{-1})	4	0.05	8.00	3.13	2.50	0.38	1.00	5.20	7.30		20th-50th-80th	1-4-10		
		DON (μgL^{-1})	4	79.00	108.95	96.34	96.95	83.90	93.00	101.75	106.85					
		DOP (μgL^{-1})	4	0.00	3.00	1.00	1.00	0.00	0.40	1.00	2.30					
		Chla (μgL^{-1})	4	0.23	1.21	0.57	0.49	0.27	0.38	0.68	1.04		20th-50th-80th	0.5-1.0-1.5		
		NOx (μgL^{-1})	4	1.05	14.00	6.03	6.03	1.40	3.25	7.00	11.55		20th-50th-80th	1-2-10		
		PN (μgL^{-1})	4	1.00	31.00	10.88	7.00	1.00	1.40	19.20	27.15					
		FRP (μgL^{-1})	4	2.00	4.00	2.63	2.50	2.00	2.00	3.00	3.65		20th-50th-80th	1-1-3		
		PP (μgL^{-1})	4	1.00	3.00	1.75	2.00	1.00	1.00	2.00	2.65					
		Secchi (m)	4	1.60	3.70	2.29	1.93	1.60	1.72	3.00	3.70					
		TSS (mgL^{-1})	4	3.00	8.20	4.24	3.90	3.07	3.24	4.24	6.87					
Cape York Open Coastal Zone	Pascoe River	DIN (μgL^{-1})	4	4.05	10.05	6.66	6.53	4.42	5.46	7.63	9.35					
		NH$_3$ (μgL^{-1})	4	0.05	5.00	2.13	1.50	0.38	1.00	3.60	4.65		20th-50th-80th annual	0-1-3		
		DON (μgL^{-1})	4	71.95	105.95	86.46	81.45	74.07	78.00	97.96	103.87					
		DOP (μgL^{-1})	4	1.00	4.00	2.25	2.00	1.00	1.40	3.00	3.65					
		Chla (μgL^{-1})	4	0.29	1.30	0.53	0.40	0.29	0.31	0.63	1.11		20th-50th-80th		0.16-0.25-0.46	
		NOx (μgL^{-1})	4	0.10	6.05	4.53	5.53	0.78	3.23	6.00	6.03		20th-50th-80th		0-0-1	
		PN (μgL^{-1})	4	2.00	25.00	8.88	7.00	2.00	2.80	12.20	20.80		Mean		≤ 16	

WET and DRY SEASON COMBINED 2016-17																
								Quantiles				Guidelines				
Region/ Water body	Site	Measure	N	Min	Max	Mean	Median	Q5	Q20	Q80	Q95	DirectionOf Failure	Statistic	Base Flow/ Annual	Dry	Wet
		FRP (µgL^{-1})	4	2.00	5.00	2.75	2.00	2.00	2.00	3.60	4.65		20th-50th-80th		0-2-3	
		PP (µgL^{-1})	4	0.00	1.00	0.50	0.50	0.00	0.00	1.00	1.00		Mean		≤ 2.3	
		Secchi (m)	4	2.50	7.80	5.14	5.13	2.50	2.80	7.48	7.80		Annual Mean	≥ 10		
		TSS (mgL^{-1})	4	2.40	3.60	2.86	2.75	2.47	2.60	3.14	3.50		Mean		≤ 1.6	
Cape York Mid Shelf Zone	Pascoe River	DIN (µgL^{-1})	10	4.05	59.05	11.85	7.03	4.07	5.66	8.24	36.53					
		NH$_3$ (µgL^{-1})	10	0.05	58.00	7.52	1.00	0.05	0.05	4.60	35.05		20th-50th-80th	0-1-3		
		DON (µgL^{-1})	10	55.95	93.90	79.16	82.50	63.17	72.76	84.95	91.67					
		DOP (µgL^{-1})	10	0.00	6.00	2.30	2.00	0.00	0.80	4.00	5.10					
		Chla (µgL^{-1})	10	0.23	1.01	0.51	0.46	0.26	0.35	0.68	0.87		20th-50th-80th	0.18-0.27-0.45		
		NOx (µgL^{-1})	10	0.10	8.00	4.33	6.00	0.10	0.86	7.20	8.00		20th-50th-80th	0-0-1		
		PN (µgL^{-1})	10	1.00	14.00	6.80	6.50	1.45	2.00	12.00	13.10		20th-50th-80th	14-18-22		
		FRP (µgL^{-1})	10	2.00	5.00	2.60	2.00	2.00	2.00	3.00	4.10		20th-50th-80th	0-1-2		
		PP (µgL^{-1})	10	0.00	2.00	0.80	1.00	0.00	0.00	1.20	2.00		20th-50th-80th	1.5-2.0-2.8		
		Secchi (m)	10	4.90	8.10	7.10	7.80	4.90	6.26	8.10	8.10		Mean	≥10		
		TSS (mgL^{-1})	10	1.60	3.30	2.22	2.05	1.65	1.78	2.60	3.17		20th-50th-80th	0.9-1.5-2.3		

Table E-3: Summary statistics for direct water sampling data from inshore lagoon sites (other than Cape York) from June 2016 to June 2017. N = number of sampling occasions. Data are in mg L^{-1} for total suspended solids (TSS) and m for Secchi depth. All other parameters are in µg L^{-1} (see main report for abbreviations). Averages that exceed available Water Quality Guidelines (DERM, 2009; GBRMPA, 2010) are shaded in red.

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOf Failure	Location	Annual	Dry	Wet
Wet Tropics	Cape Tribulation	DIN (µgL^{-1})	3	1.20	1.37	0.75	0.96	1.48	1.54			NA	NA	NA
		DOC (mgL^{-1})	3	1039.41	1031.72	875.36	927.48	1149.81	1208.85			NA	NA	NA
		DON (µgL^{-1})	3	86.61	86.61	84.43	85.15	88.06	88.79			NA	NA	NA
		DOP (µgL^{-1})	3	5.22	5.34	4.65	4.88	5.58	5.71			NA	NA	NA
		Chla (µgL^{-1})	3	0.57	0.49	0.42	0.44	0.67	0.76	1	1	0.45	NA	NA
		NOx (µgL^{-1})	3	0.57	0.67	0.37	0.47	0.69	0.70	1	2	0.35	NA	NA
		PN (µgL^{-1})	3	13.73	12.57	12.27	12.37	14.86	16.01	1	1	20.00	NA	NA
		PO4 (µgL^{-1})	3	2.43	2.75	1.86	2.15	2.77	2.77	1	2	2.00	NA	NA
		PP (µgL^{-1})	3	2.91	2.84	2.65	2.71	3.09	3.21	1	1	2.80	NA	NA
		Secchi (m)	3	3.83	4.00	3.55	3.70	4.00	4.00	2	1	10.00	NA	NA
		TSS (mgL^{-1})	3	1.27	1.22	1.06	1.12	1.41	1.51	1	1	2.00	NA	NA
	Port Douglas	DIN (µgL^{-1})	3	1.11	0.67	0.67	0.67	1.46	1.86			NA	NA	NA
		DOC (mgL^{-1})	3	1026.82	1106.17	885.71	959.20	1110.32	1112.40			NA	NA	NA
		DON (µgL^{-1})	3	80.39	80.39	76.57	77.84	82.94	84.22			NA	NA	NA
		DOP (µgL^{-1})	3	4.54	4.43	4.17	4.26	4.80	4.99			NA	NA	NA
		Chla (µgL^{-1})	3	0.52	0.58	0.37	0.44	0.62	0.63	1	2	0.30	0.32	0.63
		NOx (µgL^{-1})	3	0.77	0.60	0.19	0.33	1.18	1.46	1	2	0.31	NA	NA
		PN (µgL^{-1})	3	14.19	13.87	13.39	13.55	14.76	15.21	1	2	14.00	16.00	25.00
		PO4 (µgL^{-1})	3	2.12	2.53	1.09	1.57	2.75	2.85	1	2	2.00	NA	NA
		PP (µgL^{-1})	3	2.80	2.71	2.55	2.60	2.98	3.12	1	2	2.00	2.30	3.30
		Secchi (m)	3	5.17	4.00	3.55	3.70	6.40	7.60	2	2	13.00	NA	NA
		TSS (mgL^{-1})	3	1.15	1.16	0.95	1.02	1.28	1.34	1	2	1.20	1.60	2.40
	Double	DIN (µgL^{-1})	3	0.78	0.77	0.55	0.62	0.94	1.02			NA	NA	NA
		DOC (mgL^{-1})	3	1022.68	968.11	959.69	962.49	1071.96	1123.88			NA	NA	NA
		DON (µgL^{-1})	3	80.81	80.81	77.59	78.66	82.96	84.04			NA	NA	NA
		DOP (µgL^{-1})	3	5.07	5.56	4.06	4.56	5.68	5.74			NA	NA	NA
		Chla (µgL^{-1})	3	0.44	0.35	0.30	0.32	0.55	0.65	1	2	0.30	0.32	0.63
		NOx (µgL^{-1})	3	0.35	0.27	0.15	0.19	0.49	0.60	1	2	0.31	NA	NA
		PN (µgL^{-1})	3	14.18	14.36	11.11	12.19	16.20	17.13	1	2	14.00	16.00	25.00

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOf Failure	Location	Annual	Dry	Wet
		PO4 (µgL^{-1})	3	1.68	2.05	0.90	1.29	2.15	2.21	1	2	2.00	NA	NA
		PP (µgL^{-1})	3	2.62	2.64	2.40	2.48	2.76	2.82	1	2	2.00	2.30	3.30
		Secchi (m)	3	4.67	4.00	3.55	3.70	5.50	6.25	2	2	13.00	NA	NA
		TSS (mgL^{-1})	3	1.20	1.33	0.91	1.05	1.38	1.41	1	2	1.20	1.60	2.40
	Green	DIN (µgL^{-1})	3	1.10	1.14	0.45	0.68	1.52	1.71			NA	NA	NA
		DOC (mgL^{-1})	3	984.49	999.66	895.27	930.07	1041.94	1063.08			NA	NA	NA
		DON (µgL^{-1})	3	93.52	93.52	77.18	82.63	104.41	109.86			NA	NA	NA
		DOP (µgL^{-1})	3	4.51	4.46	3.81	4.03	4.99	5.25			NA	NA	NA
		Chla (µgL^{-1})	3	0.26	0.18	0.17	0.18	0.33	0.41	1	2	0.30	0.32	0.63
		NOx (µgL^{-1})	3	0.81	0.98	0.27	0.51	1.15	1.23	1	2	0.31	NA	NA
		PN (µgL^{-1})	3	10.62	9.68	8.88	9.15	11.90	13.01	1	2	14.00	16.00	25.00
		PO4 (µgL^{-1})	3	1.55	1.41	0.97	1.11	1.96	2.24	1	2	2.00	NA	NA
		PP (µgL^{-1})	3	1.77	1.52	1.34	1.40	2.09	2.37	1	2	2.00	2.30	3.30
		Secchi (m)	3	8.00	8.00	7.55	7.70	8.30	8.45	2	2	13.00	NA	NA
		TSS (mgL^{-1})	3	0.46	0.45	0.32	0.36	0.56	0.61	1	2	1.20	1.60	2.40
	Yorkey's Knob	DIN (µgL^{-1})	3	2.03	1.06	0.90	0.95	2.92	3.85			NA	NA	NA
		DOC (mgL^{-1})	3	1058.35	987.80	978.97	981.92	1120.67	1187.10			NA	NA	NA
		DON (µgL^{-1})	3	89.47	89.47	77.83	81.71	97.23	101.11			NA	NA	NA
		DOP (µgL^{-1})	3	4.95	4.87	4.35	4.53	5.36	5.61			NA	NA	NA
		Chla (µgL^{-1})	3	0.74	0.74	0.36	0.49	1.00	1.13	1	1	0.45	NA	NA
		NOx (µgL^{-1})	3	1.61	0.58	0.23	0.35	2.67	3.72	1	2	0.35	NA	NA
		PN (µgL^{-1})	3	18.18	18.46	13.35	15.05	21.37	22.83	1	1	20.00	NA	NA
		PO4 (µgL^{-1})	3	2.24	2.61	1.50	1.87	2.69	2.73	1	2	2.00	NA	NA
		PP (µgL^{-1})	3	4.90	5.67	3.58	4.28	5.68	5.68	1	1	2.80	NA	NA
		Secchi (m)	3	2.50	2.50	2.05	2.20	2.80	2.95	2	1	10.00	NA	NA
		TSS (mgL^{-1})	3	3.67	3.28	3.08	3.15	4.11	4.53	1	1	2.00	NA	NA
	Fairlead Buoy	DIN (µgL^{-1})	3	0.60	0.41	0.34	0.36	0.80	0.99			NA	NA	NA
		DOC (mgL^{-1})	3	1041.15	994.17	978.88	983.98	1088.93	1136.32			NA	NA	NA
		DON (µgL^{-1})	3	87.67	87.67	74.82	79.11	96.24	100.52			NA	NA	NA
		DOP (µgL^{-1})	3	4.66	4.46	3.73	3.98	5.31	5.73			NA	NA	NA
		Chla (µgL^{-1})	3	0.74	0.57	0.54	0.55	0.90	1.06	1	1	0.45	NA	NA
		NOx (µgL^{-1})	3	0.21	0.24	0.15	0.18	0.25	0.26	1	2	0.35	NA	NA

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOf Failure	Location	Annual	Dry	Wet
		PN (µgL^{-1})	3	18.90	17.77	14.82	15.80	21.78	23.78	1	1	20.00	NA	NA
		PO4 (µgL^{-1})	3	2.08	2.33	1.04	1.47	2.73	2.93	1	2	2.00	NA	NA
		PP (µgL^{-1})	3	5.10	5.00	4.85	4.90	5.29	5.43	1	1	2.80	NA	NA
		Secchi (m)	3	2.33	2.00	2.00	2.00	2.60	2.90	2	1	10.00	NA	NA
		TSS (mgL^{-1})	3	4.91	3.61	3.45	3.50	6.05	7.27	1	1	2.00	NA	NA
	Fitzroy West	DIN (µgL^{-1})	8	NaN	NA	NA	NA	NA	NA			NA	NA	NA
		DOC (mgL^{-1})	8	1196.44	1151.81	1065.70	1085.28	1277.48	1401.95			NA	NA	NA
		DON (µgL^{-1})	8	87.86	84.51	81.30	82.37	92.68	96.77			NA	NA	NA
		DOP (µgL^{-1})	8	5.54	4.71	4.27	4.46	5.91	8.37			NA	NA	NA
		Chla (µgL^{-1})	8	0.33	0.33	0.15	0.16	0.50	0.60	1	1	0.45	NA	NA
		NOx (µgL^{-1})	8	2.80	2.00	0.98	1.32	4.59	5.14	1	2	0.35	NA	NA
		PN (µgL^{-1})	8	22.38	19.97	15.14	15.36	27.49	33.95	1	1	20.00	NA	NA
		PO4 (µgL^{-1})	8	2.23	2.58	1.23	1.66	2.75	2.93	1	2	2.00	NA	NA
		PP (µgL^{-1})	8	2.59	2.34	2.26	2.27	2.88	3.19	1	1	2.80	NA	NA
		Secchi (m)	8	9.90	8.00	6.00	7.50	13.40	14.60	2	1	10.00	NA	NA
		TSS (mgL^{-1})	8	0.89	0.61	0.11	0.37	1.08	2.33	1	1	2.00	NA	NA
	RM3	DIN (µgL^{-1})	5	NaN	NA	NA	NA	NA	NA			NA	NA	NA
		DOC (mgL^{-1})	5	1291.01	1289.80	1065.24	1123.52	1421.21	1555.30			NA	NA	NA
		DON (µgL^{-1})	5	81.06	79.70	76.31	77.44	84.42	86.77			NA	NA	NA
		DOP (µgL^{-1})	5	4.63	4.63	3.70	4.12	4.96	5.74			NA	NA	NA
		Chla (µgL^{-1})	5	0.48	0.50	0.31	0.41	0.56	0.62	1	2	0.30	0.32	0.63
		NOx (µgL^{-1})	5	0.44	0.41	0.14	0.14	0.60	0.89	1	2	0.31	NA	NA
		PN (µgL^{-1})	5	22.40	21.26	18.22	18.63	26.74	27.16	1	2	14.00	16.00	25.00
		PO4 (µgL^{-1})	5	2.45	2.60	1.64	1.72	2.99	3.29	1	2	2.00	NA	NA
		PP (µgL^{-1})	5	2.85	2.79	2.66	2.73	2.99	3.07	1	2	2.00	2.30	3.30
		Secchi (m)	5	8.90	6.00	3.90	5.10	12.80	16.70	2	2	13.00	NA	NA
		TSS (mgL^{-1})	5	0.97	0.85	0.27	0.67	1.37	1.71	1	2	1.20	1.60	2.40
	High West	DIN (µgL^{-1})	8	NaN	NA	NA	NA	NA	NA			NA	NA	NA
		DOC (mgL^{-1})	8	1327.15	1317.43	1125.00	1182.61	1480.97	1529.74			NA	NA	NA
		DON (µgL^{-1})	8	104.71	106.02	95.51	99.02	110.67	113.00			NA	NA	NA
		DOP (µgL^{-1})	8	4.99	4.90	4.60	4.79	5.22	5.44			NA	NA	NA
		Chla (µgL^{-1})	8	0.53	0.58	0.22	0.35	0.65	0.87	1	1	0.45	NA	NA

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOf Failure	Location	Annual	Dry	Wet
		NOx (µgL^{-1})	8	0.66	0.52	0.34	0.36	0.92	1.18	1	2	0.35	NA	NA
		PN (µgL^{-1})	8	19.73	17.11	10.98	13.55	24.38	32.62	1	1	20.00	NA	NA
		PO4 (µgL^{-1})	8	2.49	2.67	1.33	1.78	3.11	3.57	1	2	2.00	NA	NA
		PP (µgL^{-1})	8	3.18	3.03	2.41	2.61	3.60	4.26	1	1	2.80	NA	NA
		Secchi (m)	8	6.60	6.50	3.30	4.20	9.20	9.80	2	1	10.00	NA	NA
		TSS (mgL^{-1})	8	1.04	0.94	0.37	0.66	1.34	1.95	1	1	2.00	NA	NA
	Russell Mulgrave Mouth Mooring	DIN (µgL^{-1})	8	NaN	NA	NA	NA	NA	NA			NA	NA	NA
		DOC (mgL^{-1})	8	1393.95	1219.97	1101.64	1180.95	1631.00	1836.19			NA	NA	NA
		DON (µgL^{-1})	8	89.47	80.63	73.64	75.97	101.21	111.50			NA	NA	NA
		DOP (µgL^{-1})	8	4.37	4.68	3.49	3.58	4.93	5.15			NA	NA	NA
		Chla (µgL^{-1})	8	0.67	0.69	0.13	0.45	0.99	1.10	1	1	0.45	NA	NA
		NOx (µgL^{-1})	8	1.64	0.75	0.14	0.14	2.80	4.38	1	2	0.35	NA	NA
		PN (µgL^{-1})	8	22.34	22.01	13.98	15.01	29.23	31.44	1	1	20.00	NA	NA
		PO4 (µgL^{-1})	8	3.07	3.29	1.73	2.61	3.79	3.96	1	2	2.00	NA	NA
		PP (µgL^{-1})	8	5.47	5.69	3.46	4.70	6.72	6.81	1	1	2.80	NA	NA
		Secchi (m)	8	2.75	2.50	1.18	1.70	4.00	5.00	2	1	10.00	NA	NA
		TSS (mgL^{-1})	8	4.05	3.85	1.06	1.48	6.77	7.17	1	1	2.00	NA	NA
	Franklands West	DIN (µgL^{-1})	7	NaN	NA	NA	NA	NA	NA			NA	NA	NA
		DOC (mgL^{-1})	7	1360.19	1281.40	1139.57	1175.34	1579.73	1624.92			NA	NA	NA
		DON (µgL^{-1})	7	86.99	85.15	84.29	84.58	89.03	90.97			NA	NA	NA
		DOP (µgL^{-1})	7	4.43	4.46	3.94	4.21	4.61	4.95			NA	NA	NA
		Chla (µgL^{-1})	7	0.36	0.37	0.24	0.31	0.40	0.48	1	2	0.30	0.32	0.63
		NOx (µgL^{-1})	7	2.21	0.66	0.35	0.56	2.38	7.12	1	2	0.31	NA	NA
		PN (µgL^{-1})	7	18.23	17.72	14.70	15.34	20.92	22.49	1	2	14.00	16.00	25.00
		PO4 (µgL^{-1})	7	2.34	2.69	1.67	1.73	2.77	2.83	1	2	2.00	NA	NA
		PP (µgL^{-1})	7	2.75	2.55	2.24	2.41	2.85	3.70	1	2	2.00	2.30	3.30
		Secchi (m)	7	7.70	6.50	5.20	5.80	10.20	10.80	2	2	13.00	NA	NA
		TSS (mgL^{-1})	7	0.83	0.75	0.34	0.46	1.26	1.39	1	2	1.20	1.60	2.40
	Clump Point East	DIN (µgL^{-1})	5	NaN	NA	NA	NA	NA	NA			NA	NA	NA
		DOC (mgL^{-1})	5	1263.74	1321.39	1078.50	1205.83	1348.47	1364.52			NA	NA	NA
		DON (µgL^{-1})	5	91.27	93.06	76.65	82.12	100.79	104.65			NA	NA	NA

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOf Failure	Location	Annual	Dry	Wet
		DOP (µgL^{-1})	5	4.50	4.34	3.25	3.27	5.51	6.15			NA	NA	NA
		Chla (µgL^{-1})	5	0.32	0.34	0.23	0.29	0.35	0.37	1	2	0.30	0.32	0.63
		NOx (µgL^{-1})	5	0.39	0.45	0.18	0.30	0.48	0.52	1	2	0.31	NA	NA
		PN (µgL^{-1})	5	17.05	14.72	13.49	13.96	20.23	22.84	1	2	14.00	16.00	25.00
		PO4 (µgL^{-1})	5	1.59	1.76	0.74	0.75	2.24	2.44	1	2	2.00	NA	NA
		PP (µgL^{-1})	5	3.01	3.59	1.84	2.15	3.67	3.83	1	2	2.00	2.30	3.30
		Secchi (m)	5	12.00	13.00	7.20	10.80	14.20	14.80	2	2	13.00	NA	NA
		TSS (mgL^{-1})	5	0.59	0.45	0.31	0.39	0.80	0.98	1	2	1.20	1.60	2.40
	Dunk North	DIN (µgL^{-1})	5	NaN	NA	NA	NA	NA	NA			NA	NA	NA
		DOC (mgL^{-1})	5	1327.36	1327.93	1210.62	1271.98	1384.04	1442.23			NA	NA	NA
		DON (µgL^{-1})	5	90.33	92.42	71.53	78.49	102.58	107.65			NA	NA	NA
		DOP (µgL^{-1})	5	5.10	5.34	4.10	4.85	5.47	5.76			NA	NA	NA
		Chla (µgL^{-1})	5	0.54	0.55	0.39	0.40	0.63	0.76	1	1	0.45	NA	NA
		NOx (µgL^{-1})	5	0.78	0.46	0.33	0.40	1.21	1.52	1	2	0.35	NA	NA
		PN (µgL^{-1})	5	21.77	22.40	14.30	19.07	24.12	28.98	1	1	20.00	NA	NA
		PO4 (µgL^{-1})	5	2.15	2.71	0.60	0.66	3.11	3.66	1	2	2.00	NA	NA
		PP (µgL^{-1})	5	4.80	3.99	3.35	3.54	6.51	6.61	1	1	2.80	NA	NA
		Secchi (m)	5	4.84	5.00	2.66	4.04	5.50	7.00	2	1	10.00	NA	NA
		TSS (mgL^{-1})	5	2.97	1.82	0.97	1.12	4.07	6.85	1	1	2.00	NA	NA
	Dunk South	DIN (µgL^{-1})	5	NaN	NA	NA	NA	NA	NA			NA	NA	NA
		DOC (mgL^{-1})	5	1221.01	1268.56	993.82	1045.24	1347.37	1450.07			NA	NA	NA
		DON (µgL^{-1})	5	92.12	93.48	71.48	78.81	105.69	111.80			NA	NA	NA
		DOP (µgL^{-1})	5	5.25	5.37	4.66	4.95	5.57	5.71			NA	NA	NA
		Chla (µgL^{-1})	5	0.68	0.56	0.37	0.45	0.76	1.26	1	1	0.45	NA	NA
		NOx (µgL^{-1})	5	0.61	0.35	0.14	0.14	0.80	1.61	1	2	0.35	NA	NA
		PN (µgL^{-1})	5	20.94	18.99	15.34	17.56	25.40	27.41	1	1	20.00	NA	NA
		PO4 (µgL^{-1})	5	2.25	2.46	0.89	1.35	3.18	3.35	1	2	2.00	NA	NA
		PP (µgL^{-1})	5	3.93	3.36	2.32	2.73	5.45	5.81	1	1	2.80	NA	NA
		Secchi (m)	5	8.40	7.50	3.40	6.10	12.20	12.80	2	1	10.00	NA	NA
		TSS (mgL^{-1})	5	2.20	0.89	0.23	0.41	2.76	6.68	1	1	2.00	NA	NA
	Between Tam O'Shanter and Timana	DIN (µgL^{-1})	5	NaN	NA	NA	NA	NA	NA			NA	NA	NA
		DOC (mgL^{-1})	5	1323.55	1363.22	1137.39	1266.02	1396.96	1454.16			NA	NA	NA

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOf Failure	Location	Annual	Dry	Wet
		DON (μgL^{-1})	5	86.81	84.27	82.46	83.06	90.06	92.95			NA	NA	NA
		DOP (μgL^{-1})	5	5.47	5.55	4.44	4.85	6.25	6.29			NA	NA	NA
		Chla (μgL^{-1})	5	0.49	0.50	0.41	0.44	0.53	0.59	1	1	0.45	NA	NA
		NOx (μgL^{-1})	5	4.49	0.43	0.14	0.14	5.93	15.82	1	2	0.35	NA	NA
		PN (μgL^{-1})	5	22.16	24.94	12.50	19.31	26.29	27.78	1	1	20.00	NA	NA
		PO4 (μgL^{-1})	5	2.33	2.52	0.76	1.83	3.18	3.35	1	2	2.00	NA	NA
		PP (μgL^{-1})	5	4.42	4.62	2.97	3.59	5.19	5.75	1	1	2.80	NA	NA
		Secchi (m)	5	4.60	4.50	2.70	3.30	6.10	6.40	2	1	10.00	NA	NA
		TSS (mgL^{-1})	5	1.54	1.60	0.43	0.65	2.05	2.96	1	1	2.00	NA	NA
	Bedarra	DIN (μgL^{-1})	5	NaN	NA	NA	NA	NA	NA			NA	NA	NA
		DOC (mgL^{-1})	5	1256.17	1339.01	1045.24	1092.65	1364.92	1439.05			NA	NA	NA
		DON (μgL^{-1})	5	90.94	93.12	83.61	86.78	95.54	96.75			NA	NA	NA
		DOP (μgL^{-1})	5	5.57	5.89	4.72	4.78	6.13	6.31			NA	NA	NA
		Chla (μgL^{-1})	5	0.59	0.55	0.39	0.48	0.67	0.87	1	1	0.45	NA	NA
		NOx (μgL^{-1})	5	0.50	0.61	0.14	0.14	0.69	0.92	1	2	0.35	NA	NA
		PN (μgL^{-1})	5	21.40	21.97	15.28	18.85	24.21	26.69	1	1	20.00	NA	NA
		PO4 (μgL^{-1})	5	2.27	2.51	0.94	1.62	2.93	3.35	1	2	2.00	NA	NA
		PP (μgL^{-1})	5	4.46	4.63	3.67	3.88	5.07	5.08	1	1	2.80	NA	NA
		Secchi (m)	5	5.00	5.00	2.40	3.60	6.10	7.90	2	1	10.00	NA	NA
		TSS (mgL^{-1})	5	1.91	1.01	0.67	0.87	3.48	3.53	1	1	2.00	NA	NA
	Tully Mouth Mooring	DIN (μgL^{-1})	8	NaN	NA	NA	NA	NA	NA			NA	NA	NA
		DOC (mgL^{-1})	8	1348.63	1312.72	1201.74	1262.12	1433.10	1533.44			NA	NA	NA
		DON (μgL^{-1})	8	99.99	107.54	74.98	85.83	115.65	119.70			NA	NA	NA
		DOP (μgL^{-1})	8	5.93	5.63	4.95	5.10	6.59	7.37			NA	NA	NA
		Chla (μgL^{-1})	8	1.04	0.95	0.47	0.74	1.12	1.98	1	2	1.10	0.32	0.63
		NOx (μgL^{-1})	8	5.97	0.59	0.24	0.25	9.10	19.65	1	2	3.00	NA	NA
		PO4 (μgL^{-1})	8	3.13	2.50	1.07	1.88	4.78	5.43	1	2	3.00	NA	NA
		Secchi (m)	8	3.38	3.00	1.50	1.90	4.50	6.47	2	2	1.60	NA	NA
		TSS (mgL^{-1})	8	3.85	2.39	0.85	1.50	6.20	8.55	1	2	5.00	1.60	2.40
Burdekin	Palms West	DIN (μgL^{-1})	5	NaN	NA	NA	NA	NA	NA			NA	NA	NA
		DOC (mgL^{-1})	5	1055.09	1061.08	1010.29	1027.22	1084.16	1095.70			NA	NA	NA
		DON (μgL^{-1})	5	81.38	81.38	76.95	78.43	84.34	85.81			NA	NA	NA

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOf Failure	Location	Annual	Dry	Wet
		DOP (µgL^{-1})	5	4.68	4.56	3.57	3.90	5.43	5.87			NA	NA	NA
		Chla (µgL^{-1})	5	0.36	0.38	0.22	0.27	0.44	0.47	1	2	0.35	0.32	0.63
		NOx (µgL^{-1})	5	1.24	0.88	0.47	0.61	1.81	2.27	1	2	0.28	NA	NA
		PN (µgL^{-1})	5	17.80	19.63	14.58	16.26	19.71	19.75	1	2	12.00	16.00	25.00
		PO4 (µgL^{-1})	5	1.39	0.92	0.73	0.79	1.90	2.39	1	2	1.00	NA	NA
		PP (µgL^{-1})	5	2.30	2.17	1.98	2.04	2.52	2.70	1	2	2.20	2.30	3.30
		Secchi (m)	5	13.67	14.00	11.30	12.20	15.20	15.80	2	1	10.00	NA	NA
		TSS (mgL^{-1})	5	0.79	0.78	0.35	0.38	1.18	1.23	1	2	1.20	1.60	2.40
	Pandora	DIN (µgL^{-1})	5	NaN	NA	NA	NA	NA	NA			NA	NA	NA
		DOC (mgL^{-1})	5	1136.57	1131.62	1095.34	1107.44	1164.71	1181.25			NA	NA	NA
		DON (µgL^{-1})	5	95.04	95.04	87.83	90.23	99.84	102.25			NA	NA	NA
		DOP (µgL^{-1})	5	4.70	4.74	3.62	3.99	5.41	5.75			NA	NA	NA
		Chla (µgL^{-1})	5	0.29	0.25	0.22	0.24	0.31	0.41	1	2	0.35	0.32	0.63
		NOx (µgL^{-1})	5	1.97	2.12	0.34	0.93	3.04	3.51	1	2	0.28	NA	NA
		PN (µgL^{-1})	5	24.14	27.20	15.94	19.70	29.20	30.19	1	2	12.00	16.00	25.00
		PO4 (µgL^{-1})	5	2.15	1.39	0.75	0.96	3.18	4.07	1	2	1.00	NA	NA
		PP (µgL^{-1})	5	2.57	2.55	2.32	2.40	2.74	2.84	1	2	2.20	2.30	3.30
		Secchi (m)	5	9.67	8.50	8.05	8.20	10.90	12.10	2	1	10.00	NA	NA
		TSS (mgL^{-1})	5	1.19	0.84	0.43	0.68	1.95	2.02	1	2	1.20	1.60	2.40
	Magnetic	DIN (µgL^{-1})	5	NaN	NA	NA	NA	NA	NA			NA	NA	NA
		DOC (mgL^{-1})	5	1169.98	1147.62	1123.61	1131.61	1203.87	1232.00			NA	NA	NA
		DON (µgL^{-1})	5	93.20	93.20	84.42	87.35	99.05	101.98			NA	NA	NA
		DOP (µgL^{-1})	5	5.02	5.04	4.49	4.68	5.38	5.55			NA	NA	NA
		Chla (µgL^{-1})	5	0.44	0.42	0.27	0.33	0.54	0.64	1	2	0.59	0.32	0.63
		NOx (µgL^{-1})	5	0.59	0.56	0.34	0.41	0.76	0.86	1	2	0.28	NA	NA
		PN (µgL^{-1})	5	20.91	18.61	16.92	17.48	23.87	26.51	1	2	17.00	16.00	25.00
		PO4 (µgL^{-1})	5	1.96	1.43	0.42	0.76	3.06	3.88	1	2	1.00	NA	NA
		PP (µgL^{-1})	5	3.58	3.06	2.98	3.01	4.06	4.55	1	1	2.80	NA	NA
		Secchi (m)	5	6.50	7.00	5.65	6.10	7.00	7.00	2	2	4.00	NA	NA
		TSS (mgL^{-1})	5	1.38	1.24	0.90	0.92	1.52	2.32	1	2	1.90	1.60	2.40
	Haughton	DIN (µgL^{-1})	2	NaN	NA	NA	NA	NA	NA			NA	NA	NA
		DOC (mgL^{-1})	2	1330.44	1330.44	1313.86	1319.39	1341.49	1347.01			NA	NA	NA

