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Preface

Management of human pressures on regional and local scales, such as increased nutrient runoff and overfishing, 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 (GBRMPA) to ensure the long-term protection of the coastal and inshore ecosystems of the Great Barrier Reef (GBR) (GBRMPA, 2014 a, 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 Programme 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 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 Reef Plan Report Card for 2009 serves as a baseline for future assessments, and report cards for 2010, 2011, 2012–13 and 2014 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. Lønborg et al., 2016) and is carried out in partnership with the other MMP components including pesticide monitoring (Grant et al., 2017), coral monitoring (Thomson 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 GBRMPA to provide monitoring activities under the MMP for the 2015–16 monitoring year. 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.

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

Executive Summary

The program

The management of water quality remains an essential requirement to ensure the long-term protection of the coastal and inshore ecosystems of the Great Barrier Reef (Reef) (Commonwealth of Australia, 2015). The land management initiatives under the Australian and Queensland Government's Reef Water Quality Protection Plan (Reef Plan) 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) and James Cook University (JCU) as part of the Marine Monitoring Program (MMP) in 2015–16, with reference to previous data from 2005 to 2015. The results of three case studies are also presented in the Appendices. These case studies are completed annually and are intended to provide investigation of new approaches or more in-depth data analysis to inform future improvements to the program.

The objective of the MMP is to assess trends in ecosystem health and resilience indicators for the Great Barrier Reef (Reef) in relation to water quality and its linkages to end-of-catchment loads. The focus of this report is on assessing temporal and spatial trends in inshore marine water quality, and linking river discharge and pollutant concentrations to end-of-catchment loads. The inshore water quality monitoring component is designed for the detection of changes in the inshore GBR lagoon in high risk areas in response to changes in end-of-catchment loads. Until the end of 2014, water quality monitoring for a range of water quality parameters was carried out in four Natural Resource Management (NRM) regions: Wet Tropics (comprising three sub-regions), Burdekin, Mackay Whitsunday and Fitzroy. After a review of the program in 2013 and 2014, a new sampling design was adopted in 2015 and more intensive sampling was focussed in in three NRM regions: Wet Tropics (two sub-regions), Burdekin and Mackay Whitsunday in an attempt to improve the link to end-of-catchment loads. As before, sampling locations were selected along gradients of exposure to land runoff to ensure representativeness of a range of environmental conditions. Sampling of six open water stations along the ‘Cairns Transect’ is also continued in the new design for the implicit value of the long-term data set it provides, starting in 1989. The revised program design included collecting water samples along transects in the focus areas year round, with higher frequency sampling in the wet season to captured flood events and being able to detect changes over shorter timescales. The more frequent sampling in the wet season, combined with analyses of remote sensing data and exposure models, provided information for characterising the spatial and temporal variability of land-sourced pollutant transport associated with flood plumes. This is the second full year of implementation for the revised design.

Drivers, activities, impacts and pressures

The 2015–16 wet season was relatively dry with below median rainfall and river flow. The total GBR river inputs were less than 40,000,000 ML, making it the fourth driest year in 15 years (over 2001–02 to 2015–16 seasons). In February 2016, Tropical Cyclone Tatiana developed in the Coral Sea approximately 1,000km northeast of Mackay, but posed no threat to the Queensland coast. There were no other cyclones in the region during 2015–16.

End of catchment pollutant loads calculated for 2015–16 showed distinct variations between the focus regions, with the Russell-Mulgrave-Johnstone and the Tully-Murray-Herbert regions dominating the dissolved inorganic nitrogen (DIN) exports compared to the Daintree-Mossman-Barron, Burdekin-Haughton and Proserpine-O’Connell-Pioneer-Plane focus regions. Loads of total suspended solids (TSS) and particulate nitrogen (PN) were fairly comparable across the focus regions for the dry 2015–16 year, although in the wetter years TSS and PN loads were dominated by the Burdekin-Haughton focus region. To provide context for the water quality monitoring results, calculated end of catchment pollutant loads derived from the Paddock to Reef Program are included in this report, and presented for the rivers influencing each sampling region in the Regional results (Section 6).

Cumulative exposure maps were used to estimate the extent of river influence in the GBR lagoon using numerical tracer experiments within the eReefs hydrodynamic model. These tracer maps indicate the spatial extent of influence of individual rivers and can help to identify where rivers are likely to have influenced other areas. The tracer maps confirmed that the areas exposed to flood river plumes (hereafter, river plumes) in 2015–16 were similar to 2014–15 and much smaller for all focus areas compared to the extreme wet season of 2010–11.

Mapping wet season conditions and the exposure of the Great Barrier Reef lagoon to turbid waters and river discharge

Understanding the exposure of the GBR ecosystems to pollutant concentrations during high flow events and resulting changes in ecosystem health conditions is important to facilitate management of the GBR to respond to anthropogenic pressures under a changing climate. The remote sensing component of the MMP wet season monitoring produces several products including maps of wet season conditions (though the Primary, Secondary, Tertiary water type classification), frequency of the occurrence of wet season water types, and models that summarise transport of land-sourced pollutants and describe water quality concentrations during wet season conditions.

The wet season water type maps provide information on the composition of the waters during the wet season through the Primary, Secondary, and Tertiary water type classification (of the brownish, greenish and greenish-blue turbid waters, respectively) and link to the *in-situ* water quality data. The frequency maps predict the GBR marine areas affected by the three wet season water types (Primary, Secondary and Tertiary) over the 2015–16 wet season and the long-term (2002–03 to 2015–16 wet seasons) time frames. These maps predict the spatial distribution and frequencies of the occurrence of the wet season water types combined (i.e., of the turbid waters) and individually. These products illustrated a well-documented inshore to offshore spatial pattern, with the highest frequency of the Primary water type in the coastal areas, and offshore areas most frequently exposed to the Tertiary water type. Higher frequency areas were more constrained to the inshore areas in comparison to previous year.

The 2015–16 wet season was characterised by low rainfall and consequently low river discharge, resulting in river plumes that were not well developed. This considerably reduced the ability to characterise the water quality conditions associated with river plumes. It is also expected that during wet seasons characterised by relatively low flow, elevated turbidity along the coastline (and therefore, the frequency and spatial distribution of the wet season colour classes), are mainly driven by the re-suspension of sediment as well as metocean drivers of water circulation in the region (for example, winds, currents) rather than being directly related to the volume discharge of the GBR rivers. The data presented in this report need to be considered in this context. To assist in interpretation of these outputs, panels of weekly wet season water type maps were produced for each focus region for the first time, to illustrate the potential influence of river discharge in driving these wet season water types as opposed to other factors such as resuspension which is more likely the case in low flow conditions.

In a collaborative effort between the MMP monitoring providers (JCU water quality and seagrass teams and the AIMS coral monitoring team), an updated exposure/potential risk assessment framework was developed. Seasonal and long-term surface exposure maps (hereafter, exposure maps) were used to represent the wet season and long-term frequency of exposure to TSS, chlorophyll a (Chl-a), PP and PN-enriched surface waters assessed against the TSS, Chl-a, PP and PN-Water Quality Guidelines to represent the magnitude and duration of pollutant exceedance in the wet season(s). The wet season seasonal and long-term exposure maps were overlaid with information on the presence or distribution of GBR ecosystems (coral reefs and seagrass) to help identify ecosystems which may experience acute or chronic high exposure to land-sourced pollutants and thus, help to evaluate the susceptibility of GBR ecosystems. During 2015–16, it was estimated that 82% of the GBR coral reefs were exposed to turbid waters (combined Primary, Secondary and Tertiary water types), at least during one week of wet season. However, no corals were in the highest potential risk category (IV) from exposure and very few (<1%) were in the exposure categories III. It was estimated that 95% of the GBR seagrasses were exposed to turbid waters, at least during one week of wet season. However, no seagrasses were in the highest potential risk category (IV) from exposure, and very few (7.7%) were in exposure category III, although there was considerable regional variation. These exposures indicate *'potential' risk* as the exposure maps have not been validated against ecological health data to confirm the ecological consequences of the risk. The seagrass and coral areas in the higher potential risk categories were greater in the long-term than in 2015–16, which was logical with the characteristic of a relatively dry wet season.

New panels showing the pressures combined with the wet season water types and frequency maps for each NRM region provide a new and 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. This method will be 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. These results were first reported in the 2014–15 report (Lønborg et al., 2016), although not all 35 GBR basins were included in this previous analysis. The updated model combines in-situ data, Moderate Resolution Imaging Spectroradiometer (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 a relationship between river discharge and plume extent 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).

The maps are presented as a time series from 2003 to 2016 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 2015–16 outputs show relatively constrained loading of all parameters along the GBR coast, especially in comparison to the combined 2003 to 2016 multi-annual output. 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 shows the greatest areas of change around the Wet Tropics region and to a lesser extent, the Mackay Whitsunday region. The TSS loading assessment showed the Burdekin region as the greatest area of change. The time series from 2003 to present 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 incorporation of a new 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 in 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). 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 provides detailed information on the temporal trends of water quality indicators relative the Water Quality Guidelines for the GBR, throughout the year.

The key water quality indicators were aggregated into a site-specific Water Quality Index, which is summarised at the scale of NRM regions to give an overview of major trends in the water quality along sections of the northern, central and southern GBR (Figure i). In 2015–16, 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 by both AIMS and JCU and apply wet/dry guidelines, we calculated a separate score shown as a single point in Figure i. These regional Water Quality Index scores are currently based on a selected set of variables for which GBR water quality guidelines are available and uses data from permanent sites that were sampled from 2005 to 2015 and the new sites established in 2015. The scores provide a representation of water quality condition in the inshore GBR; however, it is important to note that a more comprehensive index would encompass a much wider range of variables and all sampling sites in a region; this would capture a wider range 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 also urgently required. In addition, the data collected prior to implementation of the new monitoring design in 2015 were dominated by dry season conditions and stations further offshore; the incorporation of wet season data and more inshore stations is likely to present a different perspective of overall water quality conditions.

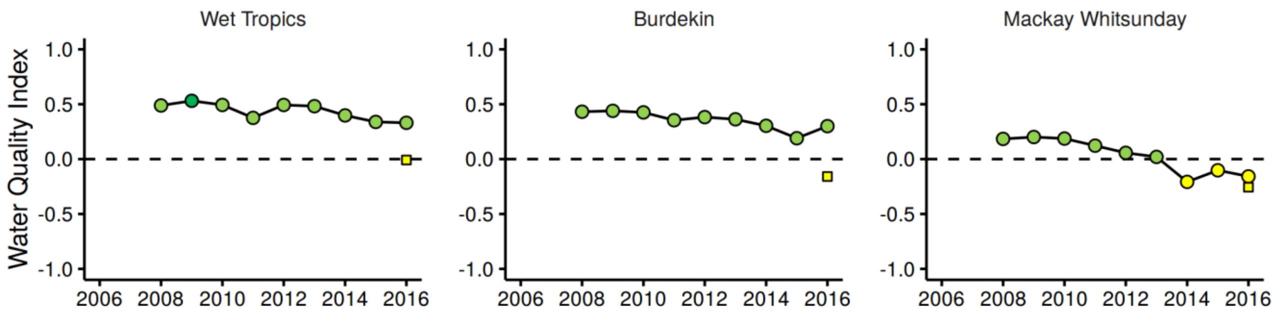

Figure i: Results of the site-specific Water Quality Index from 2006–07 to 2015–16 for the Wet Tropics, Burdekin and Mackay Whitsunday regions. Note that this year the Water Quality Index was calculated in two different ways. First, for continuity of the long-term trend an index score was calculated using the same approach as in previous years (circles). Second, to include data collected by both AIMS and JCU and apply wet/dry guidelines we calculated a separate score shown as a single point in the figures (squares). The Water Quality Index aggregates scores for five variables: concentrations of dissolved oxidised nitrogen, particulate nitrogen and phosphorus, Chl-a and a combined water clarity indicator (TSS, turbidity and Secchi depth), relative to Guideline values (DERM, 2009; GBRMPA, 2010). Water Quality Index colour coding: dark green- 'very good'; light green-'good'; yellow – 'moderate; orange – 'poor'; red – 'very poor'.

The long-term Water Quality Index showed 'good' scores maintained for the **Wet Tropics** region throughout the program, while the combined AIMS/JCU score calculated for this year showed a 'moderate' rating. The multi-year trends of the wet season water quality showed a reduction in concentrations of dissolved nutrients and PP after 2012, when river flow returned to lower values than experienced in the previous years.

The long-term Water Quality Index calculated for the sites in the **Burdekin** region has remained more or less 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 wet season water quality showed a reduction in concentrations of dissolved nutrients and coloured dissolved organic matter (a proxy for freshwater inputs) after 2012, when river flow returned to lower values.

Long-term Water Quality Index scores in the **Mackay Whitsunday** region steadily declined over the course of the MMP monitoring period but maintained a 'moderate' index score for the third consecutive year. A similar score was found for the combined AIMS/JCU index. These scores reflect Chl-a, turbidity and PP levels the above guidelines.

In the past, the Reef Plan Report Card included a Water Quality Metric based on remote sensing data for Chl-a and TSS concentrations. The metric is currently being revised as part of a project under the National Environmental Science Program to address issues with data confidence in some regions and the sensitivity of the metric to annual variations, and will be reported separately in 2017.

Conclusions

River discharge in the 2015–16 sampling period was below median discharge in all rivers in the GBR catchments. This resulted in a reduced area of influence from river plumes in the GBR compared to previous sampling years. However, this did not necessarily result in improvements in water quality parameters, with many parameters showing stable or increasing concentrations.

After 10 years of continuous sampling it is not clear whether there has been measurable change in the water quality of the GBR lagoon. Most parameters show minor fluctuations over the monitoring period with no clear trend. The general increase measured in turbidity over the monitoring period suggests that the water transparency has decreased, thereby reducing the light available for plankton and coral symbiont and seagrass productivity. These increased turbidity levels are strongly influenced by variations in the inflow of particles from the catchment and resuspension by wind, currents and tides. Overall, this does not necessarily mean that concentrations of TSS have increased, but it may be that the proportion of smaller particles and dissolved compounds (e.g. colloidal material) that increase turbidity have increased over the period.

Plankton biomass production in the GBR is considered to be limited by the availability of nitrogen. An increase, despite being minor, in readily available dissolved oxidised nitrogen (NO_x) concentrations, as found over the monitoring period, was therefore unexpected. There are two plausible explanations: either the plankton community is obtaining enough nitrogen from other sources (e.g. ammonium or dissolved organic nitrogen), or their growth is limited by other factors than nitrogen (e.g. light). The increases in turbidity, suggest that plankton growth might be light-limited and the plankton community is not able to use the extra NO_x. If this NO_x is not used within the coastal area it will be exported further offshore, where it may promote plankton production.

Over the monitoring period, an increase in the organic carbon concentrations was found in all regions. Organic carbon constitutes the major carbon source for heterotrophic microbial growth in marine pelagic systems and increases in organic carbon have previously been shown to promote microbial activity and coral diseases. The observed increases in organic carbon in the inshore GBR lagoon may have several probable, though not necessarily mutually exclusive, explanations: either the coral and plankton community have increased primary production or they are directing more of their production towards organic carbon release, or there is an enhanced export of organic carbon from the catchment, e.g. as eroded soils.

Our finding of increased concentrations of dissolved organic carbon, NO_x and increases in turbidity levels in all regions suggest that the mechanisms controlling the carbon and nutrient cycle in the GBR lagoon have undergone changes. The coincidence of these changes with a period of elevated runoff as a result of high rainfall in previous years implies the responsiveness of these fundamental cycles to terrestrial inputs.

The variability in the ambient *in-situ* water quality results highlights the complexity of the relationship between river inputs and ambient water quality and also the need for a range of monitoring approaches to capture the influence of flood plumes, resuspension events as well as the ambient conditions. The wet season mapping products are continuously improving and the inclusion of weekly panels for each focus region provides another step towards characterising, and ultimately distinguishing, wet season and plume conditions. The final categories of the exposure maps are now also 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 allows comparison between years.

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) 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 tropic rivers (Brodie et al., 2012; Devlin and Brodie, 2005; Devlin and Schaffelke, 2009; Petus et al., 2014a, 2015).

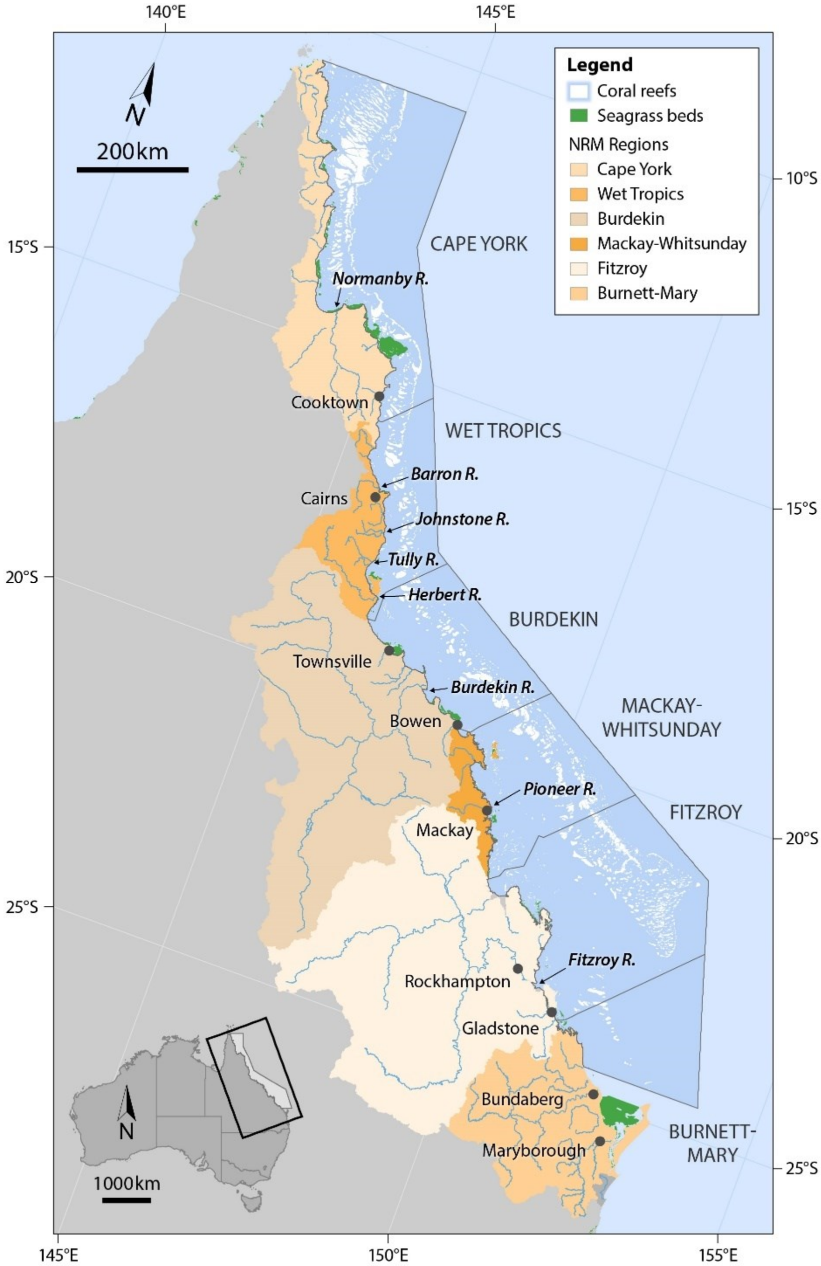

Figure 1-1: The Great Barrier Reef Marine Park, major marine ecosystems (coral reefs and surveyed seagrass beds), Natural Resource Management (NRM) regions and marine NRM regions (delineated by dark grey lines) and major rivers.

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 (Brodie et al., 2013a, b). In contrast, the Wet Tropics, Burdekin, Mackay Whitsunday, Fitzroy and the 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 (Brodie et al., 2013b; Waterhouse et al., 2012).

Coastal areas around the world 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). Water quality in the GBR is influenced by an array of factors including diffuse source land-based runoff, point source contamination, and extreme weather conditions. It is well documented that sediment and nutrient loads carried by rainfall-driven land runoff into the coastal and inshore zones of the GBR have increased since European settlement (e.g., Kroon et al., 2012; Waters et al., 2014).

Nutrients are naturally occurring in the water and 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 runoff is suggested to be the largest source of new nutrients to the inshore GBR (ibid.), especially during monsoonal flood events (Devlin and Schaffelke, 2009). These nutrients augment 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 (Furnas et al., 2005, 2011).

Water quality parameters in the GBR vary along cross-shelf, seasonal and latitudinal gradients (e.g. Lønborg et al. 2016; Thompson et al., 2016) reflecting differences in inputs and transport. There is also high variability between years, driven by La Niña and El Niño cycles. Elevated concentrations of dissolved inorganic nitrogen (DIN) in coastal waters has been related to fertilised agriculture (predominantly sugarcane) in the Wet Tropics region, while high total suspended solids (TSS) concentrations are mainly linked to grazing activities in the dry tropics and in particular the Burdekin catchment (Brodie et al., 2013a, 2013b; Joo et al., 2012; Waterhouse et al., 2012; Waters et al., 2014).

Concern about the effects of land runoff triggered the formulation of the Reef Plan for catchments adjacent to the GBRWHA by the Australian and Queensland governments in 2003 (Anon, 2003, 2009). Reef Plan was revised and updated in 2009 and 2013 (Anon, 2013). More recently, UNESCO raised concerns regarding the current state and management of the GBRWHA which led to the development of the 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 show responses to gradients in water quality, especially of water turbidity, sedimentation rate and nutrient availability (e.g. Thompson et al., 2010, 2016; Uthicke et al., 2010), improved land management practices have the potential to reduce levels of environmental stresses that impact on coral reef communities. However, recent assessments raise the question whether these actions will be sufficient to ensure the resilience of the GBR ecosystems into the future (Bartley et al., 2014a, b; Kroon et al., 2014; Brodie and Pearson, 2016).

Reef Plan actions also include the establishment of the Paddock to Reef program, extending from the paddock to the Reef, to assess the effectiveness of the implementation of Reef Plan actions. The MMP is an integral part of this monitoring 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.

Monitoring the impacts of land based runoff into the GBR includes more intense sampling during the wet season and high flow events to characterise the input of terrestrially sourced pollutants delivered through river discharge to the GBR (e.g. Devlin et al. 2015a; Lønborg et al., 2016; Schroeder et al., 2012). The information gathered under the current MMP inshore water quality sampling program has improved our understanding of the spatial distribution and temporal variability of water quality in the coastal and inshore GBR. This includes detailed information about the temporal/spatial trends in water quality around inshore coral reefs, detailed information about water quality in flood plumes (both included in this report). 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 et al., 2017).

This report integrates the results of the AIMS and JCU 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 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 Great Barrier Reef Marine Park (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 program methods and results in 2015–16 are presented in this report with regional and GBR-wide interpretation.

2. Methods summary

2.1 Overview

This section provides an overview of the sampling design and indicators that are monitored as part of the program. More details of the data collection, preparation and analytical methods are presented in Appendix D and F, and in an annually updated QA/QC report (Great Barrier Reef Marine Park Authority [GBRMPA], 2016). 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 a specific ambient water quality program conducted by AIMS, and a wet season monitoring program 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 Table 2-1);
- A total of 20 stations were sampled 3 times a year (wet, early and late dry seasons) across the Wet Tropics, Burdekin and Mackay Whitsunday regions (see Table 2-1);
- 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 of the NRM regions (where relevant) (most frequently in Tully, Russell-Mulgrave, Burdekin, Fitzroy and Normanby).

In 2014–15, GBRMPA led a review of the MMP design, which resulted in a new sampling design for the inshore water quality monitoring program, 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 second 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., 2013b) and availability/quality of long-term data. The Tully River catchment is also the ideal location to assess the long-term effectiveness of Reef Plan as it is the wettest catchment in Australia. Repeated sampling in the Tully focus area also adds value to the long-term data set 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 water quality gradients (exposure to runoff). This was largely determined by increasing distance from a river mouth in a northerly direction to reflect the predominantly northward flow of surface water 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, and provide data for the validation of the eReefs model suite.

Figure 2-1 and Table 2-1 provide an overview of the geographic locations of the current sampling sites.

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

- Continuous measurement of salinity at eight stations;
- Continuous measurement of Chl-a and turbidity at 15 stations;
- A total of 32 stations sampled during the year with more frequent sampling during the wet season; and
- A total of 27 additional stations sampled during high flow conditions (flood response).

Temperature is also continuously monitored at 33 stations as part of the inshore coral reef monitoring program.

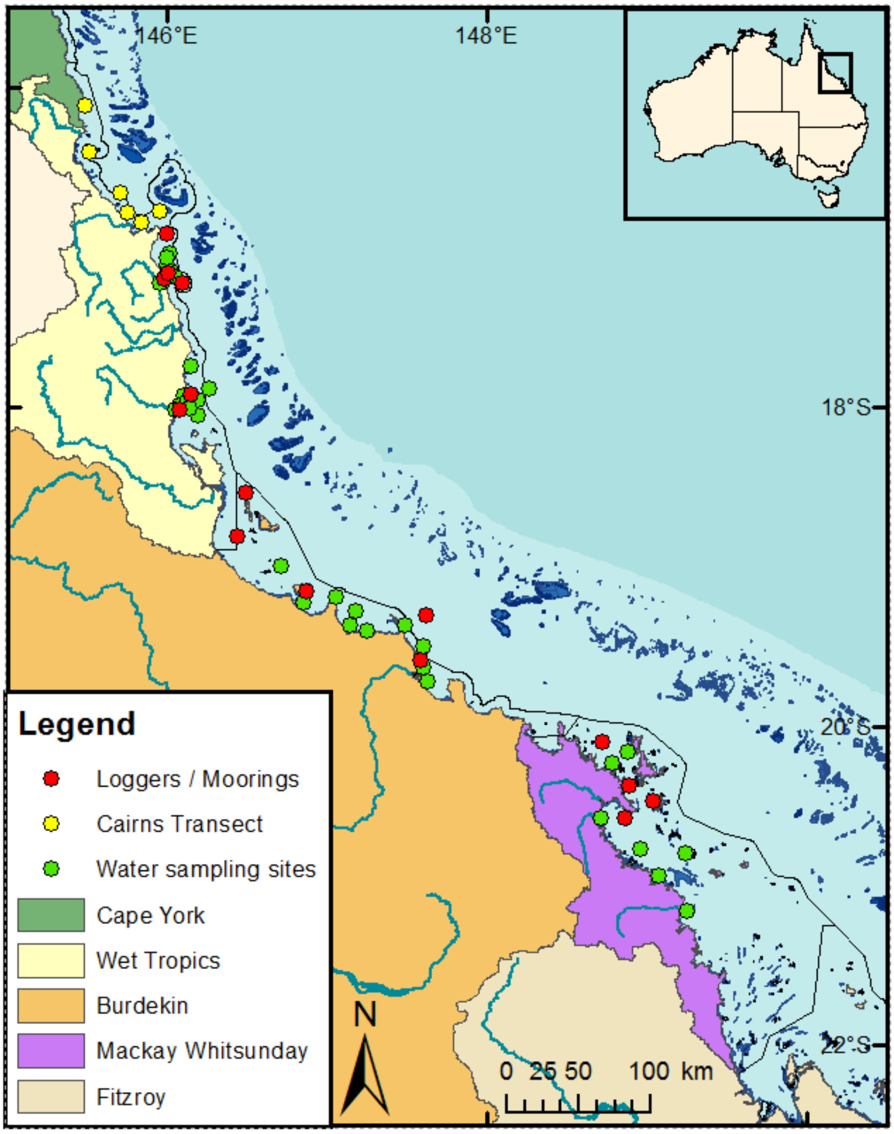

Figure 2-1: Sampling locations of the MMP water quality monitoring sampled from 2015 onwards. Refer to Figure 1-1 for river names. See Table 2-1 for details of the monitoring activities undertaken at each location. NRM region boundaries are represented by coloured catchment areas.

Table 2-1: Description of the water quality stations sampled by AIMS and JCU during 2015–16. Stations in bold font were part of the ambient monitoring design from 2005–2015. See Table 2-2 for the parameters measured.