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOf Failure	Location	Annual	Dry	Wet
		DON (µgL^{-1})	2	83.46	83.46	81.88	82.41	84.52	85.05			NA	NA	NA
		DOP (µgL^{-1})	2	5.59	5.59	4.55	4.90	6.28	6.63			NA	NA	NA
		Chla (µgL^{-1})	2	0.37	0.37	0.33	0.35	0.39	0.40	1	1	0.45	NA	NA
		NOx (µgL^{-1})	2	0.34	0.34	0.20	0.25	0.43	0.47	1	2	1.00	NA	NA
		PN (µgL^{-1})	2	14.64	14.64	14.23	14.37	14.92	15.06	1	2	13.00	16.00	25.00
		PO4 (µgL^{-1})	2	0.72	0.72	0.35	0.47	0.97	1.09	1	2	2.00	NA	NA
		PP (µgL^{-1})	2	3.20	3.20	3.19	3.19	3.20	3.20	1	2	2.10	2.30	3.30
		Secchi (m)	2	8.00	8.00	8.00	8.00	8.00	8.00	2	1	10.00	NA	NA
		TSS (mgL^{-1})	2	0.97	0.97	0.84	0.88	1.05	1.10	1	2	1.20	1.60	2.40
	Yongala	DIN (µgL^{-1})	6	NaN	NA	NA	NA	NA	NA			NA	NA	NA
		DOC (mgL^{-1})	6	1292.04	1304.20	1056.89	1117.10	1353.86	1565.52			NA	NA	NA
		DON (µgL^{-1})	6	97.90	100.69	91.19	94.16	101.29	102.16			NA	NA	NA
		DOP (µgL^{-1})	6	5.01	5.07	3.72	4.21	5.88	6.19			NA	NA	NA
		Chla (µgL^{-1})	6	0.36	0.27	0.17	0.25	0.45	0.69	1	2	0.33	0.32	0.63
		NOx (µgL^{-1})	6	0.85	0.47	0.14	0.14	1.11	2.33	1	2	0.28	NA	NA
		PN (µgL^{-1})	6	14.66	12.96	10.62	11.20	19.98	20.30	1	2	14.00	16.00	25.00
		PO4 (µgL^{-1})	6	1.13	1.08	0.35	0.47	1.69	2.04	1	2	1.00	NA	NA
		PP (µgL^{-1})	6	2.38	2.03	1.49	1.66	3.31	3.69	1	2	2.00	2.30	3.30
		Secchi (m)	6	15.33	15.00	11.75	12.50	18.00	19.50	2	1	10.00	NA	NA
		TSS (mgL^{-1})	6	0.63	0.62	0.16	0.47	0.85	1.06	1	2	0.80	1.60	2.40
	Burdekin Mouth Mooring	DIN (µgL^{-1})	3	NaN	NA	NA	NA	NA	NA			NA	NA	NA
		DOC (mgL^{-1})	3	1367.13	1367.13	1226.23	1273.19	1461.06	1508.03			NA	NA	NA
		DON (µgL^{-1})	3	99.35	99.35	99.19	99.24	99.46	99.52			NA	NA	NA
		DOP (µgL^{-1})	3	5.90	5.90	4.90	5.23	6.56	6.89			NA	NA	NA
		Chla (µgL^{-1})	3	0.53	0.53	0.49	0.50	0.56	0.58	1	2	1.00	0.32	0.63
		NOx (µgL^{-1})	3	1.15	1.15	0.93	1.01	1.30	1.37	1	2	4.00	NA	NA
		PO4 (µgL^{-1})	3	1.04	1.04	0.38	0.60	1.48	1.70	1	2	1.00	NA	NA
		Secchi (m)	3	6.00	6.00	5.10	5.40	6.60	6.90	2	2	1.50	NA	NA
		TSS (mgL^{-1})	3	2.51	2.03	0.63	1.10	3.83	4.73	1	2	2.00	1.60	2.40
Mackay Whitsunday	Double Cone	DIN (µgL^{-1})	5	NaN	NA	NA	NA	NA	NA			NA	NA	NA
		DOC (mgL^{-1})	5	1119.79	1115.53	1094.21	1102.88	1134.99	1151.34			NA	NA	NA
		DON (µgL^{-1})	5	96.64	101.73	79.24	86.73	107.57	110.49			NA	NA	NA

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOf Failure	Location	Annual	Dry	Wet
		DOP (μgL^{-1})	5	5.62	5.32	4.66	4.75	6.37	7.00			NA	NA	NA
		Chla (μgL^{-1})	5	1.03	0.84	0.49	0.71	1.50	1.60	1	2	0.36	0.32	0.63
		NOx (μgL^{-1})	5	2.67	2.64	0.65	1.35	3.97	4.72	1	2	1.00	NA	NA
		PN (μgL^{-1})	5	27.58	27.85	22.23	24.21	31.05	32.54	1	1	14.00	NA	NA
		PO4 (μgL^{-1})	5	1.74	1.16	0.84	0.94	2.30	3.44	1	2	1.00	NA	NA
		PP (μgL^{-1})	5	5.37	5.91	3.07	4.29	6.66	6.91	1	2	2.30	2.30	3.30
		Secchi (m)	5	3.81	3.50	2.01	2.80	4.70	6.05	2	1	10.00	NA	NA
		TSS (mgL^{-1})	5	3.94	4.08	1.63	2.75	4.81	6.40	1	2	1.40	1.60	2.40
	Pine	DIN (μgL^{-1})	5	NaN	NA	NA	NA	NA	NA			NA	NA	NA
		DOC (mgL^{-1})	5	1079.37	1081.21	998.37	1012.75	1146.73	1157.79			NA	NA	NA
		DON (μgL^{-1})	5	87.41	90.07	75.27	80.20	95.15	97.68			NA	NA	NA
		DOP (μgL^{-1})	5	5.16	5.45	3.25	4.38	6.05	6.64			NA	NA	NA
		Chla (μgL^{-1})	5	0.95	0.81	0.71	0.72	1.21	1.32	1	2	0.36	0.32	0.63
		NOx (μgL^{-1})	5	9.04	10.29	4.28	6.71	11.87	12.04	1	2	1.00	NA	NA
		PN (μgL^{-1})	5	20.26	19.65	14.07	16.99	23.28	27.30	1	1	14.00	NA	NA
		PO4 (μgL^{-1})	5	3.13	2.74	1.68	2.06	4.05	5.15	1	2	1.00	NA	NA
		PP (μgL^{-1})	5	6.26	6.72	3.31	4.19	8.51	8.56	1	2	2.30	2.30	3.30
		Secchi (m)	5	3.00	2.25	1.50	1.50	4.20	5.55	2	1	10.00	NA	NA
		TSS (mgL^{-1})	5	7.14	6.24	1.00	1.41	12.77	14.30	1	2	1.40	1.60	2.40
	Seaforth	DIN (μgL^{-1})	6	NaN	NA	NA	NA	NA	NA			NA	NA	NA
		DOC (mgL^{-1})	6	1109.58	1104.77	988.52	999.44	1217.80	1237.38			NA	NA	NA
		DON (μgL^{-1})	6	88.50	89.00	86.91	87.61	89.50	89.74			NA	NA	NA
		DOP (μgL^{-1})	6	4.60	4.91	2.78	3.83	5.50	5.98			NA	NA	NA
		Chla (μgL^{-1})	6	0.95	0.84	0.64	0.77	1.27	1.35	1	2	0.36	0.32	0.63
		NOx (μgL^{-1})	6	5.18	4.97	2.42	2.51	7.77	8.26	1	2	1.00	NA	NA
		PN (μgL^{-1})	6	24.05	23.56	19.15	19.64	28.26	29.62	1	1	14.00	NA	NA
		PO4 (μgL^{-1})	6	2.72	2.06	1.64	1.71	3.48	4.73	1	2	1.00	NA	NA
		PP (μgL^{-1})	6	5.27	5.21	3.68	3.85	6.67	6.95	1	2	2.30	2.30	3.30
		Secchi (m)	6	3.44	3.75	2.01	2.80	4.20	4.42	2	1	10.00	NA	NA
		TSS (mgL^{-1})	6	3.63	2.90	1.40	1.85	4.93	7.20	1	2	1.40	1.60	2.40
		DIN (μgL^{-1})	4	NaN	NA	NA	NA	NA	NA			NA	NA	NA

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOf Failure	Location	Annual	Dry	Wet
	O'Connell Mouth	DOC (mgL^{-1})	4	1588.94	1629.27	1405.11	1510.54	1683.47	1716.29			NA	NA	NA
		DON (µgL^{-1})	4	118.47	118.47	111.06	113.53	123.42	125.89			NA	NA	NA
		DOP (µgL^{-1})	4	5.70	5.38	4.83	5.01	6.33	6.80			NA	NA	NA
		Chla (µgL^{-1})	4	1.94	1.81	1.01	1.20	2.64	3.07	1	2	1.30	0.32	0.63
		NOx (µgL^{-1})	4	3.02	3.62	0.76	1.71	4.45	4.87	1	2	4.00	NA	NA
		PO4 (µgL^{-1})	4	5.38	4.41	4.36	4.38	6.20	7.09	1	2	3.00	NA	NA
		Secchi (m)	4	2.31	1.88	1.54	1.65	2.80	3.70	2	2	1.60	NA	NA
		TSS (mgL^{-1})	4	5.41	3.54	3.40	3.43	6.65	10.04	1	2	5.00	1.60	2.40
	Repulse	DIN (µgL^{-1})	6	NaN	NA	NA	NA	NA	NA			NA	NA	NA
		DOC (mgL^{-1})	6	1281.77	1303.40	1143.50	1187.45	1384.74	1389.76			NA	NA	NA
		DON (µgL^{-1})	6	95.00	90.60	84.60	86.60	102.53	108.50			NA	NA	NA
		DOP (µgL^{-1})	6	5.04	4.97	3.71	4.17	5.88	6.46			NA	NA	NA
		Chla (µgL^{-1})	6	0.91	0.80	0.62	0.64	1.06	1.41	1	1	0.45	NA	NA
		NOx (µgL^{-1})	6	5.31	3.66	2.23	2.65	7.31	10.68	1	2	0.25	NA	NA
		PN (µgL^{-1})	6	26.96	25.34	19.33	21.78	31.48	36.85	1	2	18.00	16.00	25.00
		PO4 (µgL^{-1})	6	3.96	3.85	2.87	2.98	4.90	5.21	1	2	2.00	NA	NA
		PP (µgL^{-1})	6	7.29	7.86	4.83	6.34	8.47	8.95	1	2	2.10	2.30	3.30
		Secchi (m)	6	2.56	2.12	1.54	1.65	3.30	4.20	2	1	10.00	NA	NA
		TSS (mgL^{-1})	6	5.86	3.74	1.67	2.66	11.28	12.13	1	2	1.60	1.60	2.40

Table E-4: Summary statistics for direct water sampling data from inshore lagoon sites from August 2005 to June 2017. N = number of sampling occasions. Data are in mg L^{-1} for total suspended solids (TSS) and metres for Secchi depth. All other parameters are in µg L^{-1} (see main report for abbreviations). Long-term averages that exceed available Water Quality Guidelines (DERM 2009, GBRMPA 2010) are shaded in red.

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOf Failure	Location	Annual	Dry	Wet
Wet Tropics	Cape Tribulation	DIN (µgL^{-1})	33	1.46	1.42	0.57	0.68	1.76	2.35			NA	NA	NA
		DOC (mgL^{-1})	33	851.40	869.70	639.10	741.22	932.64	1062.97			NA	NA	NA
		DON (µgL^{-1})	33	78.85	81.23	40.49	60.04	93.25	108.96			NA	NA	NA
		DOP (µgL^{-1})	33	4.75	4.32	1.72	2.50	5.97	7.79			NA	NA	NA
		Chla (µgL^{-1})	33	0.42	0.41	0.22	0.29	0.54	0.75	1	1	0.45	NA	NA
		NOx (µgL^{-1})	33	0.74	0.66	0.01	0.28	1.29	1.51	1	2	0.35	NA	NA
		PN (µgL^{-1})	33	12.64	12.24	9.19	10.45	14.53	18.26	1	1	20.00	NA	NA
		PO4 (µgL^{-1})	33	2.42	2.38	0.58	1.65	3.20	3.62	1	2	2.00	NA	NA
		PP (µgL^{-1})	33	2.80	2.63	1.89	2.08	3.33	4.30	1	1	2.80	NA	NA
		Secchi (m)	33	6.48	6.00	3.25	4.00	9.00	11.00	2	1	10.00	NA	NA
		TSS (mgL^{-1})	33	1.49	1.22	0.61	0.87	1.79	3.21	1	1	2.00	NA	NA
	Port Douglas	DIN (µgL^{-1})	34	1.16	0.90	0.21	0.61	1.59	2.86			NA	NA	NA
		DOC (mgL^{-1})	34	832.89	825.28	651.60	735.38	911.54	1090.32			NA	NA	NA
		DON (µgL^{-1})	34	75.63	73.44	36.32	54.19	94.76	124.08			NA	NA	NA
		DOP (µgL^{-1})	34	4.20	3.60	1.83	2.39	4.91	6.89			NA	NA	NA
		Chla (µgL^{-1})	34	0.39	0.35	0.22	0.27	0.54	0.68	1	2	0.30	0.32	0.63
		NOx (µgL^{-1})	34	0.75	0.48	0.01	0.14	1.25	1.62	1	2	0.31	NA	NA
		PN (µgL^{-1})	34	12.57	12.59	9.27	10.61	14.18	17.00	1	2	14.00	16.00	25.00
		PO4 (µgL^{-1})	34	2.25	2.26	0.53	1.33	3.07	3.68	1	2	2.00	NA	NA
		PP (µgL^{-1})	34	2.54	2.45	1.52	2.17	3.02	3.58	1	2	2.00	2.30	3.30
		Secchi (m)	34	6.32	6.00	3.33	4.00	8.40	10.35	2	2	13.00	NA	NA
		TSS (mgL^{-1})	34	1.43	1.36	0.66	0.92	1.87	2.26	1	2	1.20	1.60	2.40
	Double	DIN (µgL^{-1})	33	1.04	0.77	0.08	0.31	1.67	2.58			NA	NA	NA
		DOC (mgL^{-1})	33	832.73	821.82	676.78	725.07	951.01	1031.39			NA	NA	NA
		DON (µgL^{-1})	33	77.61	76.43	39.52	62.02	93.73	113.72			NA	NA	NA
		DOP (µgL^{-1})	33	4.78	4.00	2.50	3.03	5.52	7.57			NA	NA	NA
		Chla (µgL^{-1})	33	0.39	0.35	0.19	0.29	0.51	0.63	1	2	0.30	0.32	0.63
		NOx (µgL^{-1})	33	0.66	0.30	0.01	0.10	1.18	2.00	1	2	0.31	NA	NA
		PN (µgL^{-1})	33	11.74	11.75	8.12	9.88	13.36	15.14	1	2	14.00	16.00	25.00

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOf Failure	Location	Annual	Dry	Wet
		PO4 (µgL⁻¹)	33	2.04	2.05	0.57	1.19	2.63	4.02	1	2	2.00	NA	NA
		PP (µgL⁻¹)	33	2.73	2.41	1.60	1.97	2.90	3.47	1	2	2.00	2.30	3.30
		Secchi (m)	33	6.92	6.25	3.27	4.00	9.90	13.72	2	2	13.00	NA	NA
		TSS (mgL⁻¹)	33	1.22	1.15	0.55	0.90	1.41	1.97	1	2	1.20	1.60	2.40
	Green	DIN (µgL⁻¹)	34	1.51	1.43	0.30	0.51	2.15	3.65			NA	NA	NA
		DOC (mgL⁻¹)	34	813.91	817.58	609.92	711.80	898.84	990.59			NA	NA	NA
		DON (µgL⁻¹)	34	77.04	77.62	45.01	58.76	95.69	109.36			NA	NA	NA
		DOP (µgL⁻¹)	34	5.00	4.42	2.27	2.89	6.59	8.63			NA	NA	NA
		Chla (µgL⁻¹)	34	0.29	0.24	0.12	0.14	0.38	0.67	1	2	0.30	0.32	0.63
		NOx (µgL⁻¹)	34	0.90	0.74	0.11	0.27	1.53	2.17	1	2	0.31	NA	NA
		PN (µgL⁻¹)	34	10.03	9.77	7.54	8.31	11.52	13.08	1	2	14.00	16.00	25.00
		PO4 (µgL⁻¹)	34	2.06	1.97	1.02	1.43	2.70	3.43	1	2	2.00	NA	NA
		PP (µgL⁻¹)	34	1.67	1.59	0.93	1.17	2.12	2.51	1	2	2.00	2.30	3.30
		Secchi (m)	34	11.50	12.00	5.15	8.00	14.40	18.35	2	2	13.00	NA	NA
		TSS (mgL⁻¹)	34	0.53	0.41	0.10	0.17	0.77	1.30	1	2	1.20	1.60	2.40
	Yorkey's Knob	DIN (µgL⁻¹)	34	1.43	1.05	0.22	0.61	1.98	3.49			NA	NA	NA
		DOC (mgL⁻¹)	34	860.28	844.48	629.87	756.81	975.77	1162.42			NA	NA	NA
		DON (µgL⁻¹)	34	75.49	74.70	38.91	55.46	93.91	107.56			NA	NA	NA
		DOP (µgL⁻¹)	34	5.13	4.53	1.97	2.99	6.51	10.49			NA	NA	NA
		Chla (µgL⁻¹)	34	0.61	0.54	0.32	0.42	0.75	1.10	1	1	0.45	NA	NA
		NOx (µgL⁻¹)	34	0.90	0.54	0.01	0.21	1.48	2.78	1	2	0.35	NA	NA
		PN (µgL⁻¹)	34	16.24	15.34	12.16	12.80	18.45	23.77	1	1	20.00	NA	NA
		PO4 (µgL⁻¹)	34	2.14	1.99	0.65	1.29	2.93	3.97	1	2	2.00	NA	NA
		PP (µgL⁻¹)	34	4.14	3.84	2.81	3.32	5.03	5.71	1	1	2.80	NA	NA
		Secchi (m)	34	3.51	3.00	2.00	2.50	5.00	6.67	2	1	10.00	NA	NA
		TSS (mgL⁻¹)	34	3.12	2.58	1.38	1.92	4.29	6.28	1	1	2.00	NA	NA
	Fairlead Buoy	DIN (µgL⁻¹)	34	1.38	1.10	0.36	0.54	2.22	2.82			NA	NA	NA
		DOC (mgL⁻¹)	34	861.52	871.89	653.11	748.47	966.98	1025.93			NA	NA	NA
		DON (µgL⁻¹)	34	77.19	75.64	37.46	58.21	92.46	104.98			NA	NA	NA
		DOP (µgL⁻¹)	34	4.94	4.34	1.55	3.14	5.71	9.10			NA	NA	NA
		Chla (µgL⁻¹)	34	0.62	0.55	0.33	0.39	0.74	1.15	1	1	0.45	NA	NA
		NOx (µgL⁻¹)	34	0.66	0.31	0.01	0.12	1.22	1.73	1	2	0.35	NA	NA

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOf Failure	Location	Annual	Dry	Wet
		PN (µgL⁻¹)	34	16.56	16.10	11.28	14.07	19.26	23.03	1	1	20.00	NA	NA
		PO4 (µgL⁻¹)	34	2.18	2.28	0.65	1.22	2.92	3.92	1	2	2.00	NA	NA
		PP (µgL⁻¹)	34	4.61	4.45	2.53	3.28	5.47	7.59	1	1	2.80	NA	NA
		Secchi (m)	34	3.21	3.00	1.50	2.00	4.00	6.50	2	1	10.00	NA	NA
		TSS (mgL⁻¹)	34	4.19	2.93	0.77	2.04	6.23	10.90	1	1	2.00	NA	NA
	Fitzroy West	DIN (µgL⁻¹)	46	3.06	2.32	0.69	1.31	3.85	8.32			NA	NA	NA
		DOC (mgL⁻¹)	46	881.78	848.95	638.54	713.28	1034.12	1254.11			NA	NA	NA
		DON (µgL⁻¹)	46	77.44	77.57	40.52	61.52	92.85	115.86			NA	NA	NA
		DOP (µgL⁻¹)	46	5.08	4.70	1.26	2.80	6.39	8.37			NA	NA	NA
		Chla (µgL⁻¹)	46	0.33	0.33	0.14	0.18	0.44	0.62	1	1	0.45	NA	NA
		NOx (µgL⁻¹)	46	1.90	1.71	0.24	0.54	2.60	5.58	1	2	0.35	NA	NA
		PN (µgL⁻¹)	46	13.19	11.47	7.44	9.84	15.40	22.83	1	1	20.00	NA	NA
		PO4 (µgL⁻¹)	46	2.33	2.34	0.66	1.41	3.07	4.30	1	2	2.00	NA	NA
		PP (µgL⁻¹)	46	2.09	2.01	1.37	1.62	2.43	3.16	1	1	2.80	NA	NA
		Secchi (m)	46	9.15	9.00	5.08	7.10	11.00	13.20	2	1	10.00	NA	NA
		TSS (mgL⁻¹)	46	0.88	0.77	0.27	0.47	1.11	1.82	1	1	2.00	NA	NA
	RM3	DIN (µgL⁻¹)	12	2.16	2.16	2.16	2.16	2.16	2.16			NA	NA	NA
		DOC (mgL⁻¹)	12	1134.99	1133.99	899.19	933.65	1270.49	1477.08			NA	NA	NA
		DON (µgL⁻¹)	12	80.35	76.36	47.45	67.86	94.49	123.07			NA	NA	NA
		DOP (µgL⁻¹)	12	4.89	4.66	3.53	3.80	5.69	6.70			NA	NA	NA
		Chla (µgL⁻¹)	12	0.45	0.47	0.16	0.28	0.58	0.70	1	2	0.30	0.32	0.63
		NOx (µgL⁻¹)	12	0.80	0.51	0.14	0.17	1.29	2.14	1	2	0.31	NA	NA
		PN (µgL⁻¹)	12	20.57	19.72	12.29	12.90	27.16	31.01	1	2	14.00	16.00	25.00
		PO4 (µgL⁻¹)	12	2.26	2.06	1.01	1.63	2.83	4.06	1	2	2.00	NA	NA
		PP (µgL⁻¹)	12	2.69	2.76	1.92	2.02	3.07	3.62	1	2	2.00	2.30	3.30
		Secchi (m)	12	9.62	8.50	4.32	5.60	14.30	16.35	2	2	13.00	NA	NA
		TSS (mgL⁻¹)	12	0.90	0.82	0.30	0.57	1.22	1.61	1	2	1.20	1.60	2.40
	High West	DIN (µgL⁻¹)	47	2.95	2.38	0.74	1.36	3.85	5.80			NA	NA	NA
		DOC (mgL⁻¹)	47	933.52	886.44	659.26	734.05	1108.53	1339.52			NA	NA	NA
		DON (µgL⁻¹)	47	81.12	82.19	45.07	64.43	96.48	108.35			NA	NA	NA
		DOP (µgL⁻¹)	47	4.97	4.84	2.05	2.55	6.61	7.96			NA	NA	NA
		Chla (µgL⁻¹)	47	0.48	0.38	0.24	0.29	0.74	1.00	1	1	0.45	NA	NA

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOf Failure	Location	Annual	Dry	Wet
		NOx (µgL⁻¹)	47	2.01	1.27	0.22	0.52	2.64	7.63	1	2	0.35	NA	NA
		PN (µgL⁻¹)	47	14.60	12.66	9.10	10.98	16.92	24.79	1	1	20.00	NA	NA
		PO4 (µgL⁻¹)	47	2.29	2.18	0.81	1.35	3.05	4.33	1	2	2.00	NA	NA
		PP (µgL⁻¹)	47	2.85	2.55	1.78	2.19	3.40	4.51	1	1	2.80	NA	NA
		Secchi (m)	47	6.57	6.50	2.80	4.10	9.00	12.00	2	1	10.00	NA	NA
		TSS (mgL⁻¹)	47	1.36	1.04	0.34	0.74	2.09	2.95	1	1	2.00	NA	NA
	Russell Mulgrave Mouth Mooring	DIN (µgL⁻¹)	18	23.06	23.06	23.06	23.06	23.06	23.06			NA	NA	NA
		DOC (mgL⁻¹)	18	1194.14	1121.89	930.13	1048.10	1224.40	1699.40			NA	NA	NA
		DON (µgL⁻¹)	18	80.89	79.72	30.11	71.56	113.70	114.60			NA	NA	NA
		DOP (µgL⁻¹)	18	4.85	4.86	2.28	3.78	5.44	7.71			NA	NA	NA
		Chla (µgL⁻¹)	18	0.70	0.67	0.27	0.42	1.04	1.14	1	1	0.45	NA	NA
		NOx (µgL⁻¹)	18	5.79	1.18	0.14	0.14	7.65	24.72	1	2	0.35	NA	NA
		PN (µgL⁻¹)	18	21.27	21.64	13.65	15.27	27.32	30.40	1	1	20.00	NA	NA
		PO4 (µgL⁻¹)	18	2.48	2.40	1.01	1.48	3.55	4.05	1	2	2.00	NA	NA
		PP (µgL⁻¹)	18	5.36	5.69	3.04	3.92	6.78	7.61	1	1	2.80	NA	NA
		Secchi (m)	18	3.34	3.00	0.95	2.00	5.00	5.90	2	1	10.00	NA	NA
		TSS (mgL⁻¹)	18	3.55	2.98	0.89	1.25	6.17	6.97	1	1	2.00	NA	NA
	Franklands West	DIN (µgL⁻¹)	47	1.83	1.82	0.85	1.00	2.53	2.90			NA	NA	NA
		DOC (mgL⁻¹)	47	895.14	853.75	652.85	756.74	974.99	1295.57			NA	NA	NA
		DON (µgL⁻¹)	47	78.54	77.56	43.15	65.16	91.47	109.98			NA	NA	NA
		DOP (µgL⁻¹)	47	5.04	4.48	1.40	2.93	6.53	10.11			NA	NA	NA
		Chla (µgL⁻¹)	47	0.34	0.32	0.17	0.20	0.44	0.67	1	2	0.30	0.32	0.63
		NOx (µgL⁻¹)	47	1.21	0.84	0.13	0.43	2.05	2.55	1	2	0.31	NA	NA
		PN (µgL⁻¹)	47	13.61	11.68	8.23	9.71	15.52	23.50	1	2	14.00	16.00	25.00
		PO4 (µgL⁻¹)	47	2.18	2.15	0.82	1.32	2.89	3.28	1	2	2.00	NA	NA
		PP (µgL⁻¹)	47	2.17	2.18	1.26	1.65	2.55	3.20	1	2	2.00	2.30	3.30
		Secchi (m)	47	9.12	9.00	5.00	6.00	12.00	13.00	2	2	13.00	NA	NA
		TSS (mgL⁻¹)	47	0.73	0.68	0.20	0.42	0.98	1.41	1	2	1.20	1.60	2.40
	Clump Point East	DIN (µgL⁻¹)	12	NaN	NA	NA	NA	NA	NA			NA	NA	NA
		DOC (mgL⁻¹)	12	1107.06	1074.21	890.65	972.15	1306.77	1355.16			NA	NA	NA
		DON (µgL⁻¹)	12	80.00	73.18	39.53	64.66	95.64	130.74			NA	NA	NA
		DOP (µgL⁻¹)	12	4.73	4.71	2.54	3.31	6.07	7.49			NA	NA	NA

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOf Failure	Location	Annual	Dry	Wet
		Chla (µgL^{-1})	12	0.28	0.30	0.14	0.21	0.35	0.39	1	2	0.30	0.32	0.63
		NOx (µgL^{-1})	12	0.57	0.46	0.14	0.32	1.00	1.20	1	2	0.31	NA	NA
		PN (µgL^{-1})	12	17.02	16.82	11.95	13.49	19.10	24.53	1	2	14.00	16.00	25.00
		PO4 (µgL^{-1})	12	1.68	1.69	0.75	1.29	2.12	2.64	1	2	2.00	NA	NA
		PP (µgL^{-1})	12	2.36	2.15	1.50	1.75	3.32	3.73	1	2	2.00	2.30	3.30
		Secchi (m)	12	12.88	12.50	7.65	10.20	14.80	18.92	2	2	13.00	NA	NA
		TSS (mgL^{-1})	12	0.51	0.44	0.23	0.28	0.76	0.89	1	2	1.20	1.60	2.40
	Dunk North	DIN (µgL^{-1})	42	2.65	2.02	0.36	1.19	3.27	7.54			NA	NA	NA
		DOC (mgL^{-1})	42	978.28	921.49	713.45	810.61	1190.16	1362.27			NA	NA	NA
		DON (µgL^{-1})	42	81.72	76.02	40.24	66.91	97.72	115.75			NA	NA	NA
		DOP (µgL^{-1})	42	5.09	5.06	2.13	3.16	6.32	9.18			NA	NA	NA
		Chla (µgL^{-1})	42	0.53	0.44	0.18	0.30	0.60	1.40	1	1	0.45	NA	NA
		NOx (µgL^{-1})	42	1.47	0.96	0.01	0.22	1.62	5.16	1	2	0.35	NA	NA
		PN (µgL^{-1})	42	16.71	14.57	10.09	12.18	21.40	25.31	1	1	20.00	NA	NA
		PO4 (µgL^{-1})	42	2.09	2.19	0.65	1.18	2.84	3.30	1	2	2.00	NA	NA
		PP (µgL^{-1})	42	3.57	3.26	1.77	2.34	4.63	6.47	1	1	2.80	NA	NA
		Secchi (m)	42	5.08	5.00	2.17	3.52	6.50	8.15	2	1	10.00	NA	NA
		TSS (mgL^{-1})	42	2.25	1.37	0.50	1.03	2.38	7.59	1	1	2.00	NA	NA
	Dunk South	DIN (µgL^{-1})	12	NaN	NA	NA	NA	NA	NA			NA	NA	NA
		DOC (mgL^{-1})	12	1100.28	1047.26	903.67	962.83	1259.04	1390.16			NA	NA	NA
		DON (µgL^{-1})	12	90.36	86.67	46.18	68.26	114.19	143.70			NA	NA	NA
		DOP (µgL^{-1})	12	5.36	5.45	2.72	4.12	5.85	8.30			NA	NA	NA
		Chla (µgL^{-1})	12	0.58	0.52	0.28	0.35	0.67	1.12	1	1	0.45	NA	NA
		NOx (µgL^{-1})	12	0.64	0.36	0.14	0.16	1.09	1.61	1	2	0.35	NA	NA
		PN (µgL^{-1})	12	19.68	18.68	14.39	17.64	22.76	26.24	1	1	20.00	NA	NA
		PO4 (µgL^{-1})	12	1.98	1.79	0.88	1.44	2.66	3.25	1	2	2.00	NA	NA
		PP (µgL^{-1})	12	3.53	3.27	2.17	2.35	4.84	5.60	1	1	2.80	NA	NA
		Secchi (m)	12	7.58	7.50	2.50	4.80	10.90	12.45	2	1	10.00	NA	NA
		TSS (mgL^{-1})	12	1.84	1.10	0.29	0.52	1.89	5.93	1	1	2.00	NA	NA
	Between Tam O'Shanter and Timana	DIN (µgL^{-1})	12	NaN	NA	NA	NA	NA	NA			NA	NA	NA
		DOC (mgL^{-1})	12	1246.18	1321.56	986.09	1058.70	1374.96	1482.90			NA	NA	NA
		DON (µgL^{-1})	12	80.92	83.44	51.51	75.10	94.05	98.77			NA	NA	NA

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOf Failure	Location	Annual	Dry	Wet
		DOP (µgL^{-1})	12	5.77	5.66	2.86	4.43	6.22	9.60			NA	NA	NA
		Chla (µgL^{-1})	12	0.58	0.50	0.27	0.33	0.82	1.15	1	1	0.45	NA	NA
		NOx (µgL^{-1})	12	3.32	0.80	0.14	0.15	5.49	13.13	1	2	0.35	NA	NA
		PN (µgL^{-1})	12	23.15	24.24	10.05	16.50	27.33	36.70	1	1	20.00	NA	NA
		PO4 (µgL^{-1})	12	2.13	2.22	0.86	1.56	2.85	3.25	1	2	2.00	NA	NA
		PP (µgL^{-1})	12	4.50	3.93	2.72	3.36	4.93	7.81	1	1	2.80	NA	NA
		Secchi (m)	12	4.54	4.50	1.82	2.70	5.90	7.40	2	1	10.00	NA	NA
		TSS (mgL^{-1})	12	2.47	1.33	0.38	0.76	2.67	8.02	1	1	2.00	NA	NA
	Bedarra	DIN (µgL^{-1})	12	NaN	NA	NA	NA	NA	NA			NA	NA	NA
		DOC (mgL^{-1})	12	1148.80	1082.99	931.05	1020.36	1334.10	1395.80			NA	NA	NA
		DON (µgL^{-1})	12	81.12	83.60	50.90	75.16	93.91	97.00			NA	NA	NA
		DOP (µgL^{-1})	12	6.25	5.63	3.79	4.50	6.31	11.93			NA	NA	NA
		Chla (µgL^{-1})	12	0.55	0.53	0.27	0.36	0.63	1.02	1	1	0.45	NA	NA
		NOx (µgL^{-1})	12	0.91	0.61	0.14	0.21	1.21	2.47	1	2	0.35	NA	NA
		PN (µgL^{-1})	12	21.63	22.44	11.86	16.29	27.15	30.60	1	1	20.00	NA	NA
		PO4 (µgL^{-1})	12	1.99	1.81	1.12	1.55	2.46	3.10	1	2	2.00	NA	NA
		PP (µgL^{-1})	12	4.01	3.88	2.57	3.20	4.98	5.45	1	1	2.80	NA	NA
		Secchi (m)	12	5.29	5.50	1.55	2.80	7.80	8.72	2	1	10.00	NA	NA
		TSS (mgL^{-1})	12	1.87	0.98	0.49	0.62	3.35	4.74	1	1	2.00	NA	NA
	Tully Mouth Mooring	DIN (µgL^{-1})	18	28.13	28.13	28.13	28.13	28.13	28.13			NA	NA	NA
		DOC (mgL^{-1})	18	1271.52	1312.72	1063.42	1094.25	1378.95	1511.37			NA	NA	NA
		DON (µgL^{-1})	18	88.17	85.48	53.20	73.18	107.54	128.01			NA	NA	NA
		DOP (µgL^{-1})	18	6.55	6.00	3.57	4.64	7.54	11.88			NA	NA	NA
		Chla (µgL^{-1})	18	0.96	0.84	0.32	0.53	1.23	1.93	1	2	1.10	0.32	0.63
		NOx (µgL^{-1})	18	7.46	1.86	0.20	0.28	18.55	24.08	1	2	3.00	NA	NA
		PO4 (µgL^{-1})	18	2.53	2.11	1.04	1.61	3.45	5.00	1	2	3.00	NA	NA
		Secchi (m)	18	3.22	3.00	0.88	1.50	4.50	7.00	2	2	1.60	NA	NA
		TSS (mgL^{-1})	18	5.25	2.59	0.95	1.45	9.07	11.90	1	2	5.00	1.60	2.40
Burdekin	Palms West	DIN (µgL^{-1})	43	2.66	1.70	0.65	1.17	3.02	8.38			NA	NA	NA
		DOC (mgL^{-1})	43	869.17	866.66	657.19	740.24	980.49	1100.72			NA	NA	NA
		DON (µgL^{-1})	43	77.42	78.31	30.28	59.38	98.05	109.74			NA	NA	NA
		DOP (µgL^{-1})	43	5.22	5.19	1.84	3.09	6.19	7.17			NA	NA	NA

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOf Failure	Location	Annual	Dry	Wet
		Chla (μgL^{-1})	43	0.40	0.37	0.17	0.23	0.54	0.74	1	2	0.35	0.32	0.63
		NOx (μgL^{-1})	43	1.44	0.91	0.14	0.49	2.39	2.89	1	2	0.28	NA	NA
		PN (μgL^{-1})	43	13.38	12.34	8.16	9.74	17.68	22.41	1	2	12.00	16.00	25.00
		PO4 (μgL^{-1})	43	2.28	2.22	0.76	1.36	3.06	3.84	1	2	1.00	NA	NA
		PP (μgL^{-1})	43	2.18	2.08	1.34	1.57	2.61	3.45	1	2	2.20	2.30	3.30
		Secchi (m)	43	9.07	9.00	4.00	6.00	11.40	15.35	2	1	10.00	NA	NA
		TSS (mgL^{-1})	43	0.82	0.66	0.19	0.36	1.21	1.97	1	2	1.20	1.60	2.40
	Pandora	DIN (μgL^{-1})	46	3.12	2.62	0.61	1.52	5.31	6.70			NA	NA	NA
		DOC (mgL^{-1})	46	910.38	873.45	672.24	762.41	1051.08	1217.23			NA	NA	NA
		DON (μgL^{-1})	46	82.25	80.20	41.64	70.50	94.68	105.70			NA	NA	NA
		DOP (μgL^{-1})	46	5.03	4.76	1.16	2.38	6.92	8.50			NA	NA	NA
		Chla (μgL^{-1})	46	0.38	0.33	0.16	0.25	0.52	0.76	1	2	0.35	0.32	0.63
		NOx (μgL^{-1})	46	1.88	1.40	0.01	0.31	3.58	5.25	1	2	0.28	NA	NA
		PN (μgL^{-1})	46	14.27	12.80	9.31	10.47	17.47	21.18	1	2	12.00	16.00	25.00
		PO4 (μgL^{-1})	46	2.51	2.53	1.00	1.44	3.29	4.25	1	2	1.00	NA	NA
		PP (μgL^{-1})	46	2.67	2.45	1.68	1.97	3.17	4.10	1	2	2.20	2.30	3.30
		Secchi (m)	46	6.89	6.00	3.62	4.50	9.00	12.12	2	1	10.00	NA	NA
		TSS (mgL^{-1})	46	1.23	0.93	0.31	0.63	1.48	2.76	1	2	1.20	1.60	2.40
	Magnetic	DIN (μgL^{-1})	46	4.97	3.18	0.82	1.41	8.93	11.40			NA	NA	NA
		DOC (mgL^{-1})	46	962.06	960.52	707.11	812.35	1120.94	1246.40			NA	NA	NA
		DON (μgL^{-1})	46	81.77	85.70	39.70	59.14	102.60	110.82			NA	NA	NA
		DOP (μgL^{-1})	46	5.09	4.79	1.55	3.16	6.89	8.44			NA	NA	NA
		Chla (μgL^{-1})	46	0.58	0.49	0.26	0.32	0.75	0.94	1	2	0.59	0.32	0.63
		NOx (μgL^{-1})	46	2.79	1.80	0.10	0.60	4.82	8.25	1	2	0.28	NA	NA
		PN (μgL^{-1})	46	17.66	16.64	11.14	13.06	19.96	29.49	1	2	17.00	16.00	25.00
		PO4 (μgL^{-1})	46	3.05	2.88	1.18	1.85	4.15	5.22	1	2	1.00	NA	NA
		PP (μgL^{-1})	46	3.68	3.51	1.88	2.49	4.37	6.01	1	1	2.80	NA	NA
		Secchi (m)	46	4.59	4.50	2.00	2.70	6.50	8.15	2	2	4.00	NA	NA
		TSS (mgL^{-1})	46	2.04	1.58	0.57	0.91	2.77	4.14	1	2	1.90	1.60	2.40
	Haughton	DIN (μgL^{-1})	8	NaN	NA	NA	NA	NA	NA			NA	NA	NA
		DOC (mgL^{-1})	8	1173.66	1127.34	1036.09	1046.46	1329.60	1346.21			NA	NA	NA
		DON (μgL^{-1})	8	100.89	98.67	68.99	79.81	122.12	136.77			NA	NA	NA

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOf Failure	Location	Annual	Dry	Wet
		DOP (µgL⁻¹)	8	5.21	5.40	3.81	4.30	5.98	6.48			NA	NA	NA
		Chla (µgL⁻¹)	8	0.43	0.40	0.26	0.33	0.50	0.66	1	1	0.45	NA	NA
		NOx (µgL⁻¹)	8	0.48	0.49	0.16	0.19	0.73	0.82	1	2	1.00	NA	NA
		PN (µgL⁻¹)	8	15.54	14.39	12.61	13.71	16.43	21.27	1	2	13.00	16.00	25.00
		PO4 (µgL⁻¹)	8	1.09	1.11	0.40	0.66	1.51	1.75	1	2	2.00	NA	NA
		PP (µgL⁻¹)	8	3.07	3.20	2.30	2.56	3.53	3.72	1	2	2.10	2.30	3.30
		Secchi (m)	8	6.81	7.00	4.50	4.90	8.00	9.30	2	1	10.00	NA	NA
		TSS (mgL⁻¹)	8	1.26	1.10	0.84	0.86	1.56	2.00	1	2	1.20	1.60	2.40
	Yongala	DIN (µgL⁻¹)	21	NaN	NA	NA	NA	NA	NA			NA	NA	NA
		DOC (mgL⁻¹)	21	1106.77	1042.31	909.67	974.22	1282.44	1367.97			NA	NA	NA
		DON (µgL⁻¹)	21	103.43	100.69	66.37	88.26	111.87	156.02			NA	NA	NA
		DOP (µgL⁻¹)	21	5.06	5.29	3.31	4.13	6.05	6.29			NA	NA	NA
		Chla (µgL⁻¹)	21	0.26	0.25	0.10	0.15	0.32	0.46	1	2	0.33	0.32	0.63
		NOx (µgL⁻¹)	21	0.76	0.39	0.14	0.14	1.14	2.78	1	2	0.28	NA	NA
		PN (µgL⁻¹)	21	11.80	11.19	7.34	9.84	13.12	19.98	1	2	14.00	16.00	25.00
		PO4 (µgL⁻¹)	21	1.32	1.49	0.31	0.65	1.79	2.05	1	2	1.00	NA	NA
		PP (µgL⁻¹)	21	1.73	1.50	1.07	1.25	2.00	3.31	1	2	2.00	2.30	3.30
		Secchi (m)	21	15.07	13.00	11.00	12.00	18.20	20.25	2	1	10.00	NA	NA
		TSS (mgL⁻¹)	21	0.35	0.33	0.02	0.12	0.48	0.85	1	2	0.80	1.60	2.40
	Burdekin Mouth Mooring	DIN (µgL⁻¹)	9	NaN	NA	NA	NA	NA	NA			NA	NA	NA
		DOC (mgL⁻¹)	9	1238.77	1209.73	1110.26	1161.73	1272.45	1443.30			NA	NA	NA
		DON (µgL⁻¹)	9	105.11	98.83	69.12	87.76	105.71	167.18			NA	NA	NA
		DOP (µgL⁻¹)	9	5.24	5.24	2.91	4.47	6.71	6.93			NA	NA	NA
		Chla (µgL⁻¹)	9	0.90	0.65	0.40	0.52	0.95	2.01	1	2	1.00	0.32	0.63
		NOx (µgL⁻¹)	9	1.11	1.10	0.17	0.40	1.68	2.18	1	2	4.00	NA	NA
		PO4 (µgL⁻¹)	9	1.61	1.60	0.58	1.20	2.26	2.37	1	2	1.00	NA	NA
		Secchi (m)	9	4.12	4.25	2.17	2.90	4.80	6.30	2	2	1.50	NA	NA
		TSS (mgL⁻¹)	9	2.26	1.83	0.78	1.24	3.32	4.66	1	2	2.00	1.60	2.40
Mackay Whitsunday	Double Cone	DIN (µgL⁻¹)	43	2.75	1.73	0.85	1.05	3.25	8.78			NA	NA	NA
		DOC (mgL⁻¹)	43	880.86	863.20	627.94	736.56	1075.85	1133.81			NA	NA	NA
		DON (µgL⁻¹)	43	79.36	76.85	47.07	58.71	98.29	121.01			NA	NA	NA
		DOP (µgL⁻¹)	43	5.09	4.30	2.10	3.44	5.77	8.67			NA	NA	NA

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOf Failure	Location	Annual	Dry	Wet
		Chla (µgL^{-1})	43	0.52	0.44	0.18	0.27	0.69	1.09	1	2	0.36	0.32	0.63
		NOx (µgL^{-1})	43	1.61	1.10	0.08	0.51	1.94	4.28	1	2	1.00	NA	NA
		PN (µgL^{-1})	43	15.98	13.65	8.89	11.32	19.74	30.23	1	1	14.00	NA	NA
		PO4 (µgL^{-1})	43	2.87	2.96	1.00	1.87	3.76	4.69	1	2	1.00	NA	NA
		PP (µgL^{-1})	43	3.03	2.72	1.56	1.95	3.89	5.54	1	2	2.30	2.30	3.30
		Secchi (m)	43	5.92	6.00	2.88	4.00	7.00	10.62	2	1	10.00	NA	NA
		TSS (mgL^{-1})	43	1.83	1.40	0.51	0.88	2.46	4.36	1	2	1.40	1.60	2.40
	Pine	DIN (µgL^{-1})	44	6.17	3.31	0.80	1.57	8.34	24.46			NA	NA	NA
		DOC (mgL^{-1})	44	879.28	878.55	633.42	758.83	1012.69	1162.32			NA	NA	NA
		DON (µgL^{-1})	44	82.84	80.11	50.64	60.02	98.37	125.00			NA	NA	NA
		DOP (µgL^{-1})	44	4.99	4.19	2.11	3.45	6.71	8.19			NA	NA	NA
		Chla (µgL^{-1})	44	0.63	0.57	0.37	0.46	0.76	1.04	1	2	0.36	0.32	0.63
		NOx (µgL^{-1})	44	3.97	2.22	0.18	0.51	5.63	13.34	1	2	1.00	NA	NA
		PN (µgL^{-1})	44	15.05	13.85	10.19	11.91	18.01	19.84	1	1	14.00	NA	NA
		PO4 (µgL^{-1})	44	3.62	3.30	1.50	2.50	4.86	6.36	1	2	1.00	NA	NA
		PP (µgL^{-1})	44	3.54	2.92	2.06	2.45	4.19	7.06	1	2	2.30	2.30	3.30
		Secchi (m)	44	4.94	5.00	1.50	3.00	7.00	9.00	2	1	10.00	NA	NA
		TSS (mgL^{-1})	44	3.68	2.41	0.87	1.33	5.61	10.91	1	2	1.40	1.60	2.40
	Seaforth	DIN (µgL^{-1})	19	NaN	NA	NA	NA	NA	NA			NA	NA	NA
		DOC (mgL^{-1})	19	1042.55	1040.84	883.04	956.12	1135.26	1219.97			NA	NA	NA
		DON (µgL^{-1})	19	85.26	89.00	46.74	58.74	94.56	134.22			NA	NA	NA
		DOP (µgL^{-1})	19	4.89	4.91	2.76	3.57	6.00	6.99			NA	NA	NA
		Chla (µgL^{-1})	19	0.65	0.56	0.32	0.44	0.83	1.28	1	2	0.36	0.32	0.63
		NOx (µgL^{-1})	19	2.76	1.87	0.52	1.29	3.20	7.82	1	2	1.00	NA	NA
		PN (µgL^{-1})	19	19.74	19.56	12.17	16.48	22.05	28.41	1	1	14.00	NA	NA
		PO4 (µgL^{-1})	19	2.72	2.60	1.45	1.65	3.40	4.60	1	2	1.00	NA	NA
		PP (µgL^{-1})	19	4.08	3.75	2.67	3.08	4.77	6.70	1	2	2.30	2.30	3.30
		Secchi (m)	19	4.31	4.50	2.44	3.60	5.00	6.00	2	1	10.00	NA	NA
		TSS (mgL^{-1})	19	2.80	2.22	1.12	1.53	3.53	5.93	1	2	1.40	1.60	2.40
	O'Connell Mouth	DIN (µgL^{-1})	12	NaN	NA	NA	NA	NA	NA			NA	NA	NA
		DOC (mgL^{-1})	12	1433.07	1370.94	1051.63	1226.05	1644.28	1870.64			NA	NA	NA

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOf Failure	Location	Annual	Dry	Wet
		DON (μgL^{-1})	12	111.00	114.23	73.66	91.64	129.48	142.78			NA	NA	NA
		DOP (μgL^{-1})	12	6.55	5.57	4.48	4.77	7.33	10.79			NA	NA	NA
		Chla (μgL^{-1})	12	1.23	1.10	0.23	0.69	1.45	2.69	1	2	1.30	0.32	0.63
		NOx (μgL^{-1})	12	1.50	0.56	0.14	0.14	2.50	4.31	1	2	4.00	NA	NA
		PO4 (μgL^{-1})	12	4.19	4.41	0.65	2.70	5.38	7.08	1	2	3.00	NA	NA
		Secchi (m)	12	3.77	3.50	1.50	1.80	5.40	6.90	2	2	1.60	NA	NA
		TSS (mgL^{-1})	12	3.10	2.39	0.77	1.46	3.60	7.34	1	2	5.00	1.60	2.40
	Repulse	DIN (μgL^{-1})	19	NaN	NA	NA	NA	NA	NA			NA	NA	NA
		DOC (mgL^{-1})	19	1156.38	1126.22	913.02	1016.87	1349.52	1415.36			NA	NA	NA
		DON (μgL^{-1})	19	107.25	90.60	53.55	83.93	110.49	209.34			NA	NA	NA
		DOP (μgL^{-1})	19	5.69	5.42	3.80	4.47	6.57	8.31			NA	NA	NA
		Chla (μgL^{-1})	19	0.81	0.71	0.47	0.61	0.99	1.31	1	1	0.45	NA	NA
		NOx (μgL^{-1})	19	2.91	2.32	0.18	0.52	4.05	8.32	1	2	0.25	NA	NA
		PN (μgL^{-1})	19	24.78	25.03	16.86	18.79	29.51	34.91	1	2	18.00	16.00	25.00
		PO4 (μgL^{-1})	19	3.37	3.43	1.15	2.75	4.40	4.94	1	2	2.00	NA	NA
		PP (μgL^{-1})	19	5.98	5.44	3.45	4.35	7.98	8.55	1	2	2.10	2.30	3.30
		Secchi (m)	19	3.02	2.50	1.50	1.55	4.50	5.00	2	1	10.00	NA	NA
		TSS (mgL^{-1})	19	5.24	4.41	1.39	2.31	8.67	11.39	1	2	1.60	1.60	2.40

Table E-5: Summary of turbidity (NTU) data from ECO FLNTUSB instruments. N = number of daily means in the annual time series (October to September); SE = standard error; “% d> guideline values (GV)” refers to the percentage of days within the annual record with mean values above the GVs in the GBRMPA Water Quality Guidelines for the Great Barrier Reef Marine Park (GBRMPA, 2010). Red shading highlights the annual means that are above GV. The turbidity GV (1.5 NTU) was derived by transforming the TSS GV in the Guidelines (2 mg L^{-1}) using an equation based on a comparison between direct water samples and instrumental turbidity readings (see Appendix B). “% 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.

		Oct2007 - Sept2008						Oct2008 - Sept2009						Oct2009 - Sept2010					
Region	Reef	N	Annual Mean	SE	Annual Median	%d > Trigger	%d > 5 Trigger	N	Annual Mean	SE	Annual Median	%d > Trigger	%d > 5 Trigger	N	Annual Mean	SE	Annual Median	%d > Trigger	%d > 5 Trigger
Johnstone Russell Mulgrave	Fitzroy West	251	0.85	0.05	0.7	21.29	0.8	228	0.89	0.09	0.7	17.34	0.58	365	0.88	0.05	0.67	21.63	1.12
	Franklands West	357	0.49	0.01	0.42	21.57	0	365	0.63	0.02	0.54	35.07	0	352	0.71	0.03	0.52	40.91	0.57
	High West	356	0.81	0.03	0.67	19.1	0.56	365	0.84	0.03	0.69	22.47	0.27	365	1.2	0.07	0.78	32.33	2.74
	Russell Mulgrave Mouth Mooring																		
Tully Herbert	Dunk North	277	2.17	0.16	1.06	54.51	13	246	2.34	0.2	1.19	62.3	9.43	130	3.09	0.31	1.39	70.77	17.69
	Tully Mouth Mooring																		
Burdekin	Burdekin Mouth Mooring																		
	Magnetic	269	2.07	0.17	1.09	41.73	8.65	365	2.33	0.24	1.31	50.41	7.67	291	1.79	0.09	1.26	47.42	4.81
	Palms West	258	0.5	0.01	0.48	2.71	0	365	0.74	0.04	0.56	15.07	0.55	365	0.6	0.03	0.52	9.09	0.55
	Pandora	358	0.96	0.04	0.71	40.78	1.12	365	1.17	0.14	0.74	41.37	2.19	365	1.1	0.05	0.85	56.16	1.1
Mackay Whitsunday	Double Cone	199	1.15	0.07	0.84	26.63	2.01	273	1.42	0.07	0.99	43.96	1.83	360	1.74	0.09	1.19	54.72	2.5
	Pine	296	3.12	0.18	2.2	81.42	14.86	365	3.12	0.15	2.18	79.58	17.99	276	3.5	0.27	1.8	78.68	17.44
	Repulse																		
	Seaforth																		

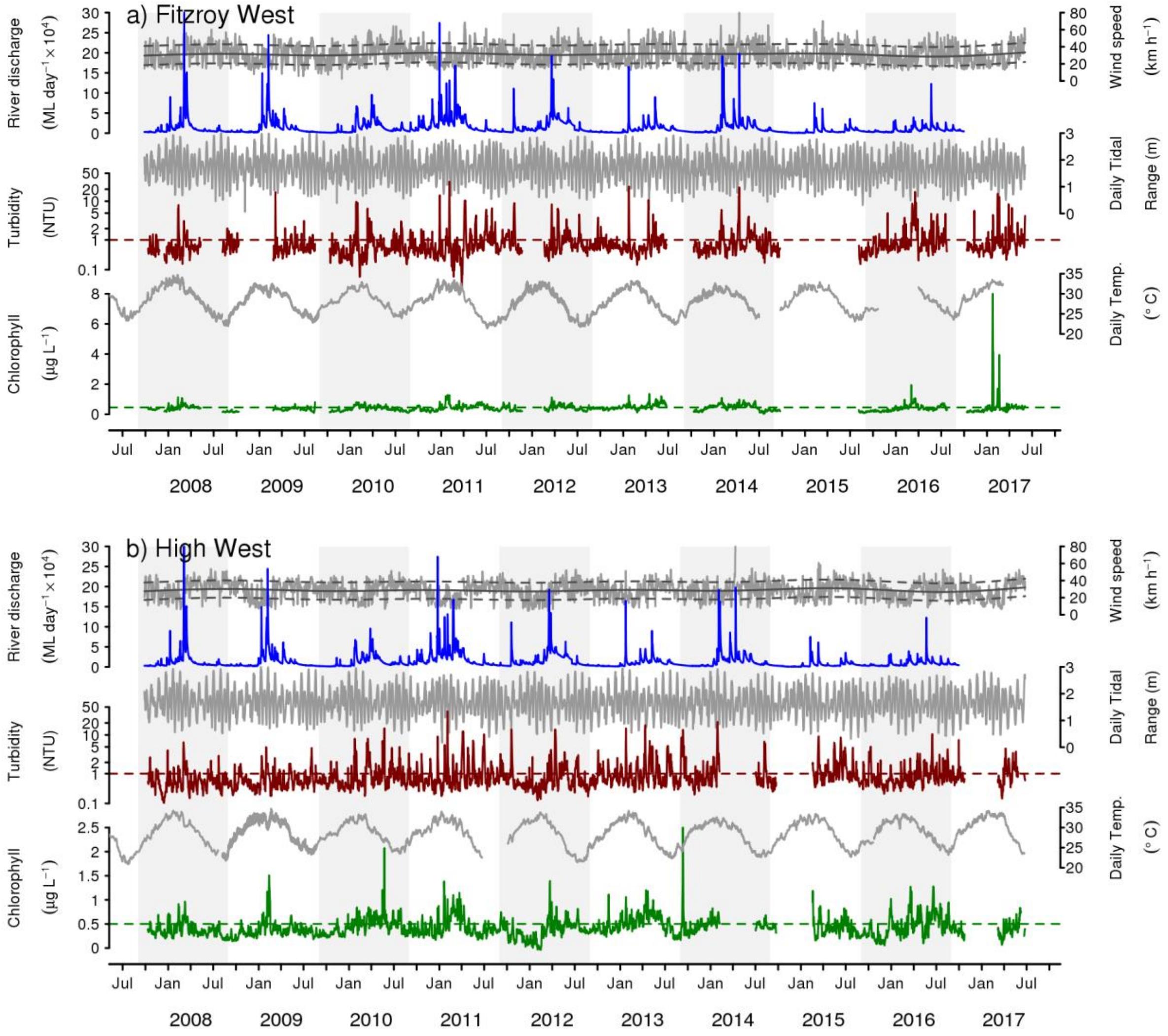

Figure E-1: Time series of daily means of chlorophyll (green line) and turbidity (red line) collected by ECO FLNTUSB instruments; a) Fitzroy West; b) High West. Additional panels represent daily discharge from nearest rivers (blue line) and daily wind speeds (grey line) from the nearest weather stations. Horizontal green and red lines are the GBR Water Quality Guidelines values (GBRMPA, 2010). Turbidity guideline values (GV) (red line, 1.5 NTU) were derived by transforming the suspended solids GV (see Schaffelke et al., 2009). Plots represent locations of FLNTUUSB instruments.

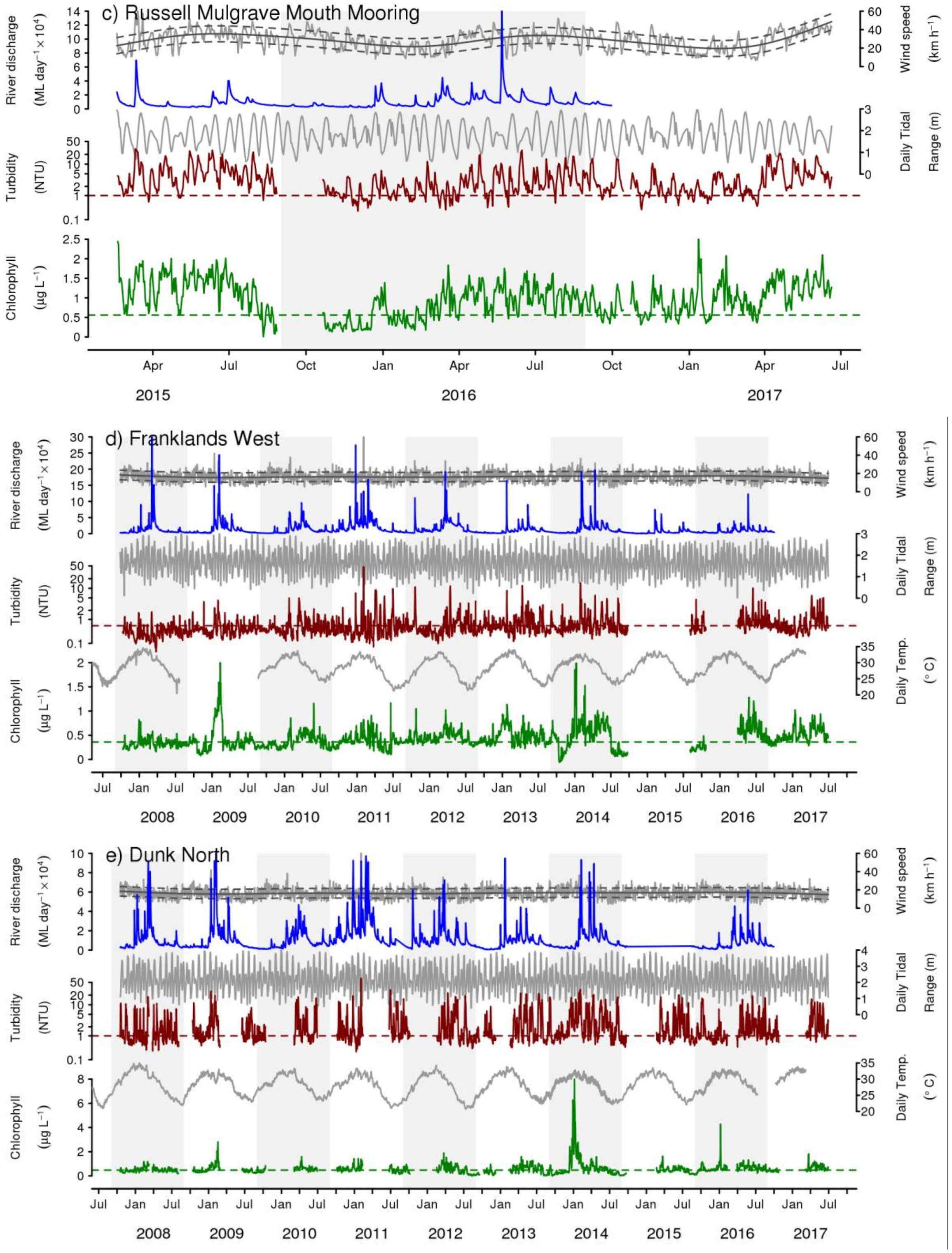

Figure E-1: Continued - c) Russell-Mulgrave Mouth Mooring, d) Franklands West, e) Dunk North.

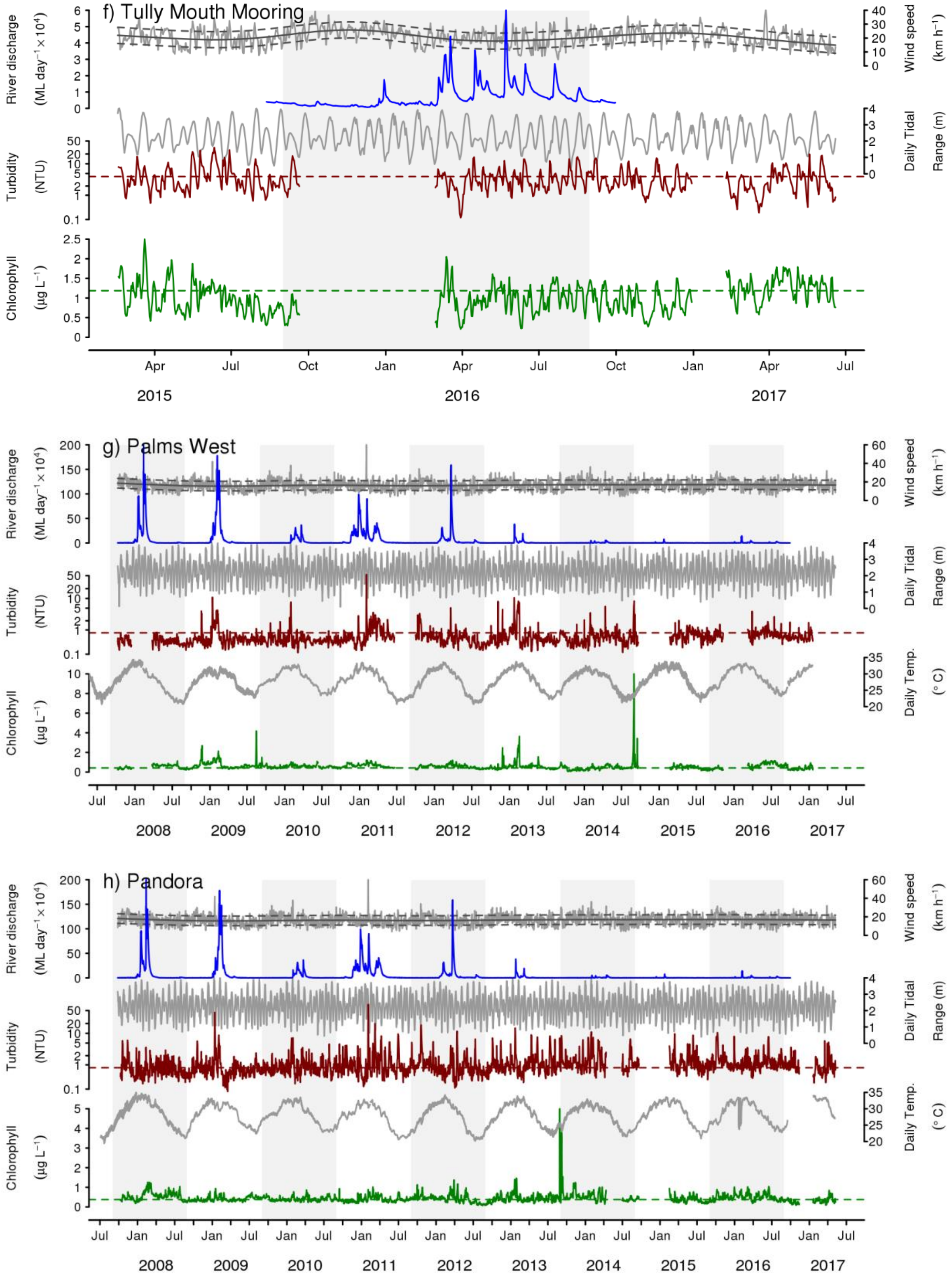

Figure E-1: Continued - f) Tully Mouth Mooring, g) Palms West, h) Pandora.