NRM region	Location	Loggers		Routine sampling throughout the year with higher frequency in wet season		Flood response sampling
		Turbidity and Chl-a	Salinity	AIMS and JCU	AIMS only	JCU only
Wet Tropics	***Cairns Long-term transect***					
	Cape Tribulation				√	
	Port Douglas				√	
	Double Island				√	
	Yorkey's Knob				√	
	Fairlead Buoy				√	
	Green Island				√	
	Russell Mulgrave Focus Area					
	Fitzroy Island West	√			√	
	RM2					√
	RM3			√		
	RM4					√
	High Island East					√
	Normanby Island					√
	Frankland Group West (Russell Island)	√		√		
	High Island West	√	√	√		
	Palmer Point					√
	Russell-Mulgrave River mouth mooring	√	√	√		
	Russell-Mulgrave River mouth					√
	Russell-Mulgrave junction [River]					√
	Tully Focus Area					
	King Reef					√
	East Clump Point			√		
	Dunk Island North	√	√	√		
	South Mission Beach					√
	Dunk Island South East			√		
	Between Tam O'Shanter and Timana			√		
	Hull River mouth					√
	Bedarra Island			√		
	Triplets					√
	Tully River mouth mooring	√	√	√		
	Tully River					√
Burdekin	***Burdekin Focus Area***					
	Pelorus and Orpheus Island West	√		√		
	Pandora Reef	√		√		
	Cordelia Rocks					√
	Magnetic Island (Geoffrey Bay)	√		√		

NRM region	Location	Loggers		Routine sampling throughout the year with higher frequency in wet season		Flood response sampling
		Turbidity and Chl-a	Salinity	AIMS and JCU	AIMS only	JCU only
	Inner Cleveland Bay					√
	Cape Cleveland					√
	Haughton 2			√		
	Haughton River mouth					√
	Barratta Creek					√
	Yongala IMOS NRS	√	√		√	
	Cape Bowling Green					√
	Plantation Creek					√
	Burdekin River mouth mooring	√	√	√		
	Burdekin Mouth 2					√
	Burdekin Mouth 3					√
Mackay Whitsunday	***Whitsunday focus area***					
	Double Cone Island	√		√		
	Hook Island W					√
	North Molle Island					√
	Pine Island	√		√		
	Seaforth Island	√		√		
	O'Connell River mouth			√		
	Repulse Islands dive mooring	√	√	√		
	Rabbit Island NE					√
	Brampton Island					√
	Sand Bay					√
	Pioneer River mouth					√

Table 2-2: 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 phosphate	DIP	µg/L
	Silica	Si	µg/L

Condition	Parameter	Abbreviation	Units of Measure
	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
Productivity	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*			

2.3 Water quality sampling methods

A more detailed description of methodologies is provided in Appendix D. At each of the sampling locations (see Table 2-1), 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 for example, 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, 1m from the seabed, while 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, m^{-1}) was also calculated using the Lambert-Beer equation on the CTD light profile with a summary of the parameters collected in the program provided in Table 2-2.

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 in close proximity to Russell-Mulgrave, Tully and Burdekin River mouths (Figure 2-1, Table 2-1; Figure D-1). Additional temperature loggers are also deployed at all MMP inshore coral reef monitoring sites (reported in Thompson et al., 2017).

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.

2.4 Data analyses – ambient water quality

Generalised additive mixed effects 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 - some flood plumes were sampled 10 times in some years, while AIMS collected samples 3 times a year. Therefore, including the historical JCU data would skew the whole data set and trends, giving a false representation of annual water quality conditions. Details of the methods used for the calculation of the site-specific Water Quality Index are presented in Appendix D-6.

2.5 Data analyses – wet season water quality

The wet season water quality data were used for several purposes: to characterise water quality gradients in the wet season and during high flow conditions; to investigate the transport and/or transformation of key pollutants when they are discharged into the GBR lagoon; to identify where measured values were above the water quality guideline values (GVs); and 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 in the wet season can 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 guideline values were investigated by plotting the mean water quality concentrations (long-term and 2015–16) against their water type and colour class categories. Presently, the mean water quality concentrations are calculated <u>using all JCU data collected between November and April</u>, assuming that the JCU dataset are representative of high flow conditions (i.e., responsive sampling). In future years the wet season data collected by AIMS will also be included in this analysis, with a focus on sampling in 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 2017-18 for comparison and assessment of any significant differences over the sampling years.

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

Understanding the exposure of the GBR ecosystems to pollutant concentrations during high flow events and resulting changes in ecosystem health conditions is important to facilitate management of the GBR to respond to anthropogenic pressures under a changing climate. The remote sensing component of the MMP wet season monitoring produces several products as illustrated in Figure 2-2 (Devlin et al., 2015b), including maps of wet season conditions (through the Primary, Secondary, Tertiary classification), frequency of occurrence of wet season water types, and models that summarise transport of land-sourced pollutants and describe water quality concentrations during wet season conditions.

Wet-season water-type maps were produced using MODIS true colour imagery reclassified to three distinct wet season water types 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). Each of the three wet season water types (Primary, Secondary and Tertiary) was characterised by different concentrations of optically active components (TSS, CDOM, and Chl-a) which influence the light attenuation, as well as different pollutant concentrations which can vary the impact on the underlying ecological systems. The wet season water types were further classified into six categories (or colour classes) with classes 1 to 4 corresponding to Primary waters, class 5 to Secondary waters and class 6 to Tertiary waters. The primary waters (or colour classes 1 to 4) correspond to the brownish, very turbid, water masses with high sediment and CDOM concentrations, the Secondary waters (or colour class 5) to the turbid greenish water masses (intermediate turbidity) with lower sediment concentrations favouring increased coastal productivity, and the Tertiary waters (colour class 6) is the transitional, greenish-blue water mass between plume waters and marine waters. The colour classification allowed a finer-scale characterisation of the water constituents inside of the Primary water type.

The frequency maps predict the GBR marine areas affected by the three wet season water types (Primary, Secondary and Tertiary) over the seasonal (2015–16 wet season) and the long-term (2002–03 to 2015–16 wet seasons) time frames (Figure 2-2). These maps predict the spatial distribution and frequencies of occurrence of the wet season water types combined (i.e., of the turbid waters) and individually (i.e., of the brownish, greenish and greenish-blue turbid waters, respectively). The wet season water type maps provide information on the composition of the waters during the wet season through the Primary, Secondary and Tertiary water type classification and link to the in-situ water quality data.

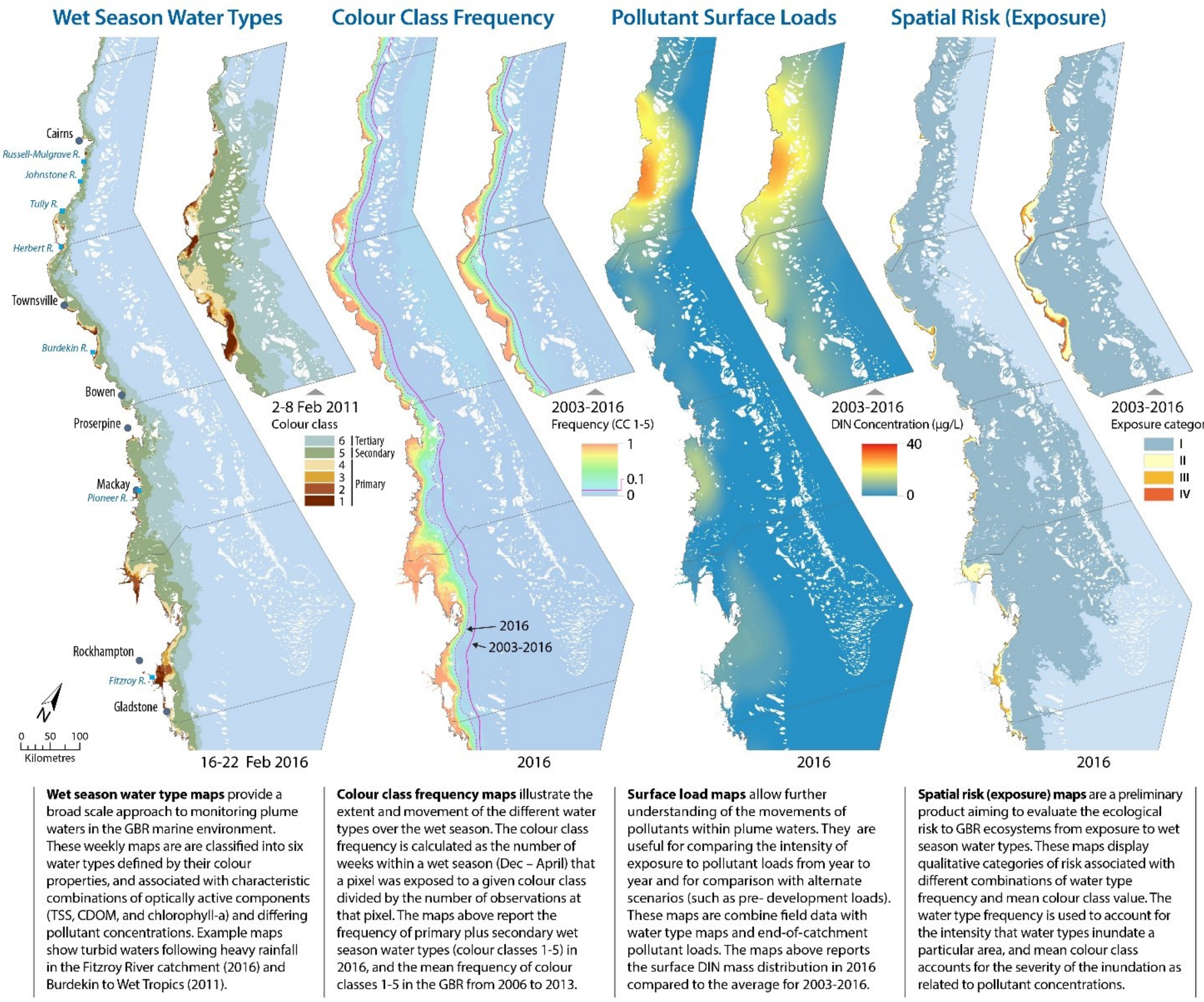

Figure 2-2: Summary description of the wet season water quality products derived from remote sensing information in the MMP.

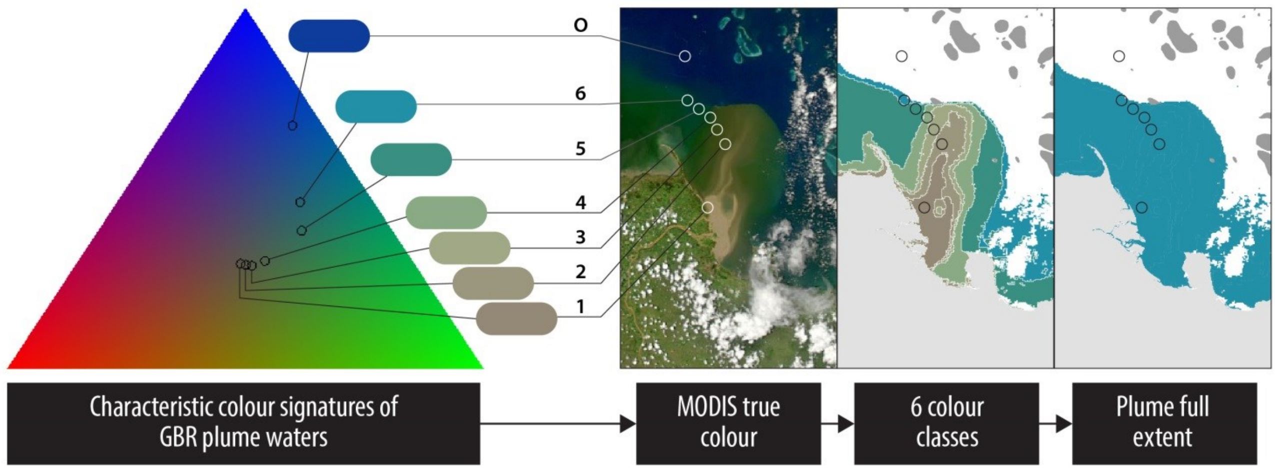

Figure 2-3: Triangular colour plot showing the characteristic colour signatures of the Great Barrier Reef river plume waters in the Red-Green-Blue (or true colour) space. Álvarez-Romero et al. (2013) developed a method to map these characteristic coastal water masses in the GBR using a supervised classification of MODIS true colour data (modified from Devlin et al., 2015b).

A new product that integrates these methods into a single risk assessment framework is presented. It builds on exposure framework presented in the previous MMP reports (Figure 2-4) and methods of last year's case study (Petus et al., 2016).

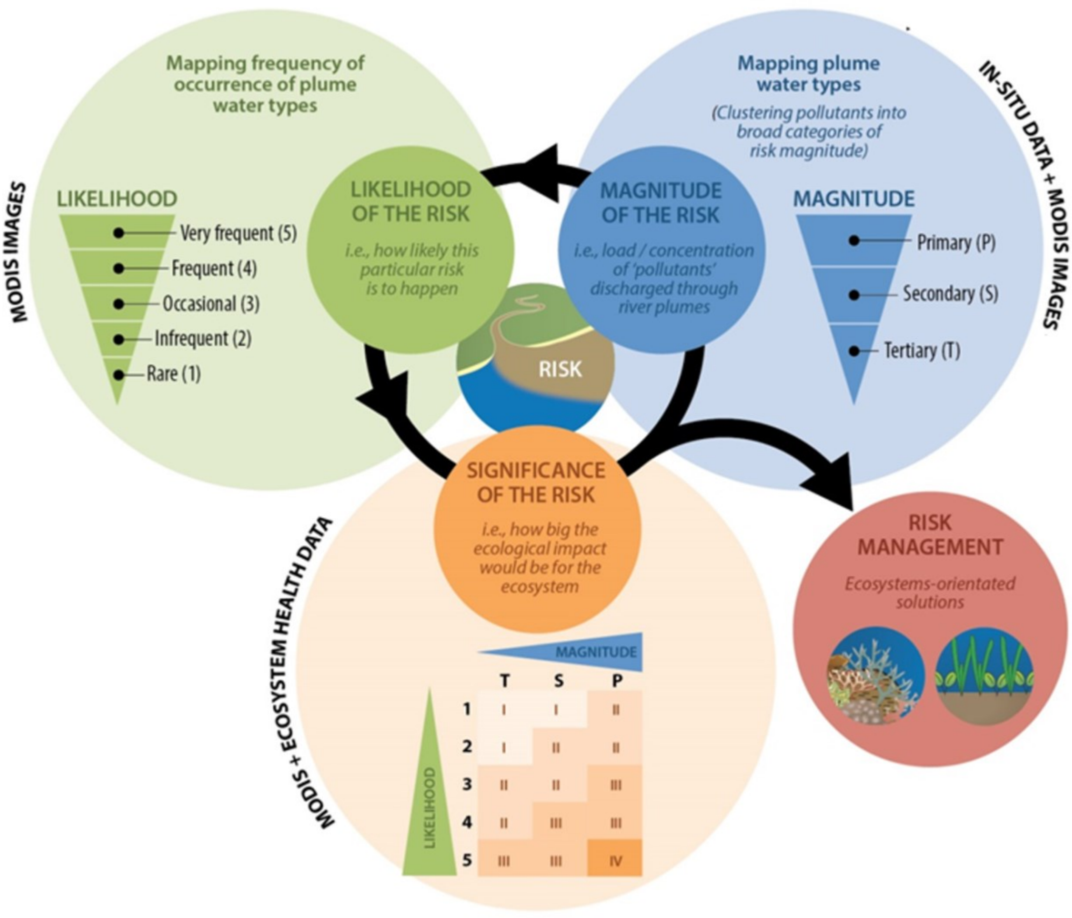

Figure 2-4: Conceptual scheme of the risk framework proposed in Petus et al. (2014a) used for developing the exposure maps.

In the previous MMP report, the 'potential risk' was assessed as exposure to land-sourced pollutants concentrated in river plume waters (Figure 2-4). 'The magnitude of the risk' corresponded to the concentration of pollutant discharged through the river plume and mapped through the Primary, Secondary, 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. The potential risk categories were then a combination of the wet season water type (3 categories: Primary, Secondary and Tertiary) and Primary, Secondary andTertiary frequency (five categories: 0-0.2, 0.2-0.4, 0.4-0.6, 0.6-0.8, 0.8-1) and based on the risk matrix modified from Castillo et al. (2012).

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 has been developed (modified from Petus et al., 2016), where the 'potential risk' corresponds to an exposure to above guideline concentrations of land-sourced pollutants during high flow conditions and focuses on the TSS, Chl-a, particulate phosphorus (PP) and particulate nitrogen (PN) concentrations. The *'magnitude of the exposure'* corresponds to the concentration of pollutants (proportional exceedance of the guideline) mapped through the Primary, Secondary, 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 × 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:

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

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

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

With $water\ type$: the Primary, Secondary or Tertiary wet season water types, $[Poll.]_{water\ type}$: the wet season or long-term mean TSS, Chl-a, PN or PP concentration measured in each respective wet season water types and $guideline$ the 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:

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

Finally, the overall exposure score (ranging from 0 to 8) are categorised into four equal potential risk categories ([>0-2] = cat. I, [2-4] = cat. II, [4-6] = cat III and [6-8] = cat IV).

For example, using the long-term mean chl-a values measured during high flow conditions in the Primary, Secondary and Tertiary water type:

$$Chla\_exp_{Primary} = \frac{1.7-0.63}{0.63} \times frequency_{water\ type\ (0-1, cell-specific)}$$

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

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

The total exposure for Chl:

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

The methods for the remote sensing products are all described in further detail in Appendix D-7, D-8 and D-9.

2.7 River discharge

River flow is reported annually and can be derived from several sources. In many cases river flow gauges which 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 such 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 ‘correction’ 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 2-3; DNRM, 2016). 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 which 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, Boyne River), the gauge from the nearest neighbouring basin was used coupled with the relevant area adjustment.

Table 2-3. The 35 basins of the Great Barrier Reef catchment, the gauges used to examine flow and the corrections required to upscale flows to provide annual discharge estimates.

NRM Region	Basin	AWRC No.	Basin area (km^2)	Relevant gauges	Percentage of Basin covered by key gauges	Correction factor
Cape York	Jacky Jacky Creek	101	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

NRM Region	Basin	AWRC No.	Basin area (km^2)	Relevant gauges	Percentage of Basin covered by key gauges	Correction factor
	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 are indicated with *

2.8 Load mapping

An ocean colour-based model has been used to estimate the dispersion of DIN ($\mathrm{DIN} = NH_4^+ + NO_2^- + NO_3^-$) delivered by river plumes to GBR waters (da Silva et al., in prep.) (Figure 2-5). This model, built on a method by Álvarez-Romero et al. (2013), combines *in-situ* data, Moderate Resolution Imaging Spectroradiometer (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 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 (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.

The 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 2-5 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, like those produced for the GBR (see Remote Sensing section in this report), 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 x 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. In the following these four major steps are presented, starting with the generation of individual river plumes.

For the first time, the difference between the estimated wet season DIN concentration and TSS concentrations in the GBR lagoon for the 2016 water year (1 October to 30 September) 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, the 2010–11 (large wet season) and current (2015–16) water years, which represent two extreme years of DIN loads discharged into the GBR lagoon over the 14 years analysed. 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 results (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-10.

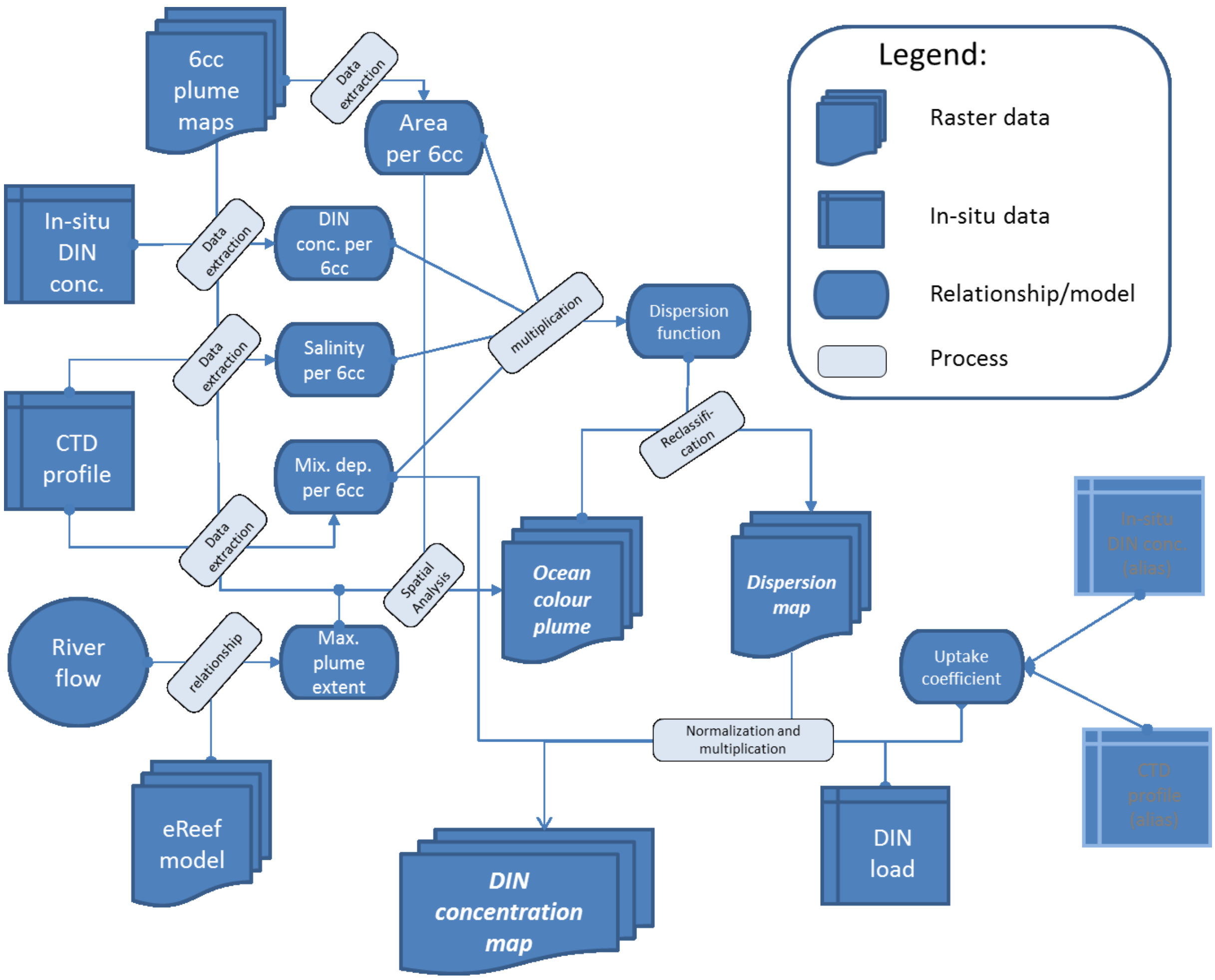

Figure 2-5: Conceptual model for DIN concentration load mapping. Note: 6cc = 6 colour class classifications.

2.9 'Zones of influence' for river plumes

Hydrodynamic models provide a tool for identifying, quantifying and communicating the spatial impact of discharges from various rivers into the GBR lagoon. For the MMP, hindcast simulations were performed for the 2015–16 wet season, defined as 1 November 2015 until 31 March 2016. 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, while 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. The comparison between the eReefs model outputs and MMP data is provided in each regional report, with additional information shown in Appendix E, Figure E-3 and E-4.

3. Results

3.1 Overview

The design of the MMP and the structure of the reporting follows a Driver-Pressure-State-Impact-Response 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.

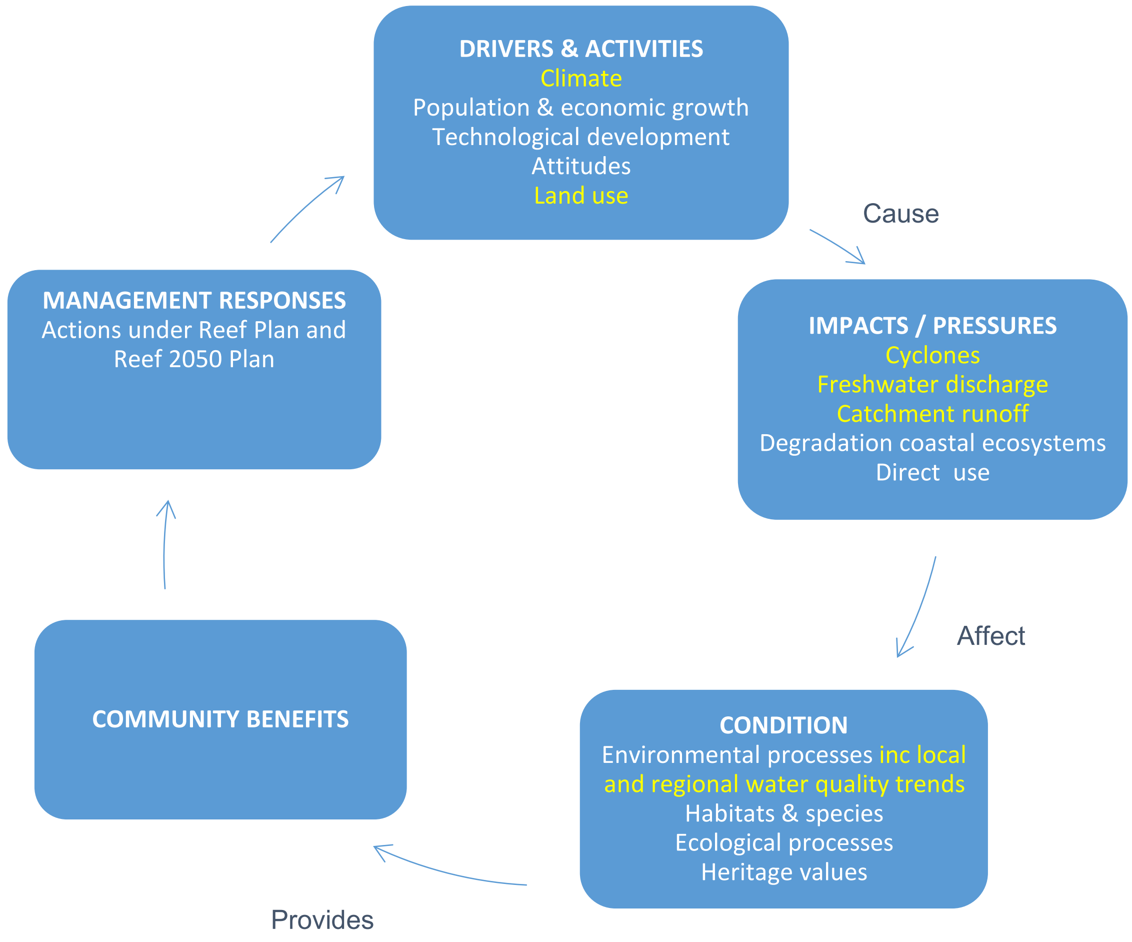

Figure 3-1: DPSIR framework used to guide the structure of the MMP, derived from the Great Barrier Reef Strategic Assessment (2015). The aspects highlighted in yellow are included in this report.

3.2 Drivers, activities, impacts and pressures 2015–16

3.2.1 Cyclone activity

The 2015–16 Australian region cyclone season was amongst the least active tropical cyclone season since reliable records started during 1969, with only three named tropical cyclones developing in the region (Bureau of Meteorology, 2016). Only one of these systems was in Queensland—Tropical Cyclone Tatiana—that developed in the Coral Sea approximately 1,000km northeast of Mackay in February 2016, but posed no threat to the Queensland or GBR coast. In addition, the remnants of ex-Tropical Cyclone Winston, which impacted Fiji, influenced the southern GBR region in February-March 2016. Indeed, the rain, wind and cloud cover from ex-Winston helped cool the water in the central and southern areas of the GBR and likely prevented mass bleaching in these regions (Hughes et al., 2017).

Figure 3-2 shows the cyclones that have crossed the GBR coast in the eleven years since the MMP began in 2005. Nine 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. There were no cyclones along the GBR coast in 2015–16.

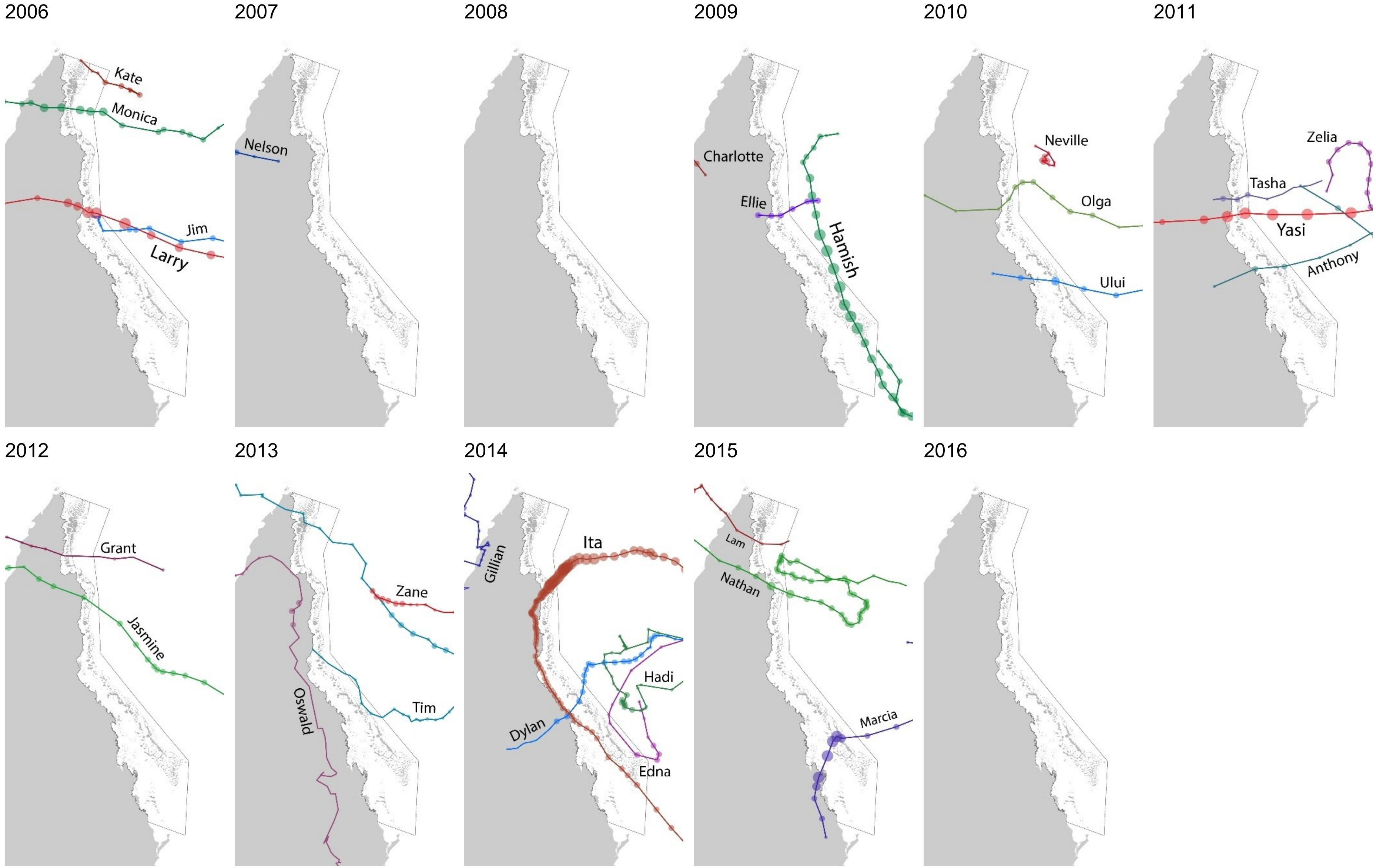

Figure 3-2: Trajectories of tropical cyclones affecting the Great Barrier Reef in 2015–16 and in previous years (2006 to 2015).