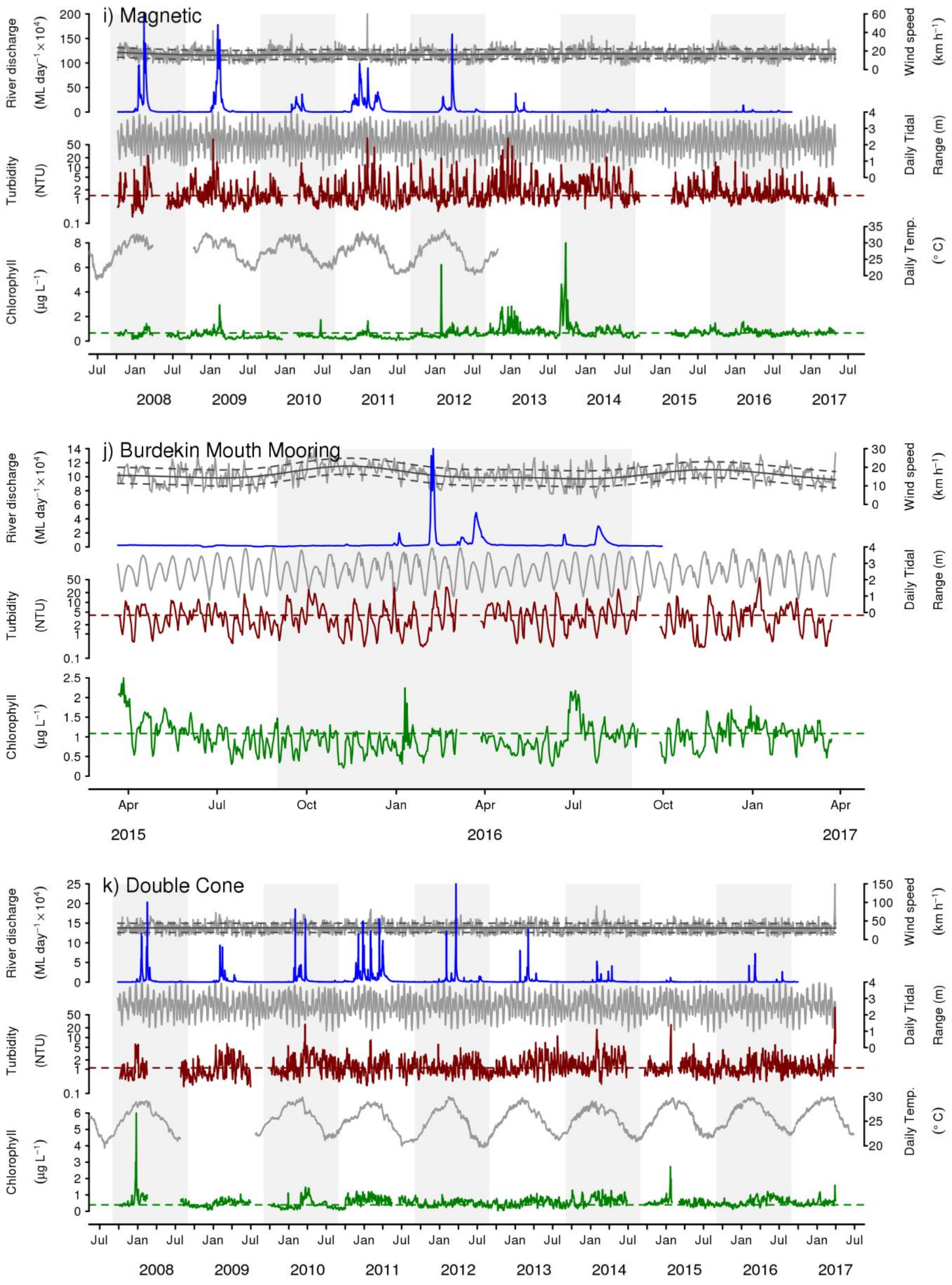

Figure E-1: Continued - i) Magnetic, j) Burdekin Mouth Mooring, k) Double Cone.

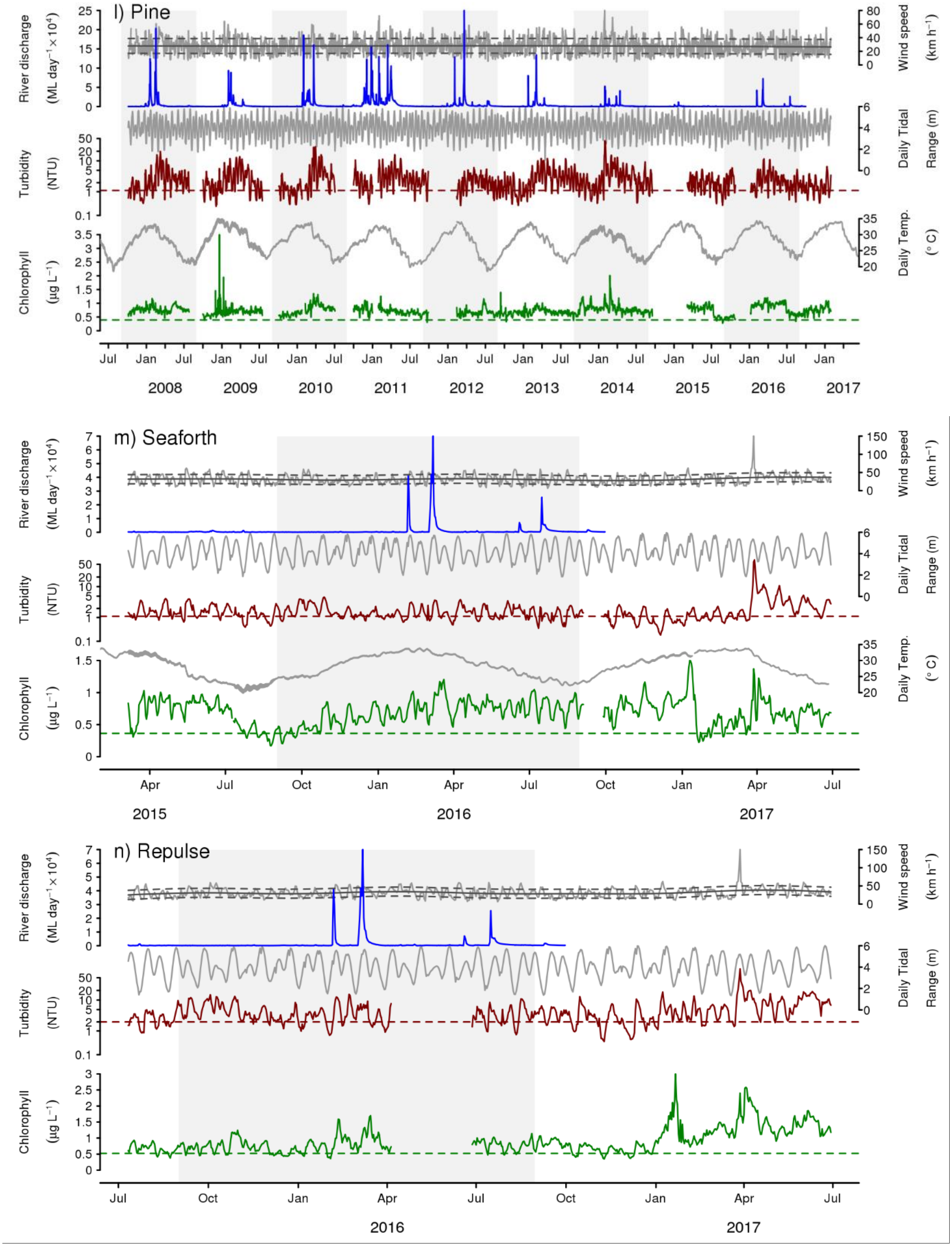

Figure E-1: Continued - l) Pine, m) Seaforth, n) Repulse.

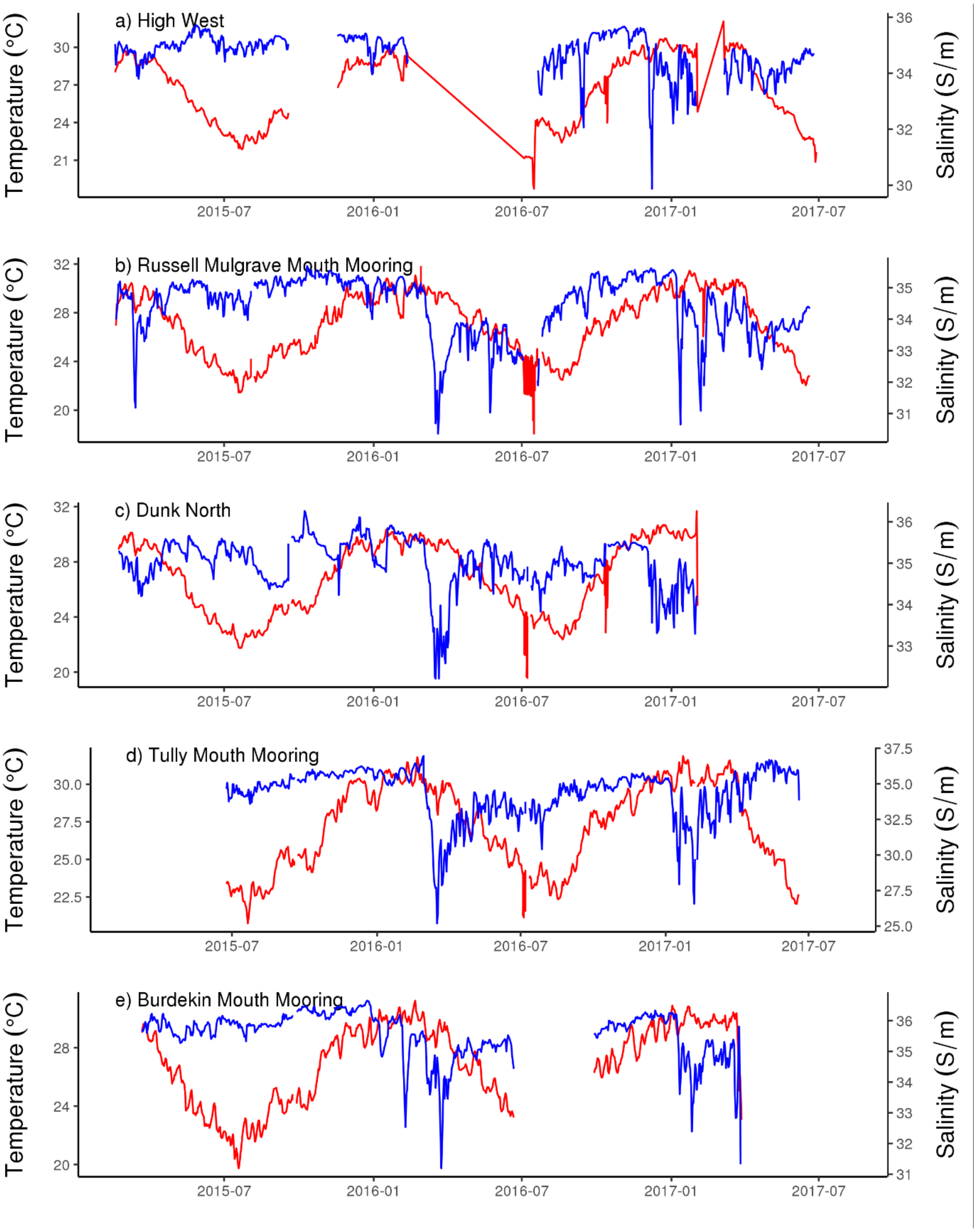

Figure E-2: Time series of daily means of temperature (red line) and salinity (blue line) derived from the Sea-Bird Electronics (SBE) CTD profilers. Plots represent locations of SBE CTD profilers; a) High West; b) Russel Mulgrave Mouth Mooring; c) Dunk North; d) Tully River Mouth Mooring; e) Burdekin Mouth Mooring.

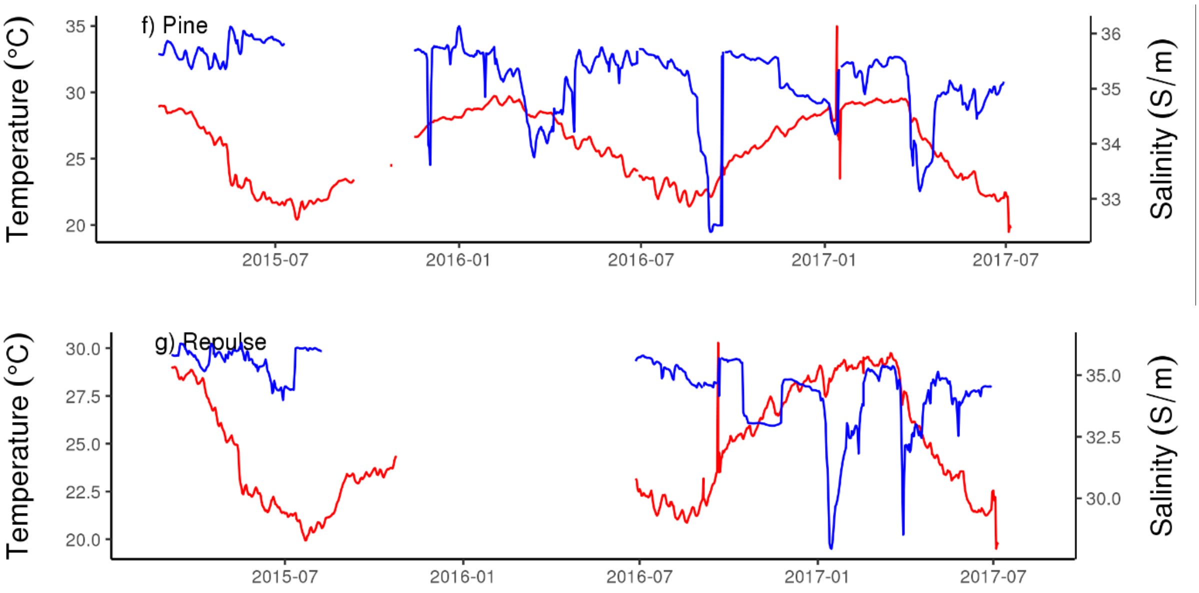

Figure E-2: Continued - f) Pine, g) Repulse.

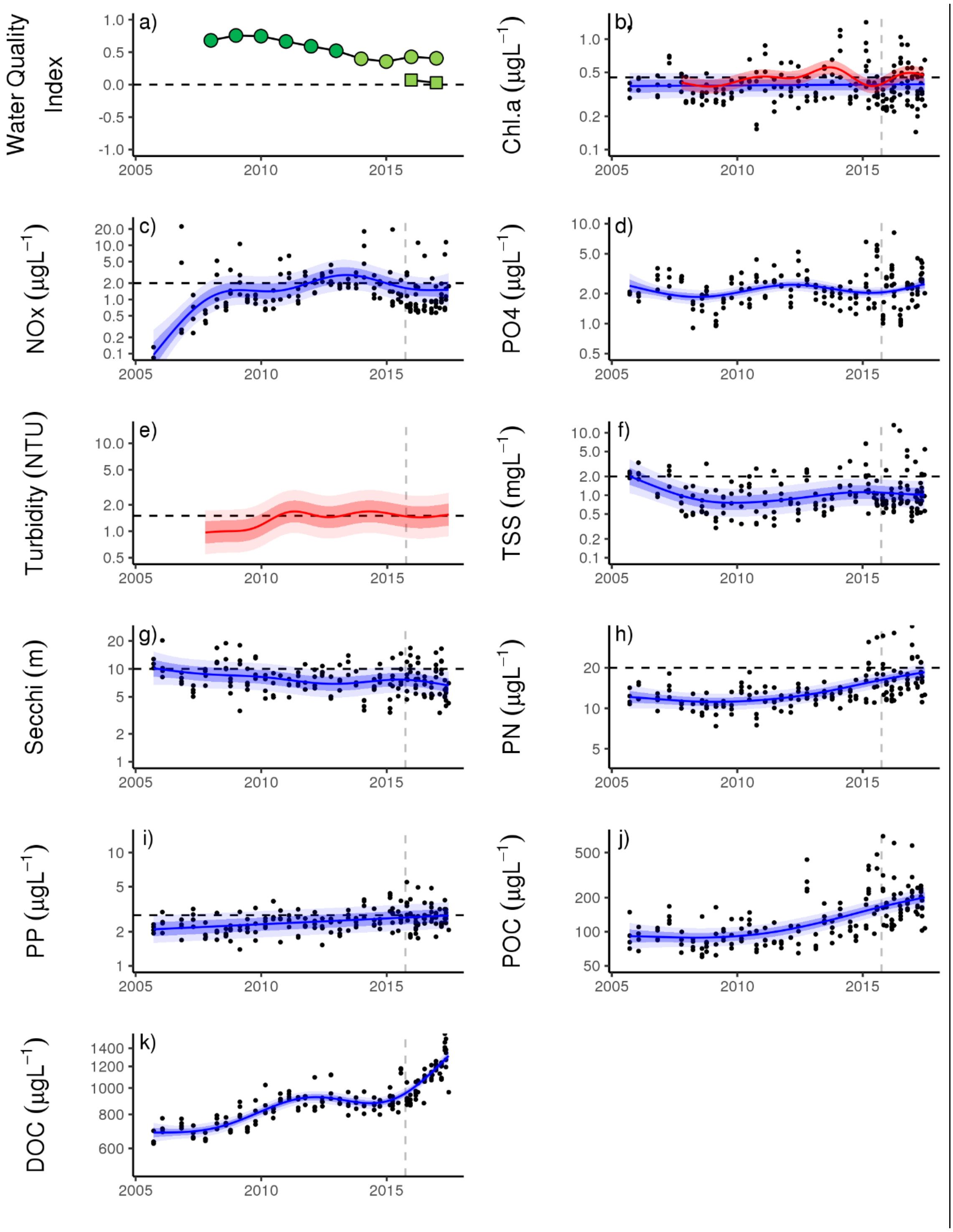

Figure E-3: Temporal trends in water quality for the Russell-Mulgrave sub-region. a) Water Quality Index b) Chl-a , c) nitrate/nitrite, d) phosphate, e) turbidity, f) TSS, g) Secchi depth, h) PN, i) PP, j) POC and k) DOC. Water Quality Index colour coding: dark green – 'very good'; light green – 'good'; yellow – 'moderate; orange – 'poor'; red – 'very poor. Note that from 2015-16 onwards a separate score for AIMS data was calculated using the wet/dry guidelines that are shown as two separate points in Figure E-3a. The calculations are described in Appendix D-6. 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, black dots represent the observed data. Trends of records from ECO FLNTUSB instruments are represented in red, individual records are not displayed. Dashed horizontal reference lines indicate yearly guideline values and the vertical dashed lines represent when the sampling design was changed (February 2015), both lines are only shown for reference.

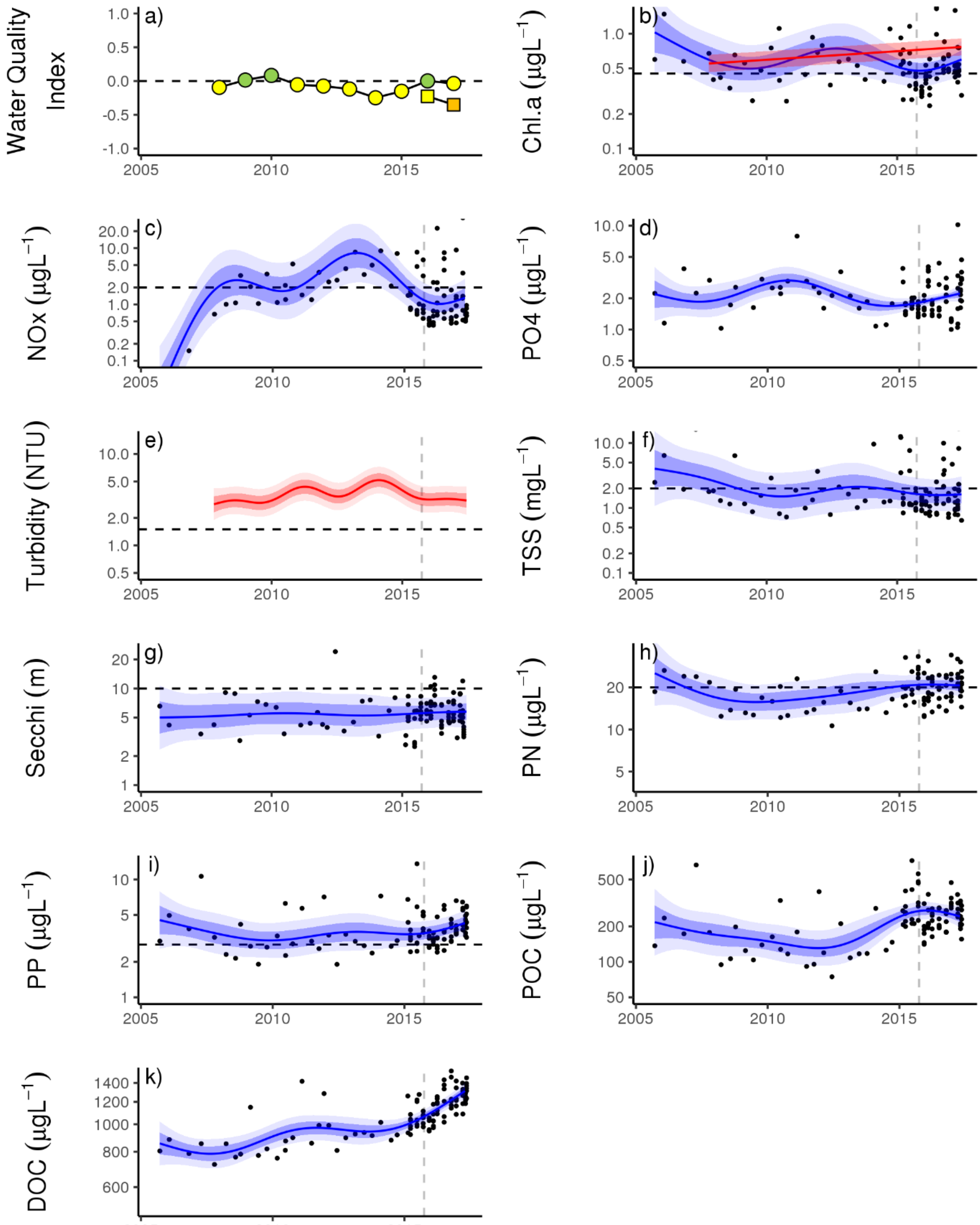

Figure E-4: Temporal trends in water quality for the Tully sub-region. a) Water Quality Index, b) Chl-a, c) nitrate/nitrite, d) phosphate, e) turbidity, f) TSS, g) Secchi depth, h) PN, i) PP, j) POC and k) DOC. Water Quality Index colour coding: dark green –'very good'; light green – 'good'; yellow – 'moderate; orange – 'poor'; red – 'very poor'. Note that from 2015-16 onwards a separate score for AIMS data was calculated using the wet/dry guidelines that are shown as two separate points in Figure E-4a. The calculations are described in Appendix D-6. 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, black dots represent the observed data. Trends of records from ECO FLNTUSB instruments are represented in red, individual records are not displayed. Dashed horizontal reference lines indicate yearly guideline values and the vertical dashed lines represent when the sampling design was changed (Feb-2015), both lines are only shown for reference.

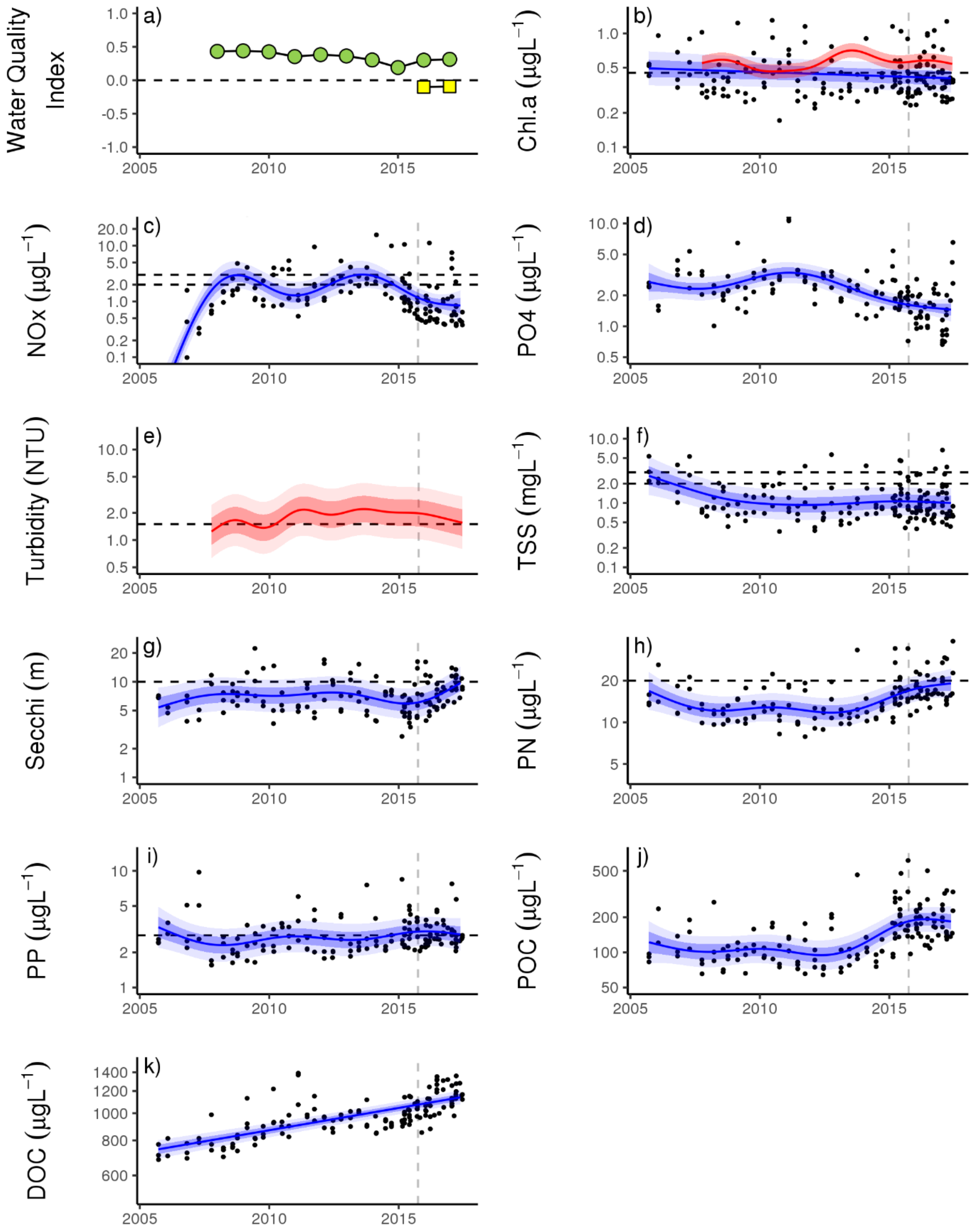

Figure E-5: Temporal trends in water quality for the Burdekin focus area. a) Water Quality Index, b) Chl-a, c) nitrate/nitrite, d) phosphate, e) turbidity, f) TSS, g) Secchi depth, h) PN, i) PP, j) POC and k) DOC. Water Quality Index colour coding: dark green- 'very good'; light green- 'good'; yellow – 'moderate; orange – 'poor'; red – 'very poor'. Note that from 2015-16 onwards a separate score for AIMS data was calculated using the wet/dry guidelines that are shown as two separate points in Figure E-5a.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, black dots represent the observed data. Trends of records from ECO FLNTUSB instruments are represented in red, individual records are not displayed. Dashed horizontal reference lines indicate yearly guideline values and the vertical dashed lines represent when the sampling design was changed (Feb-2015), both lines are only shown for reference.

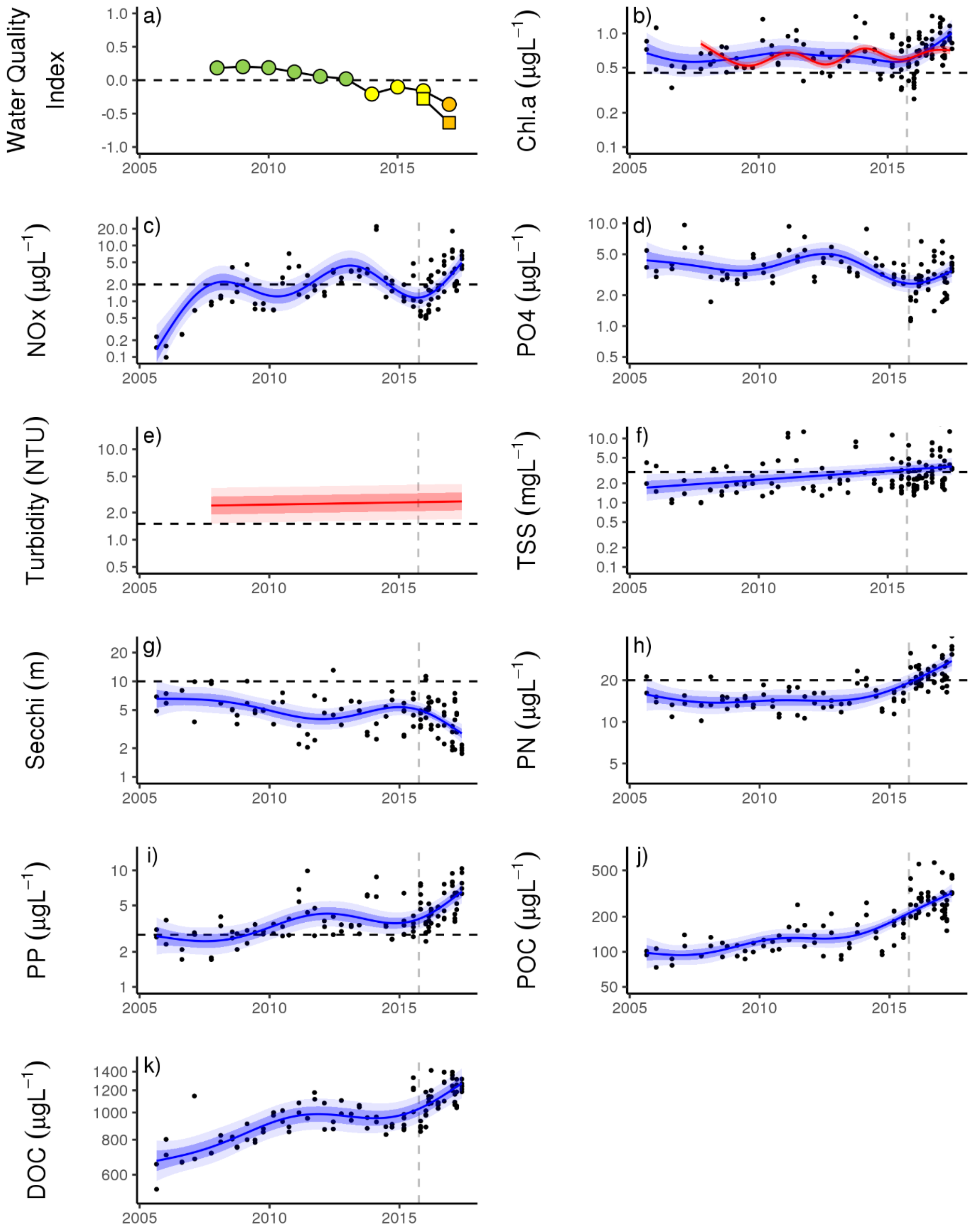

Figure E-6: Temporal trends in water quality for the Mackay Whitsunday focus-region. a) Water Quality Index, b) Chl-a, c) nitrate/nitrite, d) phosphate, e) turbidity, f) TSS, g) Secchi depth, h) PN, i) PP, j) POC and k) DOC. Water Quality Index colour coding: dark green – 'very good'; light green – 'good'; yellow – 'moderate; orange – 'poor'; red – 'very poor'. Note that from 2015-16 onwards a separate score for AIMS data was calculated using the wet/dry guidelines that are shown as two separate points in Figure E-6a, 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, black dots represent the observed data. Trends of records from ECO FLNTUSB instruments are represented in red, individual records are not displayed. Dashed horizontal reference lines indicate yearly guideline values and the vertical dashed lines represent when the sampling design was changed (Feb-2015), both lines are only shown for reference.