3.2.2 Rainfall

Annual rainfall across the central and northern GBR catchments was below the annual and wet season averages in 2015–16 with the greatest differences in the Wet Tropics and Cape York catchments (Figure 3-3 and Figure 3-4). Only the Normanby catchment had above average rainfall, but this was only marginal (Figure 3-3).

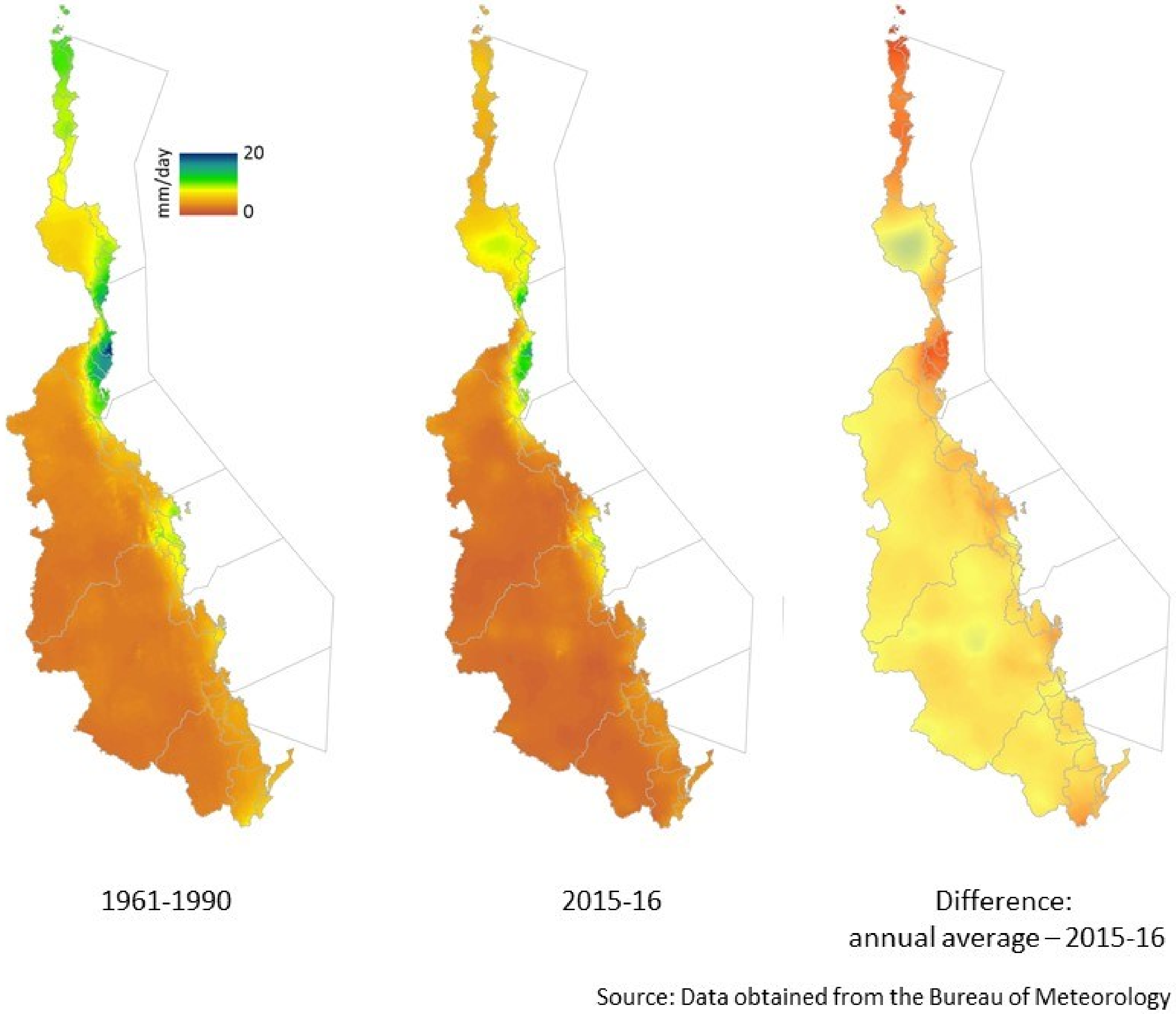

Figure 3-3: Average daily rainfall (mm/day) in the GBR catchment: (left) long-term annual average (1961–1990; time period produced by the Bureau of Meteorology), (centre) 2015–16 and (right) the difference between the long-term annual average and 2015–16 rainfall patterns.

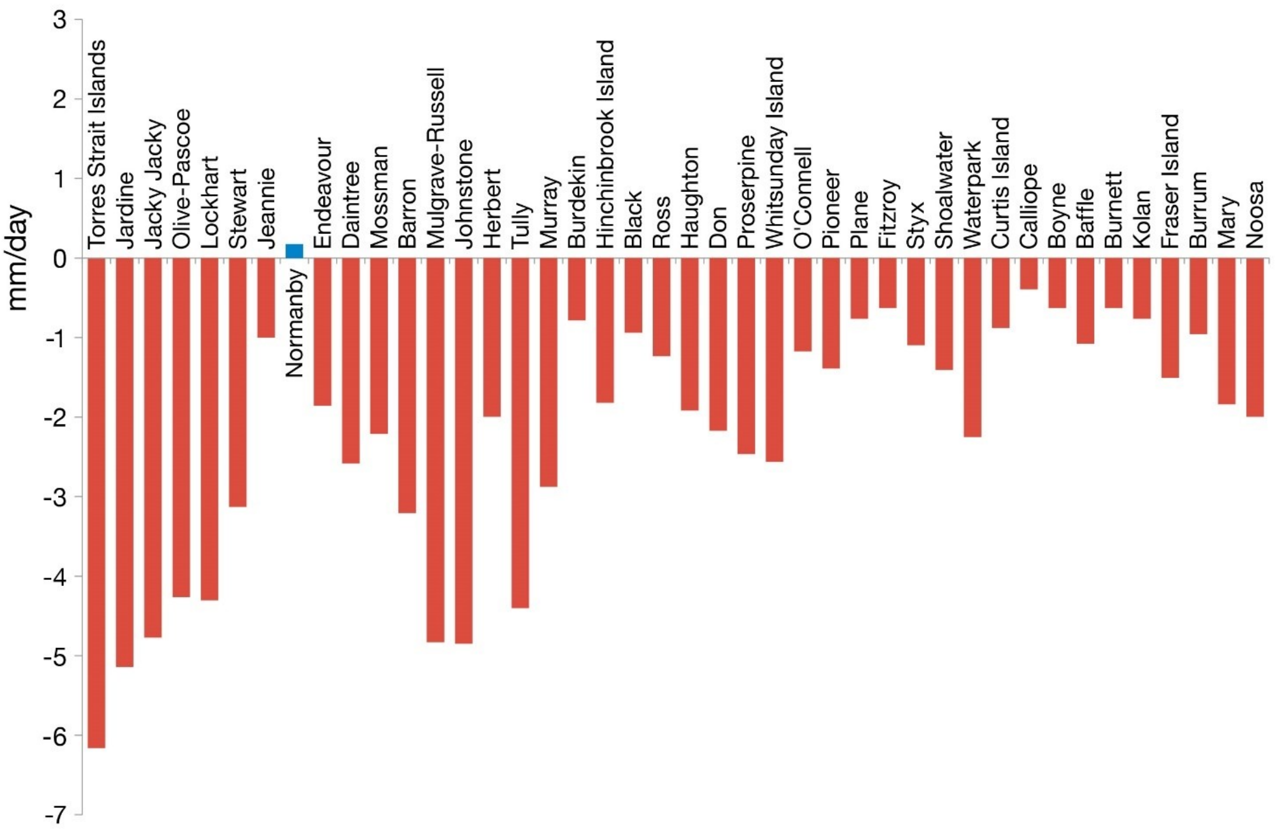

Figure 3-4: Annual average wet season rainfall (December 2015–April 2016) compared to the long-term wet season rainfall average (1961–1990). Red and blue bars denote catchments with rainfall below and above the long-term average, respectively. Note that the catchments are ordered from north to south (left to right).

3.2.3 Freshwater discharge

The 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 E1). All regions had relatively low annual discharge, similar to 2014–15 and the levels in the period between 2000 and 2007.

Wet season discharge for the 35 GBR basins 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;
- A total of 2 to 3 times long-term median flow: Kolan River; and
- A total of 1.5 to 2 times long-term median flow: Styx River, Shoalwater River, Waterpark River and Burnett River.

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

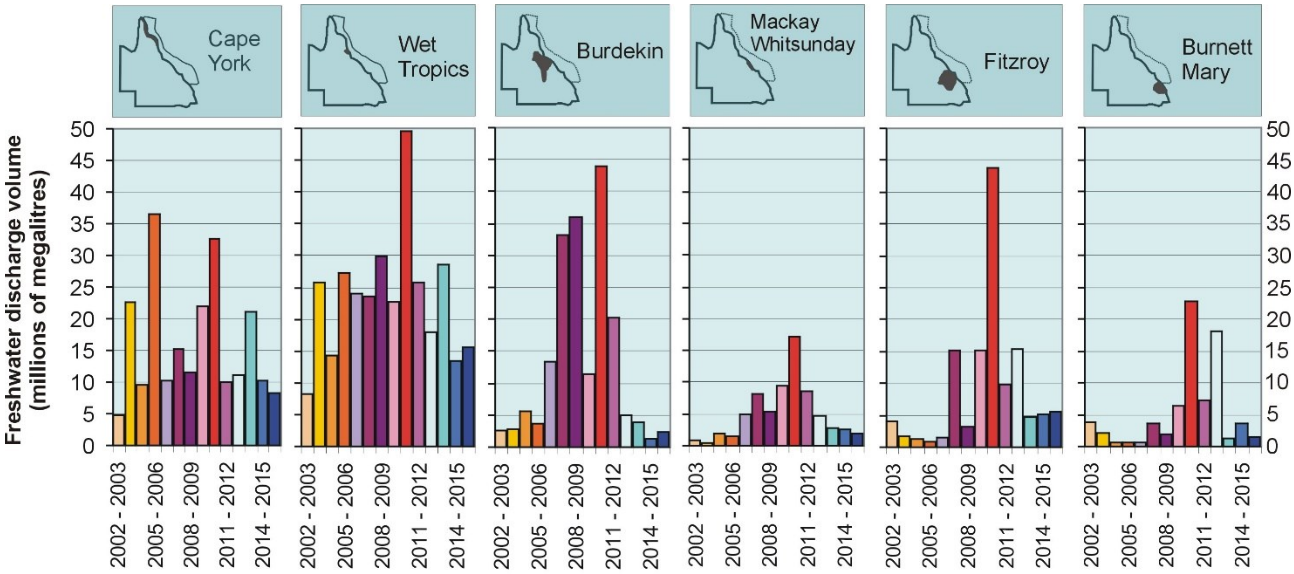

Figure 3-5: Corrected annual hydrological/water year (1 October to 30 September) discharge from each NRM region (using the correction factors in Table 2-3) for 2002–03 to 2015–16 in million litres (ML) per year. Data derived from DNRM (2016).

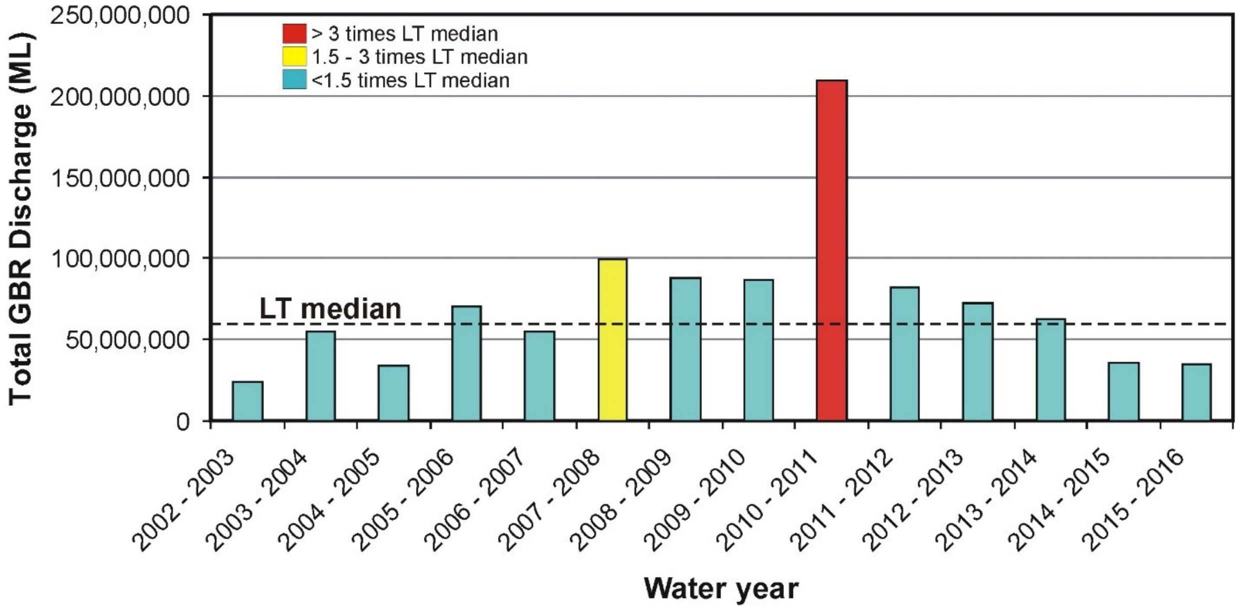

Figure 3-6: Long-term total discharge in million litres (ML) (hydrological year: 1 October to 30 September) for the 35 main GBR Rivers. Source: DNRM, http://watermonitoring.dnrm.qld.gov.au/host.htm.

Table 3-1: Wet season discharge (ML; million litres) of the main GBR rivers (1 October 2015 to 30 September 2016, inclusive) compared to the previous four wet seasons and long-term (LT) median discharge (1986–87 to 2015–16). Colours indicate levels above the long-term median: yellow for 1.5 to 2 times; orange for 2 to 3 times, and red for greater than 3 times. Data source: DNRM. (– = data not available).

Basin	LT median	2010 - 2011	2011 - 2012	2012 - 2013	2013 - 2014	2014 - 2015	2015 - 2016
Jacky Jacky Creek	2,021,488	4,735,197	1,820,422	1,986,825	3,790,832	1,498,138	630,787
Olive Pascoe River	2,526,860	5,918,996	2,275,527	2,483,531	4,738,541	1,872,672	788,484
Lockhart River	1,600,345	3,748,697	1,441,167	1,572,903	3,001,076	1,186,026	499,373
Stewart River	674,618	2,180,850	616,070	523,353	1,311,775	298,816	311,901
Normanby River	4,159,062	11,333,284	2,181,990	3,462,238	5,059,657	2,914,859	3,407,359
Jeannie River	1,263,328	2,824,817	1,048,269	695,195	1,869,982	1,434,447	1,581,015
Endeavour River	821,163	1,836,131	681,375	451,877	1,215,488	932,391	1,027,660
Daintree River	1,722,934	3,936,470	2,396,905	1,668,302	5,137,023	1,905,224	1,623,478
Mossman River	1,207,012	2,014,902	1,526,184	1,147,367	1,918,522	874,068	1,245,275
Barron River	526,686	2,119,801	852,055	328,260	663,966	380,395	182,999
Mulgrave-Russell River	4,457,940	7,892,713	5,696,594	3,529,862	5,420,678	3,145,787	3,253,825
Johnstone River	4,743,915	9,276,874	5,338,591	3,720,020	5,403,534	3,044,680	3,416,331
Tully River	3,536,054	7,442,768	3,425,096	3,341,887	4,322,496	2,659,775	2,942,770
Murray River	1,227,888	4,267,125	2,062,103	1,006,286	1,531,172	366,212	974,244
Herbert River	3,556,376	12,593,674	4,545,193	3,189,804	4,281,607	1,095,372	1,895,526
Black River	228,629	1,424,283	747,328	188,468	419,290	17,654	129,783
Ross River	445,106	2,092,684	1,324,707	276,584	1,177,255	-	-
Haughton River	553,292	2,415,758	1,755,712	517,069	573,976	120,674	267,986
Burdekin River	4,406,780	34,834,316	15,568,159	3,424,572	1,458,772	880,951	1,807,104
Don River	342,257	3,136,184	802,738	578,391	324,120	171,305	101,562
Proserpine River	887,771	4,582,697	2,171,287	851,504	720,427	157,123	316,648
O'Connell River	796,718	4,112,676	1,948,591	764,170	646,537	141,008	284,171
Pioneer River	776,984	3,630,422	1,567,684	1,162,871	635,315	2,028,936	597,117
Plane Creek	1,052,831	4,809,239	2,854,703	1,948,929	737,580	241,254	832,508
Styx River	187,756	906,144	275,219	968,106	544,155	376,009	343,877
Shoalwater Creek	213,653	1,031,129	313,180	1,101,638	619,211	427,872	391,308
Water Park Creek	563,267	2,718,432	825,657	2,904,319	1,632,466	1,128,027	1,031,630
Fitzroy River	2,852,307	37,942,149	7,993,273	8,530,491	1,578,610	2,681,949	3,589,342
Calliope River	152,965	1,000,032	345,703	1,558,380	283,790	479,868	148,547
Boyne River	38,691	252,949	87,443	394,178	71,782	121,378	37,574
Baffle Creek	367,525	3,650,093	1,775,749	2,030,545	275,517	710,352	257,093
Kolan River	47,866	779,168	307,837	810,411	45,304	213,857	111,172
Burnett River	234,463	9,421,517	643,137	7,581,543	218,087	853,349	381,054
Burrum River	63,918	114,492	117,762	90,921	62,188	150,113	334,681
Mary River	1,144,714	8,719,106	4,340,275	7,654,320	594,612	1,651,901	480,854

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 4-8.
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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 2015–16 wet season were calculated using numerical tracer experiments within the eReefs hydrodynamic model, and are presented in the Regional results for each of the MMP water quality 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. The 2015–16 wet season had a very rainfall, and in most of drainage basins, caused a very low volumetric discharge of the rivers (below the long-term median – see Section 3.2).

The results of the tracer simulations confirmed that the areas exposed to the water from individual rivers in 2015–16 were much smaller, spatially and their respective levels of cumulative exposure, for all focus regions than during the extreme wet season of 2010–11. The tracer maps are useful in complementing the overall exposure maps as they allow quantification of the footprint of individual rivers, and the level of exposure to river water within this footprint. This information can be used to provide context for any changes in the local inshore water quality in the light of changes in the delivery of runoff from certain catchments. However, only the eReefs model will, in the future, 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. In this year's report (2015–16) an initial comparison between the eReefs outputs and the MMP data was also performed, with an overall good comparability for especially the salinity data (Appendix E, Figure E3 and E4).

3.3.2 Wet season water type maps and exposure assessment

The frequency maps predict the GBR marine areas affected by the three wet season water types (Primary, Secondary and Tertiary water types). The outputs predict the spatial distribution and frequencies of occurrence of these wet season water types combined (*i.e.,* of the turbid waters: Figure 3-7) and individually (i.e. of the Primary, Secondary and Tertiary water types, respectively: Figure 3-8) during the 2015–16 wet season (Figure 3-7 and Figure 3-8) and during the long term (2002–03 to 2015–16) and the wettest wet season monitored (2010–11) (Figure 3-7). The individual wet season water type maps provide information on the composition of the waters during the wet season (through the Primary, Secondary, and Tertiary water type classification linked to the in-situ water quality data) and the frequency of occurrence (or likelihood) of these wet season water types. The wet season water types are further classified into six categories (or colour classes) with classes 1 to 4 corresponding to Primary waters, class 5 to Secondary waters and class 6 to Tertiary waters. This classification allows a finer-scale characterisation of the water constituents inside of the Primary water type. Note that this mapping exercise is not identifying scale or extent of the impact across all GBR ecosystems.

The 2015–16 wet season was characterised by low rainfall and consequent river discharge, resulting in river plumes that were not well developed therefore, the sampling sites did not receive high riverine influence. This considerably reduced the ability to characterise the water quality conditions within river plumes this season. It is also expected that during wet seasons characterised by relatively low flow, elevated turbidity along the coastline, (and therefore, the frequency and spatial distribution of the wet season colour classes), are mainly driven by the re-suspension of sediment as well as metocean drivers of water circulation in the region (for example, winds, currents) rather than being directly related to the volume discharge of the GBR rivers.

The frequency maps illustrate a well-documented inshore to offshore spatial pattern (e.g., Devlin et al., 2015b), 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 is 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). The frequency of occurrence and total area (in km^2) of the GBR affected by the turbid waters (combined Primary, Secondary and Tertiary water types) increased during the wettest wet seasons and decreased during the driest wet seasons. The 2016 turbid area (183,693 km^2 or 53% of the GBR) was below the long-term turbid area (251,686 km^2 or 72% of the GBR) and the 2011 area (237,616 km^2, or 68% of the GBR). The Primary waters in 2015–16 covered 15,501 km^2 (4%) of the GBR. The extent of the Secondary and Tertiary water type frequency is rarely attributed to an individual river and is usually merged into one heterogeneous area. The Secondary and Tertiary water types in 2015–16 covered 68,018 km^2 (20%) and 173,204 km^2 (50%) of the GBR, respectively.

A summary of water quality parameters in the six colour classes in 2015–16 is shown in Figure 3-9 and Figure 3-10, respectively, and detailed characteristics are provided in the Appendix E for GBR (Table E-5), Wet Tropics (Table E-6), Burdekin (Table E-7) and Mackay Whitsunday (Table E-8). Most of key water quality parameters in both the long-term dataset (2003 to 2016) and in the reporting year 2015–16 followed published trends i.e., decreasing values from the Primary (colour classes 1 to 4) to the Tertiary water type. While Devlin et al. (2012a) reported higher Chl-a concentration in the Secondary water type in comparison to the Primary water type, this wet season (similarly to last year results) showed greater mean Chl-a concentrations in the Primary water type (0.9 ± 0.4 µg L^{-1}) than in the Secondary water type (0.73 ± 0.54 µg L^{-1}). Chl-a concentrations were, however, greater in colour classes 3 and 4 (1.1 ± 0.3 µg L^{-1} and 0.9 ± 0.4 µg L^{-1}, respectively) than in the colour class 1 (0.84 ± 0.30 µg L^{-1}) (Figure 3-10). This result underlines the importance of the sub-classification into colour classes in order to better illustrate fine-scale coastal processes, in the Primary waters.

The results support the findings of Devlin et al. (2013), which reported a peak of Chl-a concentration in samples located in transition zones between the Primary and Secondary water types (driven by a reduction in both TSS and the vertical light attenuation coefficient (Kd) in the photosynthetically active radiation (PAR) or Kd(PAR) values as well as regular nutrients inputs). They also support results of this year's light case study (Appendix C) which indicated that Chl-a is a significant contributor to Kd(PAR), along with TSS and CDOM in the colour class 4 and 5, while only TSS and CDOM contribute to the light attenuation in the most coastal waters (colour class 1 and 2). The data available in the colour classes 1 to 3 were, however, limited and difficult to interpret for most of the water quality parameters (Figure 3-10). The mean water quality concentrations measured across the wet season water types and colour classes in 2015–16 were all below the long-term average concentrations, except the mean TSS, CDOM, Kd(PAR), PP and DIN measured in colour class 3 (and colour class 2 for TSS and DIN) (Figure 3-9 and Figure 3-10). These mean values were, however, in the long-term standard deviation range. The long-term and 2015–16 TSS concentrations were above the wet season guideline values in each respective wet season water types (Figure 3-9: $TSS_{Primary}$ = 12.1 ± 25.8 mg L^{-1}, $TSS_{Secondary}$ = 4.2 ± 2.3 mg L^{-1} and $TSS_{Tertiary}$ = 3.6 ± 2.9 mg L^{-1}). The 2015–16 mean Chl-a and PP concentrations were above the wet season guideline values in the Primary waters ($Chl\text{-}a_{Primary}$ = 0.9 ± 0.4 µg L^{-1}, $PP_{Primary}$ = 5.0 ± 6.9 µg L^{-1}), while PN concentrations recorded this wet season were under the guideline value in all wet season water types (Figure 3-10).

In this study, the long-term and wet season mean water quality concentration measured across the wet season water types were assessed against the Water Quality Guideline for the GBR open coastal and midshelf waters (GBRMPA, 2010), and used to derive wet season and long-term surface exposure maps, respectively.

However, further work is required to improve our understanding of the frequency, duration (number of continuous days and weeks) and consequences of exposure of seagrass and coral ecosystems to the distinct wet season water types, and to develop ecologically-relevant water quality guidelines accordingly.

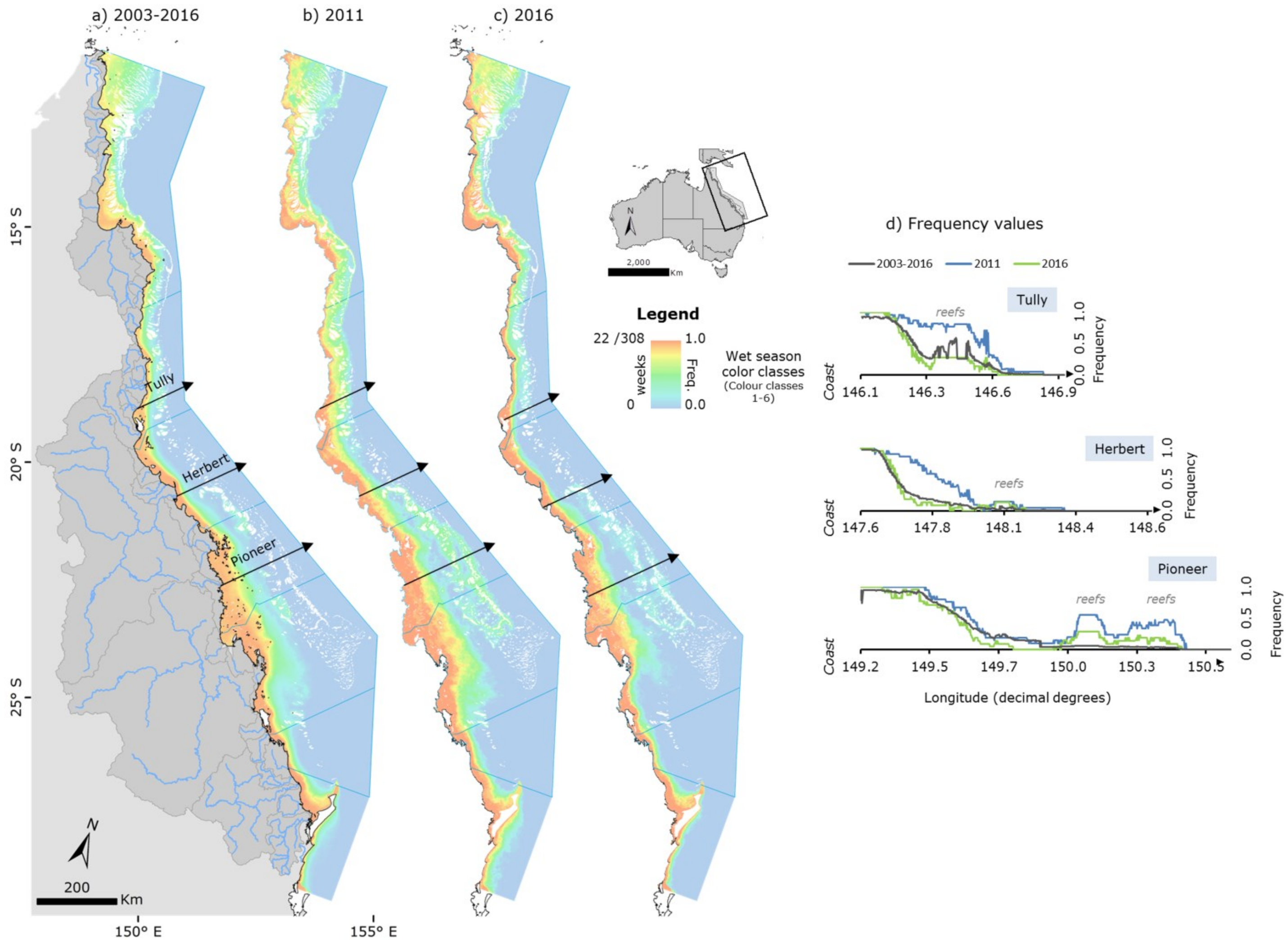

Figure 3-7: Map showing the frequency of wet season water types (turbid waters: Primary, Secondary and Tertiary water types) in the a) long-term (2002–03 to 2015–16: 308 weeks), b) 2010–11 wet season (22 weeks) and c) 2015–16 wet season (22 weeks), where the highest frequency is shown in orange and the 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.