Table E-6: Summary of water quality data collected GBR-wide 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})	Secchi depth (m)	DIN (µg L^{-1})	DIP (µg L^{-1})	PP (µg L^{-1})	PN (µg L^{-1})
GBR-wide	multi-annual	CC1	mean	46.03	2.63	1.89	0.82	72.99	23.12	29.21	123.52
			SD	71.74	4.06	1.32	0.80	52.32	25.31	37.74	111.62
			min	1.40	0.20	0.00	0.20	2.00	1.00	0.00	4.00
			max	430.00	26.70	6.03	3.60	325.00	98.00	167.00	573.00
			count	75	83	59	25	71	74	71	73
	2016-17	CC1	mean	38.90	2.30	1.20	0.70	66.00	8.30	24.30	112.30
			SD	35.10	2.30	0.80	1.10	48.60	6.80	10.00	101.70
			min	2.50	0.20	0.00	0.20	4.00	3.00	3.00	19.00
			max	110.00	6.80	2.20	3.60	128.00	25.00	35.00	290.00
			count	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
	multi-annual	CC2	mean	20.62	1.52	1.03	1.67	62.29	12.93	11.51	54.17
			SD	27.60	1.10	0.74	2.75	53.52	16.57	13.10	71.48
			min	0.43	0.20	0.03	0.00	2.00	2.00	0.00	1.00
			max	150.00	5.34	4.40	12.00	237.00	80.00	73.00	282.00
			count	63	61	51	16	52	54	53	51
	2016-17	CC2	mean	18.70	1.40	0.20	1.30	15.40	5.30	10.30	29.30
			SD	14.40	0.20	0.20	0.00	12.50	3.40	9.70	23.70
			min	7.10	1.20	0.00	1.20	5.00	2.00	2.00	1.00
			max	39.00	1.60	0.40	1.30	33.00	10.00	24.00	59.00
			count	3.00	3.00	3.00	2.00	3.00	3.00	3.00	3.00
	multi-annual	CC3	mean	15.73	2.27	0.83	1.30	58.44	15.33	12.50	63.32
			SD	13.88	3.18	0.90	0.71	49.22	14.39	13.95	64.38
			min	1.40	0.20	0.05	0.75	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	67	67	53	10	57	60	56	56
	2016-17	CC3	mean	11.20	1.10	0.90	0.80	64.50	2.00	17.50	39.50
			SD	2.80	0.30	0.80	0.00	31.50	0.00	8.50	19.50
			min	8.40	0.80	0.10	0.80	33.00	2.00	9.00	20.00
			max	14.00	1.40	1.70	0.80	96.00	2.00	26.00	59.00
			count	2.00	2.00	2.00	1.00	2.00	2.00	2.00	2.00
	multi-annual	CC4	mean	9.57	1.45	0.57	1.66	45.80	8.96	6.53	48.41
			SD	9.51	2.35	0.61	1.37	49.50	6.94	7.75	59.99
			min	0.00	0.20	0.00	0.00	2.00	0.00	0.00	0.00
			max	73.00	30.90	3.71	9.50	357.00	55.00	63.00	374.00
			count	312	310	276	90	288	292	278	281

			TSS (mg L^{-1})	Chla (µg L^{-1})	CDOM (m^{-1})	Secchi depth (m)	DIN (µg L^{-1})	DIP (µg L^{-1})	PP (µg L^{-1})	PN (µg L^{-1})
2016-17	CC4	mean	8.60	2.40	0.50	1.50	80.00	5.30	7.40	38.60
		SD	5.50	6.10	0.60	1.10	88.90	3.80	12.30	58.40
		min	0.80	0.40	0.00	0.00	3.50	2.00	0.00	3.00
		max	22.00	30.90	2.10	5.00	321.00	13.00	63.00	297.00
		count	23.00	23.00	23.00	20.00	23.00	23.00	23.00	23.00
multi-annual	P	mean	17.01	1.75	0.83	1.49	53.30	12.39	11.35	62.75
		SD	32.81	2.75	0.91	1.52	51.40	14.52	19.10	77.16
		min	0.00	0.20	0.00	0.00	2.00	0.00	0.00	0.00
		max	430.00	30.90	6.03	12.00	357.00	98.00	167.00	573.00
		count	517	521	439	141	468	480	458	461
2016-17	P	mean	16.30	2.20	0.70	1.30	70.60	5.80	12.00	54.20
		SD	21.60	5.00	0.70	1.10	77.20	4.80	13.40	74.30
		min	0.80	0.20	0.00	0.00	3.50	2.00	0.00	1.00
		max	110.00	30.90	2.20	5.00	321.00	25.00	63.00	297.00
		count	36.00	36.00	36.00	31.00	36.00	36.00	36.00	36.00
multi-annual	S (or CC5)	mean	6.76	0.81	0.29	3.90	25.36	6.88	4.01	27.93
		SD	7.29	0.85	0.42	2.28	30.14	6.31	4.47	36.28
		min	0.00	0.02	-0.08	0.40	0.00	0.00	0.00	0.00
		max	45.00	12.50	3.25	13.60	369.00	63.00	37.00	456.00
		count	640	682	513	317	655	662	645	644
2016-17	S (or CC5)	mean	4.30	0.80	0.20	4.40	27.20	3.40	3.40	30.40
		SD	5.90	1.10	0.40	2.80	36.90	2.30	2.90	38.90
		min	0.00	0.10	-0.10	0.40	0.00	0.00	0.00	0.00
		max	41.00	11.20	2.30	13.00	187.00	12.00	18.00	372.00
		count	115.00	115.00	104.00	109.00	115.00	115.00	115.00	115.00
multi-annual	T (or CC6)	mean	4.77	0.46	0.14	7.01	18.14	5.00	2.68	20.64
		SD	5.80	0.48	0.21	4.04	16.20	4.24	2.97	23.28
		min	0.01	0.02	-0.09	0.50	1.00	0.89	0.00	0.00
		max	31.00	5.34	1.38	19.00	104.00	21.00	18.00	174.00
		count	206	214	151	119	209	209	205	209
2016-17	T (or CC6)	mean	2.60	0.50	0.10	8.20	15.50	3.20	2.30	18.80
		SD	2.60	0.30	0.20	4.60	17.70	1.90	2.10	19.90
		min	0.00	0.10	-0.10	1.00	1.60	0.90	0.00	0.00
		max	16.00	1.50	0.70	19.00	82.00	10.00	10.00	108.00
		count	71.00	71.00	66.00	69.00	71.00	71.00	71.00	71.00

Table E-7: 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})	Secchi depth (m)	DIN (µg L^{-1})	DIP (µg L^{-1})	PP (µg L^{-1})	PN (µg L^{-1})
Cape York	multi-annual	CC1	mean	13.19	1.44	3.35	1.29	41.08	6.08	15.00	86.33
			SD	6.66	1.53	2.06	1.10	21.80	3.25	11.60	60.63
			min	2.50	0.20	0.00	0.21	4.00	2.00	1.00	14.00
			max	21.00	5.34	6.03	3.60	82.00	12.00	35.00	205.00
			count	7	12	10	7	12	12	12	12
	2016-17	CC1	mean	11.80	0.60	0.10	1.90	14.50	6.00	15.00	24.50
			SD	9.30	0.30	0.10	1.70	10.50	2.00	12.00	5.50
			min	2.50	0.20	0.00	0.20	4.00	4.00	3.00	19.00
			max	21.00	0.90	0.20	3.60	25.00	8.00	27.00	30.00
			count	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
	multi-annual	CC2	mean	37.09	1.32	1.99	6.60	43.67	4.67	11.11	39.56
			SD	49.14	0.59	1.33	5.40	25.18	2.71	11.37	44.57
			min	3.70	0.32	0.03	1.20	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	8	8	6	2	9	9	9	9
	2016-17	CC2	mean	7.10	1.20	0.00	1.20	8.10	2.00	2.00	1.00
			SD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			min	7.10	1.20	0.00	1.20	8.10	2.00	2.00	1.00
			max	7.10	1.20	0.00	1.20	8.10	2.00	2.00	1.00
			count	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	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
	2016-17	CC3	mean	nd.	nd.	nd.	nd.	nd.	nd.	nd.	nd.
			SD	nd.	nd.	nd.	nd.	nd.	nd.	nd.	nd.
			min	nd.	nd.	nd.	nd.	nd.	nd.	nd.	nd.
			max	nd.	nd.	nd.	nd.	nd.	nd.	nd.	nd.
			count	nd.	nd.	nd.	nd.	nd.	nd.	nd.	nd.
	multi-annual	CC4	mean	5.57	1.28	1.65	2.64	29.59	3.95	3.21	57.32
			SD	2.31	1.34	1.32	2.46	20.44	2.24	2.07	72.75
			min	2.60	0.25	0.00	1.00	5.00	2.00	0.00	5.00
			max	9.40	5.18	3.71	9.50	73.00	11.00	7.00	318.00
			count	14	19	16	9	19	19	19	19

			TSS (mg L^{-1})	Chla (µg L^{-1})	CDOM (m^{-1})	Secchi depth (m)	DIN (µg L^{-1})	DIP (µg L^{-1})	PP (µg L^{-1})	PN (µg L^{-1})
2016-17	CC4	mean	5.90	0.80	0.00	1.90	8.10	2.00	2.80	18.50
		SD	1.50	0.10	0.00	0.40	3.70	0.00	1.50	9.60
		min	4.10	0.60	0.00	1.40	5.00	2.00	1.00	8.00
		max	8.20	1.00	0.00	2.60	14.10	2.00	5.00	34.00
		count	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
multi-annual	P	mean	15.19	1.64	2.36	2.38	36.63	4.84	8.39	63.61
		SD	28.01	1.81	1.70	2.92	23.66	2.78	9.53	70.36
		min	2.50	0.20	0.00	0.21	4.00	2.00	0.00	1.00
		max	150.00	8.82	6.03	12.00	89.00	12.00	35.00	318.00
		count	32	44	37	20	45	45	44	44
2016-17	P	mean	7.80	0.80	0.00	1.80	9.90	3.10	6.10	17.70
		SD	5.68	0.29	0.05	1.00	6.91	2.10	8.59	10.73
		min	2.50	0.24	0.00	0.21	4.00	2.00	1.00	1.00
		max	21.00	1.23	0.17	3.60	25.00	8.00	27.00	34.00
		count	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00
multi-annual	S (or CC5)	mean	4.80	0.62	0.26	4.59	13.47	3.52	1.91	22.67
		SD	3.98	0.50	0.74	2.35	7.80	1.46	2.71	32.49
		min	1.10	0.07	0.00	0.48	4.05	2.00	0.00	0.00
		max	20.00	2.36	3.25	10.30	32.00	8.00	12.00	179.00
		count	24	33	20	26	33	33	33	33
2016-17	S (or CC5)	mean	4.20	0.50	0.00	4.60	8.30	3.10	2.00	16.10
		SD	4.40	0.20	0.00	2.70	6.50	1.50	3.00	16.40
		min	1.10	0.10	0.00	0.50	4.10	2.00	0.00	0.00
		max	20.00	1.10	0.10	10.30	32.00	8.00	12.00	61.00
		count	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00
multi-annual	T (or CC6)	mean	2.42	0.20	0.07	7.86	16.63	2.68	2.18	20.96
		SD	1.56	0.19	0.20	3.94	19.08	0.85	1.67	21.07
		min	1.00	0.02	0.00	2.19	3.05	1.00	0.00	2.00
		max	8.70	0.78	0.76	17.40	104.00	4.00	5.00	84.00
		count	26	28	15	13	28	28	28	28
2016-17	T (or CC6)	mean	2.00	0.30	0.00	8.00	5.50	2.50	1.50	9.10
		SD	0.70	0.20	0.00	4.30	2.50	1.10	1.40	6.20
		min	1.00	0.10	0.00	2.20	3.10	1.00	0.00	2.00
		max	3.60	0.80	0.00	17.40	13.10	4.00	5.00	23.00
		count	13.00	13.00	13.00	11.00	13.00	13.00	13.00	13.00

Table E- 8: 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.

Wet Tropics

			TSS (mg L^{-1})	Chla (µg L^{-1})	CDOM (m^{-1})	Secchi depth (m)	DIN (µg L^{-1})	DIP (µg L^{-1})	PP (µg L^{-1})	PN (µg L^{-1})
multi-annual	CC1	mean	12.15	1.36	1.16	0.84	54.83	4.50	9.00	57.67
		SD	8.81	1.56	0.50	0.50	47.58	2.14	11.90	50.47
		min	2.10	0.20	0.26	0.20	18.00	3.00	0.00	23.00
		max	38.00	6.14	1.82	1.80	140.00	8.00	32.00	167.00
		count	13	13	13	8	6	6	5	6
2016-17	CC1	mean	nd.	nd.	nd.	nd.	nd.	nd.	nd.	nd.
		SD	nd.	nd.	nd.	nd.	nd.	nd.	nd.	nd.
		min	nd.	nd.	nd.	nd.	nd.	nd.	nd.	nd.
		max	nd.	nd.	nd.	nd.	nd.	nd.	nd.	nd.
		count	nd.	nd.	nd.	nd.	nd.	nd.	nd.	nd.
multi-annual	CC2	mean	14.51	1.62	0.93	0.90	80.33	8.88	9.87	47.83
		SD	17.07	1.16	0.38	0.73	64.96	4.60	11.22	62.05
		min	2.30	0.20	0.33	0.00	12.00	2.00	0.00	2.00
		max	92.00	5.34	1.80	2.25	237.00	18.00	52.00	263.00
		count	34	32	33	11	24	24	23	23
2016-17	CC2	mean	nd.	nd.	nd.	nd.	nd.	nd.	nd.	nd.
		SD	nd.	nd.	nd.	nd.	nd.	nd.	nd.	nd.
		min	nd.	nd.	nd.	nd.	nd.	nd.	nd.	nd.
		max	nd.	nd.	nd.	nd.	nd.	nd.	nd.	nd.
		count	nd.	nd.	nd.	nd.	nd.	nd.	nd.	nd.
multi-annual	CC3	mean	11.03	1.51	0.51	1.10	68.15	11.67	7.17	48.42
		SD	7.96	1.58	0.28	0.41	59.39	5.82	5.25	35.90
		min	1.40	0.20	0.10	0.75	6.00	2.00	0.00	2.00
		max	34.00	7.48	1.11	1.80	218.00	21.00	21.00	134.00
		count	35	34	31	4	27	27	24	26
2016-17	CC3	mean	nd.	nd.	nd.	nd.	nd.	nd.	nd.	nd.
		SD	nd.	nd.	nd.	nd.	nd.	nd.	nd.	nd.
		min	nd.	nd.	nd.	nd.	nd.	nd.	nd.	nd.
		max	nd.	nd.	nd.	nd.	nd.	nd.	nd.	nd.
		count	nd.	nd.	nd.	nd.	nd.	nd.	nd.	nd.
multi-annual	CC4	mean	7.86	1.32	0.54	1.46	55.83	8.46	6.23	40.39
		SD	7.93	2.31	0.48	1.05	58.28	5.02	8.41	57.16
		min	0.00	0.20	0.00	0.00	3.00	0.00	0.00	0.00
		max	70.00	30.90	3.11	5.00	357.00	21.00	63.00	374.00
		count	207	205	194	57	181	181	170	177

			TSS (mg L^{-1})	Chla (µg L^{-1})	CDOM (m^{-1})	Secchi depth (m)	DIN (µg L^{-1})	DIP (µg L^{-1})	PP (µg L^{-1})	PN (µg L^{-1})
2016-17	CC4	mean	8.00	4.20	1.00	1.50	155.70	5.80	11.90	55.10
		SD	5.70	8.90	0.60	1.40	87.50	3.20	17.60	83.90
		min	0.80	0.40	0.10	0.00	3.50	2.00	1.00	3.00
		max	21.00	30.90	2.10	5.00	321.00	11.00	63.00	297.00
		count	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
multi-annual	P	mean	9.22	1.38	0.62	1.30	59.67	8.77	6.77	42.47
		SD	9.79	2.10	0.48	0.98	59.41	5.17	8.64	55.68
		min	0.00	0.20	0.00	0.00	3.00	0.00	0.00	0.00
		max	92.00	30.90	3.11	5.00	357.00	21.00	63.00	374.00
		count	289	284	271	80	238	238	222	232
2016-17	P	mean	8.00	4.20	1.00	1.50	155.70	5.80	11.90	55.10
		SD	5.74	8.94	0.64	1.36	87.46	3.21	17.56	83.93
		min	0.78	0.39	0.15	0.00	3.48	2.00	1.00	3.00
		max	21.00	30.90	2.07	5.00	321.00	11.00	63.00	297.00
		count	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
multi-annual	S (or CC5)	mean	5.71	0.81	0.32	3.91	30.01	6.78	3.69	26.78
		SD	5.50	0.74	0.44	2.37	37.49	4.86	3.83	32.29
		min	0.00	0.02	-0.08	0.50	1.61	0.00	0.00	0.00
		max	33.00	11.24	2.74	13.00	369.00	22.00	29.00	372.00
		count	384	404	340	191	377	378	364	365
2016-17	S (or CC5)	mean	3.00	0.80	0.40	5.00	42.70	3.40	3.10	38.90
		SD	3.40	1.50	0.50	3.10	47.20	2.10	2.10	50.20
		min	0.00	0.20	-0.10	0.50	1.60	0.30	0.00	2.00
		max	15.00	11.20	2.30	13.00	187.00	10.00	10.00	372.00
		count	56.00	56.00	47.00	55.00	56.00	56.00	56.00	56.00
multi-annual	T (or CC6)	mean	5.41	0.51	0.16	7.48	20.96	5.39	2.33	20.81
		SD	6.37	0.57	0.21	4.30	17.12	4.51	2.52	25.49
		min	0.01	0.02	0.00	0.50	1.00	0.98	0.00	0.00
		max	31.00	5.34	1.38	19.00	82.00	21.00	17.00	174.00
		count	128	130	101	78	125	125	123	124
2016-17	T (or CC6)	mean	2.20	0.50	0.20	9.30	22.40	3.40	2.50	21.60
		SD	2.50	0.40	0.20	4.80	20.50	2.00	2.30	22.60
		min	0.00	0.20	0.00	1.00	1.60	1.00	0.00	0.00
		max	16.00	1.50	0.70	19.00	82.00	10.00	10.00	108.00
		count	41.00	41.00	36.00	41.00	41.00	41.00	41.00	41.00

Table E-9: 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})	Secchi depth (m)	DIN (µg L^{-1})	DIP (µg L^{-1})	PP (µg L^{-1})	PN (µg L^{-1})
Burdekin	multi-annual	CC 1	mean	72.88	1.55	1.88	0.66	83.96	12.11	41.19	128.70
			SD	81.52	1.29	0.98	0.67	61.69	7.34	49.20	123.07
			min	1.40	0.20	0.28	0.20	2.00	1.00	0.00	14.00
			max	260.00	5.48	3.48	2.00	325.00	29.00	167.00	573.00
			count	25	28	15	5	25	27	26	27
	2016-17	CC 1	mean	23.00	2.20	2.10	0.40	122.30	4.30	29.00	209.30
			SD	4.10	2.30	0.10	0.00	8.00	1.90	5.40	99.60
			min	18.00	0.40	1.90	0.30	111.00	3.00	22.00	69.00
			max	28.00	5.50	2.20	0.40	128.00	7.00	35.00	290.00
			count	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
	multi-annual	CC 2	mean	21.23	1.39	0.42	1.20	32.33	6.56	15.00	53.51
			SD	35.46	0.98	0.40	0.54	27.91	4.40	21.97	75.21
			min	0.43	0.20	0.04	0.50	2.00	3.00	0.00	1.00
			max	120.00	3.40	1.06	1.80	90.00	16.00	73.00	255.00
			count	9	10	4	3	9	9	9	9
	2016-17	CC 2	mean	10.00	1.60	0.40	1.30	5.00	4.00	5.00	28.00
			SD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			min	10.00	1.60	0.40	1.30	5.00	4.00	5.00	28.00
			max	10.00	1.60	0.40	1.30	5.00	4.00	5.00	28.00
			count	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	multi-annual	CC 3	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
	2016-17	CC 3	mean	8.40	0.80	1.70	0.80	96.00	2.00	26.00	59.00
			SD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			min	8.40	0.80	1.70	0.80	96.00	2.00	26.00	59.00
			max	8.40	0.80	1.70	0.80	96.00	2.00	26.00	59.00
			count	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	multi-annual	CC 4	mean	9.52	1.31	0.24	1.74	12.73	4.40	4.70	47.55
			SD	12.48	2.52	0.34	0.84	10.40	3.33	4.07	46.95
			min	0.43	0.20	0.03	1.00	2.00	1.00	0.00	3.00
			max	73.00	13.78	1.38	4.00	62.00	14.00	18.00	239.00
			count	31	27	16	16	30	30	30	30

			TSS (mg L^{-1})	Chla (µg L^{-1})	CDOM (m^{-1})	Secchi depth (m)	DIN (µg L^{-1})	DIP (µg L^{-1})	PP (µg L^{-1})	PN (µg L^{-1})
2016-17	CC 4	mean	5.30	0.90	0.40	1.50	20.80	2.80	3.30	40.50
		SD	0.60	0.30	0.60	0.30	23.90	0.40	2.00	18.20
		min	4.60	0.40	0.00	1.10	5.00	2.00	0.00	11.00
		max	6.00	1.20	1.40	2.00	62.00	3.00	5.00	56.00
		count	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
multi-annual	P	mean	32.68	1.48	0.92	1.41	42.42	7.86	20.33	80.79
		SD	57.40	1.99	1.03	0.87	50.72	6.54	35.31	96.31
		min	0.43	0.20	0.03	0.20	2.00	1.00	0.00	1.00
		max	260.00	13.78	3.48	4.00	325.00	29.00	167.00	573.00
		count	75	74	39	26	72	74	73	74
2016-17	P	mean	12.00	1.40	1.10	1.00	61.20	3.30	14.60	97.40
		SD	8.26	1.49	0.88	0.56	52.28	1.41	12.75	98.83
		min	4.60	0.39	0.05	0.30	5.00	2.00	0.00	11.00
		max	28.00	5.48	2.23	2.00	128.00	7.00	35.00	290.00
		count	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
multi-annual	S (or CC 5)	mean	4.54	0.63	0.11	3.94	14.97	3.74	2.96	25.77
		SD	2.76	0.40	0.11	2.07	7.92	3.49	2.87	23.36
		min	0.27	0.10	0.00	1.00	0.00	0.31	0.00	0.00
		max	12.00	2.94	0.53	13.60	42.00	22.00	15.00	112.00
		count	118	117	66	79	117	117	116	117
2016-17	S (or CC 5)	mean	3.00	0.50	0.10	3.90	10.90	2.90	2.40	16.20
		SD	1.20	0.20	0.10	1.70	8.10	2.20	1.80	18.60
		min	0.40	0.20	0.00	2.00	2.20	0.30	0.00	1.00
		max	5.00	0.90	0.20	8.00	37.00	9.00	6.00	59.00
		count	21.00	21.00	20.00	21.00	21.00	21.00	21.00	21.00
multi-annual	T (or CC 6)	mean	3.78	0.42	0.12	5.32	11.88	4.51	2.61	21.30
		SD	2.70	0.23	0.22	2.70	8.63	3.19	2.64	21.63
		min	0.15	0.17	-0.09	1.40	1.00	0.99	0.00	0.00
		max	12.00	1.14	1.11	13.00	40.00	12.00	11.00	80.96
		count	37	36	28	25	37	37	35	37
2016-17	T (or CC 6)	mean	4.40	0.40	0.10	5.80	6.30	3.40	2.30	16.40
		SD	3.50	0.20	0.10	3.10	2.30	1.90	1.90	17.30
		min	0.10	0.20	-0.10	2.00	2.70	1.00	0.00	0.00
		max	12.00	1.10	0.40	13.00	10.00	8.00	8.00	73.00
		count	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00

Table E-10: 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})	Secchi depth (m)	DIN (µg L^{-1})	DIP (µg L^{-1})	PP (µg L^{-1})	PN (µg L^{-1})
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
2016-17	CC1	mean	73.00	3.70	1.10	0.40	44.00	13.70	25.70	73.70
		SD	36.10	2.30	0.40	0.10	27.00	8.40	7.70	40.20
		min	24.00	1.40	0.80	0.20	15.00	5.00	15.00	32.00
		max	110.00	6.80	1.80	0.50	80.00	25.00	33.00	128.00
		count	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
multi-annual	CC2	mean	22.35	0.92	0.11	nd.	27.50	8.00	14.50	32.00
		SD	16.65	0.65	0.03	nd.	5.50	2.00	9.50	27.00
		min	5.70	0.27	0.07	nd.	22.00	6.00	5.00	5.00
		max	39.00	1.56	0.14	nd.	33.00	10.00	24.00	59.00
		count	2	2	2	nd.	2	2	2	2
2016-17	CC2	mean	39.00	1.60	0.10	nd.	33.00	10.00	24.00	59.00
		SD	0.00	0.00	0.00	nd.	0.00	0.00	0.00	0.00
		min	39.00	1.60	0.10	nd.	33.00	10.00	24.00	59.00
		max	39.00	1.60	0.10	nd.	33.00	10.00	24.00	59.00
		count	1.00	1.00	1.00	nd.	1.00	1.00	1.00	1.00
multi-annual	CC3	mean	14.00	1.35	0.14	nd.	58.50	8.00	12.50	15.00
		SD	0.00	0.05	0.00	nd.	25.50	6.00	3.50	5.00
		min	14.00	1.30	0.14	nd.	33.00	2.00	9.00	10.00
		max	14.00	1.40	0.15	nd.	84.00	14.00	16.00	20.00
		count	2	2	2	nd.	2	2	2	2
2016-17	CC3	mean	14.00	1.40	0.10	nd.	33.00	2.00	9.00	20.00
		SD	0.00	0.00	0.00	nd.	0.00	0.00	0.00	0.00
		min	14.00	1.40	0.10	nd.	33.00	2.00	9.00	20.00
		max	14.00	1.40	0.10	nd.	33.00	2.00	9.00	20.00
		count	1.00	1.00	1.00	nd.	1.00	1.00	1.00	1.00
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

			TSS (mg L^{-1})	Chla (µg L^{-1})	CDOM (m^{-1})	Secchi depth (m)	DIN (µg L^{-1})	DIP (µg L^{-1})	PP (µg L^{-1})	PN (µg L^{-1})
2016-17	CC4	mean	14.80	1.30	0.20	0.50	33.40	9.20	5.60	20.20
		SD	4.40	0.20	0.00	0.20	5.20	3.90	2.10	8.30
		min	9.00	0.80	0.10	0.40	27.00	2.00	3.00	10.00
		max	22.00	1.50	0.20	0.70	40.00	13.00	9.00	33.00
		count	5.00	5.00	5.00	2.00	5.00	5.00	5.00	5.00
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
2016-17	P	mean	34.60	2.00	0.40	0.40	36.50	9.90	13.80	40.10
		SD	32.92	1.66	0.51	0.17	16.01	6.27	10.42	33.64
		min	9.00	0.79	0.10	0.20	15.00	2.00	3.00	10.00
		max	110.00	6.78	1.75	0.70	80.00	25.00	33.00	128.00
		count	10.00	10.00	10.00	5.00	10.00	10.00	10.00	10.00
multi-annual	S (or CC5)	mean	7.47	1.07	0.20	2.46	19.30	5.95	5.52	24.00
		SD	8.51	0.65	0.18	1.58	14.19	3.55	5.17	16.94
		min	0.10	0.24	0.01	0.40	0.00	0.00	1.00	0.00
		max	41.00	3.88	0.88	6.00	64.00	15.00	37.00	85.00
		count	68	68	39	16	68	68	68	68
2016-17	S (or CC5)	mean	9.40	1.20	0.20	2.50	17.70	3.90	6.30	33.30
		SD	10.60	0.70	0.20	1.60	11.30	2.90	3.50	20.70
		min	0.80	0.60	0.00	0.40	0.00	0.00	1.00	0.00
		max	41.00	3.90	0.70	6.00	37.00	12.00	18.00	66.00
		count	21.00	21.00	20.00	16.00	21.00	21.00	21.00	21.00
multi-annual	T (or CC6)	mean	2.05	0.67	0.03	5.00	7.15	2.75	3.25	20.71
		SD	3.26	0.23	0.01	1.08	9.21	1.63	2.19	8.80
		min	0.11	0.25	0.02	4.00	1.00	0.89	1.00	10.00
		max	12.00	1.19	0.04	6.50	35.00	7.00	10.00	36.87
		count	12	12	3	3	11	11	12	12
2016-17	T (or CC6)	mean	1.20	0.60	0.00	5.00	5.60	1.40	3.30	34.80
		SD	0.30	0.10	0.00	1.10	0.90	0.40	0.80	2.30
		min	0.90	0.40	0.00	4.00	4.50	0.90	2.40	31.70
		max	1.60	0.70	0.00	6.50	6.60	1.70	4.30	36.90
		count	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00

Table E-11: Interim Water Quality Index for each water quality sampling location in 2015–16 and 2016–17, calculated using wet and dry season samples. See Section 2.2 (Interim site-specific Water Quality Index) for details on index calculation. Empty cells indicate data not available

						Annual			Dry Season			Wet Season			
Region	Subregion	Reef	Year	Measure	Stat.	GL	Mean	Median	GL	Mean	Median	GL	Mean	Median	Index
Wet Tropics	Barron Daintree	Cape Tribulation	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.51	0.63		0.22	0.17
			2015 - 2016	NOx (µgL^{-1})	Median	0.35		0.63							-0.85
			2015 - 2016	PN (µgL^{-1})	Median				16		12.07	25		10.16	0.7
			2015 - 2016	PP (µgL^{-1})	Median				2.3		2.19	3.3		2.28	0.3
			2015 - 2016	Secchi (m)	Mean	10	6.83								-0.55
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		1.02	2.4		1.03	0.82
			2016 - 2017	Chla (µgL^{-1})	Median				0.32		0.45	0.63		0.79	-0.42
			2016 - 2017	NOx (µgL^{-1})	Median	0.35		0.67							-0.94
			2016 - 2017	PN (µgL^{-1})	Median				16		12.4	25		16.39	0.49
			2016 - 2017	PP (µgL^{-1})	Median				2.3		2.73	3.3		3.25	-0.11
			2016 - 2017	Secchi (m)	Mean	10	3.83								-1
			2016 - 2017	TSS (mgL^{-1})	Median				1.6		1.29	2.4		1.22	0.64
		Port Douglas	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.52	0.63		0.26	0.15
			2015 - 2016	NOx (µgL^{-1})	Median	0.31		0.14							1
			2015 - 2016	PN (µgL^{-1})	Median				16		10.61	25		10.5	0.8
			2015 - 2016	PP (µgL^{-1})	Median				2.3		2.23	3.3		2.36	0.26
			2015 - 2016	Secchi (m)	Median	13		7							-0.89
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		2.09	2.4		1.54	0.12
			2016 - 2017	Chla (µgL^{-1})	Median				0.32		0.49	0.63		0.58	-0.25
			2016 - 2017	NOx (µgL^{-1})	Median	0.31		0.6							-0.96
			2016 - 2017	PN (µgL^{-1})	Median				16		14.61	25		13.34	0.52
			2016 - 2017	PP (µgL^{-1})	Median				2.3		2.85	3.3		2.71	-0.01
			2016 - 2017	Secchi (m)	Median	13		4							-1

						Annual			Dry Season			Wet Season			
Region	Subregion	Reef	Year	Measure	Stat.	GL	Mean	Median	GL	Mean	Median	GL	Mean	Median	Index
			2016 - 2017	TSS (mgL^{-1})	Median				1.6		1.26	2.4		0.92	0.67
		Double	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.38	0.63		0.38	0.25
			2015 - 2016	NOx (µgL^{-1})	Median	0.31		0.14							1
			2015 - 2016	PN (µgL^{-1})	Median				16		9.9	25		10.74	0.85
			2015 - 2016	PP (µgL^{-1})	Median				2.3		13	3.3		2.62	-0.33
			2015 - 2016	Secchi (m)	Median	13		5.5							-1
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		0.78	2.4		1.14	1
			2016 - 2017	Chla (µgL^{-1})	Median				0.32		0.32	0.63		0.68	-0.06
			2016 - 2017	NOx (µgL^{-1})	Median	0.31		0.27							0.21
			2016 - 2017	PN (µgL^{-1})	Median				16		14.09	25		14.36	0.49
			2016 - 2017	PP (µgL^{-1})	Median				2.3		2.51	3.3		2.84	0.05
			2016 - 2017	Secchi (m)	Median	13		4							-1
			2016 - 2017	TSS (mgL^{-1})	Median				1.6		1.38	2.4		0.86	0.61
		Yorkey's Knob	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.53	0.63		0.46	-0.13
			2015 - 2016	NOx (µgL^{-1})	Median	0.35		0.29							0.27
			2015 - 2016	PN (µgL^{-1})	Median				16		13.88	25		13.68	0.54
			2015 - 2016	PP (µgL^{-1})	Median				2.3		3.75	3.3		4.12	-0.51
			2015 - 2016	Secchi (m)	Mean	10	3								-1
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		2.57	2.4		2.54	-0.38
			2016 - 2017	Chla (µgL^{-1})	Median				0.32		0.53	0.63		1.17	-0.81
			2016 - 2017	NOx (µgL^{-1})	Median	0.35		0.58							-0.73
			2016 - 2017	PN (µgL^{-1})	Median				16		15.62	25		23.31	0.07
			2016 - 2017	PP (µgL^{-1})	Median				2.3		4.51	3.3		5.68	-0.88
			2016 - 2017	Secchi (m)	Mean	10	2.5								-1

						Annual			Dry Season			Wet Season			
Region	Subregion	Reef	Year	Measure	Stat.	GL	Mean	Median	GL	Mean	Median	GL	Mean	Median	Index
			2016 - 2017	TSS (mgL^{-1})	Median				1.6		3.98	2.4		3.06	-0.67
		Fairlead Buoy	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.62	0.63		0.47	-0.26
			2015 - 2016	NOx (µgL^{-1})	Median	0.35		0.41							-0.24
			2015 - 2016	PN (µgL^{-1})	Median				16		14.45	25		14.4	0.47
			2015 - 2016	PP (µgL^{-1})	Median				2.3		3.83	3.3		4.27	-0.55
			2015 - 2016	Secchi (m)	Mean	10	2.83								-1
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		2.95	2.4		2.65	-0.51
			2016 - 2017	Chla (µgL^{-1})	Median				0.32		0.56	0.63		1.12	-0.81
			2016 - 2017	NOx (µgL^{-1})	Median	0.35		0.24							0.56
			2016 - 2017	PN (µgL^{-1})	Median				16		19.47	25		17.77	0.1
			2016 - 2017	PP (µgL^{-1})	Median				2.3		5.15	3.3		5	-0.8
			2016 - 2017	Secchi (m)	Mean	10	2.33								-1
			2016 - 2017	TSS (mgL^{-1})	Median				1.6		5.64	2.4		3.43	-0.76
	Johnstone Russell Mulgrave	Green	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.25	0.63		0.25	0.67
			2015 - 2016	NOx (µgL^{-1})	Median	0.31		0.2							0.65
			2015 - 2016	PN (µgL^{-1})	Median				16		10.64	25		10.5	0.79
			2015 - 2016	PP (µgL^{-1})	Median				2.3		1.76	3.3		1.83	0.62
			2015 - 2016	Secchi (m)	Median	13		9.5							-0.45
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		2.29	2.4		0.32	0.24
			2016 - 2017	Chla (µgL^{-1})	Median				0.32		0.18	0.63		0.43	0.7
			2016 - 2017	NOx (µgL^{-1})	Median	0.31		0.98							-1
			2016 - 2017	PN (µgL^{-1})	Median				16		9.23	25		13.38	0.85
			2016 - 2017	PP (µgL^{-1})	Median				2.3		1.42	3.3		2.47	0.56
			2016 - 2017	Secchi (m)	Median	13		8							-0.7