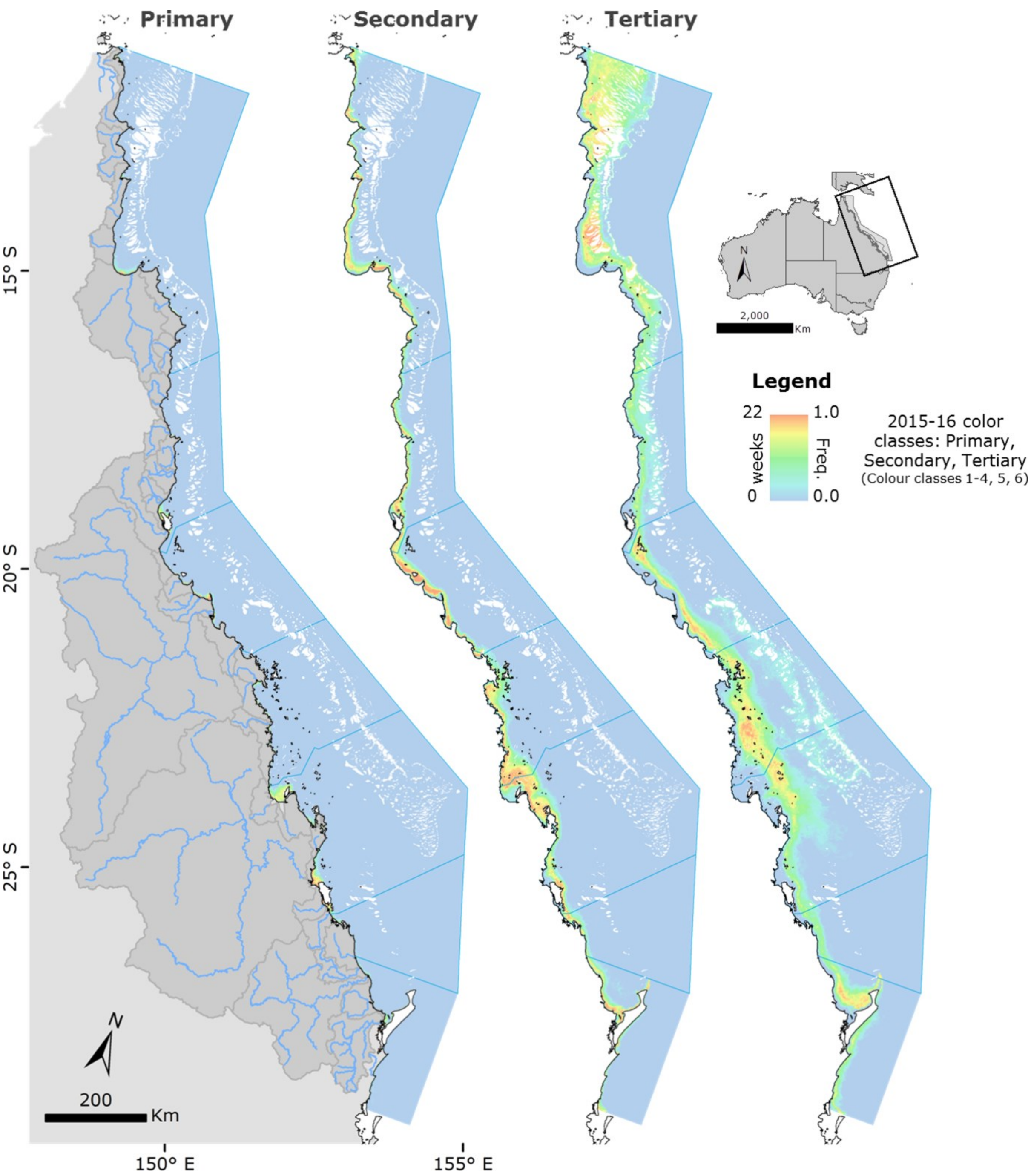

Figure 3-8: Map showing the frequency of Primary, Secondary and Tertiary plume water types in the 2015–16 wet season (22 weeks), where the highest frequency is shown in orange and the lowest frequency is shown in blue.

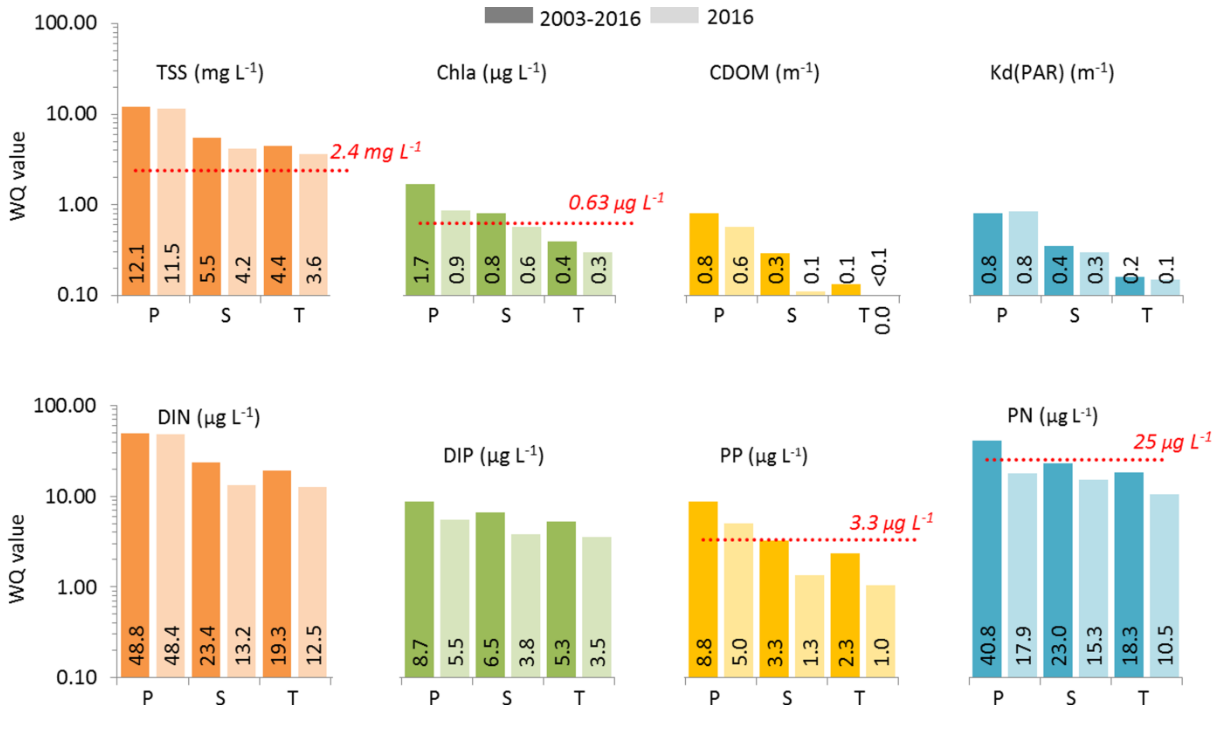

Figure 3-9: Mean water quality concentrations across the three wet season water types: comparison between the mean multi-annual values (2002–03 to 2015–16; dark colours), the 2015–16 values (light colour) and wet season guideline values for the open coastal and midshelf waters (dotted red lines).

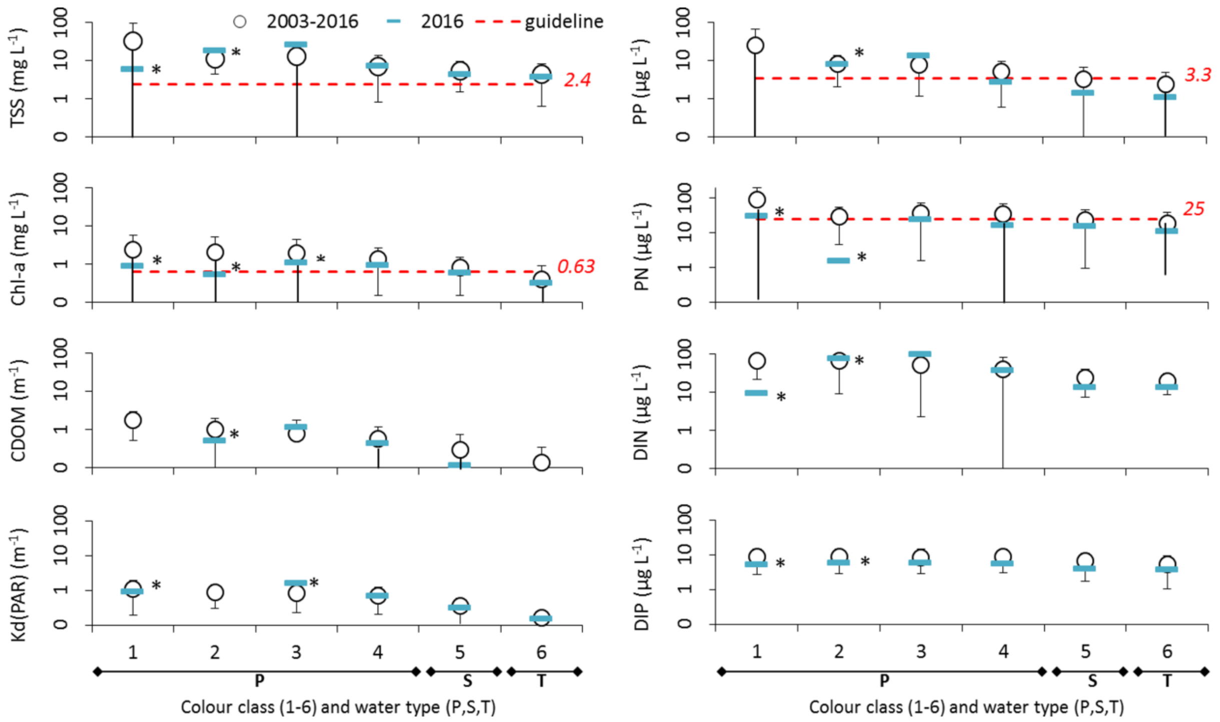

Figure 3-10: Mean water quality concentrations and standard deviation across the six colour classes: comparison between the mean multi-annual values (2002–03 to 2015–16; circles with error bars) and the 2015–16 values (blue rectangles). Black asterisks indicate that the number of data was ≤ 3 and the red dotted line shows the wet season guideline for the open coastal and midshelf waters.

3.3.3 Surface exposure to Great Barrier Reef ecosystems 2015–16

As described in Section 2.6, the exposure maps can be overlaid with information on the presence or distribution of GBR ecosystems to help identify ecosystems that may experience acute or chronic high exposure to pollutants during the wet season (exposure assessment), and thus help to evaluate the susceptibility of GBR ecosystems to land-sourced pollutants. The framework to produce exposure maps for seagrass and coral ecosystems is described in Section 2.7.

Measuring the magnitude of the exposure to coral reefs and seagrass beds can be challenging because of the combination of different stressors in river plume waters, the difficulty in sampling a plume sufficiently to characterise it fully to assess its effects, the ability to distinguish river discharge influences from other drivers such as wind driven resuspension, and the inherent complexity of hydrodynamics in the region. Devlin et al. (2012b) underscored the need to develop models that incorporate the cumulative effects of pollutants. Detailed methods of how these figures are derived are included in Appendix D-9. 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.

It is important to note that: (i) Any results obtained in the Cape York NRM should be considered with care. Cape York is a shallow and optically complex environment where the true colour method has not been fully validated; and (ii) Only surface areas inside the GBR marine boundaries are reported. (iii) It is also acknowledged that this assessment does not take into account 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, so the highest risk of an ecological response could be during large events when Primary/Secondary waters extend into otherwise low exposure (Tertiary) areas.

Figure 3-11 presents the exposure map of the 2015–16 wet season and Table 3-2 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 (2003-2016).

In 2015–16, the GBR lagoon was mostly influenced by the lowest exposure categories (categories I and II), in agreement to the long-term trends. Approximately 52% of the total area of the GBR was exposed to turbid waters (combined Primary, Secondary and Tertiary water types), at least during one week of the wet season. However, less than 1% of the GBR was in the higher potential risk categories (categories III and IV) from exposure. These areas were smaller than the long-term areas (Table 3-2 – 72% exposed to turbid waters, 1% to categories I, and 1% to category II), and were consistent with the characteristic of a relatively dry wet season. Regional results are presented in Section 3.4.

Coastal areas have the highest frequency of occurrence of Primary waters (Figure 3-8) and thus coastal ecosystems are most affected by the highest exposure categories (categories III and IV). Inversely, offshore areas are less frequently exposed to turbid waters 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 seeing an alternation of water types and frequencies depending on the wet season characteristics and resuspension events. In 2015–16, It was estimated that:

- A total of 82% of the GBR coral reefs were exposed to turbid waters (Primary, Secondary and Tertiary waters combined), at least during one week of wet season. However, no corals were in the highest potential risk category (IV) from exposure and very few (<1%) were in the exposure categories III.

- A total of 95% of the GBR seagrasses were exposed to turbid waters (combined Primary, Secondary and Tertiary water types), at least during one week of wet season. However, no seagrasses were in the highest potential risk category (IV) from exposure, and few (7.7%) were in exposure category III.
- The coral and seagrass areas in the highest categories of potential risk in 2015–16 were smaller than the long-term areas (Table 3-2: 0.1% of reefs and 9% of seagrasses exposed to category IV) and were logical with the characteristic of a relatively dry wet season

Table 3-2: Areas (km^2) and percentages (%) of the GBR lagoon affected by different categories of exposure within the GBR during the 2015–16 wet season *(and long-term values)*. Surface areas south of the GBRMP boundary (Hervey Bay) are not included.

NRM		Total	Potential Risk category Lowest ----------------------- highest				Total exposed	Total non-exposed
Surface area	area	348,750	177,267	3,165	1,568	-	182,001	166,749
			(239,038)	(6,609)	(2,200)	(2,009)	(249,855)	(98,895)
	%	*100%*	51	0.9	0.4	-	52	48
			(69)	(2)	(1)	(1)	(72)	(28)
Coral reefs	area	24,903	20,320	29	25	-	20,374	4,529
			(22,917)	(120)	(25)	(17)	(23,079)	(1,824)
	%	*100*	82	0.1	0.1	-	82	18
			(92)	(0.5)	(0.1)	(0.1)	(93)	(7)
Surveyed seagrass	area	4,579	3,536	467	351	-	4,354	226
			(2,734)	(868)	(349)	(413)	(4,364)	(216)
	%	*100*	77	10.2	7.7	-	95	5
			(60)	(19)	(8)	(9)	(95)	(5)

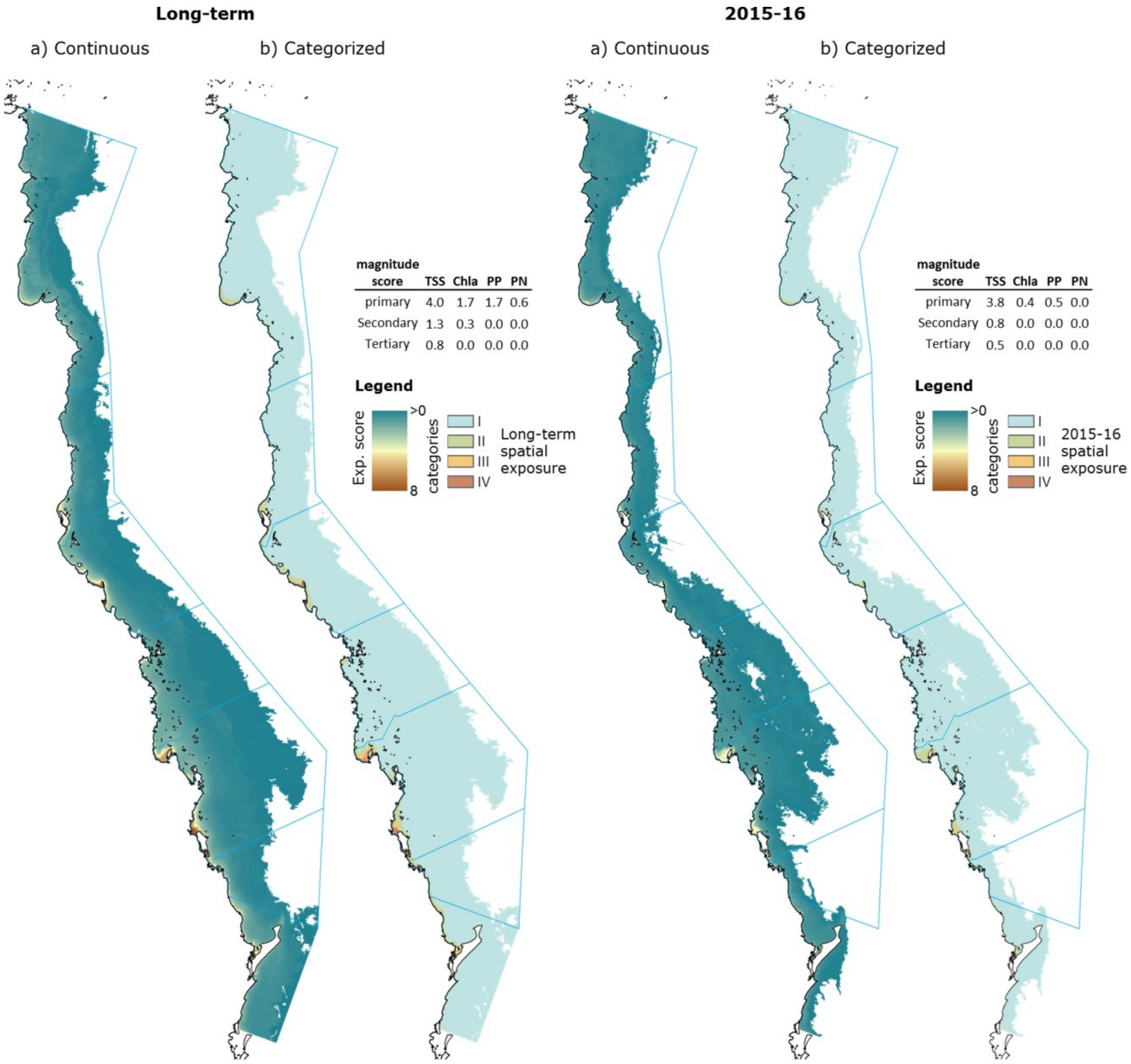

Figure 3-11: Long-term and 2015–16 maps of exposure produced using the proportional exceedance of the guideline (magnitude score) multiplied by the likelihood of exposure in each of the wet season water types (2016 method): a) continuous exposure scores and b) categorised exposure scores: [>0-2] = cat. I, [2-4] = cat. II, [4-6] = cat III and [6-8] = 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 AppendixD-10. Maps are also available for PN but are not presented here due to lower confidence in our understanding of processing and transformation of PN in river plumes and the low confidence in the end-of-basin modelled loads (see Appendix D-10 for further explanation).

(a) Mapping annual DIN concentration in the GBR 2003-2016

The model-predicted DIN export to GBR lagoon is estimated by its annual concentration (DIN, µg/L) over 14 years (Figure 3-12 and Figure 3-13). These maps provide an estimate of how far DIN can travel in GBR waters, and the areas more likely to have higher DIN concentration. The areas covered by model-predicted DIN vary over the 14 years analysed. Overall, years with very large river discharge (> 65,000,000 ML), which occurred in 2008, 2009 and 2011, 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 the other regions. Even though the Burdekin River is responsible on average for > 36% of the DIN load accounted 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 the present shows distinct differences between years, driven by river flow and pollutant loads, with relatively small areas influence in the 2015-2016. The DIN loading assessment shows the greatest areas of change around the Wet Tropics region and to a lesser extent, the Mackay Whitsunday region.

Figure 3-13 shows the difference between the estimated wet season DIN concentration in the GBR lagoon for the (left panel) 2016 water year (1 October to 30 September), 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 2016 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 region as the dominant area of change, and to a lesser extent, the Burdekin, Mackay Whitsunday and Burnett Mary regions. This analysis is consistent with previous assessments of the relative risk of river derived nitrogen to the GBR (e.g. Brodie et al., 2013a).

Figure 3-14 shows the river contributions (x-axis) to the DIN mass to the 6 NRM regions in 2010–11 (left column) and 2015–16 (right column). The preferential northward movement of the river plumes 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. Similar patterns occurred in the Mackay Whitsunday region in 2010–11 when 28% of DIN in its waters was derived from the Fitzroy River. Conversely in 2015–16, the Fitzroy River had no DIN contribution to Mackay Whitsunday region. The Wet Tropics Rivers also contribute to the Cape York NRM, and the Mossman and Daintree Rivers contributed to the region in the low discharge year of 2015–16. The Herbert River also contributes to the Burdekin NRM region, as the boundary is just south of the Herbert River mouth. The Burnett Mary rivers also contributed to the Fitzroy NRM region in the large flood event of 2010–11. These cross-regional influences are also evident in satellite imagery in the 2010–11 events.

These results indicate that the northward plume transport has the potential to increase the DIN load impact into zones outside of the NRM region. For example, the contribution of DIN loadings from the Burdekin River combined with the high DIN concentrations from the Wet Tropic rivers is in agreement with the supporting theories of land-based eutrophication as a potential trigger for crown-of-thorns starfish outbreaks (Brinkman et al., 2014; Brodie et al., 2005; Uthicke et al., 2015; Wooldridge, 2009; Wooldridge et al., 2015).

Analysis of the relative contribution of each river to the concentrations in each NRM region is presented in the regional results 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 2003-2016

The same model developed for DIN dispersion was used to produce maps for the land-sourced TSS in the GBR, except that the decay function was not included. The dispersion function in the model results in some uncertainty with the results 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. This function of the model is currently being revised and would ultimately benefit from the input of the eReefs modelling platform.

The model-predicted TSS export to the GBR lagoon was examined by its annual concentration over 14 years (Figure 3-15) with similar patterns as observed for DIN in relation to correlation with river discharge. 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 compared to the DIN assessment. High TSS values were observed in the Wet Tropics region over all of the years analysed, but high values were also observed in the Burdekin region in several years including 2005, 2007 and 2013, and in Mackay Whitsunday in 2010, 2011 and 2012 (Figure 3-15). Figure 3-16 shows the difference between the estimated wet season TSS concentration in the GBR lagoon for the (left panel) 2016 water year (1 October to 30 September), 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 2016 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 change, and to a lesser extent, the Wet Tropics, Mackay Whitsunday and Burnett Mary regions. This analysis is also consistent with previous assessments of the relative risk of river derived TSS to the GBR (e.g. Brodie et al., 2013a; Lewis et al., 2015).

Figure 3-17: shows the river contributions (x-axis) to the TSS mass for the six NRM regions in 2010–11 (left column) and 2015–16 (right column). The preferential northward movement of the river plumes 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 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 NRM region, while in 2015–16 only the Daintree and Mossman Rivers contributed to the TSS loading. The Herbert River also contributes to the Burdekin NRM region, even in the low discharge years. The Burdekin River contributed to the Cape York and Wet Tropics NRM region in 2010–11, but its influence was constrained to the Burdekin NRM region in 2015–16. The Mackay Whitsunday region received inputs from the Fitzroy River in 2010–11, and the model also shows contributions from the Styx River although this is minimal and most likely an issue of close proximity and uncertainties in the river flow and load estimates The Fitzroy River also had some contribution to the Burnett Mary region in 2010–11. The Burnett Mary rivers also contributed to the Fitzroy NRM region in the large flood event of 2010–11, and this was also most likely the case in the large discharge events in the Mary River in 2013. These cross-regional influences are also evident in satellite imagery in the 2010–11 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 results 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.

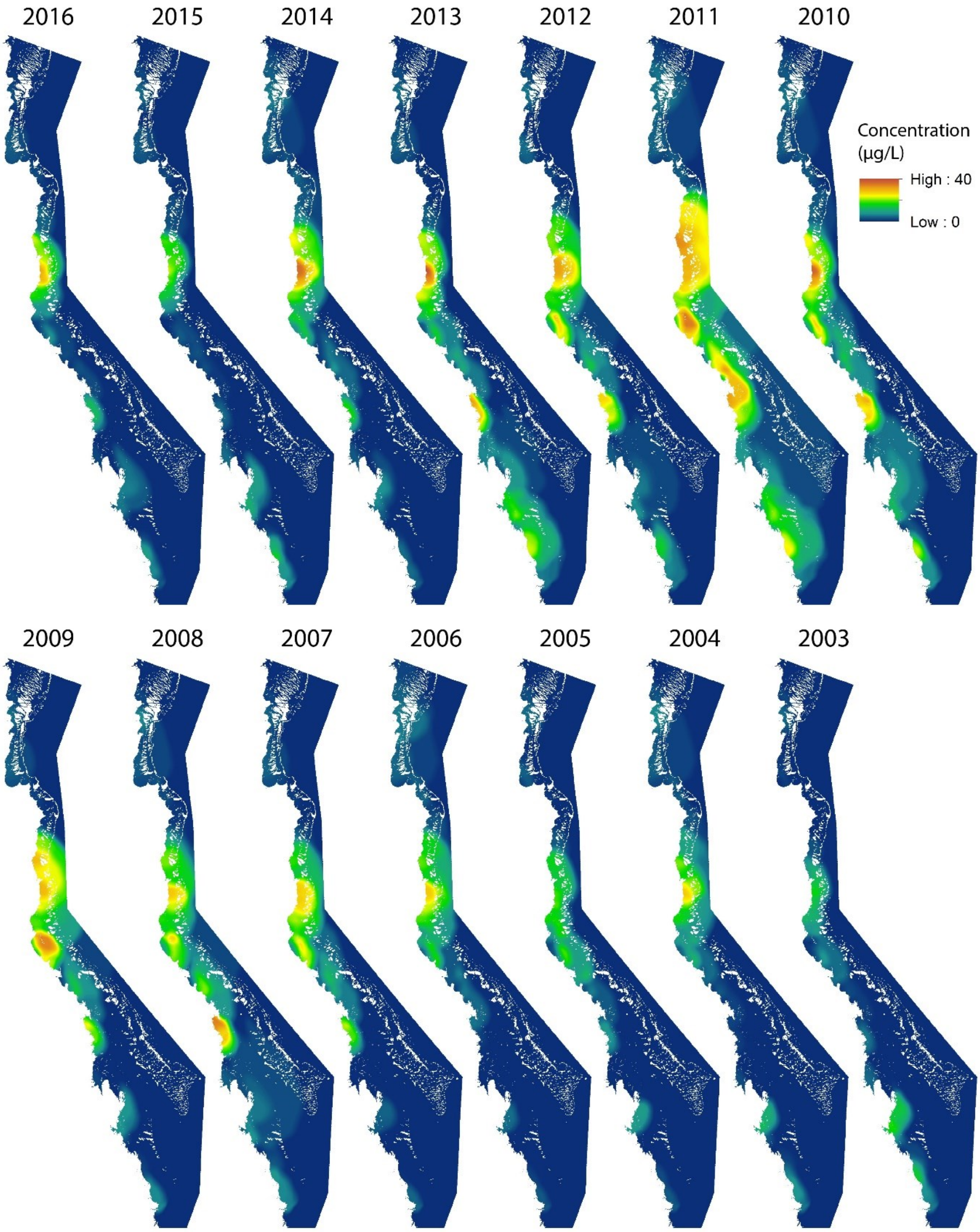

Figure 3-12: DIN (µg/L) over the GBR lagoon for the 2003 to 2016 water years (1 October to 30 September).

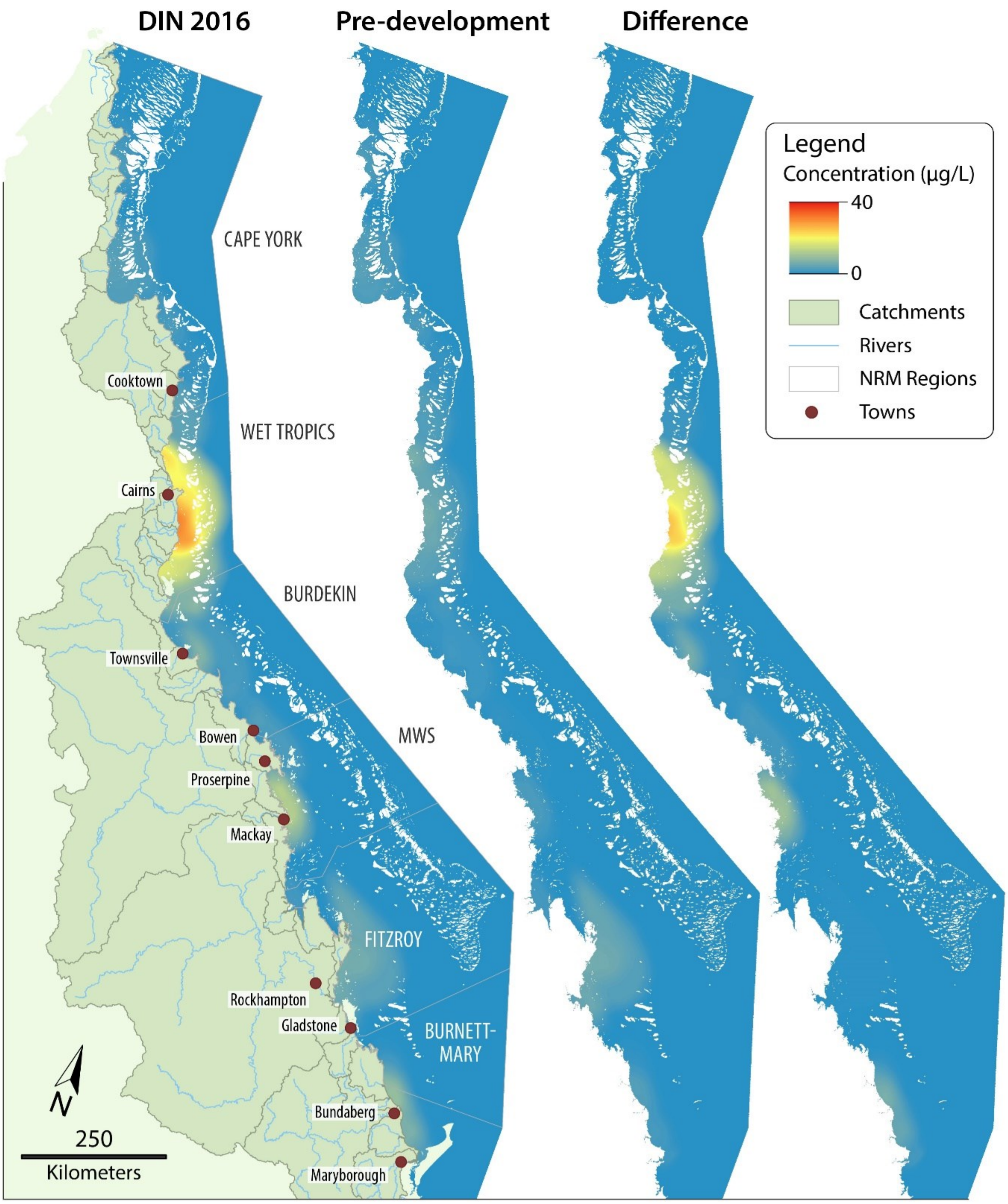

Figure 3-13: DIN concentration (µg/L) in the GBR lagoon, modelled for the (left panel) 2016 water year (1 October to 30 September), (centre panel) pre-development loads and (right panel) difference between the DIN concentration with pre-development end of catchment DIN load estimates and the 2016 estimates.

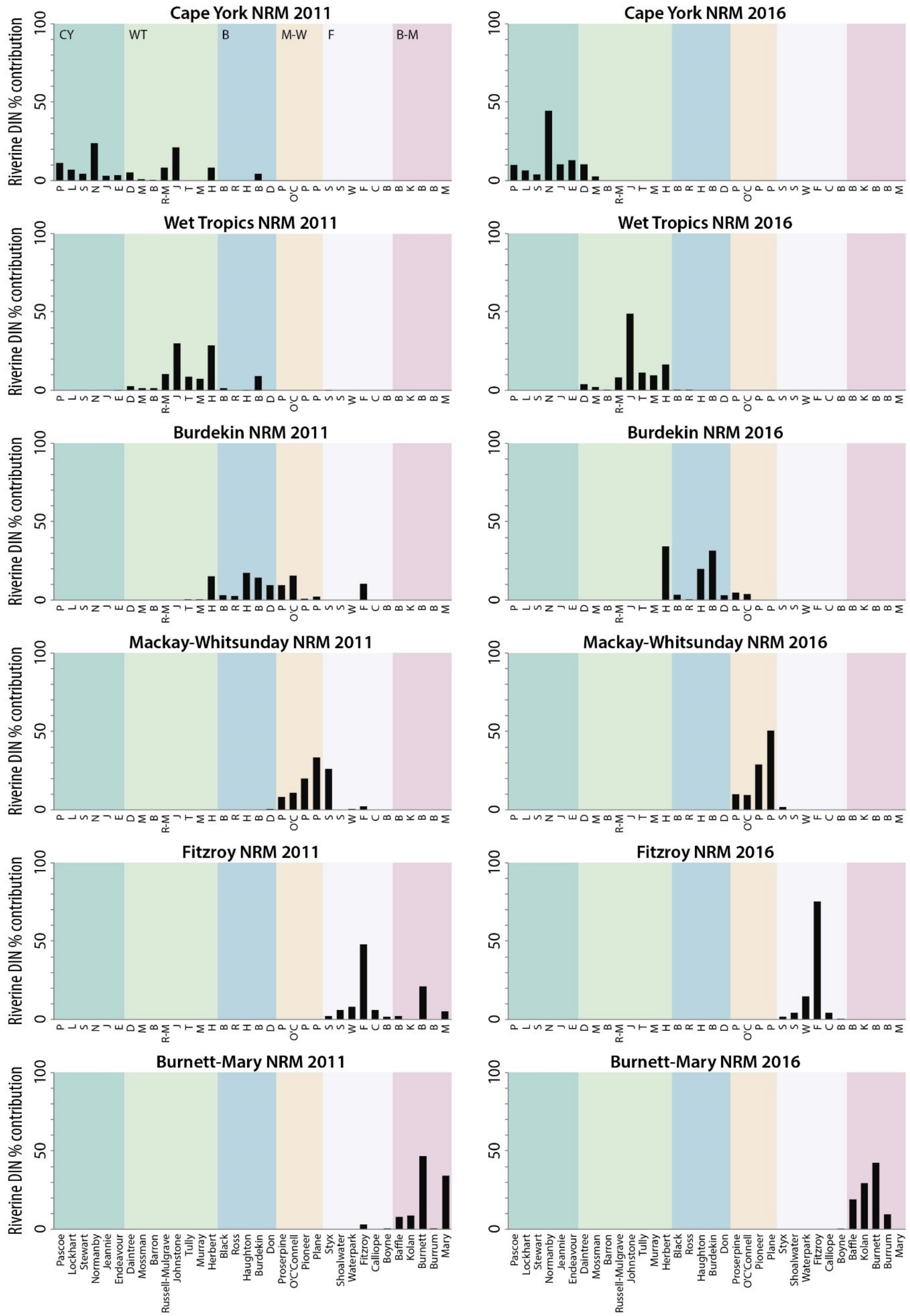

Figure 3-14. River contributions (x-axis) to the DIN mass in the six NRM regions. Shading groups rivers in the same NRM region: Cape York – dark green, Wet Tropics – light green, Burdekin – blue, Mackay Whitsunday – orange, Fitzroy – pink, Burnett Mary - red. The left panels show data for the 2010–11 water year (1 October to 30 September) and right panel for the 2015–16 water year.

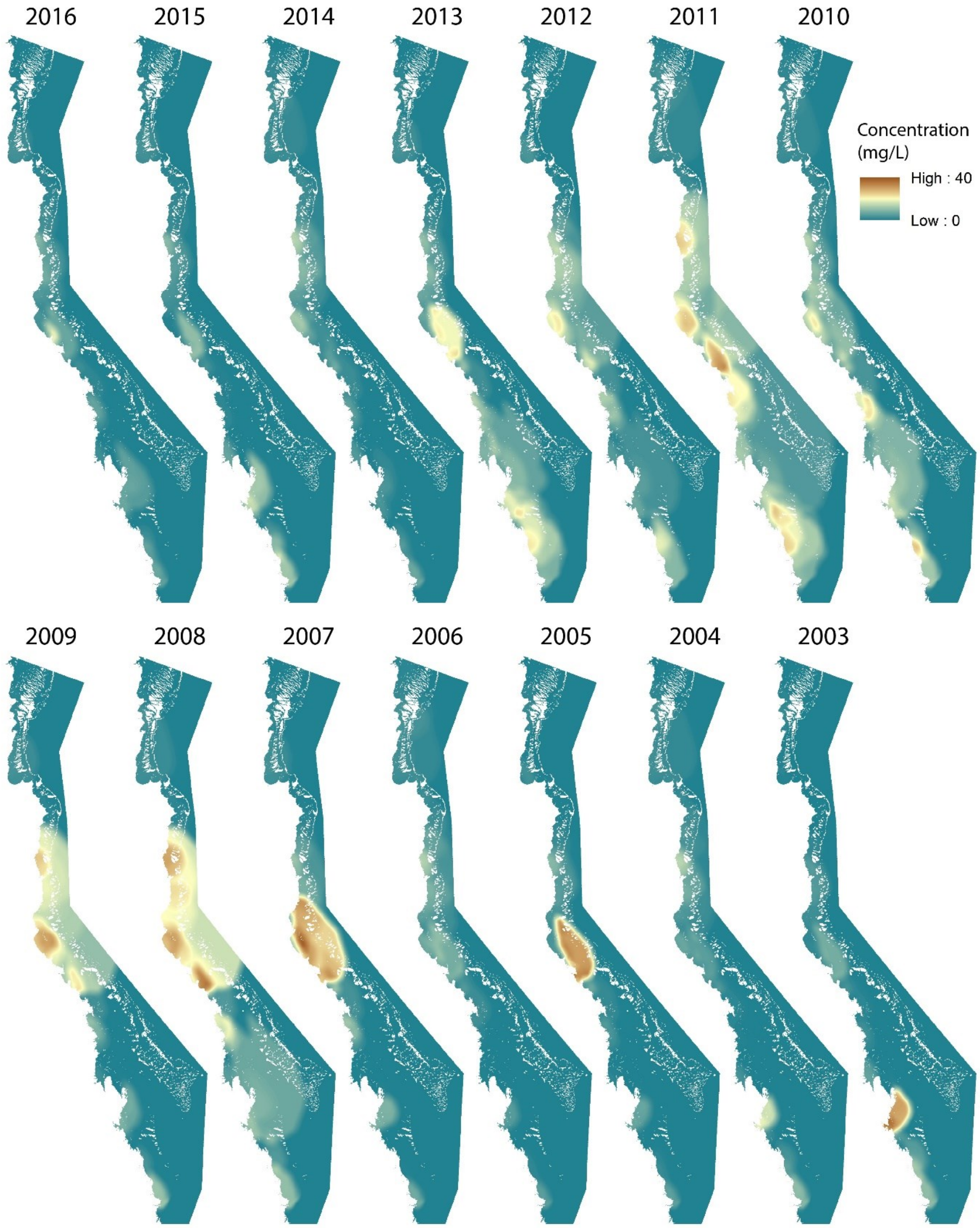

Figure 3-15: TSS (mg/L) over the GBR lagoon for the 2003 to 2016 water years (1 October to 30 September).

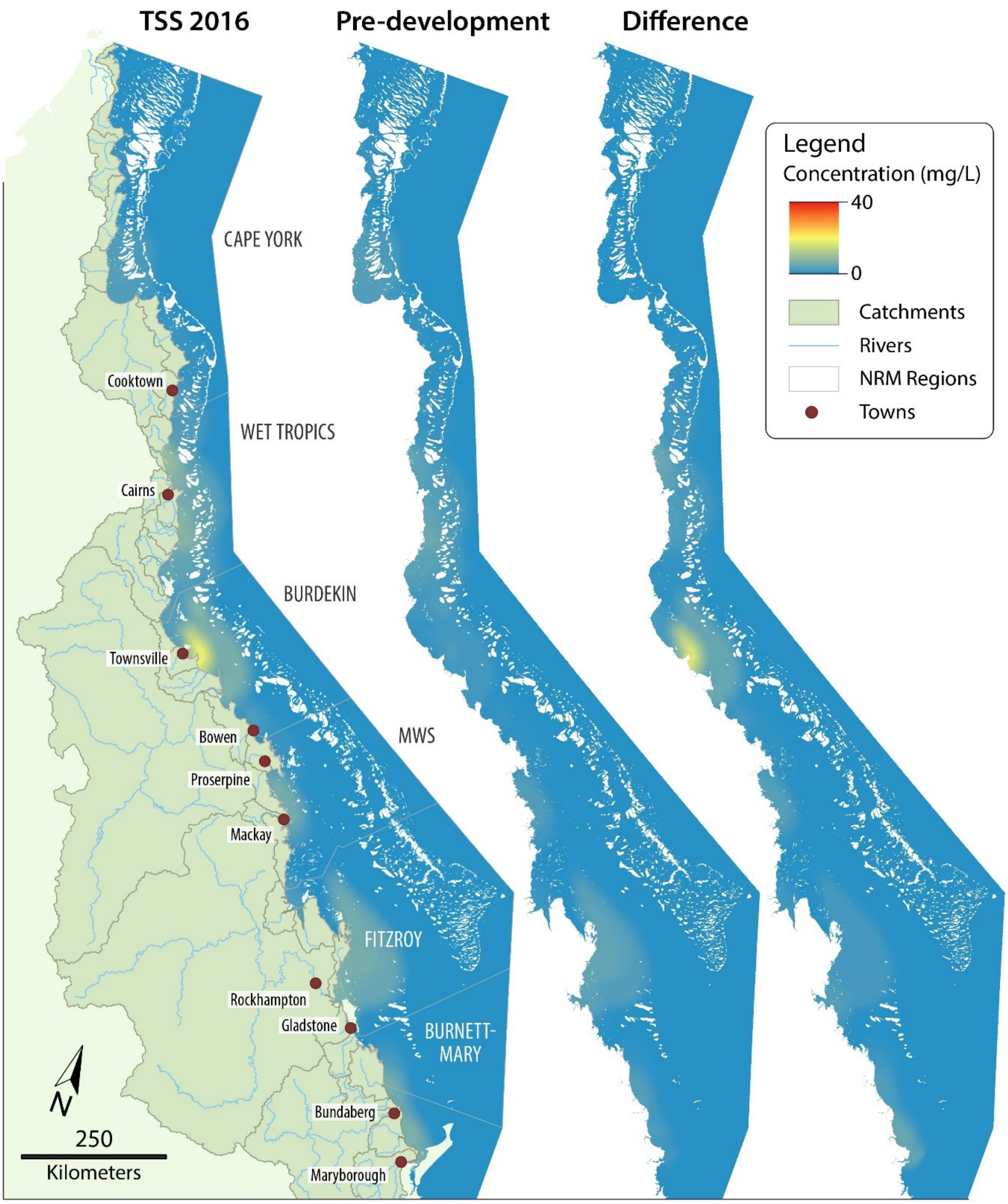

Figure 3-16: TSS (mg/L) in the GBR lagoon, modelled for the (left panel) 2016 water year (1 October to 30 September), (centre panel) pre-development loads and (right panel) the difference between TSS concentration with pre-development end of catchment TSS load estimates and the 2016 estimates.

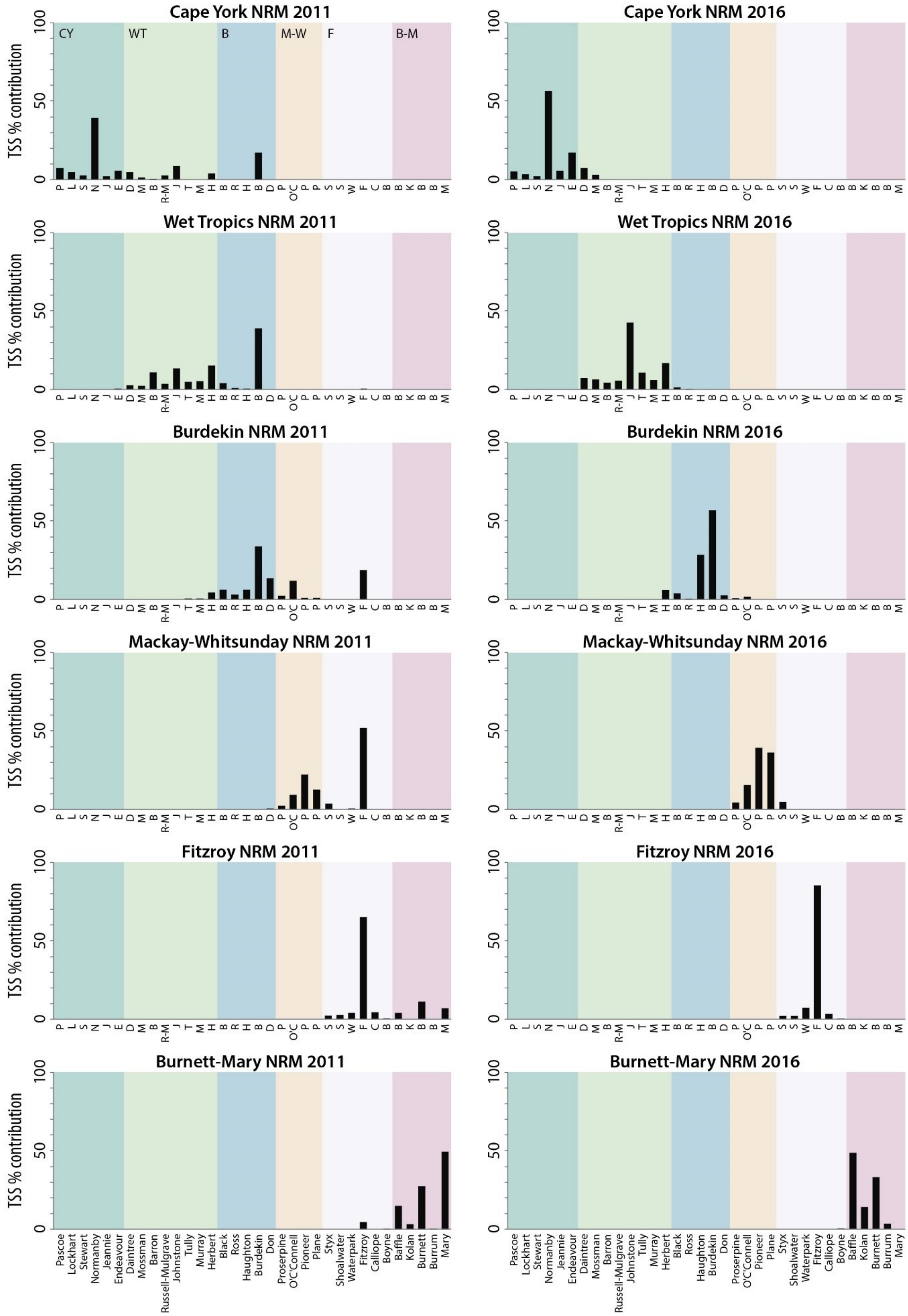

Figure 3-17: River contributions (x-axis) to the TSS mass in the six NRM regions. Shading groups rivers in the same NRM region: Cape York – dark green, Wet Tropics – light green, Burdekin – blue, Mackay Whitsunday – orange, Fitzroy – pink, Burnett Mary - red. The left panels show data for the 2010–11 water year (1 October to 30 September) and right panels for the 2015–16 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 region, 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.
- Zones of influence for major rivers.
- 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 3 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 Summary statistics for each direct water sampling variable from each monitoring location, June 2015 to June 2016.
- Table E-3 Annual summaries of direct water sampling data, August 2005 to June 2016.
- Table E-4 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 8 stations.
- Table E-5 to E-8 Summary of water quality data (collected as part of the JCU wet season sampling) across the wet season colour classes and water types for GBR wide results and each focus area.
- Table E-9 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 3.4.3. In the other regions, the loading contributions for DIN and TSS are considered in the pressures section.

3.4.1 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., 2013b). 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). 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. Under the revised MMP water quality sampling design implemented in 2015 the Snapper Island site was discontinued and this sub-region therefore now contains the six open water sites of the 'Cairns long-term water quality transect', which are sampled three times a year.

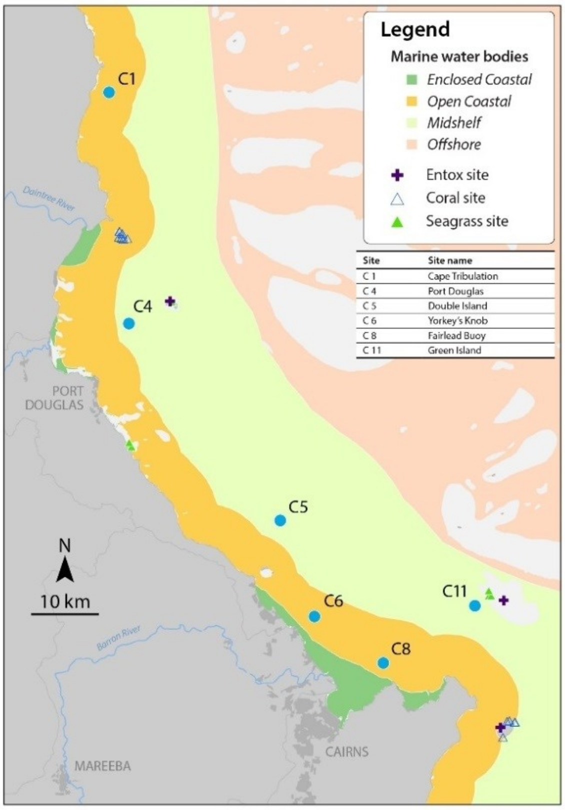

Figure 3-18: MMP water quality sampling sites in the Barron Daintree sub-region shown with water body boundaries.

Over the period 2006 to 2016, annual discharge for both the Daintree and Barron Rivers has been at, 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 3-19, 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 3-19, Table A2-1). The total discharge in the 2015–16 water year was below the long-term median discharge with only three very small flow events occurring in that year.

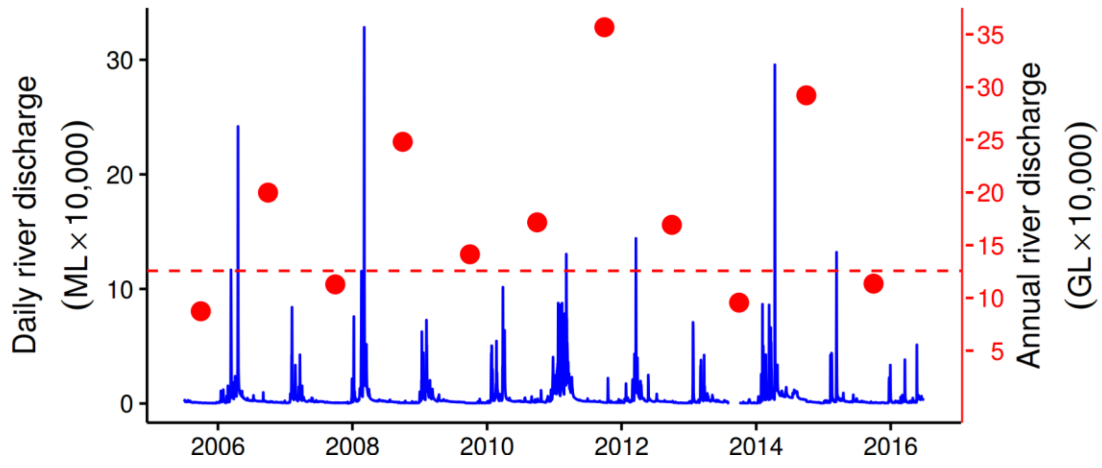

Figure 3-19: Combined discharge for the Barron (Myola gauge) and Daintree (Bairds gauge) Rivers. Daily (blue) and water year (October to September, red symbols) discharge volumes shown. Red dashed line represents long-term median of the combined annual discharge. Please note as this is the combined discharge, high flows in one river will not necessarily be visible in the graph.

The estimated area of influence for the Barron River is shown in Figure 3-20, supporting the conclusions above regarding a minimal freshwater discharge in 2015–16.

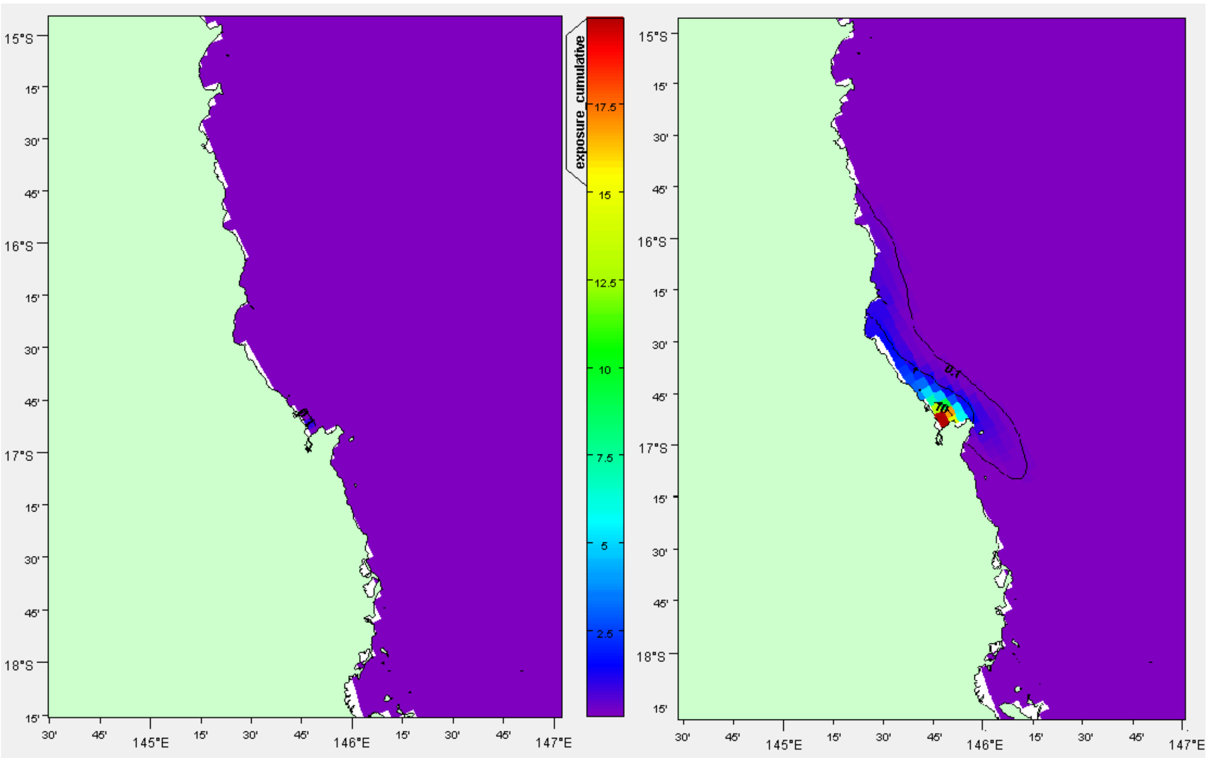

Figure 3-20: Cumulative exposure index for the Barron River in 2015–16 (left). Results for 2010–11 (right) are shown for context. The colour bar indicates the calculated cumulative exposure (concentration × days) above 1% of the incoming concentration. The colour bar is capped at 20 Conc.Days. Contours show 0.1, 1.0 and 10.0 Conc.Days exposure levels.

The combined discharge and loads calculated for the 2015–16 water year from the Barron, Daintree and Mossman Basins were among the lowest over the past 10 years (Figure 3-21). The past two water years (2014–15 and 2015–16) had very similar discharge and TSS, DIN and PN loads. Over the 10 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).

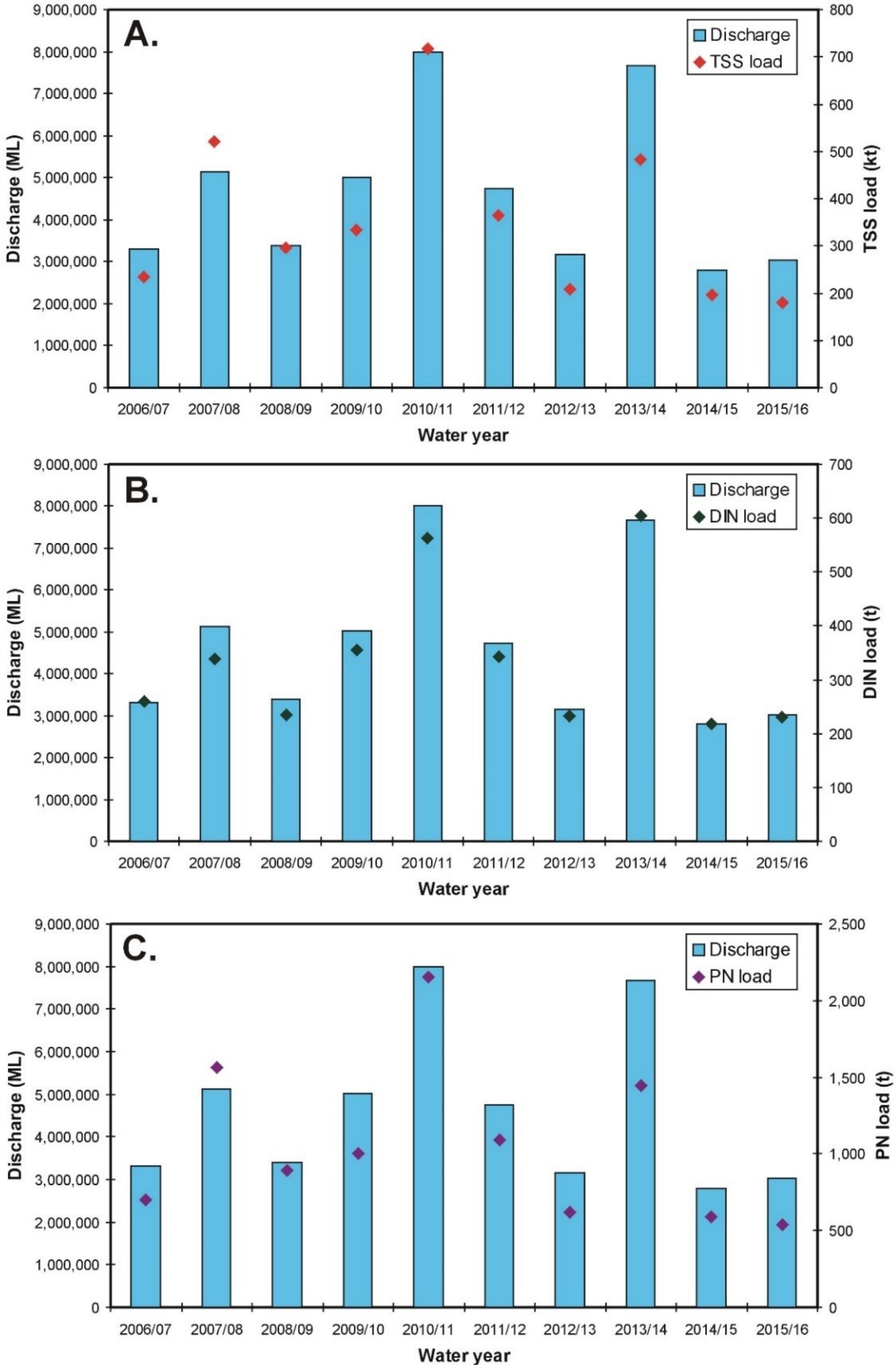

Figure 3-21. (A) Discharge and TSS, (B) DIN and (C) PN loads for the Barron, Daintree and Mossman Basins from 2006–07 to 2015–16. The loads reported here are a combination of 'best estimates' for each basin based on 'up-scaled discharge data from gauging stations, monitoring data (Barron River), the DIN model developed in Lewis et al. (2014) and annual mean concentrations and discharge from monitoring data or Source Catchments modelling data.