						Annual			Dry Season			Wet Season			
Region	Subregion	Reef	Year	Measure	Stat.	GL	Mean	Median	GL	Mean	Median	GL	Mean	Median	Index
			2016 - 2017	TSS (mgL^{-1})	Median				1.6		0.47	2.4		0.45	1
		Fitzroy West	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.36	0.63		0.33	0.37
			2015 - 2016	NOx (µgL^{-1})	Median	0.35		0.6							-0.78
			2015 - 2016	Turbidity (NTU)	Median	1		0.86							0.22
			2015 - 2016	PN (µgL^{-1})	Median				16		14.19	25		14.64	0.47
			2015 - 2016	PP (µgL^{-1})	Median				2.3		2.01	3.3		2.01	0.45
			2015 - 2016	Secchi (m)	Mean	10	10.2								0.03
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		0.88	2.4		0.48	0.93
			2016 - 2017	Chla (µgL^{-1})	Median				0.32		0.18	0.63		0.35	0.84
			2016 - 2017	NOx (µgL^{-1})	Median	0.35		2							-1
			2016 - 2017	Turbidity (NTU)	Median	1		0.77							0.37
			2016 - 2017	PN (µgL^{-1})	Median				16		15.25	25		25.34	0.02
			2016 - 2017	PP (µgL^{-1})	Median				2.3		2.53	3.3		2.34	0.18
			2016 - 2017	Secchi (m)	Mean	10	9.9								-0.01
			2016 - 2017	TSS (mgL^{-1})	Median				1.6		0.79	2.4		0.52	1
		RM2	2015 - 2016	Chla (µgL^{-1})	Median							0.63		0.23	1
			2015 - 2016	NOx (µgL^{-1})	Median	0.31		5							-1
			2015 - 2016	PN (µgL^{-1})	Median							25		3.45	1
			2015 - 2016	PP (µgL^{-1})	Median							3.3		0	1
			2015 - 2016	Secchi (m)	Median	13		4							-1
			2015 - 2016	TSS (mgL^{-1})	Median							2.4		2.85	-0.25
			2016 - 2017	Chla (µgL^{-1})	Median				0.32		0.62	0.63		0.38	-0.1
			2016 - 2017	NOx (µgL^{-1})	Median	0.31		28							-1
			2016 - 2017	PN (µgL^{-1})	Median				16		14	25		4.13	0.6

						Annual			Dry Season			Wet Season			
Region	Subregion	Reef	Year	Measure	Stat.	GL	Mean	Median	GL	Mean	Median	GL	Mean	Median	Index
			2016 - 2017	PP (µgL^{-1})	Median				2.3		0.93	3.3		0.93	1
			2016 - 2017	Secchi (m)	Median	13		8							-0.7
			2016 - 2017	TSS (mgL^{-1})	Median				1.6		1.1	2.4		2.3	0.3
		RM3	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.32	0.63		0.32	0.49
			2015 - 2016	NOx (µgL^{-1})	Median	0.31		2							-1
			2015 - 2016	PN (µgL^{-1})	Median				16		20.48	25		12.43	0.32
			2015 - 2016	PP (µgL^{-1})	Median				2.3		2.08	3.3		1.93	0.46
			2015 - 2016	Secchi (m)	Median	13		9							-0.53
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		0.94	2.4		1.7	0.63
			2016 - 2017	Chla (µgL^{-1})	Median				0.32		0.31	0.63		0.54	0.13
			2016 - 2017	NOx (µgL^{-1})	Median	0.31		3.47							-1
			2016 - 2017	PN (µgL^{-1})	Median				16		18.08	25		7.91	0.41
			2016 - 2017	PP (µgL^{-1})	Median				2.3		2.75	3.3		1.55	0.37
			2016 - 2017	Secchi (m)	Median	13		7.25							-0.84
			2016 - 2017	TSS (mgL^{-1})	Median				1.6		1.82	2.4		1.1	0.41
		RM4	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.2	0.63		0.31	0.84
			2015 - 2016	NOx (µgL^{-1})	Median	0.35		3.97							-1
			2015 - 2016	PN (µgL^{-1})	Median				16		22.82	25		12	0.24
			2015 - 2016	PP (µgL^{-1})	Median				2.3		0.46	3.3		2	0.86
			2015 - 2016	Secchi (m)	Mean	10	4.12								-1
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		2.65	2.4		3.65	-0.67
			2016 - 2017	Chla (µgL^{-1})	Median				0.32		0.36	0.63		0.84	-0.29
			2016 - 2017	NOx (µgL^{-1})	Median	0.35		27.02							-1
			2016 - 2017	PN (µgL^{-1})	Median				16		0	25		3.43	1

						Annual			Dry Season			Wet Season			
Region	Subregion	Reef	Year	Measure	Stat.	GL	Mean	Median	GL	Mean	Median	GL	Mean	Median	Index
			2016 - 2017	PP (µgL^{-1})	Median				2.3		0.93	3.3		0.93	1
			2016 - 2017	Secchi (m)	Mean	10	7.2								-0.47
			2016 - 2017	TSS (mgL^{-1})	Median				1.6		2.4	2.4		2.55	-0.34
		High East	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.23	0.63		0.36	0.64
			2015 - 2016	NOx (µgL^{-1})	Median	0.31		7							-1
			2015 - 2016	PN (µgL^{-1})	Median				16		0.84	25		6	1
			2015 - 2016	PP (µgL^{-1})	Median				2.3		0.93	3.3		0	1
			2015 - 2016	Secchi (m)	Median	13		3							-1
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		1.7	2.4		2.55	-0.09
			2016 - 2017	Chla (µgL^{-1})	Median				0.32		0.29	0.63		0.64	0.07
			2016 - 2017	NOx (µgL^{-1})	Median	0.31		7.98							-1
			2016 - 2017	PN (µgL^{-1})	Median				16		0.42	25		0.84	1
			2016 - 2017	PP (µgL^{-1})	Median				2.3		0	3.3		1.86	0.91
			2016 - 2017	Secchi (m)	Median	13		3.25							-1
			2016 - 2017	TSS (mgL^{-1})	Median				1.6		2.7	2.4		3.5	-0.65
		High West	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.33	0.63		0.45	0.23
			2015 - 2016	NOx (µgL^{-1})	Median	0.35		2.09							-1
			2015 - 2016	Turbidity (NTU)	Median	1		0.83							0.27
			2015 - 2016	PN (µgL^{-1})	Median				16		11.48	25		15.37	0.59
			2015 - 2016	PP (µgL^{-1})	Median				2.3		2.57	3.3		2	0.28
			2015 - 2016	Secchi (m)	Mean	10	5.78								-0.79
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		1.02	2.4		2.5	0.29
			2016 - 2017	Chla (µgL^{-1})	Median				0.32		0.41	0.63		0.59	-0.14
			2016 - 2017	NOx (µgL^{-1})	Median	0.35		2.11							-1

						Annual			Dry Season			Wet Season			
Region	Subregion	Reef	Year	Measure	Stat.	GL	Mean	Median	GL	Mean	Median	GL	Mean	Median	Index
			2016 - 2017	Turbidity (NTU)	Median	1		0.98							0.03
			2016 - 2017	PN (µgL^{-1})	Median				16		10.12	25		2.66	0.83
			2016 - 2017	PP (µgL^{-1})	Median				2.3		2.35	3.3		2.94	0.07
			2016 - 2017	Secchi (m)	Mean	10	6.35								-0.66
			2016 - 2017	TSS (mgL^{-1})	Median				1.6		1.42	2.4		1.31	0.53
		Palmer Point	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.26	0.63		0.41	0.46
			2015 - 2016	NOx (µgL^{-1})	Median	0.35		9							-1
			2015 - 2016	PN (µgL^{-1})	Median				16		16.66	25		10	0.47
			2015 - 2016	PP (µgL^{-1})	Median				2.3		0	3.3		1	1
			2015 - 2016	Secchi (m)	Mean	10	3.12								-1
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		10	2.4		3.5	-0.77
			2016 - 2017	Chla (µgL^{-1})	Median				0.32		0.46	0.63		0.49	-0.08
			2016 - 2017	NOx (µgL^{-1})	Median	0.35		35							-1
			2016 - 2017	PN (µgL^{-1})	Median				16		0.42	25		7.21	1
			2016 - 2017	PP (µgL^{-1})	Median				2.3		0	3.3		0.93	1
			2016 - 2017	Secchi (m)	Mean	10	4.8								-1
			2016 - 2017	TSS (mgL^{-1})	Median				1.6		2.8	2.4		3.05	-0.58
		Normanby	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.33	0.63		0.3	0.48
			2015 - 2016	NOx (µgL^{-1})	Median	0.31		7.5							-1
			2015 - 2016	PN (µgL^{-1})	Median				16		15.4	25		8	0.53
			2015 - 2016	PP (µgL^{-1})	Median				2.3		0.93	3.3		1	1
			2015 - 2016	Secchi (m)	Median	13		5							-1
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		2.3	2.4		2.4	-0.26
			2016 - 2017	Chla (µgL^{-1})	Median				0.32		0.33	0.63		0.26	0.48

						Annual			Dry Season			Wet Season			
Region	Subregion	Reef	Year	Measure	Stat.	GL	Mean	Median	GL	Mean	Median	GL	Mean	Median	Index
			2016 - 2017	NOx (µgL^{-1})	Median	0.31		21.98							-1
			2016 - 2017	PN (µgL^{-1})	Median				16		0.42	25		7.91	1
			2016 - 2017	PP (µgL^{-1})	Median				2.3		0.93	3.3		4.49	0.28
			2016 - 2017	Secchi (m)	Median	13		7.5							-0.79
			2016 - 2017	TSS (mgL^{-1})	Median				1.6		1.4	2.4		1.5	0.44
		Russell Mulgrave Mouth Mooring	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.78	0.63		0.52	-0.36
			2015 - 2016	NOx (µgL^{-1})	Median	0.35		8							-1
			2015 - 2016	Turbidity (NTU)	Median	1		1.96							-0.97
			2015 - 2016	PN (µgL^{-1})	Median				16		19.2	25		10.09	0.37
			2015 - 2016	PP (µgL^{-1})	Median				2.3		5.69	3.3		3.34	-0.51
			2015 - 2016	Secchi (m)	Mean	10	3.73								-1
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		3.12	2.4		3.16	-0.68
			2016 - 2017	Chla (µgL^{-1})	Median				0.32		0.61	0.63		1.2	-0.93
			2016 - 2017	NOx (µgL^{-1})	Median	0.35		16.42							-1
			2016 - 2017	Turbidity (NTU)	Median	1		2.22							-1
			2016 - 2017	PN (µgL^{-1})	Median				16		15.36	25		22.01	0.12
			2016 - 2017	PP (µgL^{-1})	Median				2.3		6.68	3.3		4.49	-0.72
			2016 - 2017	Secchi (m)	Mean	10	2.79								-1
			2016 - 2017	TSS (mgL^{-1})	Median				1.6		4.75	2.4		3.65	-0.8
		Franklands West	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.2	0.63		0.33	0.82
			2015 - 2016	NOx (µgL^{-1})	Median	0.31		2							-1
			2015 - 2016	Turbidity (NTU)	Median	0.6		0.84							-0.49
			2015 - 2016	PN (µgL^{-1})	Median				16		12.11	25		9.34	0.7
			2015 - 2016	PP (µgL^{-1})	Median				2.3		2.11	3.3		1.25	0.56

						Annual			Dry Season			Wet Season			
Region	Subregion	Reef	Year	Measure	Stat.	GL	Mean	Median	GL	Mean	Median	GL	Mean	Median	Index
			2015 - 2016	Secchi (m)	Median	13		6.5							-1
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		0.83	2.4		0.95	0.97
			2016 - 2017	Chla (µgL^{-1})	Median				0.32		0.33	0.63		0.4	0.29
			2016 - 2017	NOx (µgL^{-1})	Median	0.31		5.57							-1
			2016 - 2017	Turbidity (NTU)	Median	0.6		0.62							-0.05
			2016 - 2017	PN (µgL^{-1})	Median				16		14.49	25		14.49	0.46
			2016 - 2017	PP (µgL^{-1})	Median				2.3		2.18	3.3		2.48	0.25
			2016 - 2017	Secchi (m)	Median	13		8.25							-0.66
			2016 - 2017	TSS (mgL^{-1})	Median				1.6		1.08	2.4		1.69	0.54
		Russell Mulgrave Junction	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.69	0.63		0.52	-0.35
			2015 - 2016	NOx (µgL^{-1})	Median	15		144							-1
			2015 - 2016	PN (µgL^{-1})	Median				16		21.7	25		31	-0.38
			2015 - 2016	PP (µgL^{-1})	Median				2.3		3.1	3.3		5	-0.51
			2015 - 2016	Secchi (m)	Median	1.5		1.25							-0.26
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		11	2.4		4.4	-0.94
			2016 - 2017	Chla (µgL^{-1})	Median				0.32		4.37	0.63		0.9	-0.75
			2016 - 2017	NOx (µgL^{-1})	Median	15		141.83							-1
			2016 - 2017	PN (µgL^{-1})	Median				16		1.82	25		10.85	1
			2016 - 2017	PP (µgL^{-1})	Median				2.3		4.96	3.3		5.5	-0.87
			2016 - 2017	Secchi (m)	Median	1.5		0.5							-1
			2016 - 2017	TSS (mgL^{-1})	Median				1.6		4.5	2.4		7.85	-1
	Tully Herbert	King	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.33	0.63		0.46	0.2
			2015 - 2016	NOx (µgL^{-1})	Median	0.35		6							-1
			2015 - 2016	PN (µgL^{-1})	Median				16		3.22	25		13.1	0.97

						Annual			Dry Season			Wet Season			
Region	Subregion	Reef	Year	Measure	Stat.	GL	Mean	Median	GL	Mean	Median	GL	Mean	Median	Index
			2015 - 2016	PP (µgL^{-1})	Median				2.3		0.93	3.3		1	1
			2015 - 2016	Secchi (m)	Mean	10	4.08								-1
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		2.7	2.4		2.8	-0.49
			2016 - 2017	Chla (µgL^{-1})	Median				0.32		0.29	0.63		0.42	0.36
			2016 - 2017	NOx (µgL^{-1})	Median	0.35		47.46							-1
			2016 - 2017	PN (µgL^{-1})	Median				16		0	25		19.88	0.67
			2016 - 2017	PP (µgL^{-1})	Median				2.3		0.93	3.3		0	1
			2016 - 2017	Secchi (m)	Mean	10	4.12								-1
			2016 - 2017	TSS (mgL^{-1})	Median				1.6		2.4	2.4		2.6	-0.35
		Clump Point East	2015 - 2016	Chla (µgL^{-1})	Median				0.32		1.11	0.63		0.29	0
			2015 - 2016	NOx (µgL^{-1})	Median	0.31		2							-1
			2015 - 2016	PN (µgL^{-1})	Median				16		42.76	25		9	0
			2015 - 2016	PP (µgL^{-1})	Median				2.3		4.22	3.3		1.56	0.06
			2015 - 2016	Secchi (m)	Median	13		10							-0.38
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		2.28	2.4		1.9	-0.09
			2016 - 2017	Chla (µgL^{-1})	Median				0.32		0.28	0.63		0.35	0.53
			2016 - 2017	NOx (µgL^{-1})	Median	0.31		0.45							-0.54
			2016 - 2017	PN (µgL^{-1})	Median				16		14.03	25		19.36	0.28
			2016 - 2017	PP (µgL^{-1})	Median				2.3		1.99	3.3		3.62	0.04
			2016 - 2017	Secchi (m)	Median	13		13							0
			2016 - 2017	TSS (mgL^{-1})	Median				1.6		0.89	2.4		0.42	0.92
		Dunk North	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.47	0.63		0.42	0.02
			2015 - 2016	NOx (µgL^{-1})	Median	0.35		7.24							-1
			2015 - 2016	Turbidity (NTU)	Median	1		1.23							-0.3

						Annual			Dry Season			Wet Season			
Region	Subregion	Reef	Year	Measure	Stat.	GL	Mean	Median	GL	Mean	Median	GL	Mean	Median	Index
			2015 - 2016	PN (µgL^{-1})	Median				16		10.36	25		11	0.81
			2015 - 2016	PP (µgL^{-1})	Median				2.3		2.94	3.3		2	0.18
			2015 - 2016	Secchi (m)	Mean	10	4.24								-1
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		5.4	2.4		3.2	-0.71
			2016 - 2017	Chla (µgL^{-1})	Median				0.32		0.73	0.63		0.48	-0.3
			2016 - 2017	NOx (µgL^{-1})	Median	0.35		1.62							-1
			2016 - 2017	Turbidity (NTU)	Median	1		1.55							-0.64
			2016 - 2017	PN (µgL^{-1})	Median				16		12.71	25		21.53	0.27
			2016 - 2017	PP (µgL^{-1})	Median				2.3		3.61	3.3		3.19	-0.3
			2016 - 2017	Secchi (m)	Mean	10	4.86								-1
			2016 - 2017	TSS (mgL^{-1})	Median				1.6		3.14	2.4		2.09	-0.39
		Mission Beach South	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.48	0.63		0.38	0.06
			2015 - 2016	NOx (µgL^{-1})	Median	0.35		9							-1
			2015 - 2016	PN (µgL^{-1})	Median				16		13.26	25		5.39	0.64
			2015 - 2016	PP (µgL^{-1})	Median				2.3		0.46	3.3		1.5	1
			2015 - 2016	Secchi (m)	Mean	10	1.92								-1
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		4.05	2.4		3.9	-0.85
			2016 - 2017	Chla (µgL^{-1})	Median				0.32		0.49	0.63		0.39	0.04
			2016 - 2017	NOx (µgL^{-1})	Median	0.35		38.43							-1
			2016 - 2017	PN (µgL^{-1})	Median				16		0	25		9.94	1
			2016 - 2017	PP (µgL^{-1})	Median				2.3		0	3.3		0.93	1
			2016 - 2017	Secchi (m)	Mean	10	3.38								-1
			2016 - 2017	TSS (mgL^{-1})	Median				1.6		2.7	2.4		2.8	-0.49
		Dunk South	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.86	0.63		0.46	-0.28

						Annual			Dry Season			Wet Season			
Region	Subregion	Reef	Year	Measure	Stat.	GL	Mean	Median	GL	Mean	Median	GL	Mean	Median	Index
			2015 - 2016	NOx (µgL^{-1})	Median	0.35		2.94							-1
			2015 - 2016	PN (µgL^{-1})	Median				16		18.8	25		7.25	0.38
			2015 - 2016	PP (µgL^{-1})	Median				2.3		2.94	3.3		2.43	0.04
			2015 - 2016	Secchi (m)	Mean	10	5.66								-0.82
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		4.9	2.4		3	-0.66
			2016 - 2017	Chla (µgL^{-1})	Median				0.32		0.5	0.63		0.87	-0.56
			2016 - 2017	NOx (µgL^{-1})	Median	0.35		1.88							-1
			2016 - 2017	PN (µgL^{-1})	Median				16		18.3	25		16.79	0.19
			2016 - 2017	PP (µgL^{-1})	Median				2.3		2.18	3.3		3.12	0.08
			2016 - 2017	Secchi (m)	Mean	10	6.61								-0.6
			2016 - 2017	TSS (mgL^{-1})	Median				1.6		2.25	2.4		2.2	-0.18
		Between Tam O'Shanter and Timana	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.9	0.63		0.5	-0.34
			2015 - 2016	NOx (µgL^{-1})	Median	0.35		8.56							-1
			2015 - 2016	PN (µgL^{-1})	Median				16		20	25		9.83	0.34
			2015 - 2016	PP (µgL^{-1})	Median				2.3		2.01	3.3		2.67	0.25
			2015 - 2016	Secchi (m)	Mean	10	2.9								-1
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		3.6	2.4		4	-0.87
			2016 - 2017	Chla (µgL^{-1})	Median				0.32		0.54	0.63		0.67	-0.42
			2016 - 2017	NOx (µgL^{-1})	Median	0.35		10.92							-1
			2016 - 2017	PN (µgL^{-1})	Median				16		13.58	25		13.73	0.55
			2016 - 2017	PP (µgL^{-1})	Median				2.3		2.77	3.3		3.37	-0.15
			2016 - 2017	Secchi (m)	Mean	10	3.72								-1
			2016 - 2017	TSS (mgL^{-1})	Median				1.6		3.25	2.4		2.93	-0.64
		Hull Mouth	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.74	0.63		0.85	-0.72

						Annual			Dry Season			Wet Season			
Region	Subregion	Reef	Year	Measure	Stat.	GL	Mean	Median	GL	Mean	Median	GL	Mean	Median	Index
			2015 - 2016	NOx (µgL^{-1})	Median	3		16							-1
			2015 - 2016	PN (µgL^{-1})	Median				16		10.12	25		11.61	0.83
			2015 - 2016	PP (µgL^{-1})	Median				2.3		2.5	3.3		2	0.3
			2015 - 2016	Secchi (m)	Median	1.6		1.5							-0.09
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		10	2.4		6.25	-1
			2016 - 2017	Chla (µgL^{-1})	Median				0.32		0.68	0.63		0.88	-0.74
			2016 - 2017	NOx (µgL^{-1})	Median	3		60.97							-1
			2016 - 2017	PN (µgL^{-1})	Median				16		23.52	25		16.24	0.03
			2016 - 2017	PP (µgL^{-1})	Median				2.3		1.86	3.3		9.91	-0.35
			2016 - 2017	Secchi (m)	Median	1.6		1.65							0.04
			2016 - 2017	TSS (mgL^{-1})	Median				1.6		2.7	2.4		7.7	-0.88
		Bedarra	2015 - 2016	Chla (µgL^{-1})	Median				0.32		1.12	0.63		0.4	-0.16
			2015 - 2016	NOx (µgL^{-1})	Median	0.35		3.93							-1
			2015 - 2016	PN (µgL^{-1})	Median				16		16.16	25		5.5	0.49
			2015 - 2016	PP (µgL^{-1})	Median				2.3		2.48	3.3		1	0.45
			2015 - 2016	Secchi (m)	Mean	10	3.82								-1
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		5.9	2.4		3.3	-0.73
			2016 - 2017	Chla (µgL^{-1})	Median				0.32		0.52	0.63		0.61	-0.32
			2016 - 2017	NOx (µgL^{-1})	Median	0.35		1							-1
			2016 - 2017	PN (µgL^{-1})	Median				16		20.05	25		18.73	0.05
			2016 - 2017	PP (µgL^{-1})	Median				2.3		3.95	3.3		3.04	-0.33
			2016 - 2017	Secchi (m)	Mean	10	3.91								-1
			2016 - 2017	TSS (mgL^{-1})	Median				1.6		3.55	2.4		1.51	-0.16
		Tully	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.32	0.63		0.52	0.14

						Annual			Dry Season			Wet Season			
Region	Subregion	Reef	Year	Measure	Stat.	GL	Mean	Median	GL	Mean	Median	GL	Mean	Median	Index
			2015 - 2016	NOx (µgL^{-1})	Median	15		101							-1
			2015 - 2016	PN (µgL^{-1})	Median				16		23.73	25		20.16	-0.13
			2015 - 2016	PP (µgL^{-1})	Median				2.3		5.93	3.3		5.5	-0.87
			2015 - 2016	Secchi (m)	Median	1.5		1.5							0
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		8.15	2.4		15.5	-1
			2016 - 2017	Chla (µgL^{-1})	Median				0.32		0.23	0.63		0.68	0.18
			2016 - 2017	NOx (µgL^{-1})	Median	15		228.29							-1
			2016 - 2017	PN (µgL^{-1})	Median				16		1.4	25		49.28	0.01
			2016 - 2017	PP (µgL^{-1})	Median				2.3		0.93	3.3		16.1	0
			2016 - 2017	Secchi (m)	Median	1.5		0.25							-1
			2016 - 2017	TSS (mgL^{-1})	Median				1.6		2.8	2.4		21	-0.9
		Tully Mouth Mooring	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.96	0.63		1.37	-1
			2015 - 2016	NOx (µgL^{-1})	Median	3		9.8							-1
			2015 - 2016	Turbidity (NTU)	Median	4		3.07							0.38
			2015 - 2016	PN (µgL^{-1})	Median				16		23.73	25		17.62	-0.03
			2015 - 2016	PP (µgL^{-1})	Median				2.3		5.42	3.3		4.99	-0.8
			2015 - 2016	Secchi (m)	Median	1.6		1.2							-0.42
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		7.75	2.4		11.3	-1
			2016 - 2017	Chla (µgL^{-1})	Median				0.32		0.95	0.63		1.09	-0.89
			2016 - 2017	NOx (µgL^{-1})	Median	3		9.03							-1
			2016 - 2017	Turbidity (NTU)	Median	4		2.71							0.56
			2016 - 2017	PN (µgL^{-1})	Median				16		14	25		32.78	-0.1
			2016 - 2017	PP (µgL^{-1})	Median				2.3		4.74	3.3		6.92	-1
			2016 - 2017	Secchi (m)	Median	1.6		2.5							0.64

						Annual			Dry Season			Wet Season			
Region	Subregion	Reef	Year	Measure	Stat.	GL	Mean	Median	GL	Mean	Median	GL	Mean	Median	Index
			2016 - 2017	TSS (mgL^{-1})	Median				1.6		4.75	2.4		3.85	-0.84
		Triplets	2015 - 2016	Chla (μgL^{-1})	Median				0.32		1.25	0.63		0.36	-0.1
			2015 - 2016	NOx (μgL^{-1})	Median	0.35		8							-1
			2015 - 2016	PN (μgL^{-1})	Median				16		22.92	25		3	0.24
			2015 - 2016	PP (μgL^{-1})	Median				2.3		0.5	3.3		1	1
			2015 - 2016	Secchi (m)	Mean	10	3.7								-1
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		3.65	2.4		3.2	-0.71
			2016 - 2017	Chla (μgL^{-1})	Median				0.32		0.2	0.63		0.75	0.21
			2016 - 2017	NOx (μgL^{-1})	Median	0.35		23.45							-1
			2016 - 2017	PN (μgL^{-1})	Median				16		35.7	25		2.24	0
			2016 - 2017	PP (μgL^{-1})	Median				2.3		1.86	3.3		1.86	0.57
			2016 - 2017	Secchi (m)	Mean	10	6.62								-0.59
			2016 - 2017	TSS (mgL^{-1})	Median				1.6		2.2	2.4		2.8	-0.34
Burdekin	Burdekin	Palms West	2015 - 2016	Chla (μgL^{-1})	Median				0.32		0.48	0.63		0.43	-0.01
			2015 - 2016	NOx (μgL^{-1})	Median	0.28		1.99							-1
			2015 - 2016	Turbidity (NTU)	Median	0.8		0.8							0.01
			2015 - 2016	PN (μgL^{-1})	Median				16		20.06	25		15.04	0.2
			2015 - 2016	PP (μgL^{-1})	Median				2.3		2.56	3.3		1.98	0.29
			2015 - 2016	Secchi (m)	Mean	10	7.21								-0.47
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		0.28	2.4		2.09	0.6
			2016 - 2017	Chla (μgL^{-1})	Median				0.32		0.29	0.63		0.41	0.4
			2016 - 2017	NOx (μgL^{-1})	Median	0.28		2.42							-1
			2016 - 2017	Turbidity (NTU)	Median	0.8		0.65							0.3
			2016 - 2017	PN (μgL^{-1})	Median				16		10.2	25		8.12	0.82

						Annual			Dry Season			Wet Season			
Region	Subregion	Reef	Year	Measure	Stat.	GL	Mean	Median	GL	Mean	Median	GL	Mean	Median	Index
			2016 - 2017	PP (µgL^{-1})	Median				2.3		1.68	3.3		2.76	0.36
			2016 - 2017	Secchi (m)	Mean	10	7.89								-0.34
			2016 - 2017	TSS (mgL^{-1})	Median				1.6		0.39	2.4		2.73	0.41
		Pandora	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.4	0.63		0.37	0.22
			2015 - 2016	NOx (µgL^{-1})	Median	0.28		1.63							-1
			2015 - 2016	Turbidity (NTU)	Median	0.8		1.16							-0.54
			2015 - 2016	PN (µgL^{-1})	Median				16		17.49	25		12.69	0.42
			2015 - 2016	PP (µgL^{-1})	Median				2.3		3.37	3.3		1.62	0.22
			2015 - 2016	Secchi (m)	Mean	10	4.54								-1
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		0.88	2.4		2.92	0.29
			2016 - 2017	Chla (µgL^{-1})	Median				0.32		0.27	0.63		0.38	0.47
			2016 - 2017	NOx (µgL^{-1})	Median	0.28		2.94							-1
			2016 - 2017	Turbidity (NTU)	Median	0.8		0.89							-0.16
			2016 - 2017	PN (µgL^{-1})	Median				16		16.17	25		6.79	0.49
			2016 - 2017	PP (µgL^{-1})	Median				2.3		1.38	3.3		2.87	0.47
			2016 - 2017	Secchi (m)	Mean	10	5.83								-0.78
			2016 - 2017	TSS (mgL^{-1})	Median				1.6		0.84	2.4		3.42	0.2
		Cordelia	2015 - 2016	Chla (µgL^{-1})	Median							0.63		0.22	1
			2015 - 2016	NOx (µgL^{-1})	Median	0.28		4							-1
			2015 - 2016	PN (µgL^{-1})	Median							25		8	1
			2015 - 2016	PP (µgL^{-1})	Median							3.3		1	1
			2015 - 2016	Secchi (m)	Mean	10	4.67								-1
			2015 - 2016	TSS (mgL^{-1})	Median							2.4		3.2	-0.42
			2016 - 2017	Chla (µgL^{-1})	Median							0.63		0.4	0.64

						Annual			Dry Season			Wet Season			
Region	Subregion	Reef	Year	Measure	Stat.	GL	Mean	Median	GL	Mean	Median	GL	Mean	Median	Index
			2016 - 2017	NOx (µgL^{-1})	Median	0.28		3.43							-1
			2016 - 2017	PN (µgL^{-1})	Median							25		7	1
			2016 - 2017	PP (µgL^{-1})	Median							3.3		1.39	1
			2016 - 2017	Secchi (m)	Mean	10	3.5								-1
			2016 - 2017	TSS (mgL^{-1})	Median							2.4		2.5	-0.06
		Magnetic	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.48	0.63		0.54	-0.19
			2015 - 2016	NOx (µgL^{-1})	Median	0.28		5.97							-1
			2015 - 2016	Turbidity (NTU)	Median	1.3		1.49							-0.2
			2015 - 2016	PN (µgL^{-1})	Median				16		11.66	25		24.05	0.26
			2015 - 2016	PP (µgL^{-1})	Median				2.3		4.77	3.3		3.07	-0.45
			2015 - 2016	Secchi (m)	Median	4		3							-0.42
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		1.48	2.4		3.9	-0.29
			2016 - 2017	Chla (µgL^{-1})	Median				0.32		0.26	0.63		0.66	0.1
			2016 - 2017	NOx (µgL^{-1})	Median	0.28		8.61							-1
			2016 - 2017	Turbidity (NTU)	Median	1.3		1.27							0.04
			2016 - 2017	PN (µgL^{-1})	Median				16		22.08	25		6.51	0.27
			2016 - 2017	PP (µgL^{-1})	Median				2.3		3.54	3.3		2.97	-0.24
			2016 - 2017	Secchi (m)	Median	4		4							0
			2016 - 2017	TSS (mgL^{-1})	Median				1.6		1.25	2.4		3.75	-0.14
		Cape Cleveland	2015 - 2016	Chla (µgL^{-1})	Median							0.63		0.35	0.85
			2015 - 2016	NOx (µgL^{-1})	Median	1		3							-1
			2015 - 2016	PN (µgL^{-1})	Median							25		41	-0.71
			2015 - 2016	PP (µgL^{-1})	Median							3.3		1	1
			2015 - 2016	Secchi (m)	Mean	10	4.67								-1