Ambient water quality

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. The data collected at this site in previous years are still included for consistency in the long-term analysis. In the present sampling design there are no longer any Chl-a and turbidity sensors operated in this sub-region.

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 by both AIMS and JCU and apply wet/dry guidelines, a separate score was calculated and shown as a single point in Figure 3-22a. Both of these index scores showed that the Water Quality Index in this sub-region remained ‘good’ (Figure 3-22).

Concentrations of Chl-a, phosphate (PO_4), TSS, PN and PP showed minor fluctuations over the monitoring period with no clear trend (Figure 3-22:b, c, 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 decline since the beginning of the monitoring program, reaching a new minimum in 2016; however, levels throughout the monitoring period have been non-compliant with the guideline (Figure 3-22f).

The concentration of dissolved oxidised nitrogen (NO_x) increased slightly over the course of the monitoring program, approaching the Queensland 80^{th} percentile guideline value, until 2014–15 when concentrations started to decline (Figure 3-22d). The concentrations of particulate organic carbon (POC) were fairly constant over the period, while the concentrations of dissolved organic carbon (DOC) increased until 2012 and then became stable (Figure 3-22j).

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

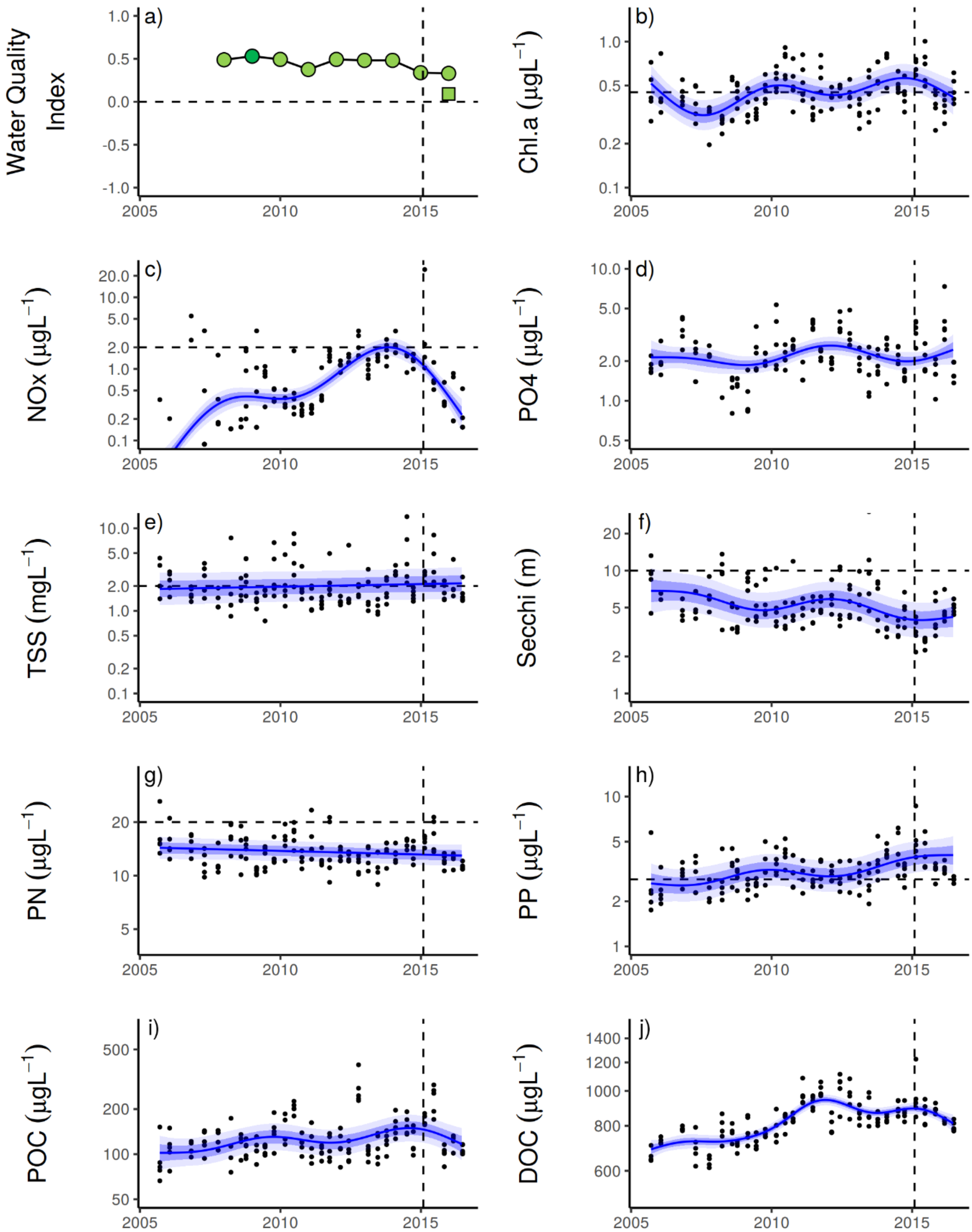

Figure 3-22: Temporal trends in water quality variables for the Barron Daintree sub-region. a) water quality index, b) Chl-a, c) nitrate/nitrite, d) phosphate, e) TSS, f) Secchi depth, g) PN, h) PP, i) POC and j) DOC. Water quality index colour coding: dark green– 'very good'; light green– 'good'; yellow – 'moderate; orange – 'poor'; red – 'very poor'. Note that in 2015–16, a separate score was calculated using the wet/dry guidelines that are shown as a single point in Figure 3-22a. 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 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.

3.4.2 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., 2013b). 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 seven only during major floods (Table 2-1). 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 Enclosed Coastal or Open Coastal water body, and 5stations are located in the midshelf water body (Figure 3-23).

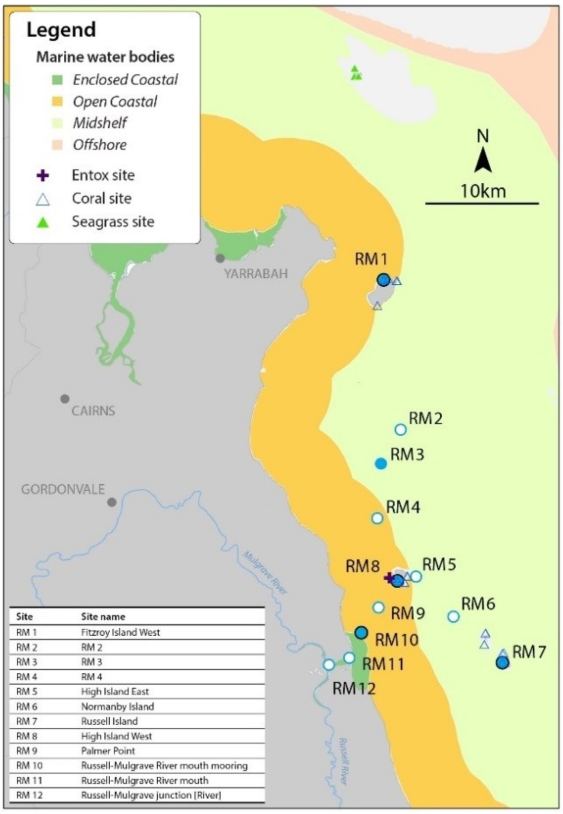

Figure 3-23: MMP sampling sites in the Russell-Mulgrave focus area, shown with the water body boundaries.

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 seen after the passing of tropical cyclones Larry in 2006, Tasha in late 2010 and Yasi in 2011 (Figure 3-24, Table A2-1). Discharge volumes in the 2015 and 2016 water years were below the long-term median (Table A2-1).

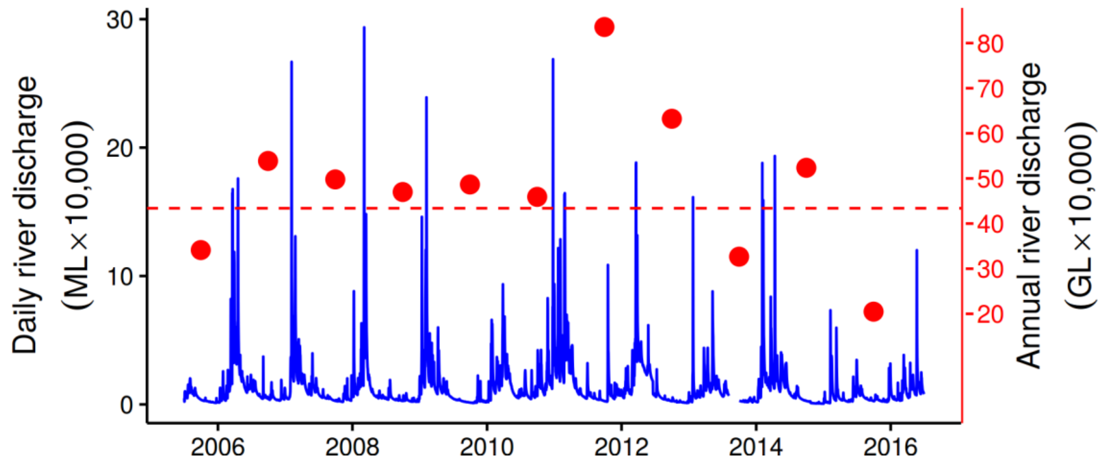

Figure 3-24: Combined discharge for the North and South Johnstone (Tung Oil and Central Mill gauges, respectively), Russell (Bucklands gauge) and Mulgrave (Peat's Bridge) Rivers. Daily (blue) and water year (October to September, red symbols) discharge is shown. Red dashed line represents the long-term 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 is shown in Figure 3-24, showing a much more constrained area of influence in 2015–16 compared to the large events of 2010–11.

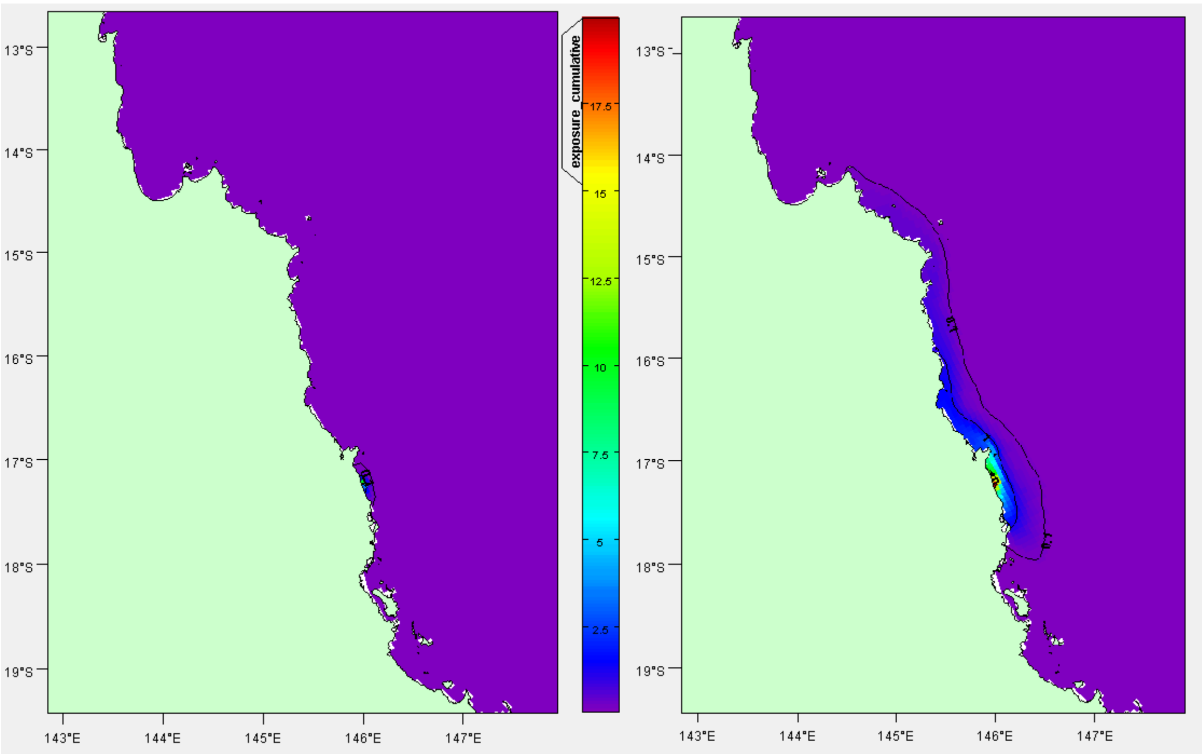

Figure 3-25: Cumulative exposure index for the Russell-Mulgrave River in 2015–16 (left). Results for 2010–11 (right) are shown for context. The colour bar indicates the calculated cumulative exposure (concentration × days) above 1% of the incoming concentration. The colour bar is capped at 20 Conc.Days. Contours show 0.1, 1.0 and 10.0 Conc. Days exposure levels.

The combined discharge and loads calculated for the 2015–16 water year from the Russell, Mulgrave and Johnstone Basins were amongst the lowest over the past 10 years with only the previous 2014–15 year having lower consistent loads in this period (Figure 3-26). The past 2 water years (2014–15 and 2015–16) had very similar discharge and TSS, DIN and PN loads. Over the 10 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 1,400 t (2014–15) 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.

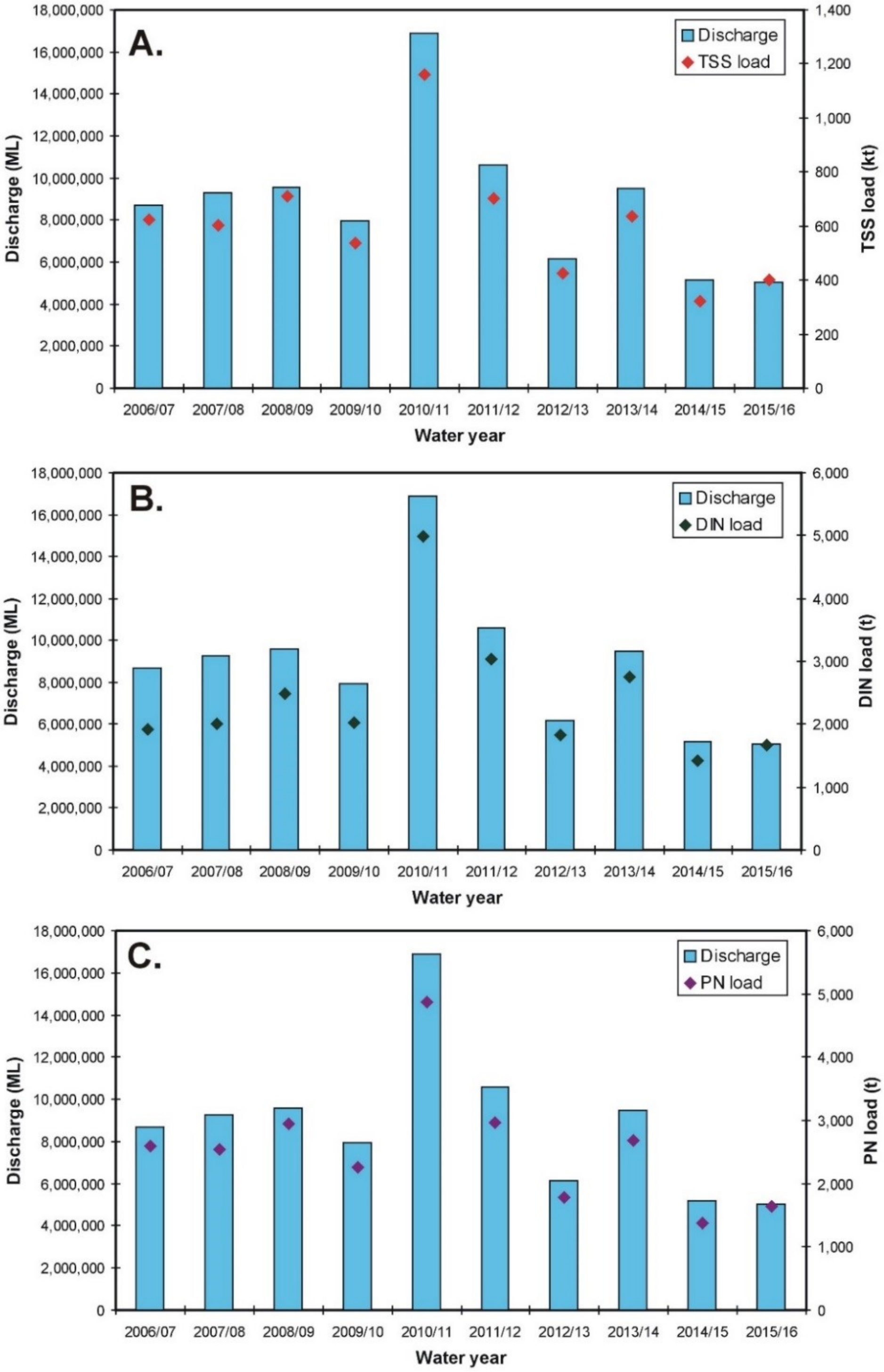

Figure 3-26: (A) Discharge and TSS, (B) DIN and (C) PN loads for the Russell, Mulgrave and Johnstone Basins from 2006–07 to 2015–16. The loads reported here are a combination of 'best estimates' for each basin based on 'up-scaled discharge data from gauging stations, monitoring data (Johnstone River), the DIN model developed in Lewis et al. (2014) and annual mean concentrations and discharge from monitoring data or Source Catchments modelling data.

Ambient water quality

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. Some of these sites are placed further inshore and they are therefore more likely to be affected by Primary and Secondary water types in the wet season which may influence the results.

This year, the Water Quality Index was calculated in two different ways. Firstly, for continuity of the long-term trend an index score was calculated using the same approach (including 3 sites) as in previous years (See Appendix D-6 for details). Secondly, to include data collected by both AIMS and JCU and apply wet/dry guidelines a separate score was calculated as a single point in Figure 3-27a. Both index scores showed that the Water Quality Index in this sub-region remained 'good', although the long-term trend has shown a slight decline since 2009 (Figure 3-27). The overall predicted trend lines for Chl-a, phosphate (PO_4), turbidity, TSS, Secchi depth and PP showed only minor changes since the beginning of the monitoring program Figure 3-27b, d, e, f, g, i). For PN, increasing concentrations were found approaching the guideline values in 2016 (Figure 3-27h). Instrumental Chl-a and turbidity records showed slightly more pronounced fluctuations than the manual sampling data (Figure 3-27b, e). For all variables, except PN, where guidelines are available, concentrations were mostly fluctuating around the annual guideline values over the entire sampling period (Figure 3-27b, e).

The concentrations of dissolved oxidised nitrogen (NO_x) increased slightly over the monitoring period fluctuating around the Queensland guideline since 2008 (Figure 3-27c). Phosphate (PO_4) concentrations have remained fairly constant over the monitoring period (Figure 3-27d).

The concentrations of particulate organic carbon (POC) have increased since 2012–13, while the dissolved organic carbon (DOC) concentrations showed a continued increase over the whole monitoring period (Figure 3-27j).

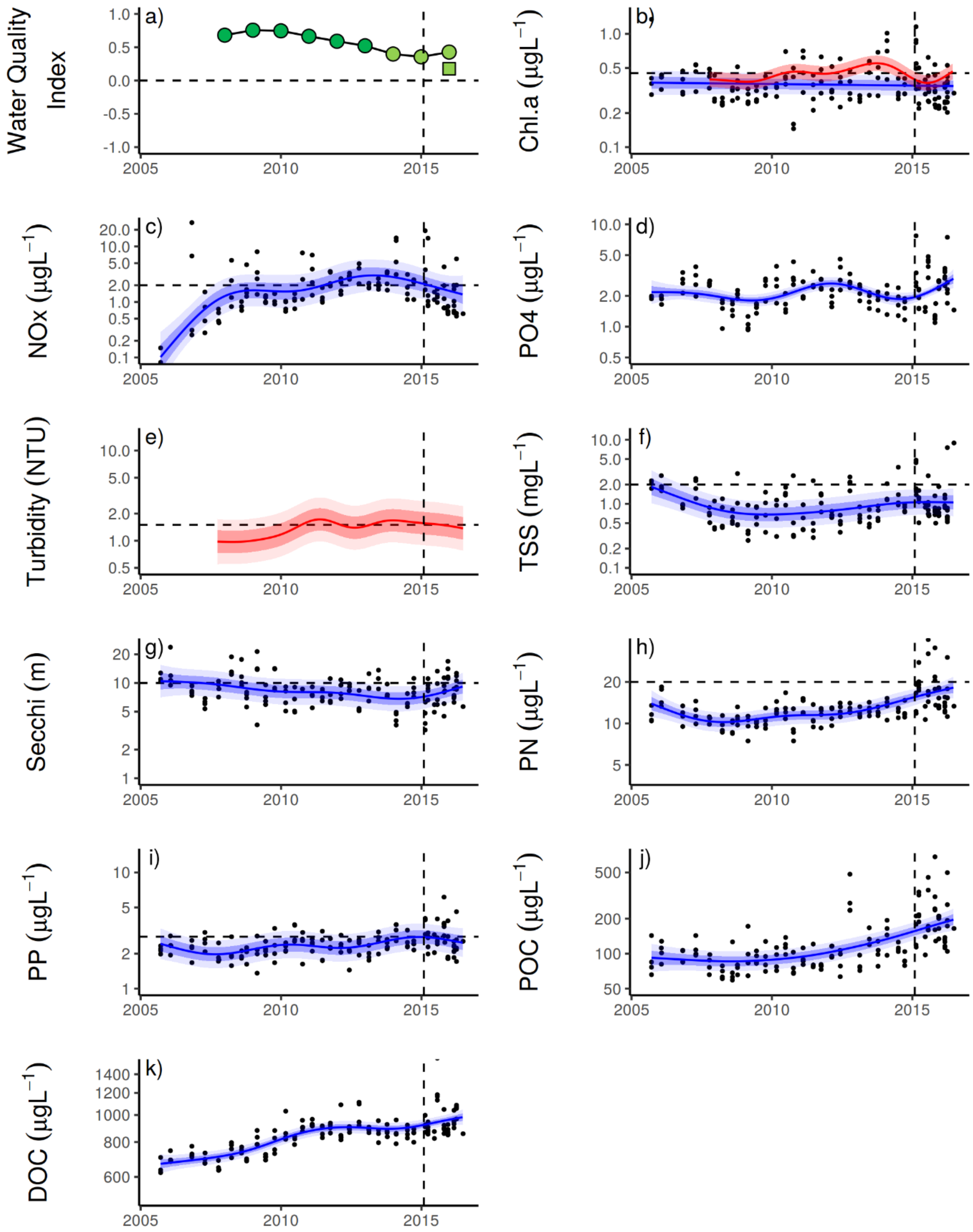

Figure 3-27: Temporal trends in water quality for the Russell-Mulgrave sub-region. a) water quality index, b) Chl-a , c) nitrate/nitrite, d) phosphate, e) turbidity, f) TSS, g) Secchi depth, h) PN, i) PP, j) POC and k) DOC. Water quality index colour coding: dark green – 'very good'; light green – 'good'; yellow – 'moderate; orange – 'poor'; red – 'very poor. Note that in 2015–16 a separate score for the data collected by both AIMS and JCU and are shown as a single point in Figure 3-27a. 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 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.

3.4.3 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., 2013b). 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 also 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 season and five 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 3-28).

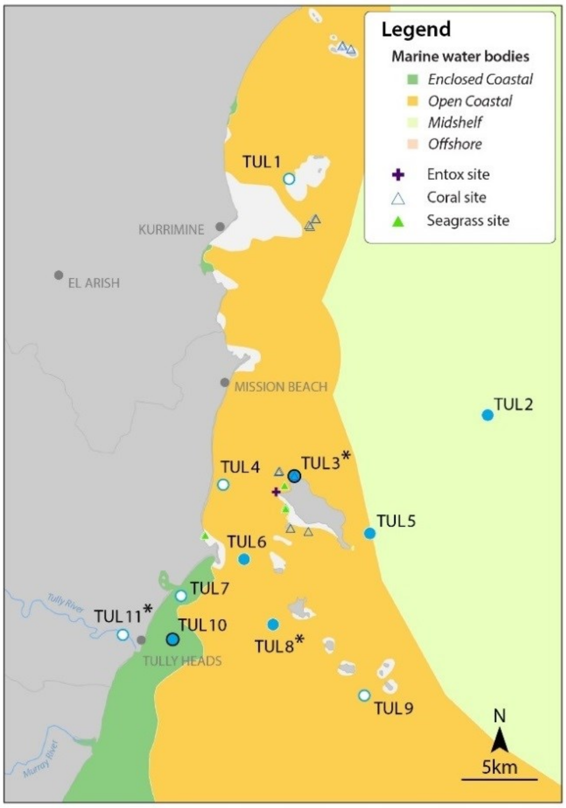

Figure 3-28: MMP sampling sites in the Tully focus area, shown with the water body boundaries.

Over the period 2006 to 2016, annual discharge for both the Tully and Herbert Rivers (Figure 3-29) has been at, or slightly above, median levels 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). Much lower discharge was recorded in 2015–16 with the peak daily flow also well below that experience in the previous wet seasons (Figure 3-29).

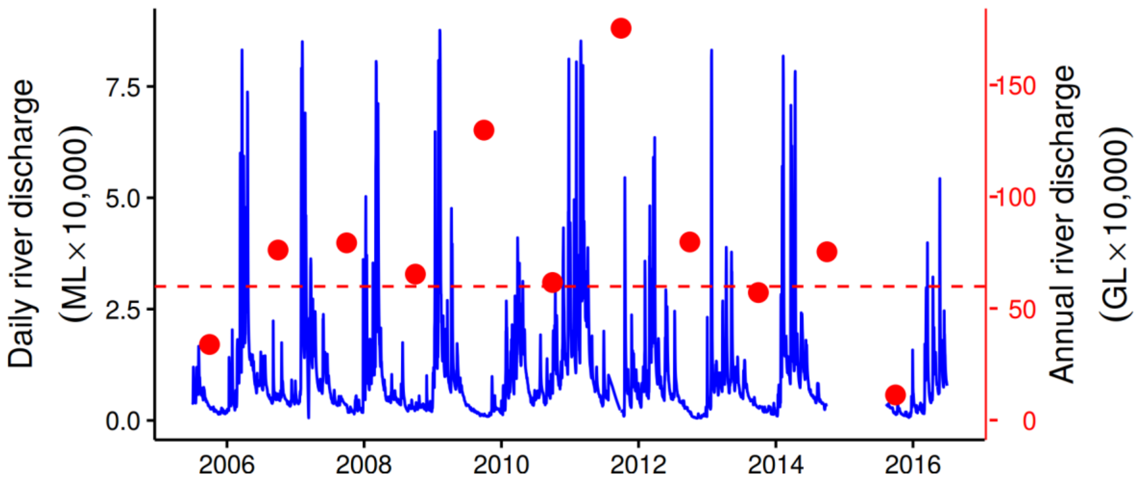

Figure 3-29: Combined discharge for Tully (Euramo gauge) and Herbert (Ingham gauge) Rivers. Daily (blue) and water year (October to September, red) discharge is shown. Red dashed line represents the long-term median of the combined annual discharge. Please note as this is the combined discharge, high 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 3-30, showing a much more constrained area of influence in 2015–16 compared to the large events of 2010–11.

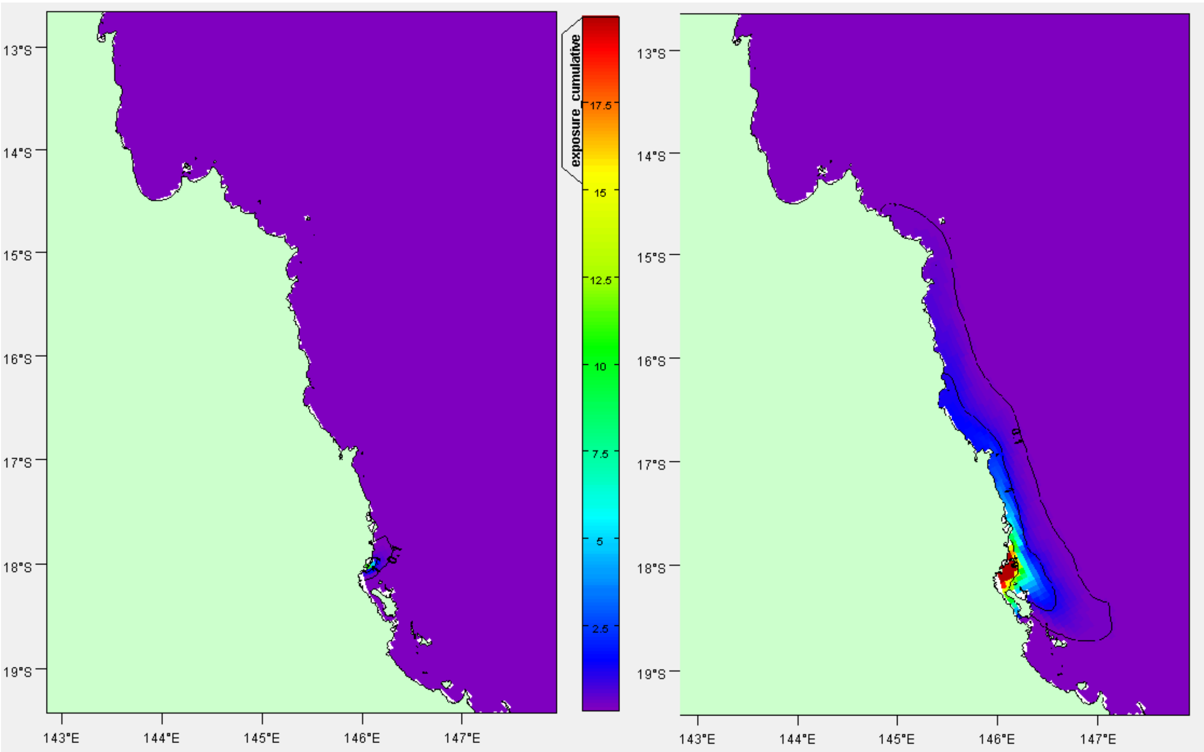

Figure 3-30: Cumulative exposure index for the Tully River in 2015–16 (left). Results for 2010–11 (right) are shown for context. The colour bar indicates the calculated cumulative exposure (concentration x days) above 1% of the incoming concentration. The colour bar is capped at 20 Conc.Days. Contours show 0.1, 1.0 and 10.0 Conc.Days exposure levels.

The combined discharge and loads calculated for the 2015–16 water year from the Tully, Murray and Herbert Basins were amongst the lowest over the past 10-years with only the previous 2014–15 year having lower discharge and loads in this period (Figure 3-31). Over the 10 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.

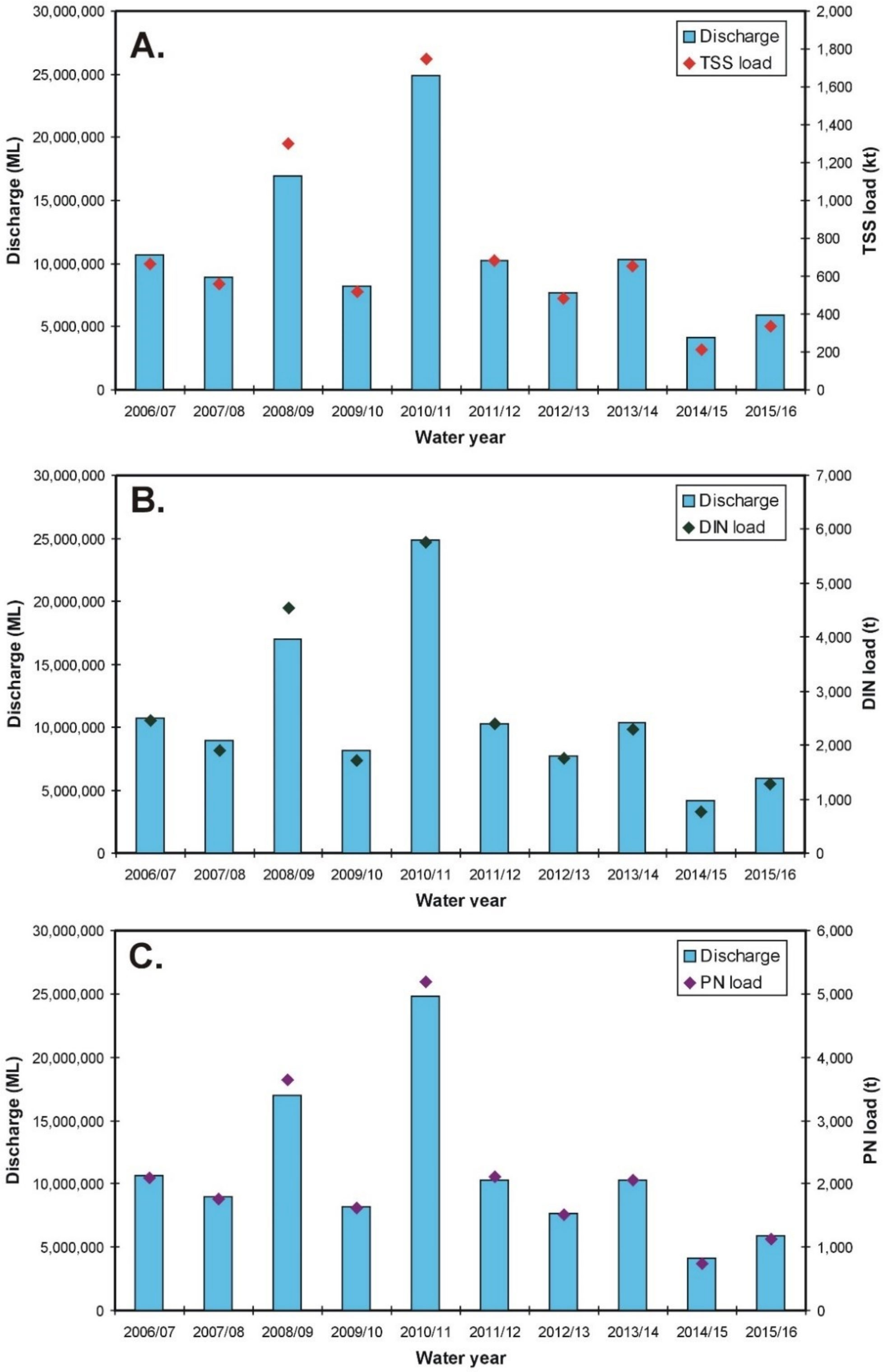

Figure 3-31: (A) Discharge and TSS, (B) DIN and (C) PN loads for the Tully, Murray and Herbert Basins from 2006–07 to 2015–16. The loads reported here are a combination of 'best estimates' for each basin based on 'up-scaled discharge data from gauging stations, monitoring data (Tully and Herbert Rivers), the DIN model developed in Lewis et al. (2014) and annual mean concentrations and discharge from monitoring data or Source Catchments modelling data.

Ambient water quality

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.

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 3-32:a).

Trend lines in concentrations of Chl-a, PN and PP showed only minor changes over the whole monitoring period (Figure 3-32:b, f, h). Since the beginning of the monitoring program the Chl-a trend-line has exceeded or been near the guideline value, but reached levels below guidelines this monitoring year (2015–16) (Figure 3-32:b). The PN and PP trend lines generally fluctuated around the water quality guidelines during the whole monitoring period (Figure 3-32:h, j). The instrumental Chl-a records showed more pronounced fluctuations than the manual sampling data (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 3-32:g). The trend lines for TSS were generally above guideline concentrations throughout the program, but decreased below the guideline values in 2015–16 (Figure 3-32:f). Secchi depth remained relatively stable with a long-term average of about 5m, which is non-compliant with the guideline (Figure 3-32:e).

The concentrations of dissolved oxidised nitrogen (NO_x) showed a slight increase at the beginning of the monitoring program with levels exceeding the Queensland guideline from 2011 to 2014 (Figure 3-32:c). Phosphate (PO_4) concentrations remained relatively constant over the monitoring period (Figure 3-32:d).

The concentrations of particulate organic carbon (POC) have increased since 2012–13, while the dissolved organic carbon (DOC) concentrations showed a continued increase over the whole monitoring period (Figure 3-32:j).

To test if our data is similar with results obtained from the eReefs model we compared both the salinity values from our moorings (Dunk Island and Tully River mouth mooring) and water quality samples collected throughout the region (Appendix E, Figure E3 and E4). For the salinity and Chl-a there is a fair agreement between them, while for TSS, Secchi depth and NOx the comparability of the trends are less evident with the model derived data showing a much larger variability than the field data (Appendix E, Figure E3 and E4).

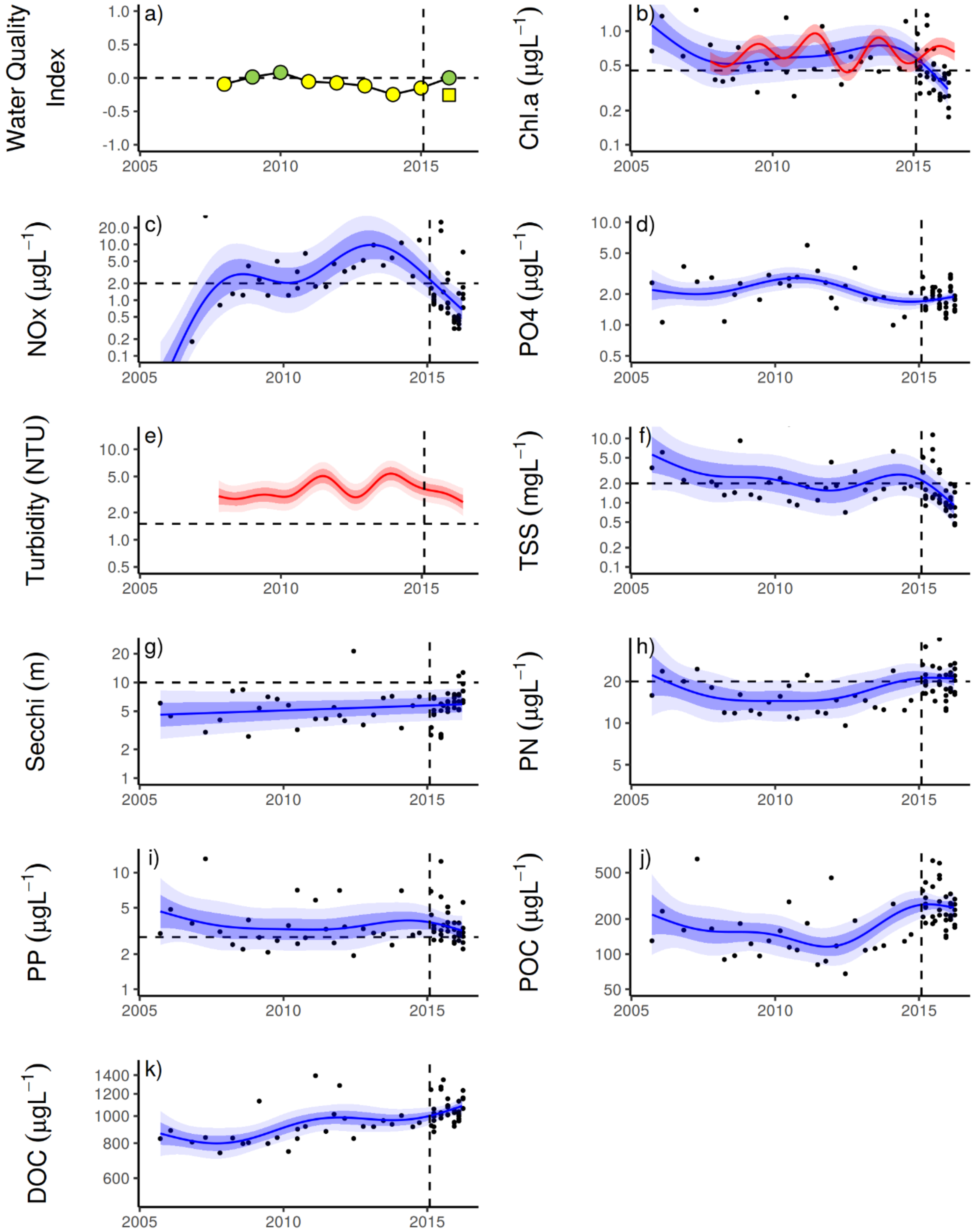

Figure 3-32: Temporal trends in water quality for the Tully sub-region. a) water quality index, b) Chl-a, c) nitrate/nitrite, d) phosphate, e) turbidity, f) TSS, g) Secchi depth, h) PN, i) PP, j) POC and k) DOC. Water quality index colour coding: dark green –'very good'; light green – 'good'; yellow – 'moderate; orange – 'poor'; red – 'very poor'. Note that in 2015–16 a separate score for the data collected by both AIMS and JCU are shown as a single point in Figure 3-32a. 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 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.

Wet Tropics Region: Mapping wet season conditions and flood events

As described in Section 2.6, mapping products are generated to represent wet season water quality conditions in the Wet Tropics region. The in-situ data collected by JCU during the wet season, including high flow periods, is used to characterise and validate these products. This data is presented in Figure 3-33 and in a panel of weekly characteristics throughout the 22 week wet season period (Figure 3-34 and Figure 3-35). Details included in the panels includes: 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 colour wet season classes.

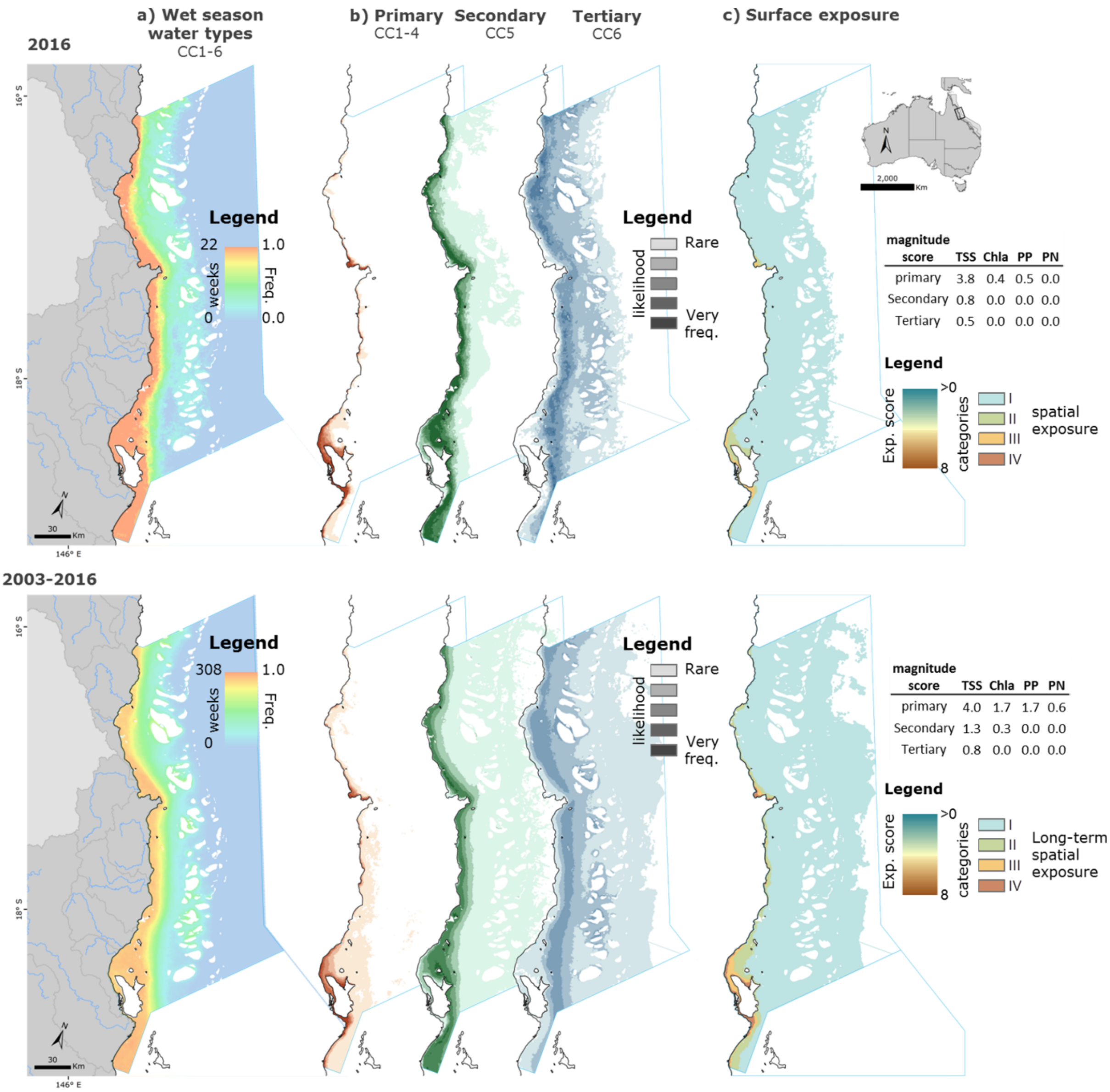

Figure 3-33: Maps showing the a) frequency of wet season water types (turbid waters: combined Primary, Secondary and Tertiary water types), b) the frequency of Primary, Secondary and Tertiary wet season water types, respectively and c) the exposure maps for the Wet Tropics region in the long-term (bottom) and 2015–16 wet season (top).

Figure 3-33 (Top) presents the frequency of turbid waters (combined Primary, Secondary and Tertiary water types), the frequency of Primary, Secondary and Tertiary water types and the exposure map in the 2015–16 wet season. Table 3-3 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 3-33 (Bottom) and Table 3-3 (numbers in brackets).

In 2015–16, the Wet Tropics region was most affected by the lowest exposure categories (categories I and II), in agreement to the long-term trends. Approximately 56% of the total area of the Wet Tropics Region was exposed to turbid waters (combined Primary, Secondary and Tertiary water types), at least during one week of the wet season. However, only 0.5% of the Wet Tropic region was exposed to the higher potential risk categories (categories III, the Wet Tropics region was not exposed to category IV in 2015–16). These areas were smaller than the long-term areas (Table 3-3: 83% exposed to turbid waters, 1% to categories I, and 1% to category II). In 2015–16, it was estimated that:

- A total of 95% of the Wet Tropics coral reefs were exposed to turbid waters (Primary, Secondary and Tertiary waters combined), at least during one week of wet season. However, no corals were in the highest potential risk category (IV) from exposure and very few (0.03%) were in the exposure categories III.
- A total of 88% of the Wet Tropics seagrasses were exposed to turbid waters, at least during one week of wet season. However, no seagrasses were in the highest potential risk category (IV) from exposure, and only 21% were in exposure category III.
- These exposures indicate potential' risk as exposure maps have not been yet validated against ecological health data to confirm the ecological consequences of the risk
- In 2015–16, the coral and seagrass areas in categories III of potential risk were smaller than the long-term areas (0.6% of reefs and 49% of seagrasses exposed to category III). These characteristics were logical with the characteristic of a relatively dry wet season.

Table 3-3: Areas (km^2) and percentages (%) of the Wet Tropics Region affected by different categories of exposure during the 2015–16 wet season and comparison with long-term values (in brackets).

NRM		Total	Potential Risk category Lowest ----------------------- highest				Total exposed	Total non-exposed
Surface area	area	31,948	17,359 *(25,115)*	362 *(940)*	156 *(324)*	- *(169)*	17,877 *(26,548)*	14,072 *(5,400)*
	%	*100*	54 *(79)*	1 *(3)*	0.5 *(1)*	- *(1)*	56 *(83)*	44 *(17)*
Coral reefs	area	2,431	2,305 *(2,387)*	1 *(20)*	0.7 *(1)*	- -	2,307 *(2,408)*	124 *(23)*
	%	*100*	95 *(98)*	0.1 *(0.8)*	0.03 *(0.06)*	- -	95 *(99)*	5 *(1)*
Surveyed seagrass	area	210	74 *(17)*	66 *(66)*	44 *(49)*	- *(54)*	184 *(185)*	26 *(25)*
	%	*100*	35 *(8)*	32 *(31)*	21 *(23)*	- *(26)*	88 *(88)*	12 *(12)*

Figure 3-34 and Figure 3-35 illustrate the changes in water quality and environmental conditions in the Wet Tropics region and focus on data collected by JCU. The 2015–16 wet season was characterised by low rainfall and consequent river discharge, resulting in river plumes that were not well developed and therefore the sampling sites did not receive a high riverine influence. Weekly river discharges in the 2015–16 sampling period were below the long-term mean weekly discharge value, except for weeks 15 and 16. An increase in water quality concentrations was observed following these 2 weeks, with TSS concentrations reaching 43 mg L^{-1} in the colour class 3. This is 18 times the wet season TSS guidelines for the open coastal and midshelf waters. The guideline however, is a seasonal mean and the ecological effect of the acute concentration peak is not known. The mean seasonal TSS concentrations measured across the Primary, Secondary and Tertiary water types were 11.5 mg L^{-1}, 4.2 mg L^{-1} and 2.6 mg. L^{-1}, i.e. approximately 4.8, 1.7 and 1.5 times the wet season TSS guidelines, respectively (Figure 3-9). The Kd(PAR) and DIN values reached 2 m^{-1} and 147 µg L^{-1} in the colour class 3 during week 16.

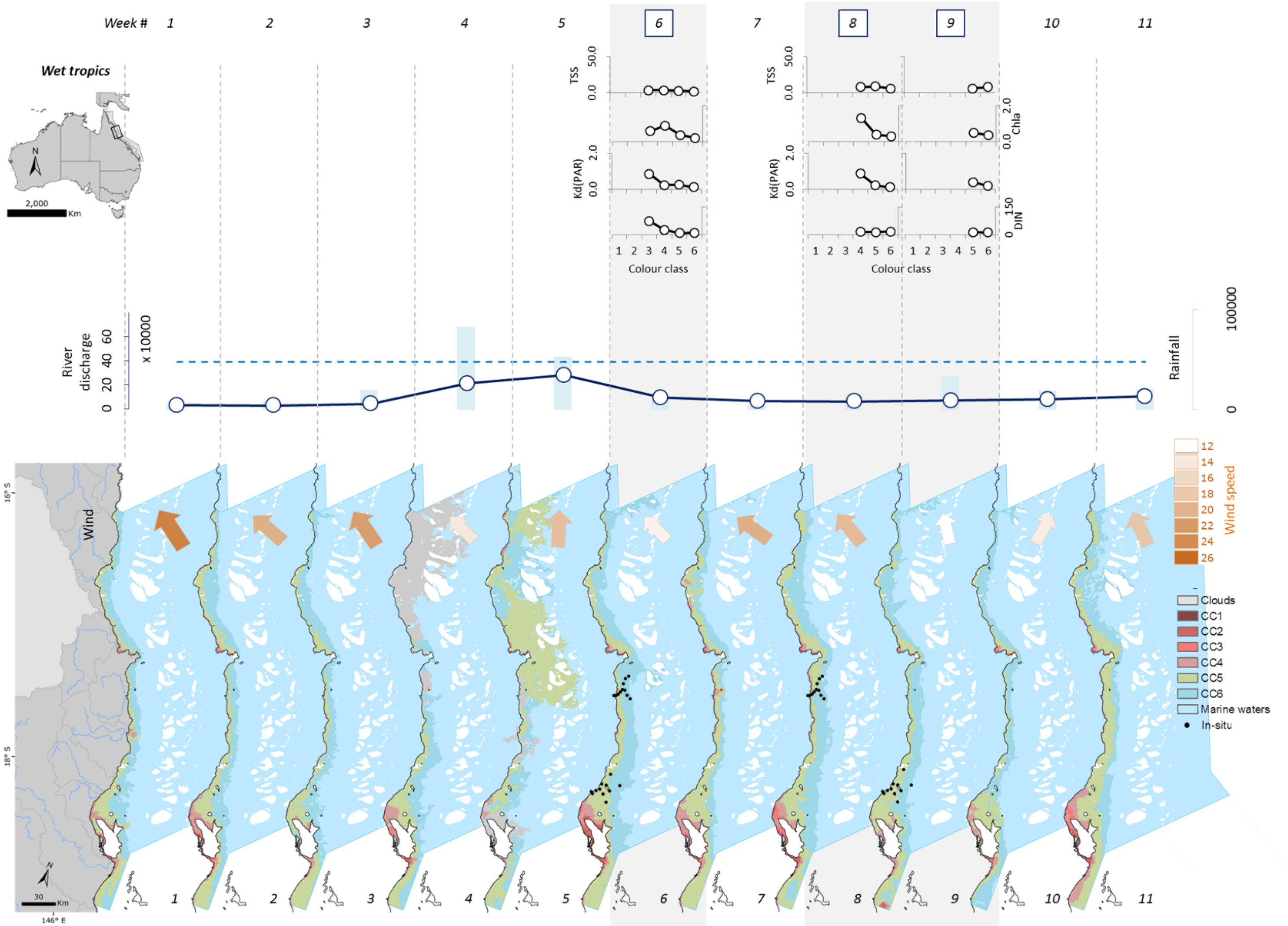

Figure 3-34: Panel of water quality and environmental characteristics in the Wet Tropics region throughout the 2015–16 wet season period: weeks 1 to 11. Details included in the panels: mean TSS (mg L^{-1}), Kd(PAR) (m^{-1}), Chl-a (µg L^{-1}) and DIN (µg L^{-1}) within each colour class; weekly river 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. The long-term mean weekly river discharge is indicated by a dotted blue line.

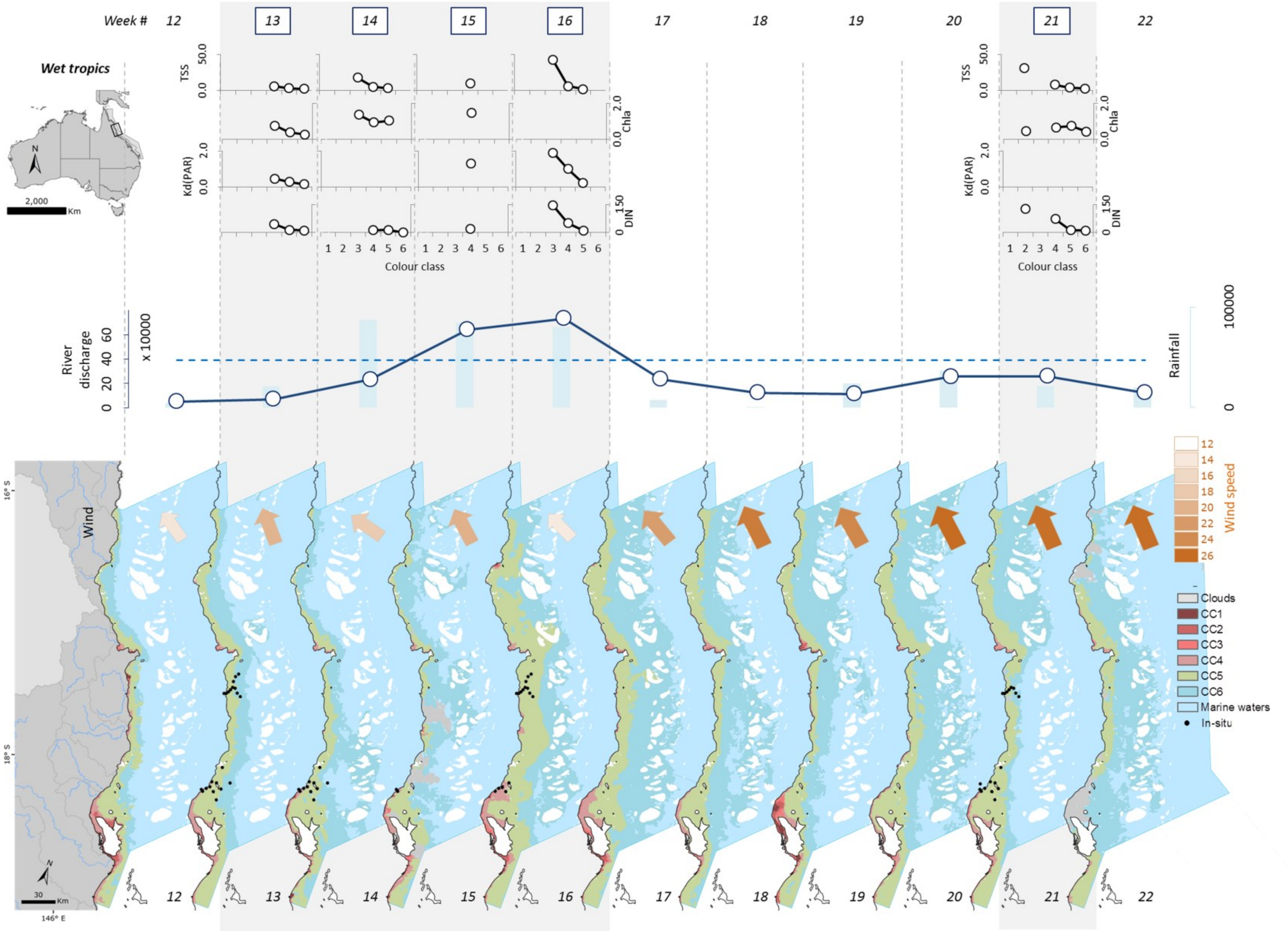

Figure 3-35: Panel of weekly water quality and environmental characteristics in the Wet Tropics region throughout the 2015–16 wet season period: weeks 12 to 22. Details included in the panels: mean TSS (mg L-1), Kd(PAR) (m-1), Chl-a (µg L-1) and DIN (µg L-1) within each colour class; weekly river discharge (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. The long-term mean weekly river discharge is indicated by a dotted blue line.