						Annual			Dry Season			Wet Season			
Region	Subregion	Reef	Year	Measure	Stat.	GL	Mean	Median	GL	Mean	Median	GL	Mean	Median	Index
			2015 - 2016	TSS (mgL^{-1})	Median							2.4		2.9	-0.27
			2016 - 2017	Chla (µgL^{-1})	Median							0.63		0.49	0.36
			2016 - 2017	NOx (µgL^{-1})	Median	1		9.94							-1
			2016 - 2017	PN (µgL^{-1})	Median							25		3.22	1
			2016 - 2017	PP (µgL^{-1})	Median							3.3		3.1	0.09
			2016 - 2017	Secchi (m)	Mean	10	3								-1
			2016 - 2017	TSS (mgL^{-1})	Median							2.4		3.5	-0.54
		Cleveland Bay	2015 - 2016	Chla (µgL^{-1})	Median							0.63		0.37	0.77
			2015 - 2016	NOx (µgL^{-1})	Median	0.5		2							-1
			2015 - 2016	PN (µgL^{-1})	Median							25		15	0.74
			2015 - 2016	PP (µgL^{-1})	Median							3.3		1	1
			2015 - 2016	Secchi (m)	Median	3		2							-0.58
			2015 - 2016	TSS (mgL^{-1})	Median							2.4		3.9	-0.7
		Haughton	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.38	0.63		0.46	0.09
			2015 - 2016	NOx (µgL^{-1})	Median	1		3.47							-1
			2015 - 2016	PN (µgL^{-1})	Median				16		11.01	25		14.37	0.67
			2015 - 2016	PP (µgL^{-1})	Median				2.3		6.39	3.3		2.4	-0.27
			2015 - 2016	Secchi (m)	Mean	10	6.29								-0.67
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		22.48	2.4		4.54	-0.96
			2016 - 2017	Chla (µgL^{-1})	Median				0.32		0.28	0.63		0.52	0.25
			2016 - 2017	NOx (µgL^{-1})	Median	1		4.76							-1
			2016 - 2017	PN (µgL^{-1})	Median				16		7.91	25		14.18	0.91
			2016 - 2017	PP (µgL^{-1})	Median				2.3		2.48	3.3		3.41	-0.08
			2016 - 2017	Secchi (m)	Mean	10	4.79								-1

						Annual			Dry Season			Wet Season			
Region	Subregion	Reef	Year	Measure	Stat.	GL	Mean	Median	GL	Mean	Median	GL	Mean	Median	Index
			2016 - 2017	TSS (mgL⁻¹)	Median				1.6		1.8	2.4		3.7	-0.4
		Yongala	2015 - 2016	Chla (µgL⁻¹)	Median				0.32		0.23	0.63		0.26	0.73
			2015 - 2016	NOx (µgL⁻¹)	Median	0.28		0.36							-0.37
			2015 - 2016	PN (µgL⁻¹)	Median				16		9.56	25		12.13	0.87
			2015 - 2016	PP (µgL⁻¹)	Median				2.3		1.3	3.3		1.69	0.9
			2015 - 2016	Secchi (m)	Mean	10	14.33								0.52
			2015 - 2016	TSS (mgL⁻¹)	Median				1.6		0.2	2.4		0.28	1
			2016 - 2017	Chla (µgL⁻¹)	Median				0.32		0.2	0.63		0.36	0.74
			2016 - 2017	NOx (µgL⁻¹)	Median	0.28		0.47							-0.74
			2016 - 2017	PN (µgL⁻¹)	Median				16		10.93	25		17.24	0.54
			2016 - 2017	PP (µgL⁻¹)	Median				2.3		1.54	3.3		2.69	0.44
			2016 - 2017	Secchi (m)	Mean	10	15.33								0.62
			2016 - 2017	TSS (mgL⁻¹)	Median				1.6		0.4	2.4		0.67	1
		Cape Bowling Green	2015 - 2016	Chla (µgL⁻¹)	Median							0.63		0.62	0.03
			2015 - 2016	NOx (µgL⁻¹)	Median	1		10.5							-1
			2015 - 2016	PN (µgL⁻¹)	Median							25		36.98	-0.56
			2015 - 2016	PP (µgL⁻¹)	Median							3.3		1.5	1
			2015 - 2016	Secchi (m)	Mean	10	2.75								-1
			2015 - 2016	TSS (mgL⁻¹)	Median							2.4		6	-1
			2016 - 2017	Chla (µgL⁻¹)	Median							0.63		1.14	-0.86
			2016 - 2017	NOx (µgL⁻¹)	Median	1		49.84							-1
			2016 - 2017	PN (µgL⁻¹)	Median							25		18.06	0.47
			2016 - 2017	PP (µgL⁻¹)	Median							3.3		3.1	0.09
			2016 - 2017	Secchi (m)	Mean	10	1.1								-1

						Annual			Dry Season			Wet Season			
Region	Subregion	Reef	Year	Measure	Stat.	GL	Mean	Median	GL	Mean	Median	GL	Mean	Median	Index
			2016 - 2017	TSS (mgL^{-1})	Median							2.4		4.8	-1
		Haughton Mouth	2015 - 2016	Chla (µgL^{-1})	Median							0.63		0.86	-0.45
			2015 - 2016	NOx (µgL^{-1})	Median	4		2							1
			2015 - 2016	PN (µgL^{-1})	Median							25		43.89	-0.81
			2015 - 2016	PP (µgL^{-1})	Median							3.3		0	1
			2015 - 2016	Secchi (m)	Median	1.5		2							0.42
			2015 - 2016	TSS (mgL^{-1})	Median							2.4		4.6	-0.94
			2016 - 2017	Chla (µgL^{-1})	Median							0.63		1.17	-0.89
			2016 - 2017	NOx (µgL^{-1})	Median	4		3.92							0.03
			2016 - 2017	PN (µgL^{-1})	Median							25		25.34	-0.02
			2016 - 2017	PP (µgL^{-1})	Median							3.3		4.96	-0.59
			2016 - 2017	Secchi (m)	Median	1.5		1.5							0
			2016 - 2017	TSS (mgL^{-1})	Median							2.4		5.6	-1
		Barratta Creek	2015 - 2016	Chla (µgL^{-1})	Median							0.63		1.44	-1
			2015 - 2016	NOx (µgL^{-1})	Median	4		10.5							-1
			2015 - 2016	PN (µgL^{-1})	Median							25		54.45	-1
			2015 - 2016	PP (µgL^{-1})	Median							3.3		5.5	-0.74
			2015 - 2016	Secchi (m)	Median	1.5		0.5							-1
			2015 - 2016	TSS (mgL^{-1})	Median							2.4		12.35	-1
			2016 - 2017	Chla (µgL^{-1})	Median							0.63		1.55	-1
			2016 - 2017	NOx (µgL^{-1})	Median	4		1.96							1
			2016 - 2017	PN (µgL^{-1})	Median							25		12.6	0.99
			2016 - 2017	PP (µgL^{-1})	Median							3.3		4.96	-0.59
			2016 - 2017	Secchi (m)	Median	1.5		1.3							-0.21

						Annual			Dry Season			Wet Season			
Region	Subregion	Reef	Year	Measure	Stat.	GL	Mean	Median	GL	Mean	Median	GL	Mean	Median	Index
			2016 - 2017	TSS (mgL^{-1})	Median							2.4		10	-1
		Plantation Creek	2015 - 2016	Chla (µgL^{-1})	Median							0.63		0.65	-0.05
			2015 - 2016	NOx (µgL^{-1})	Median	1		10							-1
			2015 - 2016	PN (µgL^{-1})	Median							25		39	-0.64
			2015 - 2016	PP (µgL^{-1})	Median							3.3		1	1
			2015 - 2016	Secchi (m)	Mean	10	3.6								-1
			2015 - 2016	TSS (mgL^{-1})	Median							2.4		2.6	-0.12
			2016 - 2017	Chla (µgL^{-1})	Median							0.63		0.77	-0.29
			2016 - 2017	NOx (µgL^{-1})	Median	1		63							-1
			2016 - 2017	PN (µgL^{-1})	Median							25		26.74	-0.1
			2016 - 2017	PP (µgL^{-1})	Median							3.3		26.01	-1
			2016 - 2017	Secchi (m)	Mean	10	0.8								-1
			2016 - 2017	TSS (mgL^{-1})	Median							2.4		8.4	-1
		Burdekin Mouth Mooring	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.6	0.63		0.53	-0.33
			2015 - 2016	NOx (µgL^{-1})	Median	4		6.16							-0.62
			2015 - 2016	Turbidity (NTU)	Median	4		3.27							0.29
			2015 - 2016	PN (µgL^{-1})	Median				16		4.27	25		23.69	0.54
			2015 - 2016	PP (µgL^{-1})	Median				2.3		2.72	3.3		1.49	0.38
			2015 - 2016	Secchi (m)	Median	1.5		2							0.42
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		3.68	2.4		3.29	-0.73
			2016 - 2017	Chla (µgL^{-1})	Median				0.32		0.48	0.63		0.54	-0.17
			2016 - 2017	NOx (µgL^{-1})	Median	4		5.78							-0.53
			2016 - 2017	Turbidity (NTU)	Median	4		3.02							0.4
			2016 - 2017	PN (µgL^{-1})	Median				16		11.34	25		18.65	0.46

						Annual			Dry Season			Wet Season			
Region	Subregion	Reef	Year	Measure	Stat.	GL	Mean	Median	GL	Mean	Median	GL	Mean	Median	Index
			2016 - 2017	PP (μgL^{-1})	Median				2.3		0.93	3.3		4.03	0.36
			2016 - 2017	Secchi (m)	Median	1.5		2.7							0.85
			2016 - 2017	TSS (mgL^{-1})	Median				1.6		3.95	2.4		4.12	-0.89
		Burdekin Mouth 2	2015 - 2016	Chla (μgL^{-1})	Median							0.63		1.32	-1
			2015 - 2016	NOx (μgL^{-1})	Median	4		8							-1
			2015 - 2016	PN (μgL^{-1})	Median							25		22.81	0.13
			2015 - 2016	PP (μgL^{-1})	Median							3.3		6	-0.86
			2015 - 2016	Secchi (m)	Median	1.5		0.8							-0.91
			2015 - 2016	TSS (mgL^{-1})	Median							2.4		5.8	-1
			2016 - 2017	Chla (μgL^{-1})	Median							0.63		5.48	-1
			2016 - 2017	NOx (μgL^{-1})	Median	4		64.96							-1
			2016 - 2017	PN (μgL^{-1})	Median							25		121.67	-1
			2016 - 2017	PP (μgL^{-1})	Median							3.3		35	-1
			2016 - 2017	Secchi (m)	Median	1.5		0.3							-1
			2016 - 2017	TSS (mgL^{-1})	Median							2.4		28	-1
		Burdekin Mouth 3	2015 - 2016	Chla (μgL^{-1})	Median							0.63		0.95	-0.59
			2015 - 2016	NOx (μgL^{-1})	Median	4		4							0
			2015 - 2016	PN (μgL^{-1})	Median							25		23.5	0.09
			2015 - 2016	PP (μgL^{-1})	Median							3.3		2	0.72
			2015 - 2016	Secchi (m)	Median	1.5		1.3							-0.21
			2015 - 2016	TSS (mgL^{-1})	Median							2.4		6.9	-1
			2016 - 2017	Chla (μgL^{-1})	Median							0.63		0.61	0.05
			2016 - 2017	NOx (μgL^{-1})	Median	4		57.96							-1
			2016 - 2017	PN (μgL^{-1})	Median							25		131.05	-1

						Annual			Dry Season			Wet Season			
Region	Subregion	Reef	Year	Measure	Stat.	GL	Mean	Median	GL	Mean	Median	GL	Mean	Median	Index
			2016 - 2017	PP (µgL^{-1})	Median							3.3		30.04	-1
			2016 - 2017	Secchi (m)	Median	1.5		0.4							-1
			2016 - 2017	TSS (mgL^{-1})	Median							2.4		18	-1
Mackay Whitsunday	Mackay Whitsunday	Double Cone	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.37	0.63		0.43	0.18
			2015 - 2016	NOx (µgL^{-1})	Median	1		1.41							-0.5
			2015 - 2016	Turbidity (NTU)	Median	1.1		1.21							-0.14
			2015 - 2016	PN (µgL^{-1})	Median				16		18.52	25		19.76	0.06
			2015 - 2016	PP (µgL^{-1})	Median				2.3		3.56	3.3		2.91	-0.22
			2015 - 2016	Secchi (m)	Mean	10	5.17								-0.95
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		1.6	2.4		0.86	0.5
			2016 - 2017	Chla (µgL^{-1})	Median				0.32		0.84	0.63		1.12	-0.92
			2016 - 2017	NOx (µgL^{-1})	Median	1		2.64							-1
			2016 - 2017	Turbidity (NTU)	Median	1.1		1.06							0.05
			2016 - 2017	PN (µgL^{-1})	Median				16		33.03	25		25.97	-0.53
			2016 - 2017	PP (µgL^{-1})	Median				2.3		7	3.3		5.38	-0.85
			2016 - 2017	Secchi (m)	Mean	10	3.81								-1
			2016 - 2017	TSS (mgL^{-1})	Median				1.6		6.93	2.4		3.6	-0.79
		Hook	2016 - 2017	Chla (µgL^{-1})	Median							0.63		0.75	-0.25
			2016 - 2017	NOx (µgL^{-1})	Median	1		25.06							-1
			2016 - 2017	PN (µgL^{-1})	Median							25		14.98	0.74
			2016 - 2017	PP (µgL^{-1})	Median							3.3		4.96	-0.59
			2016 - 2017	Secchi (m)	Mean	10	0.9								-1
			2016 - 2017	TSS (mgL^{-1})	Median							2.4		9.1	-1
		Pine	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.57	0.63		0.48	-0.22

						Annual			Dry Season			Wet Season			
Region	Subregion	Reef	Year	Measure	Stat.	GL	Mean	Median	GL	Mean	Median	GL	Mean	Median	Index
			2015 - 2016	NOx (µgL^{-1})	Median	1		2.22							-1
			2015 - 2016	Turbidity (NTU)	Median	1.1		2.06							-0.91
			2015 - 2016	PN (µgL^{-1})	Median				16		17.91	25		19.57	0.1
			2015 - 2016	PP (µgL^{-1})	Median				2.3		3.95	3.3		2.78	-0.27
			2015 - 2016	Secchi (m)	Mean	10	5.5								-0.86
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		3.01	2.4		1.06	0.04
			2016 - 2017	Chla (µgL^{-1})	Median				0.32		0.81	0.63		0.79	-0.66
			2016 - 2017	NOx (µgL^{-1})	Median	1		11.71							-1
			2016 - 2017	Turbidity (NTU)	Median	1.1		1.55							-0.49
			2016 - 2017	PN (µgL^{-1})	Median				16		28.64	25		16.34	-0.11
			2016 - 2017	PP (µgL^{-1})	Median				2.3		8.58	3.3		5.43	-0.86
			2016 - 2017	Secchi (m)	Mean	10	2.47								-1
			2016 - 2017	TSS (mgL^{-1})	Median				1.6		12.25	2.4		6.24	-1
		Seaforth	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.46	0.63		0.48	-0.06
			2015 - 2016	NOx (µgL^{-1})	Median	1		1.37							-0.45
			2015 - 2016	Turbidity (NTU)	Median	1.1		1.44							-0.39
			2015 - 2016	PN (µgL^{-1})	Median				16		19.05	25		20.34	0.02
			2015 - 2016	PP (µgL^{-1})	Median				2.3		3.88	3.3		3.42	-0.4
			2015 - 2016	Secchi (m)	Mean	10	4.75								-1
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		2.94	2.4		1.52	-0.11
			2016 - 2017	Chla (µgL^{-1})	Median				0.32		0.69	0.63		1.08	-0.89
			2016 - 2017	NOx (µgL^{-1})	Median	1		4.97							-1
			2016 - 2017	Turbidity (NTU)	Median	1.1		1.52							-0.47
			2016 - 2017	PN (µgL^{-1})	Median				16		27.05	25		20.07	-0.22

						Annual			Dry Season			Wet Season			
Region	Subregion	Reef	Year	Measure	Stat.	GL	Mean	Median	GL	Mean	Median	GL	Mean	Median	Index
			2016 - 2017	PP (µgL^{-1})	Median				2.3		6.42	3.3		4	-0.64
			2016 - 2017	Secchi (m)	Mean	10	3.44								-1
			2016 - 2017	TSS (mgL^{-1})	Median				1.6		3.88	2.4		2.4	-0.5
		O'Connell Mouth	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.92	0.63		0.96	-0.81
			2015 - 2016	NOx (µgL^{-1})	Median	4		0.35							1
			2015 - 2016	PN (µgL^{-1})	Median				16		37.62	25		27.6	-0.57
			2015 - 2016	PP (µgL^{-1})	Median				2.3		7.59	3.3		5.64	-0.89
			2015 - 2016	Secchi (m)	Median	1.6		5							1
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		1.56	2.4		2.09	0.12
			2016 - 2017	Chla (µgL^{-1})	Median				0.32		1.36	0.63		2.56	-1
			2016 - 2017	NOx (µgL^{-1})	Median	4		4.31							-0.11
			2016 - 2017	PN (µgL^{-1})	Median				16		33.34	25		30.28	-0.64
			2016 - 2017	PP (µgL^{-1})	Median				2.3		7.78	3.3		8.48	-1
			2016 - 2017	Secchi (m)	Median	1.6		1.75							0.13
			2016 - 2017	TSS (mgL^{-1})	Median				1.6		3.63	2.4		7.31	-1
		Repulse	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.71	0.63		0.79	-0.66
			2015 - 2016	NOx (µgL^{-1})	Median	0.25		1.57							-1
			2015 - 2016	Turbidity (NTU)	Mean	2	4.25								-1
			2015 - 2016	PN (µgL^{-1})	Median				16		26.09	25		28.29	-0.44
			2015 - 2016	PP (µgL^{-1})	Median				2.3		7.74	3.3		5.14	-0.82
			2015 - 2016	Secchi (m)	Mean	10	3.67								-1
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		6.11	2.4		3.66	-0.8
			2016 - 2017	Chla (µgL^{-1})	Median				0.32		0.8	0.63		1.16	-0.94
			2016 - 2017	NOx (µgL^{-1})	Median	0.25		4.31							-1

						Annual			Dry Season			Wet Season			
Region	Subregion	Reef	Year	Measure	Stat.	GL	Mean	Median	GL	Mean	Median	GL	Mean	Median	Index
			2016 - 2017	Turbidity (NTU)	Mean	2	6.6								-1
			2016 - 2017	PN (µgL^{-1})	Median				16		38.64	25		21.24	-0.38
			2016 - 2017	PP (µgL^{-1})	Median				2.3		8.04	3.3		7.87	-1
			2016 - 2017	Secchi (m)	Mean	10	2.16								-1
			2016 - 2017	TSS (mgL^{-1})	Median				1.6		8.02	2.4		2.73	-0.59
		Brampton	2016 - 2017	Chla (µgL^{-1})	Median							0.63		1.17	-0.89
			2016 - 2017	NOx (µgL^{-1})	Median	0.25		35.98							-1
			2016 - 2017	PN (µgL^{-1})	Median							25		1.4	1
			2016 - 2017	PP (µgL^{-1})	Median							3.3		0.93	1
			2016 - 2017	Secchi (m)	Mean	10	0								-1
			2016 - 2017	TSS (mgL^{-1})	Median							2.4		6.6	-1
		Sand Bay 1	2015 - 2016	Chla (µgL^{-1})	Median							0.63			🟥
			2015 - 2016	NOx (µgL^{-1})	Median	1		23							-1
			2015 - 2016	PN (µgL^{-1})	Median							25		96	-1
			2015 - 2016	PP (µgL^{-1})	Median							3.3		15	-1
			2015 - 2016	Secchi (m)	Mean	10	1								-1
			2015 - 2016	TSS (mgL^{-1})	Median							2.4		8.6	-1
			2016 - 2017	Chla (µgL^{-1})	Median							0.63		1.34	-1
			2016 - 2017	NOx (µgL^{-1})	Median	1		38.92							-1
			2016 - 2017	PN (µgL^{-1})	Median							25		6.3	1
			2016 - 2017	PP (µgL^{-1})	Median							3.3		3.1	0.09
			2016 - 2017	Secchi (m)	Mean	10	0								-1
			2016 - 2017	TSS (mgL^{-1})	Median							2.4		17	-1
		Sand Bay 2	2015 - 2016	Chla (µgL^{-1})	Median							0.63			🟥

						Annual			Dry Season			Wet Season			
Region	Subregion	Reef	Year	Measure	Stat.	GL	Mean	Median	GL	Mean	Median	GL	Mean	Median	Index
			2015 - 2016	NOx (μgL^{-1})	Median	1		11							-1
			2015 - 2016	PN (μgL^{-1})	Median							25		112	-1
			2015 - 2016	PP (μgL^{-1})	Median							3.3			🟥
			2015 - 2016	Secchi (m)	Mean	10	1								-1
			2015 - 2016	TSS (mgL^{-1})	Median							2.4		16	-1
		Pioneer Mouth	2015 - 2016	Chla (μgL^{-1})	Median							0.63			🟥
			2015 - 2016	NOx (μgL^{-1})	Median	1		17							-1
			2015 - 2016	PN (μgL^{-1})	Median							25			🟥
			2015 - 2016	PP (μgL^{-1})	Median							3.3			🟥
			2015 - 2016	Secchi (m)	Mean	10	0.5								-1
			2015 - 2016	TSS (mgL^{-1})	Median							2.4		18	-1
			2016 - 2017	Chla (μgL^{-1})	Median							0.63		1.4	-1
			2016 - 2017	NOx (μgL^{-1})	Median	1		31.92							-1
			2016 - 2017	PN (μgL^{-1})	Median							25		9.1	1
			2016 - 2017	PP (μgL^{-1})	Median							3.3		8.98	-1
			2016 - 2017	Secchi (m)	Mean	10	0								-1
			2016 - 2017	TSS (mgL^{-1})	Median							2.4		14	-1

Table E-12: Interim Water Quality Index for each water quality sampling location: Summary of four-year running means and calculation of the index. See Section 2.2 for details on index calculation. Data range = from start of the program (2005 for direct water sampling data or 2007 for water quality instruments) to September of each respective year (June for 2015). Red shaded cells are running means that did not comply with the GBRMPA Water Quality Guidelines for the Great Barrier Reef Marine Park (GBRMPA 2010). Values that did not comply with the Guidelines received a score of “1”; those that did comply were scored as “0”. The scores for suspended solids, turbidity and Secchi depth were averaged for a “combined turbidity score”. The sum of these combined scores and the scores for PN, PP and chlorophyll yielded a total score per site. This total score was converted into a percentage rating and colour-coded (see Section 2.2. for details). Empty cells indicate data not available.

		Depth-weighted means							Indicator scores									
Reef	Date range	NOx	PN	PP	Chl a	SS	Secchi	Turbidity	NOx	PN	PP	Chl a	SS	Secchi	Turbidity	Combined Turbidity	Total score	Scaled score
Cape Tribulation	2003-2006	0.01	12.19	1.82	0.31	1.90	10.00		1	0.71	0.62	0.54	0.07	0		0.07	2.94	0.59
	2004-2007	0.23	11.69	1.87	0.29	1.57	10.00		1	0.77	0.58	0.61	0.35	0		0.35	3.31	0.66
	2005-2008	0.26	12.56	2.47	0.33	1.79	7.50		1	0.67	0.18	0.43	0.16	-0.42		0.16	2.44	0.49
	2006-2009	0.39	12.36	2.39	0.33	1.65	6.63		1	0.69	0.23	0.45	0.28	-0.59		0.28	2.65	0.53
	2007-2010	0.53	12.55	2.61	0.39	1.44	6.72		1	0.67	0.1	0.22	0.48	-0.57		0.48	2.47	0.49
	2008-2011	0.45	13.74	2.84	0.46	1.54	6.30		1	0.54	-0.02	-0.02	0.37	-0.67		0.37	1.88	0.38
	2009-2012	0.61	12.96	2.66	0.44	1.22	6.39		1	0.63	0.07	0.05	0.72	-0.65		0.72	2.47	0.49
	2010-2013	0.77	12.80	2.69	0.45	1.23	7.17		1	0.64	0.06	0.01	0.7	-0.48		0.7	2.41	0.48
	2011-2014	1.04	12.28	2.83	0.42	1.19	7.29		0.94	0.7	-0.02	0.1	0.75	-0.46		0.75	2.48	0.5
	2012-2015	1.25	11.71	2.95	0.40	1.45	7.29		0.68	0.77	-0.08	0.16	0.46	-0.46		0.46	2	0.4
	2013-2016	1.19	12.16	3.11	0.42	1.70	6.92		0.75	0.72	-0.15	0.1	0.24	-0.53		0.24	1.65	0.33
	2014-2017	0.95	12.67	3.18	0.47	1.65	5.92		1	0.66	-0.18	-0.05	0.28	-0.76		0.28	1.7	0.34
	2015-2018	0.72	13.24	3.13	0.49	1.83	4.95		1	0.6	-0.16	-0.12	0.13	-1		0.13	1.45	0.29
Double	2003-2006	0.04	12.74	1.48	0.37	1.38	14.00		1	0.65	0.92	0.28	0.54	0.49		0.54	3.38	0.68
	2004-2007	0.03	12.99	1.78	0.36	1.33	9.50		1	0.62	0.65	0.31	0.59	-0.07		0.59	3.18	0.64
	2005-2008	0.02	12.69	1.93	0.35	1.18	11.00		1	0.66	0.53	0.38	0.76	0.14		0.76	3.33	0.67
	2006-2009	0.15	11.37	1.96	0.32	1.19	9.50		1	0.82	0.51	0.5	0.75	-0.07		0.75	3.57	0.71
	2007-2010	0.22	11.24	2.18	0.32	1.16	8.67		1	0.83	0.36	0.51	0.79	-0.21		0.79	3.49	0.7
	2008-2011	0.24	11.31	2.27	0.37	1.16	8.09		1	0.82	0.3	0.3	0.79	-0.31		0.79	3.21	0.64
	2009-2012	0.43	11.04	2.34	0.38	1.14	7.12		1	0.86	0.26	0.25	0.81	-0.49		0.81	3.18	0.64
	2010-2013	0.66	11.28	2.43	0.39	1.21	7.00		1	0.83	0.2	0.21	0.73	-0.51		0.73	2.96	0.59

		Depth-weighted means							Indicator scores									
Reef	Date range	NOx	PN	PP	Chl a	SS	Secchi	Turbidity	NOx	PN	PP	Chl a	SS	Secchi	Turbidity	Combined Turbidity	Total score	Scaled score
	2011-2014	1.09	11.24	2.56	0.44	1.20	6.62		0.88	0.83	0.13	0.04	0.74	-0.59		0.74	2.62	0.52
	2012-2015	1.39	11.47	2.56	0.41	1.28	6.67		0.53	0.8	0.13	0.15	0.64	-0.58		0.64	2.25	0.45
	2013-2016	1.27	11.60	2.63	0.42	1.34	6.04		0.66	0.79	0.09	0.11	0.57	-0.73		0.57	2.22	0.44
	2014-2017	0.99	12.54	3.58	0.45	1.22	5.58		1	0.67	-0.35	0.01	0.71	-0.84		0.71	2.04	0.41
	2015-2018	0.65	12.61	3.69	0.41	1.25	5.00		1	0.67	-0.4	0.13	0.67	-1		0.67	2.07	0.41
Double Cone	2003-2006	0.05	14.64	2.66	0.69	2.26	6.25		1	0.45	0.07	-0.62	0.41	-0.68		0.41	1.31	0.26
	2004-2007	0.18	12.92	2.22	0.50	1.49	7.83		1	0.63	0.34	-0.17	1	-0.35		1	2.8	0.56
	2005-2008	0.36	12.94	2.15	0.49	1.38	8.30	1.28	1	0.63	0.38	-0.14	1	-0.27	0.23	0.61	2.49	0.5
	2006-2009	1.01	12.83	2.12	0.47	1.33	7.44	1.31	0.98	0.64	0.4	-0.07	1	-0.43	0.2	0.6	2.56	0.51
	2007-2010	1.06	12.72	2.16	0.46	1.28	6.94	1.41	0.92	0.65	0.37	-0.03	1	-0.53	0.09	0.55	2.46	0.49
	2008-2011	1.31	13.15	2.54	0.51	1.78	6.25	1.49	0.61	0.61	0.14	-0.17	0.76	-0.68	0.01	0.38	1.57	0.31
	2009-2012	1.29	12.71	2.68	0.49	1.89	5.50	1.48	0.63	0.65	0.06	-0.13	0.67	-0.86	0.02	0.34	1.56	0.31
	2010-2013	1.33	12.41	2.74	0.47	1.84	6.00	1.49	0.59	0.69	0.03	-0.07	0.71	-0.74	0.01	0.36	1.59	0.32
	2011-2014	2.35	13.29	3.02	0.51	2.00	5.82	1.6	-0.23	0.59	-0.11	-0.17	0.59	-0.78	-0.09	0.25	0.32	0.06
	2012-2015	2.24	13.00	2.94	0.45	1.54	6.04	1.62	-0.16	0.62	-0.07	-0.01	0.96	-0.73	-0.11	0.42	0.8	0.16
	2013-2016	2.15	16.45	3.02	0.40	1.35	6.18	1.59	-0.11	0.28	-0.11	0.16	1	-0.69	-0.08	0.46	0.69	0.14
	2014-2017	1.94	19.35	3.51	0.55	1.82	5.38	1.74	0.04	0.05	-0.33	-0.3	0.72	-0.9	-0.22	0.25	-0.28	-0.06
	2015-2018	1.59	20.79	3.71	0.54	2.02	5.30		0.33	-0.06	-0.41	-0.27	0.57	-0.91		0.57	0.17	0.03
Dunk North	2003-2006	0.01	17.90	3.47	0.72	3.22	5.00		1	0.16	-0.31	-0.68	-0.69	-1		-0.69	-0.52	-0.1
	2004-2007	0.01	17.94	3.40	0.60	2.58	5.00		1	0.16	-0.28	-0.41	-0.37	-1		-0.37	0.1	0.02
	2005-2008	0.99	17.91	4.02	0.64	3.11	5.20	2.23	1	0.16	-0.52	-0.5	-0.64	-0.94	-0.57	-0.6	-0.47	-0.09
	2006-2009	0.96	16.15	3.57	0.56	2.77	5.00	2.38	1	0.31	-0.35	-0.32	-0.47	-1	-0.67	-0.57	0.07	0.01
	2007-2010	1.13	15.11	3.29	0.49	2.39	5.39	2.37	0.82	0.4	-0.23	-0.13	-0.25	-0.89	-0.66	-0.46	0.41	0.08
	2008-2011	1.35	14.96	3.49	0.56	2.87	5.00	2.48	0.57	0.42	-0.32	-0.32	-0.52	-1	-0.73	-0.62	-0.28	-0.06
	2009-2012	1.66	15.17	3.27	0.54	2.33	4.68	2.79	0.27	0.4	-0.23	-0.26	-0.22	-1	-0.89	-0.56	-0.37	-0.07
	2010-2013	2.02	15.14	3.23	0.54	2.16	4.99	2.85	-0.02	0.4	-0.21	-0.25	-0.11	-1	-0.93	-0.52	-0.59	-0.12
	2011-2014	2.43	15.51	3.46	0.61	2.25	4.70	3.54	-0.28	0.37	-0.31	-0.44	-0.17	-1	-1	-0.58	-1.24	-0.25
	2012-2015	2.39	15.36	3.27	0.55	1.66	4.92	3.59	-0.25	0.38	-0.22	-0.29	0.27	-1	-1	-0.37	-0.76	-0.15
	2013-2016	1.60	16.10	3.29	0.47	1.60	5.48	3.26	0.32	0.31	-0.23	-0.05	0.33	-0.87	-1	-0.34	0.01	0
	2014-2017	1.40	17.68	3.66	0.48	1.73	5.38	3.31	0.51	0.18	-0.39	-0.1	0.21	-0.9	-1	-0.39	-0.18	-0.04

		Depth-weighted means							Indicator scores									
Reef	Date range	NOx	PN	PP	Chl a	SS	Secchi	Turbidity	NOx	PN	PP	Chl a	SS	Secchi	Turbidity	Combined Turbidity	Total score	Scaled score
	2015-2018	1.00	18.74	3.88	0.45	2.03	5.21	2.82	1	0.09	-0.47	-0.01	-0.02	-0.94	-0.91	-0.46	0.15	0.03
Fairlead Buoy	2003-2006	0.01	16.03	2.68	0.47	2.68	5.50		1	0.32	0.06	-0.06	-0.42	-0.86		-0.42	0.9	0.18
	2004-2007	0.01	16.45	3.29	0.44	2.75	3.75		1	0.28	-0.23	0.02	-0.46	-1		-0.46	0.61	0.12
	2005-2008	0.03	16.31	3.45	0.47	2.70	4.50		1	0.29	-0.3	-0.06	-0.43	-1		-0.43	0.5	0.1
	2006-2009	0.12	15.68	3.70	0.47	3.10	4.06		1	0.35	-0.4	-0.06	-0.63	-1		-0.63	0.26	0.05
	2007-2010	0.24	16.02	4.32	0.49	3.82	3.65		1	0.32	-0.62	-0.14	-0.93	-1		-0.93	-0.37	-0.07
	2008-2011	0.33	16.27	4.49	0.55	4.46	3.69		1	0.3	-0.68	-0.3	-1	-1		-1	-0.68	-0.14
	2009-2012	0.55	16.54	4.60	0.56	4.42	3.35		1	0.27	-0.72	-0.31	-1	-1		-1	-0.75	-0.15
	2010-2013	0.83	16.94	4.56	0.56	4.06	3.24		1	0.24	-0.7	-0.31	-1	-1		-1	-0.78	-0.16
	2011-2014	1.10	16.13	4.32	0.60	3.60	3.53		0.86	0.31	-0.63	-0.41	-0.85	-1		-0.85	-0.71	-0.14
	2012-2015	1.29	16.19	4.93	0.66	4.30	3.11		0.63	0.3	-0.82	-0.56	-1	-1		-1	-1.44	-0.29
	2013-2016	1.27	16.29	5.13	0.72	4.64	2.82		0.65	0.3	-0.87	-0.67	-1	-1		-1	-1.59	-0.32
	2014-2017	0.95	16.17	5.26	0.79	4.85	2.73		1	0.31	-0.91	-0.8	-1	-1		-1	-1.41	-0.28
	2015-2018	0.66	17.71	5.62	0.79	5.58	2.17		1	0.18	-1	-0.81	-1	-1		-1	-1.63	-0.33
Fitzroy West	2003-2006	0.01	11.53	1.60	0.40	1.59	11.50		1	0.79	0.81	0.16	0.33	0.2		0.33	3.09	0.62
	2004-2007	1.15	11.34	1.66	0.35	1.26	10.67		0.79	0.82	0.75	0.35	0.67	0.09		0.67	3.38	0.68
	2005-2008	0.69	11.45	1.99	0.37	1.16	9.67	0.83	1	0.8	0.49	0.29	0.79	-0.05	0.85	0.82	3.41	0.68
	2006-2009	1.07	10.41	1.86	0.32	1.02	10.11	0.88	0.91	0.94	0.59	0.48	0.97	0.02	0.77	0.87	3.78	0.76
	2007-2010	1.12	10.41	1.94	0.31	0.92	8.95	0.88	0.83	0.94	0.53	0.54	1	-0.16	0.77	0.88	3.73	0.75
	2008-2011	1.49	10.41	1.94	0.30	0.85	9.05	0.94	0.42	0.94	0.53	0.59	1	-0.14	0.67	0.84	3.32	0.66
	2009-2012	1.95	10.50	1.89	0.28	0.85	8.77	1.05	0.04	0.93	0.57	0.66	1	-0.19	0.51	0.76	2.95	0.59
	2010-2013	2.14	11.05	1.95	0.30	0.84	8.00	1.07	-0.1	0.86	0.52	0.58	1	-0.32	0.48	0.74	2.61	0.52
	2011-2014	2.84	11.00	2.02	0.33	0.78	8.05	1.15	-0.5	0.86	0.47	0.46	1	-0.31	0.39	0.69	1.99	0.4
	2012-2015	2.53	11.82	2.20	0.36	0.96	8.05	1.16	-0.34	0.76	0.35	0.33	1	-0.31	0.37	0.68	1.78	0.36
	2013-2016	2.04	13.06	2.15	0.33	0.77	9.01	1.13	-0.03	0.61	0.38	0.47	1	-0.15	0.4	0.7	2.14	0.43
	2014-2017	1.76	15.79	2.21	0.32	0.73	9.74	1.17	0.19	0.34	0.34	0.47	1	-0.04	0.36	0.68	2.02	0.4
	2015-2018	1.78	17.01	2.31	0.33	0.84	9.82	1.16	0.16	0.23	0.28	0.43	1	-0.03	0.37	0.69	1.79	0.36
Franklands West	2003-2006	0.01	11.98	1.77	0.31	1.23	13.00		1	0.74	0.67	0.56	0.7	0.38		0.7	3.66	0.73

		Depth-weighted means							Indicator scores									
Reef	Date range	NOx	PN	PP	Chl a	SS	Secchi	Turbidity	NOx	PN	PP	Chl a	SS	Secchi	Turbidity	Combined Turbidity	Total score	Scaled score
	2004-2007	0.37	10.74	1.71	0.26	1.01	11.50		1	0.9	0.71	0.78	0.99	0.2		0.99	4.37	0.87
	2005-2008	0.53	11.26	1.88	0.35	0.89	10.40	0.44	1	0.83	0.58	0.38	1	0.06	1	1	3.79	0.76
	2006-2009	0.84	10.43	1.69	0.31	0.70	11.25	0.54	1	0.94	0.73	0.54	1	0.17	1	1	4.2	0.84
	2007-2010	0.98	10.50	1.85	0.32	0.59	10.35	0.6	1	0.93	0.6	0.47	1	0.05	1	1	4	0.8
	2008-2011	1.19	10.63	1.96	0.37	0.67	9.91	0.71	0.75	0.91	0.52	0.3	1	-0.01	1	1	3.48	0.7
	2009-2012	1.30	10.23	1.92	0.33	0.56	9.86	0.8	0.62	0.97	0.54	0.46	1	-0.02	0.91	0.95	3.55	0.71
	2010-2013	1.37	11.23	2.07	0.35	0.66	9.05	0.88	0.55	0.83	0.43	0.36	1	-0.14	0.77	0.88	3.06	0.61
	2011-2014	1.62	11.53	2.16	0.40	0.66	8.70	0.96	0.31	0.79	0.37	0.17	1	-0.2	0.65	0.83	2.47	0.49
	2012-2015	1.35	12.64	2.27	0.38	0.75	8.42	0.94	0.56	0.66	0.3	0.23	1	-0.25	0.68	0.84	2.6	0.52
	2013-2016	1.16	15.68	2.30	0.34	0.72	8.75	0.93	0.79	0.35	0.28	0.4	1	-0.19	0.7	0.85	2.67	0.53
	2014-2017	0.92	16.34	2.37	0.35	0.75	8.53	0.93	1	0.29	0.24	0.38	1	-0.23	0.69	0.84	2.75	0.55
	2015-2018	1.20	17.32	2.44	0.33	0.79	8.33	0.97	0.73	0.21	0.2	0.47	1	-0.26	0.63	0.82	2.42	0.48
Green	2003-2006	0.07	8.69	1.53	0.19	1.12	22.00											
	2004-2007	0.11	8.56	1.33	0.17	0.88	19.33											
	2005-2008	0.47	9.39	1.56	0.25	0.74	15.83											
	2006-2009	0.49	8.95	1.45	0.22	0.56	15.33											
	2007-2010	0.53	9.35	1.46	0.23	0.33	13.70											
	2008-2011	0.69	9.83	1.64	0.28	0.34	12.67											
	2009-2012	0.78	9.47	1.64	0.28	0.30	12.38											
	2010-2013	1.04	9.90	1.66	0.29	0.35	11.46											
	2011-2014	1.37	10.02	1.74	0.33	0.40	10.50											
	2012-2015	1.42	10.23	1.71	0.33	0.51	10.29											
	2013-2016	1.30	10.70	1.73	0.32	0.53	9.79											
	2014-2017	1.04	11.07	1.89	0.34	0.67	8.92											
	2015-2018	0.80	10.98	1.84	0.30	0.77	8.40											
Haughton	2012-2015	0.85	23.40	3.69	0.73	1.44	4.50		1	-0.23	-0.4	-0.7	1	-1		1	0.67	0.13
	2013-2016	0.58	16.33	3.18	0.47	1.40	6.10		1	0.29	-0.19	-0.05	1	-0.71		1	2.05	0.41
	2014-2017	0.48	15.54	3.07	0.43	1.26	6.81		1	0.36	-0.13	0.08	1	-0.55		1	2.31	0.46
High West	2003-2006	0.10	13.82	2.40	0.41	2.22	10.25		1	0.53	0.22	0.14	-0.15	0.04		-0.15	1.75	0.35
	2004-2007	0.17	13.01	2.34	0.37	1.83	8.83		1	0.62	0.26	0.26	0.13	-0.18		0.13	2.27	0.45
	2005-2008	0.73	13.54	2.51	0.47	1.45	8.58	0.87	1	0.56	0.16	-0.07	0.46	-0.22	0.78	0.62	2.27	0.45

		Depth-weighted means							Indicator scores									
Reef	Date range	NOx	PN	PP	Chl a	SS	Secchi	Turbidity	NOx	PN	PP	Chl a	SS	Secchi	Turbidity	Combined Turbidity	Total score	Scaled score
	2006-2009	1.38	12.68	2.53	0.45	1.33	7.89	0.82	0.54	0.66	0.15	0	0.59	-0.34	0.87	0.73	2.08	0.42
	2007-2010	1.33	12.22	2.55	0.45	1.13	7.00	0.89	0.58	0.71	0.13	-0.01	0.83	-0.51	0.76	0.79	2.21	0.44
	2008-2011	1.70	12.29	2.74	0.48	1.15	6.45	1.05	0.23	0.7	0.03	-0.1	0.8	-0.63	0.51	0.66	1.53	0.31
	2009-2012	1.83	11.58	2.64	0.44	1.04	6.00	1.13	0.13	0.79	0.08	0.04	0.95	-0.74	0.41	0.68	1.72	0.34
	2010-2013	1.85	12.22	2.60	0.46	1.10	5.77	1.23	0.11	0.71	0.11	-0.04	0.86	-0.79	0.29	0.57	1.46	0.29
	2011-2014	2.66	12.51	2.72	0.50	1.15	5.55	1.38	-0.41	0.68	0.04	-0.15	0.8	-0.85	0.12	0.46	0.62	0.12
	2012-2015	2.76	13.16	2.62	0.50	1.52	5.96	1.34	-0.47	0.6	0.09	-0.15	0.4	-0.75	0.17	0.28	0.37	0.07
	2013-2016	3.22	16.04	3.08	0.49	1.71	6.21	1.31	-0.69	0.32	-0.14	-0.12	0.22	-0.69	0.2	0.21	-0.42	-0.08
	2014-2017	2.65	17.49	3.13	0.50	1.51	6.73	1.35	-0.4	0.19	-0.16	-0.16	0.41	-0.57	0.16	0.28	-0.25	-0.05
	2015-2018	2.09	18.21	3.24	0.49	1.51	6.54	1.24	-0.06	0.14	-0.21	-0.13	0.41	-0.61	0.27	0.34	0.07	0.01
Magnetic	2003-2006	0.01	25.00	4.18	1.28	3.50	4.00		1	-0.32	-0.58	-1	-0.22	-1		-0.22	-1.12	-0.22
	2004-2007	0.21	23.85	4.68	1.09	4.07	3.33		1	-0.25	-0.74	-1	-0.44	-1		-0.44	-1.43	-0.29
	2005-2008	2.03	20.97	4.56	0.85	4.00	4.00	2.72	-0.02	-0.07	-0.7	-0.91	-0.41	-1	-0.86	-0.64	-2.34	-0.47
	2006-2009	2.44	19.38	4.00	0.73	3.21	4.28	2.51	-0.29	0.05	-0.52	-0.7	-0.1	-1	-0.74	-0.42	-1.88	-0.38
	2007-2010	2.77	17.01	3.71	0.58	2.78	4.70	2.2	-0.47	0.23	-0.41	-0.37	0.11	-1	-0.56	-0.22	-1.24	-0.25
	2008-2011	3.08	16.30	3.60	0.58	2.50	4.68	2.33	-0.62	0.3	-0.36	-0.38	0.26	-1	-0.63	-0.19	-1.25	-0.25
	2009-2012	2.82	15.49	3.26	0.53	1.84	4.86	2.28	-0.5	0.37	-0.22	-0.23	0.7	-1	-0.61	0.05	-0.52	-0.1
	2010-2013	2.91	15.00	3.37	0.52	1.85	4.98	2.63	-0.54	0.42	-0.27	-0.21	0.69	-1	-0.81	-0.06	-0.66	-0.13
	2011-2014	4.10	15.74	3.66	0.57	1.91	4.34	2.87	-1	0.35	-0.39	-0.35	0.65	-1	-0.93	-0.14	-1.53	-0.31
	2012-2015	4.13	15.37	3.50	0.54	1.65	4.56	2.86	-1	0.38	-0.32	-0.27	0.86	-1	-0.93	-0.03	-1.25	-0.25
	2013-2016	3.71	17.25	3.66	0.56	1.72	4.23	2.78	-0.89	0.21	-0.39	-0.31	0.8	-1	-0.89	-0.04	-1.42	-0.28
	2014-2017	3.09	18.77	3.79	0.54	1.61	4.32	2.27	-0.63	0.09	-0.44	-0.26	0.9	-1	-0.6	0.15	-1.09	-0.22
	2015-2018	1.96	18.90	3.60	0.50	1.51	4.83	2.02	0.03	0.08	-0.36	-0.14	0.99	-1	-0.43	0.28	-0.11	-0.02
Palms West	2003-2006	0.01	11.77	1.62	0.29	2.81	8.50		1	0.77	0.79	0.66	-0.49	-0.23		-0.49	2.72	0.54
	2004-2007	0.35	11.06	1.64	0.26	1.64	8.75		1	0.86	0.77	0.8	0.28	-0.19		0.28	3.71	0.74
	2005-2008	0.24	11.11	1.82	0.35	1.10	7.88	0.54	1	0.85	0.62	0.36	0.87	-0.34	1	0.93	3.76	0.75
	2006-2009	1.76	10.95	1.85	0.39	0.93	8.36	0.67	0.77	0.87	0.6	0.21	1	-0.26	1	1	3.44	0.69
	2007-2010	1.58	11.76	1.97	0.40	0.75	8.56	0.65	0.93	0.77	0.51	0.17	1	-0.23	1	1	3.37	0.67
	2008-2011	1.51	12.10	2.26	0.46	0.82	8.05	0.73	0.99	0.73	0.31	-0.03	1	-0.31	1	1	3	0.6
	2009-2012	1.75	11.59	2.26	0.44	0.78	8.18	0.77	0.78	0.79	0.31	0.03	1	-0.29	0.97	0.98	2.89	0.58
	2010-2013	1.21	11.69	2.25	0.40	0.75	8.45	0.81	1	0.77	0.32	0.16	1	-0.24	0.89	0.94	3.2	0.64
	2011-2014	1.57	11.15	2.26	0.41	0.74	8.59	0.81	0.94	0.84	0.31	0.15	1	-0.22	0.88	0.94	3.19	0.64

		Depth-weighted means							Indicator scores									
Reef	Date range	NOx	PN	PP	Chl a	SS	Secchi	Turbidity	NOx	PN	PP	Chl a	SS	Secchi	Turbidity	Combined Turbidity	Total score	Scaled score
	2012-2015	1.72	10.81	1.98	0.34	0.65	8.96	0.77	0.81	0.89	0.5	0.39	1	-0.16	0.96	0.98	3.57	0.71
	2013-2016	1.78	13.82	2.16	0.39	0.88	9.21	0.77	0.76	0.53	0.38	0.22	1	-0.12	0.97	0.98	2.86	0.57
	2014-2017	1.51	15.60	2.31	0.41	0.85	9.73	0.74	0.99	0.36	0.28	0.14	1	-0.04	1	1	2.77	0.55
	2015-2018	1.32	16.81	2.31	0.40	0.80	9.88	0.79	1	0.25	0.28	0.17	1	-0.02	0.92	0.96	2.66	0.53
Pandora	2003-2006	0.01	13.42	2.57	0.57	2.74	5.50		1	0.58	0.12	-0.34	0.13	-0.86		0.13	1.49	0.3
	2004-2007	0.01	12.65	2.50	0.48	2.29	5.67		1	0.66	0.16	-0.08	0.39	-0.82		0.39	2.13	0.43
	2005-2008	0.38	13.27	2.65	0.46	2.01	6.00	1.09	1	0.59	0.08	-0.03	0.58	-0.74	0.46	0.52	2.16	0.43
	2006-2009	1.43	12.40	2.36	0.41	1.65	6.81	1.14	0.48	0.69	0.25	0.15	0.86	-0.55	0.4	0.63	2.2	0.44
	2007-2010	2.07	11.80	2.24	0.35	1.24	7.89	1.08	-0.05	0.76	0.32	0.36	1	-0.34	0.47	0.74	2.13	0.43
	2008-2011	2.05	12.58	2.42	0.37	1.09	7.75	1.22	-0.03	0.67	0.21	0.28	1	-0.37	0.3	0.65	1.77	0.35
	2009-2012	2.21	12.02	2.34	0.33	0.73	8.27	1.3	-0.15	0.73	0.26	0.46	1	-0.27	0.21	0.6	1.91	0.38
	2010-2013	2.05	12.56	2.51	0.34	0.73	8.27	1.32	-0.03	0.67	0.16	0.42	1	-0.27	0.18	0.59	1.81	0.36
	2011-2014	2.20	12.68	2.59	0.34	0.74	7.64	1.52	-0.13	0.66	0.11	0.39	1	-0.39	-0.02	0.49	1.52	0.3
	2012-2015	2.39	12.50	2.72	0.37	1.18	7.09	1.5	-0.26	0.68	0.04	0.27	1	-0.5	0	0.5	1.23	0.25
	2013-2016	2.31	14.08	2.86	0.40	1.34	5.88	1.51	-0.21	0.51	-0.03	0.19	1	-0.77	-0.01	0.49	0.95	0.19
	2014-2017	2.13	15.59	2.99	0.40	1.34	5.92	1.55	-0.09	0.36	-0.09	0.17	1	-0.76	-0.05	0.48	0.82	0.16
	2015-2018	1.75	17.52	3.05	0.39	1.36	5.87	1.42	0.19	0.19	-0.12	0.19	1	-0.77	0.08	0.54	0.99	0.2
Pine	2003-2006	0.19	15.53	2.29	0.52	2.17	7.25		1	0.36	0.29	-0.22	0.46	-0.46		0.46	1.9	0.38
	2004-2007	5.28	14.37	2.30	0.50	2.07	6.38		-1	0.48	0.28	-0.16	0.53	-0.65		0.53	0.13	0.03
	2005-2008	3.85	14.36	2.40	0.54	1.84	6.90	3.23	-0.94	0.48	0.22	-0.26	0.71	-0.54	-1	-0.15	-0.65	-0.13
	2006-2009	3.38	13.93	2.43	0.56	2.02	6.44	3.24	-0.76	0.52	0.21	-0.3	0.57	-0.64	-1	-0.22	-0.55	-0.11
	2007-2010	3.23	13.62	2.52	0.58	2.10	5.89	3.08	-0.69	0.55	0.15	-0.37	0.52	-0.76	-1	-0.24	-0.59	-0.12
	2008-2011	2.16	13.29	2.85	0.60	2.57	5.61	3.23	-0.11	0.59	-0.03	-0.41	0.23	-0.83	-1	-0.39	-0.35	-0.07
	2009-2012	2.28	13.21	3.34	0.62	3.84	4.61	3.2	-0.19	0.6	-0.26	-0.47	-0.36	-1	-1	-0.68	-0.99	-0.2
	2010-2013	2.82	13.25	3.53	0.61	4.05	4.34	2.95	-0.49	0.59	-0.34	-0.45	-0.43	-1	-0.98	-0.71	-1.39	-0.28
	2011-2014	4.97	13.61	4.10	0.64	5.19	3.70	3.34	-1	0.55	-0.55	-0.51	-0.79	-1	-1	-0.9	-2.4	-0.48
	2012-2015	4.52	13.68	3.85	0.61	4.71	4.19	3.2	-1	0.55	-0.46	-0.44	-0.65	-1	-1	-0.83	-2.18	-0.44
	2013-2016	4.28	14.98	3.41	0.56	3.10	5.07	3.08	-1	0.42	-0.29	-0.32	-0.05	-0.98	-1	-0.52	-1.71	-0.34
	2014-2017	4.66	16.19	3.87	0.65	3.76	4.81	3.01	-1	0.3	-0.47	-0.54	-0.33	-1	-1	-0.66	-2.36	-0.47
	2015-2018	4.18	17.25	3.98	0.65	3.71	4.96		-1	0.21	-0.51	-0.53	-0.31	-1		-0.31	-2.13	-0.43
Port Douglas	2003-2006	0.13	15.29	1.95	0.29	1.68	9.50		1	0.39	0.52	0.65	0.25	-0.07		0.25	2.81	0.56

		Depth-weighted means							Indicator scores									
Reef	Date range	NOx	PN	PP	Chl a	SS	Secchi	Turbidity	NOx	PN	PP	Chl a	SS	Secchi	Turbidity	Combined Turbidity	Total score	Scaled score
	2004-2007	0.09	14.94	2.10	0.28	1.57	8.67		1	0.42	0.42	0.67	0.35	-0.21		0.35	2.85	0.57
	2005-2008	0.25	12.87	1.98	0.28	1.38	8.50		1	0.64	0.5	0.69	0.54	-0.23		0.54	3.36	0.67
	2006-2009	0.29	12.67	2.13	0.28	1.36	7.89		1	0.66	0.39	0.69	0.56	-0.34		0.56	3.31	0.66
	2007-2010	0.39	12.60	2.32	0.32	1.23	7.20		1	0.67	0.27	0.49	0.7	-0.47		0.7	3.13	0.63
	2008-2011	0.37	12.51	2.41	0.36	1.23	6.71		1	0.68	0.22	0.32	0.7	-0.58		0.7	2.91	0.58
	2009-2012	0.48	12.45	2.55	0.38	1.31	6.12		1	0.68	0.13	0.26	0.61	-0.71		0.61	2.68	0.54
	2010-2013	0.70	12.17	2.54	0.40	1.35	6.17		1	0.72	0.14	0.19	0.56	-0.7		0.56	2.6	0.52
	2011-2014	0.87	11.87	2.64	0.42	1.43	5.96		1	0.75	0.08	0.09	0.49	-0.75		0.49	2.41	0.48
	2012-2015	1.47	12.02	2.75	0.42	1.54	5.71		0.45	0.73	0.02	0.11	0.38	-0.81		0.38	1.69	0.34
	2013-2016	1.32	12.29	2.78	0.41	1.57	5.75		0.59	0.7	0.01	0.12	0.35	-0.8		0.35	1.78	0.36
	2014-2017	1.08	12.66	2.80	0.45	1.55	5.50		0.89	0.66	0	0.01	0.36	-0.86		0.36	1.92	0.38
	2015-2018	1.09	12.84	2.77	0.44	1.57	5.25		0.87	0.64	0.02	0.04	0.35	-0.93		0.35	1.92	0.38
Repulse	2012-2015	1.60	18.16	3.40	1.23	9.86	1.50		0.32	0.14	-0.28	-1	-1	-1		-1	-1.82	-0.36
	2013-2016	1.42	23.93	5.16	0.80	4.85	3.25	4.33	0.49	-0.26	-0.88	-0.83	-0.69	-1	-1	-0.85	-2.32	-0.46
	2014-2017	2.79	23.52	5.79	0.81	4.92	3.14	4.74	-0.48	-0.23	-1	-0.84	-0.71	-1	-1	-0.86	-3.41	-0.68
	2015-2018	2.91	24.78	5.98	0.81	5.24	3.02	5.23	-0.54	-0.31	-1	-0.84	-0.81	-1	-1	-0.9	-3.59	-0.72
Seaforth	2012-2015	2.03	9.41	3.07	0.56	1.72	5.00	1.66	-0.02	1	-0.13	-0.31	0.8	-1	-0.15	0.32	0.86	0.17
	2013-2016	1.52	17.59	3.49	0.54	2.11	4.58	1.79	0.39	0.19	-0.32	-0.25	0.51	-1	-0.26	0.12	0.14	0.03
	2014-2017	2.34	19.08	3.87	0.65	2.67	4.55	1.97	-0.23	0.07	-0.47	-0.52	0.17	-1	-0.39	-0.11	-1.26	-0.25
	2015-2018	2.76	19.74	4.08	0.65	2.80	4.31	2.09	-0.46	0.02	-0.54	-0.53	0.1	-1	-0.48	-0.19	-1.71	-0.34
Yorkey's Knob	2003-2006	0.01	20.69	4.26	0.59	4.26	3.50		1	-0.05	-0.6	-0.4	-1	-1		-1	-1.06	-0.21
	2004-2007	0.20	18.84	3.99	0.55	3.60	3.33		1	0.09	-0.51	-0.28	-0.85	-1		-0.85	-0.56	-0.11
	2005-2008	0.19	17.53	3.57	0.50	2.81	4.17		1	0.19	-0.35	-0.16	-0.49	-1		-0.49	0.19	0.04
	2006-2009	0.26	17.05	3.72	0.52	2.91	4.00		1	0.23	-0.41	-0.2	-0.54	-1		-0.54	0.08	0.02
	2007-2010	0.39	15.36	3.68	0.52	2.73	3.75		1	0.38	-0.4	-0.21	-0.45	-1		-0.45	0.33	0.07
	2008-2011	0.35	15.66	3.78	0.58	3.06	3.96		1	0.35	-0.43	-0.36	-0.61	-1		-0.61	-0.06	-0.01

		Depth-weighted means							Indicator scores									
Reef	Date range	NOx	PN	PP	Chl a	SS	Secchi	Turbidity	NOx	PN	PP	Chl a	SS	Secchi	Turbidity	Combined Turbidity	Total score	Scaled score
	2009-2012	0.60	16.07	3.99	0.62	3.06	3.67		1	0.32	-0.51	-0.46	-0.62	-1		-0.62	-0.27	-0.05
	2010-2013	0.88	15.61	3.84	0.60	2.75	3.96		1	0.36	-0.46	-0.41	-0.46	-1		-0.46	0.03	0.01
	2011-2014	1.31	15.72	3.88	0.64	2.66	4.12		0.61	0.35	-0.47	-0.5	-0.41	-1		-0.41	-0.42	-0.08
	2012-2015	1.60	15.62	4.10	0.62	2.58	3.67		0.32	0.36	-0.55	-0.46	-0.37	-1		-0.37	-0.69	-0.14
	2013-2016	1.43	15.49	4.42	0.63	3.24	3.33		0.48	0.37	-0.66	-0.48	-0.7	-1		-0.7	-0.99	-0.2
	2014-2017	1.15	16.56	4.82	0.71	3.59	2.75		0.8	0.27	-0.78	-0.67	-0.85	-1		-0.85	-1.23	-0.25
	2015-2018	1.12	16.86	4.89	0.67	3.78	2.55		0.84	0.25	-0.81	-0.57	-0.92	-1		-0.92	-1.21	-0.24

Table E-13: Guideline values used to calculate the interim Water Quality Index for each water quality sampling location. These values are part of the GBRMPA Water Quality Guidelines for the Great Barrier Reef Marine Park (GBRMPA, 2010). See Section 2.2 (Interim site-specific Water Quality Index) for details on index calculation. Water Quality Guidelines associated with each site and Measure. DOF is direction of failure. Statistic indicates whether the guideline should be applied to means or median values. Bold guidelines are the guideline values applied.

					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**
			Secchi (m)	L		**1.60**		
			TSS (mgL^{-1})	H		5.00	**1.60**	**2.40**

					Annual		Dry	Wet
GBRMPA group	GBRMPA sites	Water Body	Measure	DOF	Mean	Median	Median	Median
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**
			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		**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**
			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**

					Annual		Dry	Wet
GBRMPA group	GBRMPA sites	Water Body	Measure	DOF	Mean	Median	Median	Median
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 (GBRMPA) (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_4	0.84 µg L^{-1*}
NH_4 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

*Precision for analysis of dissolved nutrients is estimated for each individual analytical batch, the range given is the range of CVs from batches analysed with samples collected in 2016/17.; ** two different reference materials used in each batch; ***n/a = no suitable standard material available 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

*PP: data are adjusted using a batch-specific efficiency factor (recovery); **n/a= no suitable reference material available 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 particulate nitrogen (PN), particulate phosphorus (PP0, particulate organic carbon (POC) and chlorophyll a (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 suspended solids (SS) analysis (filter placed on filtration unit and wetted with filtered seawater, rinsed with distilled water, then further handled like samples) were prepared during the on-board sample preparation. The mean weight difference of these filter blanks (final weight - initial filter weight) was 0.00010 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 SS 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%

F-6 Correlation of total suspended solids measurements and ECO FLNTUSB instrument data

Validation of ECO FLNTUSB instrument data

Direct water samples were collected and analysed (see Appendix D-Materials and Methods for details) for comparison to instrument data acquired at the time of manual sampling.

Turbidity was validated against total suspended solids (TSS) concentrations in the water column. While the turbidity loggers measure the total light absorption and scattering, suspended solids are a measure of the particle dry mass on a filter (0.4 µm pore-size). The relationship between optically measured turbidity and total suspended solids analysed on filters was good (Figure F-1), and the linear equation [TSS (mgL^{-1})] = 1.3 x FLNTUSB Turbidity (NTU)] has been used for conversion between these two variables. The equation has been the same in the last four years. Though these relationships are valid it should be remembered that the two variables are measures of two different things that do not necessarily co-vary.

Using this equation, the TSS trigger value in the Guidelines of 2.0 mg L^{-1} (GBRMPA, 2010) translates into a turbidity trigger value of 1.5 NTU.

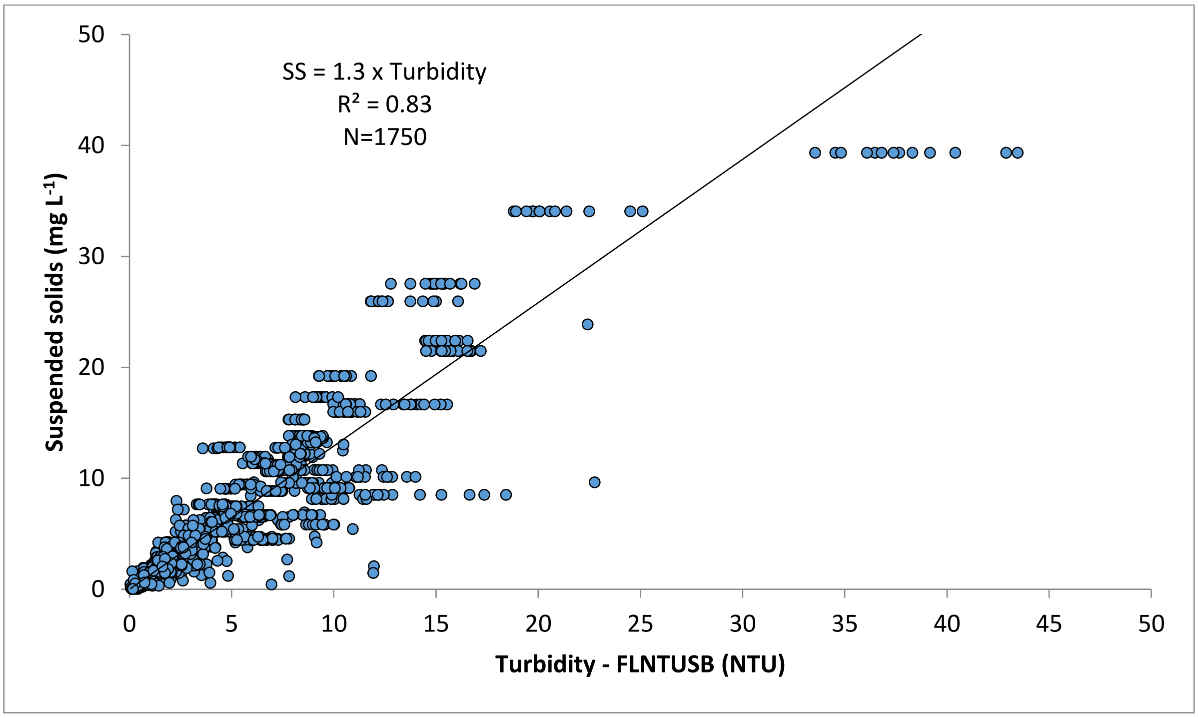

Figure F-1: Match-up of instrument readings of turbidity (NTU) from field deployments of WET Labs Eco FLNTUSB Combination Fluorometer and Turbidity Sensors with values from standard laboratory analysis of concurrently collected water samples.

Appendix G. Scientific publications and presentations associated with the program, 2016–17

G-1 Publications

Lønborg C, Álvarez-Salgado XA, Duggan S, Carreira C (2017). Organic matter bioavailability in tropical coastal waters: The Great Barrier Reef. Limnology and Oceanography doi:10.1002/lno.10717.

Petus C, Devlin M, Da Silva Teixeira E, Lewis S, Waterhouse J, Wenger A, Bainbridge Z Tracey D (in press). Defining wet season water quality target concentrations for ecosystem conservation using empirical light attenuation models: a case study in the Great Barrier Reef (Australia). Accepted for publication in Journal of Environmental Management.

Waterhouse J, Lønborg C, Logan M, Petus C, Tracey D, Lewis S, Tonin H, Skuza M, da Silva E, Carreira C, Costello P, Davidson J, Gunn K, Wright M, Zagorskis I, Brinkman R, Schaffelke B (2017). Marine Monitoring Program: Annual Report for inshore water quality monitoring 2015-2016. Report for the Great Barrier Reef Marine Park Authority, Great Barrier Reef Marine Park Authority, Townsville, 227pp.

Waterhouse J, Brodie J, Tracey D, Smith R, Vandergragt M, Collier C, Petus C, Baird M, Kroon F, Mann R, Sutcliffe T, Waters D, Adame F (2017). Scientific Consensus Statement 2017: A synthesis of the science of land-based water quality impacts on the Great Barrier Reef, Chapter 3: The risk from anthropogenic pollutants to Great Barrier Reef coastal and marine ecosystems. State of Queensland, 2017.

G-2 Presentations

Waterhouse J, Lewis S, Petus C, Tracey D, Mellors, J, Howley C, Harper E. Inshore wet season water quality monitoring in the Great Barrier Reef 2016-2017: Preliminary results. Presented at the Marine Monitoring Program Annual MERI Workshop, October 2017.

Lønborg C, Kroon F, et al. Inshore water quality monitoring in the Great Barrier Reef 2016-2017: Preliminary results. Presented at the Marine Monitoring Program Annual MERI Workshop, October 2017.