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 3-36 shows the estimated DIN and TSS contributions for the Wet Tropics region in 2010–11 and 2015–16. 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 3-14 and Figure 3-17 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 2015–16. The Herbert River also influences the Burdekin Region in most of the years modelled.

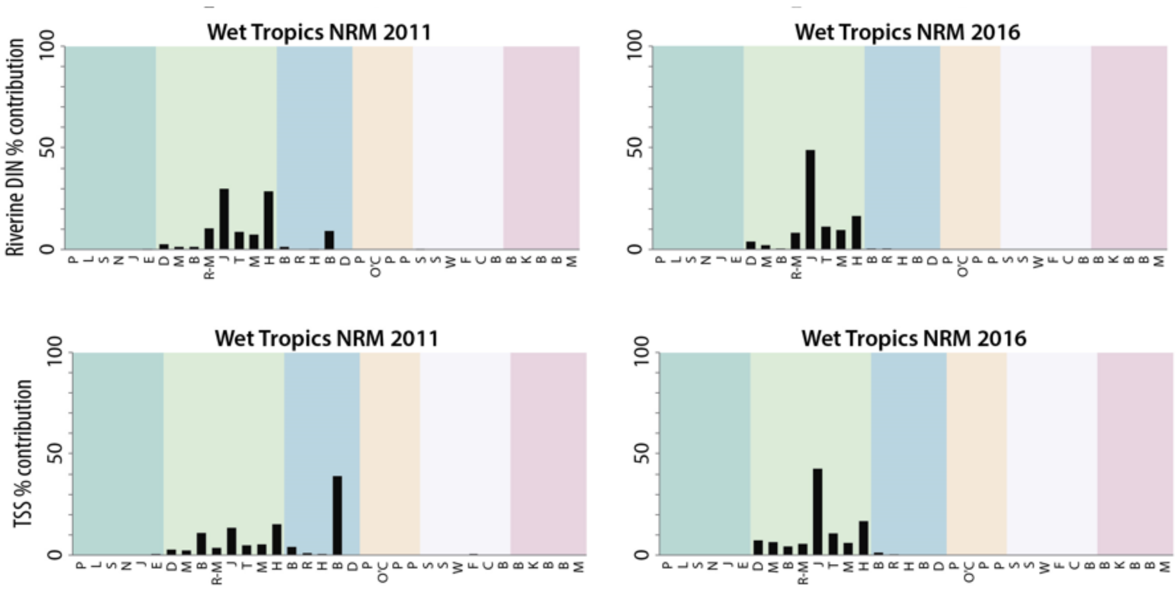

Figure 3-36. River contributions (x-axis, fully labelled in Figure 3-14) to the (top) DIN and (bottom) TSS mass to the Wet Tropics NRM region in 2010–11 (left column) and 2015–16 (right column). Shading groups rivers in the same NRM region: Cape York – dark green, Wet Tropics – light green, Burdekin - blue, Mackay Whitsunday – orange, Fitzroy – pink, Burnett Mary - red. The left panels show data for the 2010–11 water year (c.a. from 1 October to 30 September) and right panels for the 2015–16 water year.

3.4.4 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 nine times per year, with six stations sampled during both the dry and wet season, and nine 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 3-37**Error! Reference source not found.**).

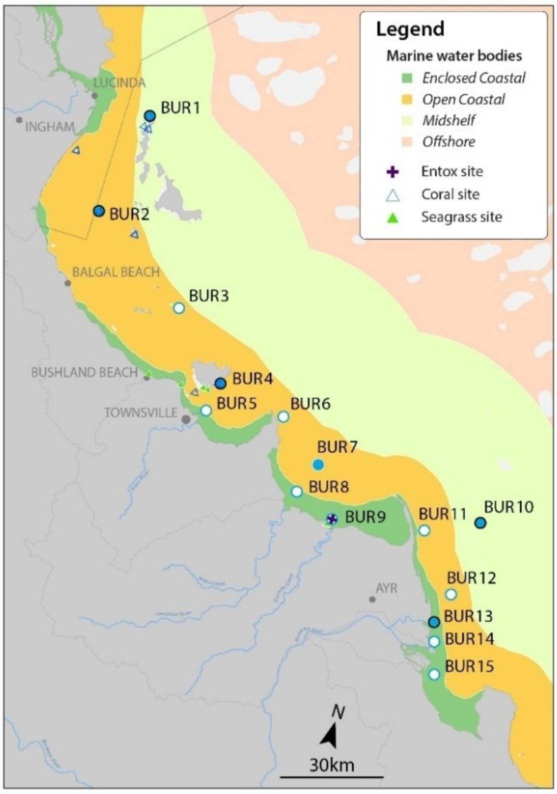

Figure 3-37: MMP sampling sites in the Burdekin focus area, shown with the water body boundaries.

Rainfall for the Burdekin Basin was very low in 2015–16 and below the long-term average in all catchments. This is reflected in the substantively lower flow than the long-term median in the Burdekin River (Figure 3-38) with a total discharge of just under 2,000,000 ML over the wet season. 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 2016) (Figure 3-38). The 2011 flood was the third largest on record, at almost six times the long-term median discharge (Table A2-1). Peak daily flows were also well below that experienced in the 2006–07 to 2011–12 period.

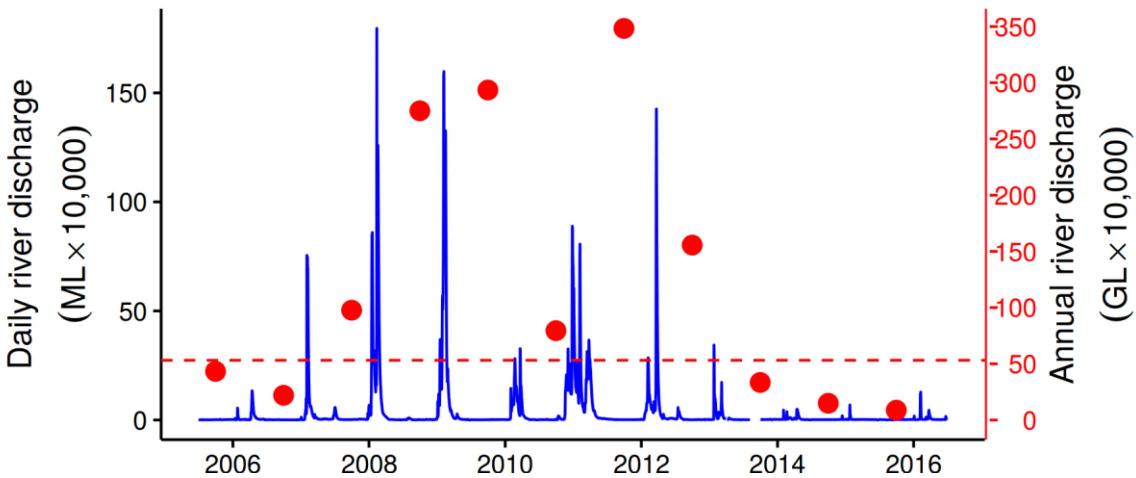

Figure 3-38: Discharge for the Burdekin River (Clare gauge). Daily (blue) and water year (October to September, red) discharge is shown. Red dashed line represents the long-term median annual discharge. Please note as this is the combined discharge, high flows in one river will not necessarily be visible in the graph.

The estimated zone of influence for the Burdekin River is presented in Figure 3-39, showing a substantially constrained zone of influence in 2015–16 compared to the large events of 2010–11, and correlated with below long-term median discharge.

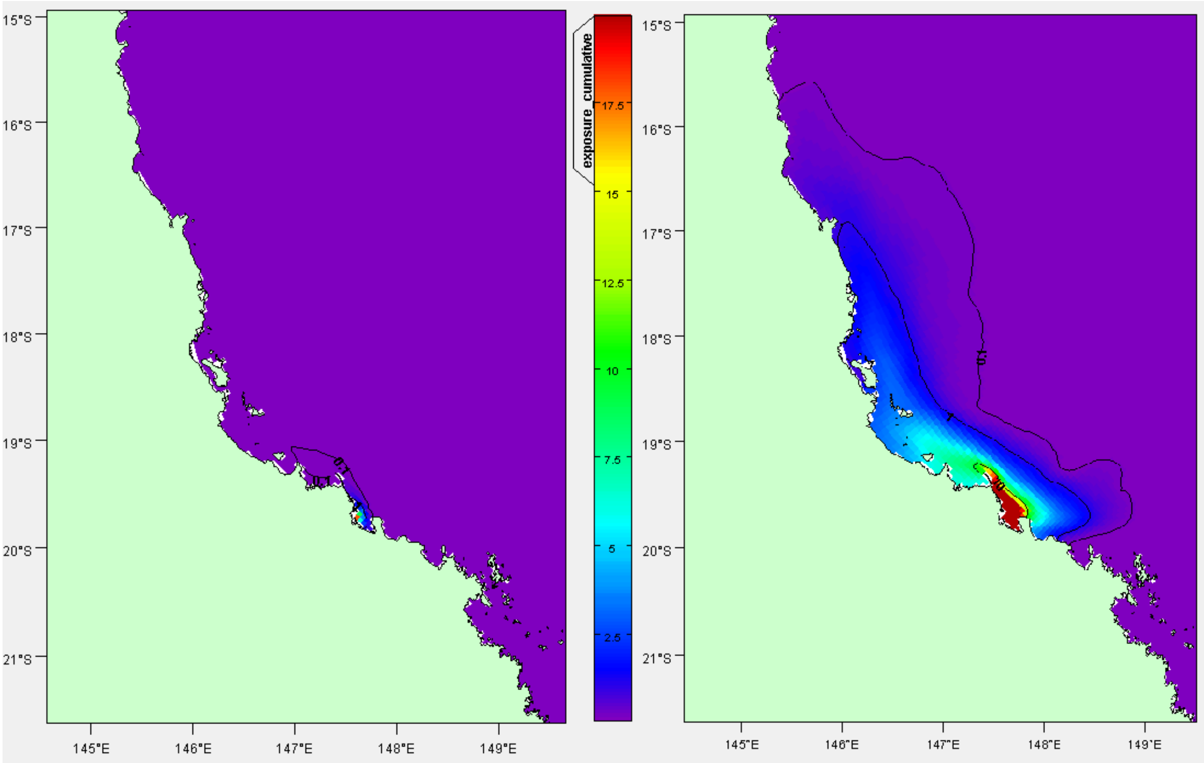

Figure 3-39: Cumulative exposure index for the Burdekin River in 2015–16 (left), results for 2010–11 (right) are shown for context. The colour bar indicates the calculated cumulative exposure (concentration x days) above 1% of the incoming concentration. The colour bar is capped at 20 Conc.Days. Contours show 0.1, 1.0 and 10.0 Conc.Days exposure levels.

The combined discharge and loads calculated for the 2015–16 water year from the Burdekin and Haughton Basins were amongst the lowest over the past 10 years (Figure 3-40). The past 3 water years (2013–14, 2014–15 and 2015–16) have had very low discharge and TSS, DIN and PN loads compared to the previous wetter period. Over the 10 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) produce 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 or lower during the high discharge years and much lower during the lower discharge years.

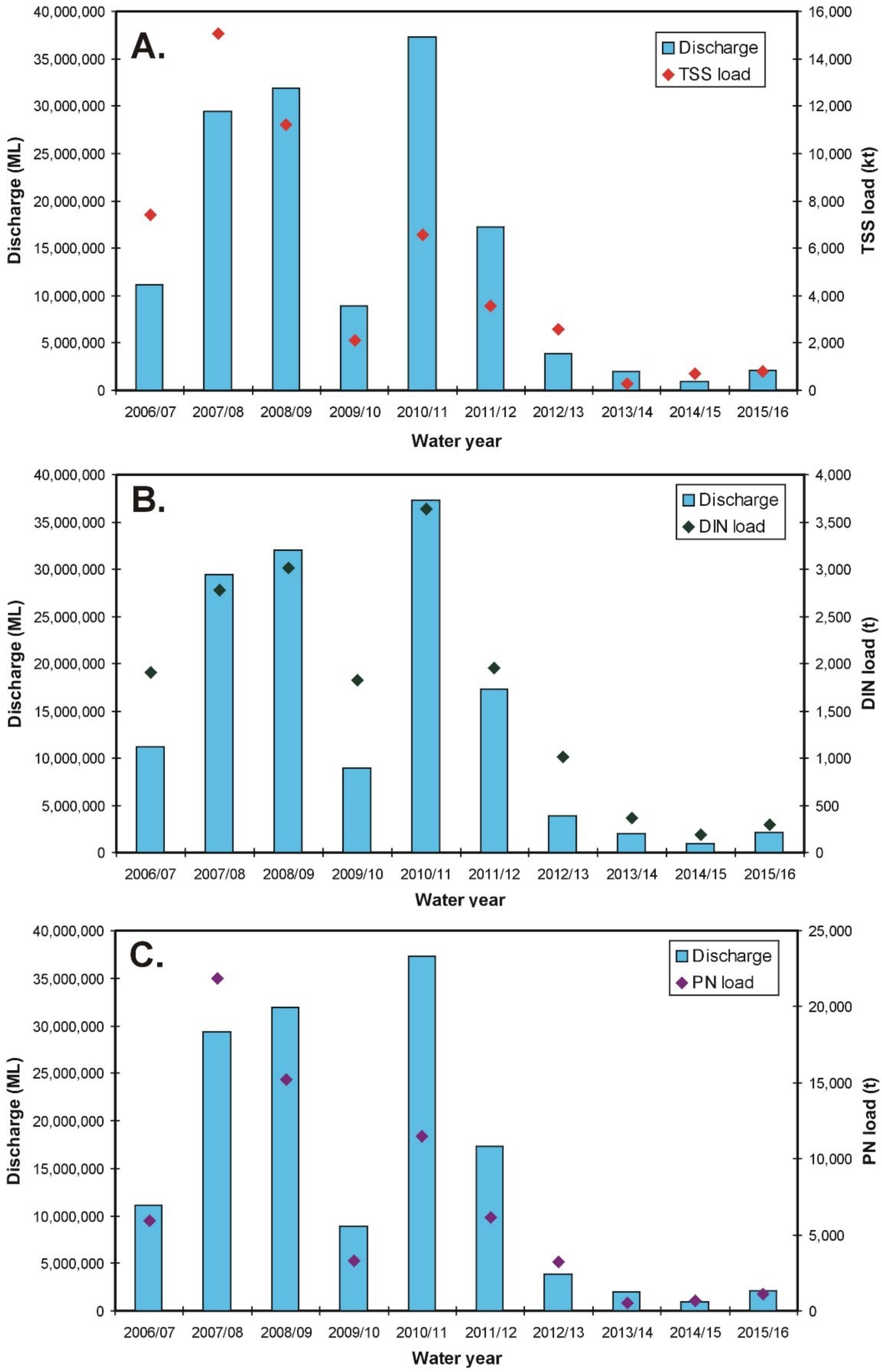

Figure 3-40. (A) Discharge and TSS, (B) DIN and (C) PN loads for the Burdekin and Haughton Basins from 2006–07 to 2015–16. The loads reported here are a combination of 'best estimates' for each basin based on 'up-scaled discharge data from gauging stations, monitoring data (Burdekin River), the DIN model developed in Lewis et al. (2014) and annual mean concentrations and discharge from monitoring data or Source Catchments modelling data.

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 3-41 shows the estimated DIN and TSS contributions for the Burdekin region in 2010–11 and 2015–16. 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 2015–16, but just from the Proserpine and O'Connell Rivers which are closer to the Burdekin NRM boundary. Figure 3-14 also shows that the Burdekin River has an important influence on the Wet Tropics region in large discharge years, especially for TSS (~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 mass). The Burdekin River did not appear to influence any other regions in the low discharge year of 2015–16 (Figure 3-14). The Herbert River also influences the Burdekin Region in most of the years modelled.

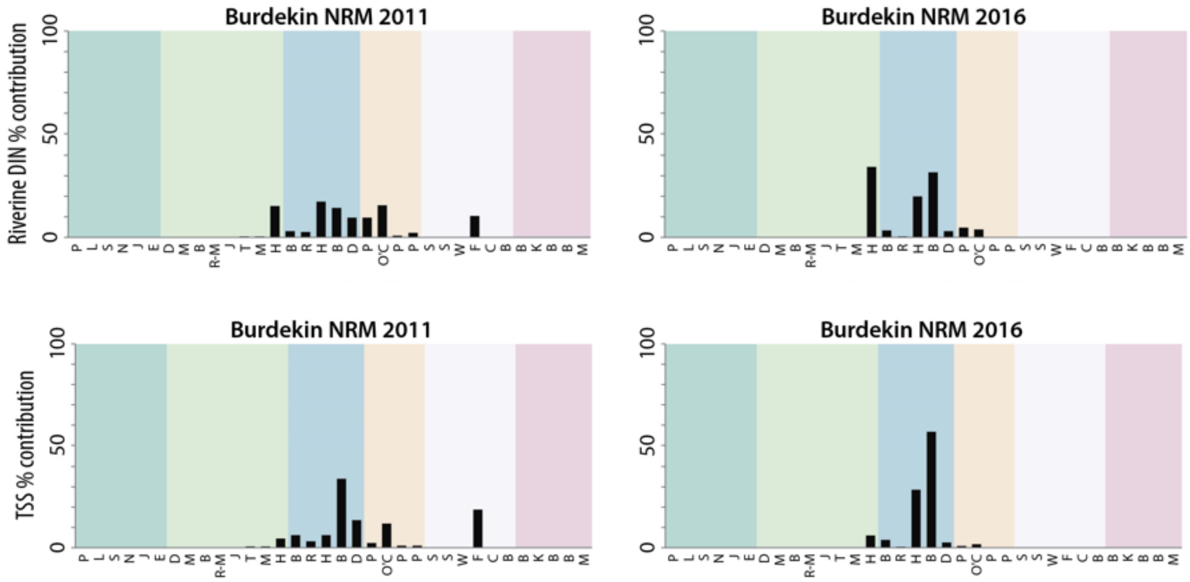

Figure 3-41. River contributions (x-axis, fully labelled in Figure 3-14) to the (top) DIN and (bottom) TSS mass to the Burdekin NRM region in 2010–11 (left column) and 2015–16 (right column). Shading groups rivers in the same NRM region: Cape York – dark green, Wet Tropics – light green, Burdekin – blue, Mackay Whitsunday – orange, Fitzroy – pink, Burnett Mary - red. The left panel show data for the 2010–11 water year (1 October to 30 September) and right panel for the 2015–16 water year.

Ambient water quality

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.

The long-term trend showed a "good" rating, while the new combined AIMS/JCU index showed a "moderate" rating (Figure 3-42a).

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 3-42b). 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 3-42b).

The TSS, PN and PP concentrations have been relatively stable over the whole monitoring period, with a minor increase in PN since 2013 (Figure 3-42f, h, i). The overall trend-lines for TSS, PN and PP were below or around GBR water quality guidelines (GBRMPA, 2010). Secchi depth remained stable and non-compliant with the guideline values over the whole sampling period, with a slight decrease since 2014 (Figure 3-42e), most likely related to reduced river discharge. The turbidity record showed relatively stable levels with a small proportion of maxima above the guideline between 2010 and 2015 (Figure 3-42e).

The concentrations of NO_x increased slightly at the beginning of the monitoring program, and have remained relatively stable at concentrations close to the Queensland guideline, with levels in 2015–16 being below this guideline value (Figure 3-42c). Phosphate (PO_4) concentrations have generally declined over the monitoring period (Figure 3-42d).

The concentrations of POC have remained relatively stable over the monitoring period, with a slight upward trend over the last two years (Figure 3-42j). The DOC concentrations have increased since the initiation of the sampling program and continued to increase in 2015–16 (Figure 3-42k).

In order to test if our data is similar with results obtained from the eReefs model we compared both the salinity values from our mooring at the Burdekin river mouth and water quality samples collected throughout the region (Appendix E, Figure E3 and E4). For salinity and Chl-a, the eReefs model generally covers the major events detected in the MMP data fairly well, while larger discrepancy between the model and the MMP data was found for TSS, Secchi depth and NOx (Appendix E, Figure E3 and E4).

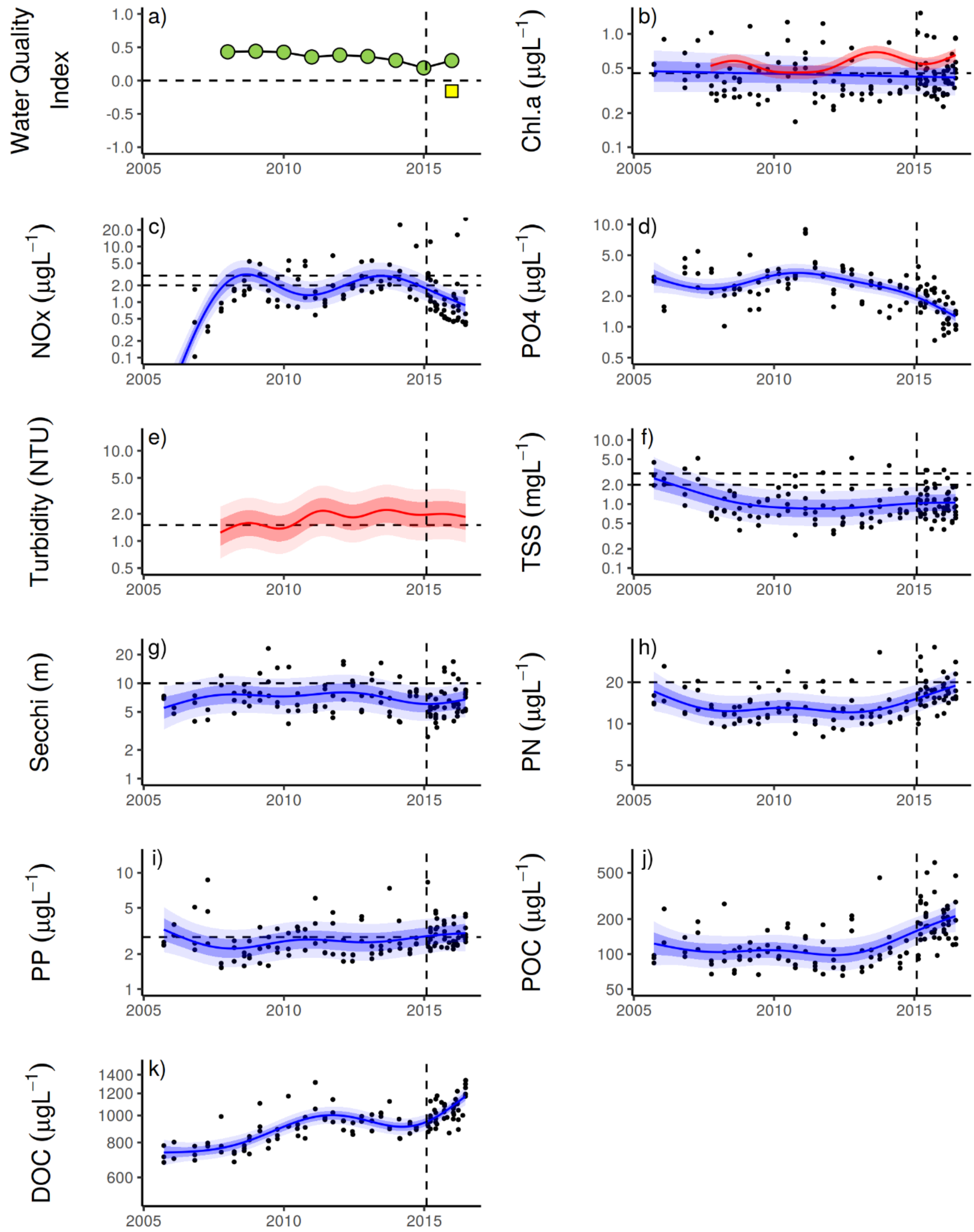

Figure 3-42: Temporal trends in water quality for the Burdekin focus area. a) water quality index, b) Chl-a, c) nitrate/nitrite, d) phosphate, e) turbidity, f) TSS, g) Secchi depth, h) PN, i) PP, j) POC and k) DOC. Water quality index colour coding: dark green- 'very good'; light green- 'good'; yellow – 'moderate; orange – 'poor'; red – 'very poor'. Note that this year a separate score for the data collected by both AIMS and JCU and apply wet/dry guidelines are shown as a single point in 3-42a.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 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.

Burdekin region: mapping wet season conditions and flood events

As described in Section 2.6, 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 during the wet season, including high flow periods, is used to characterise and validate these products. This data is presented in

Figure 3-43 and in a panel of weekly characteristics throughout the 22-week wet season period (Figure 3-44 and Figure 3-45). Details included in the panels: *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.

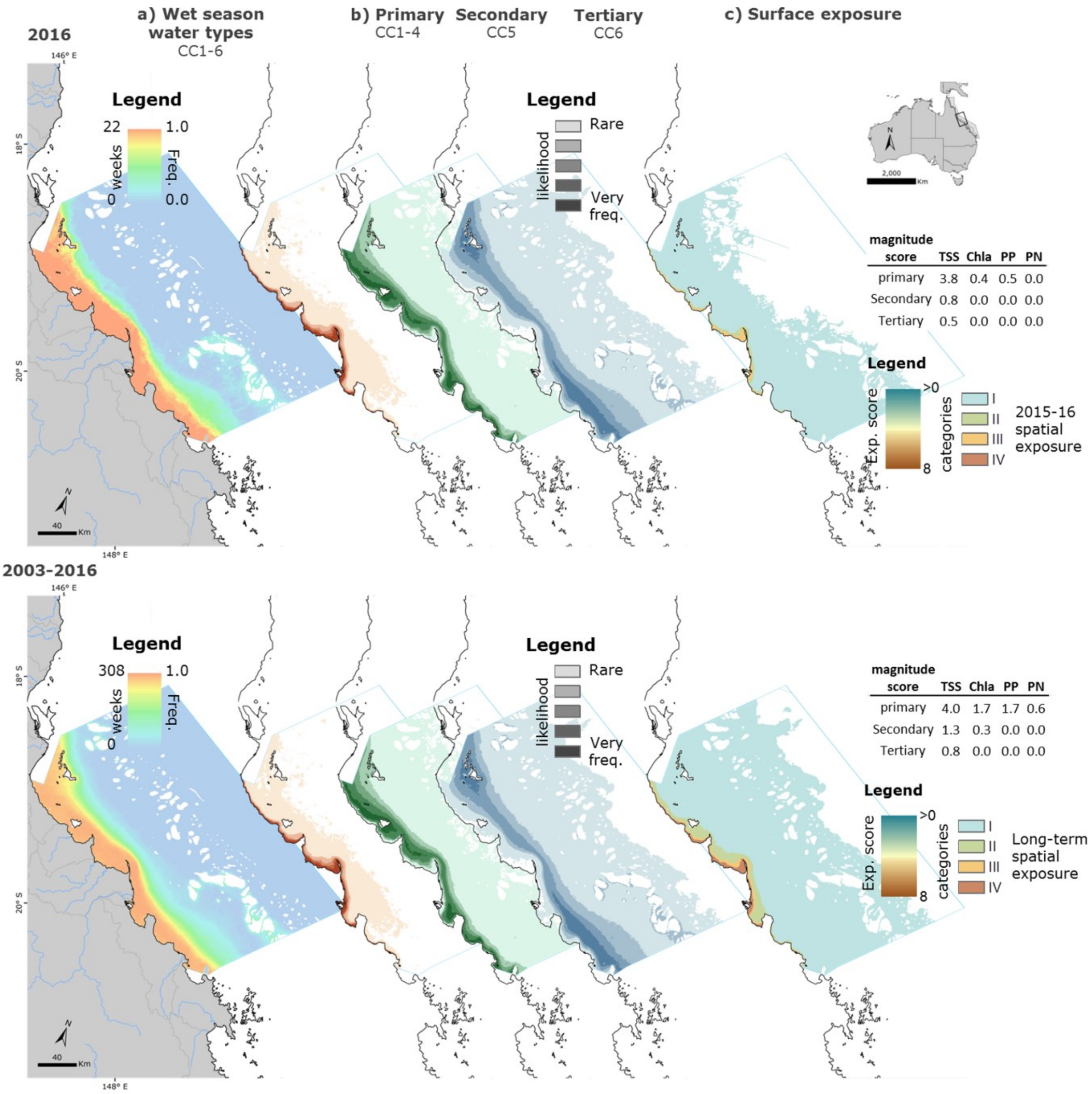

Figure 3-43: Maps showing the a) frequency of turbid waters (combined Primary, Secondary and Tertiary water types), b) the frequency of Primary, Secondary and Tertiary water types and c) the exposure maps for the Burdekin region in the long-term (bottom) and 2015–16 wet season (top).

Figure 3-43 (Top) presents the frequency of turbid waters (combined Primary, Secondary and Tertiary water type), the frequency of Primary, Secondary and Tertiary plume water types, respectively, and the exposure map in the 2015–16 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 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 maps, areas and percentage are presented in the context of the long-term exposure (2003–2016, Figure 3-43 (Bottom), and Table 3-4 - numbers in brackets.

In 2015–16, the Burdekin region was most affected by the lowest exposure categories (categories I and II), in agreement to the long-term trends. Approximately 49% of the total area of the Burdekin Region was exposed to turbid waters (combined Primary, Secondary and Tertiary water types), at least during one week of the wet season. However, only 1% of the Burdekin region was exposed to the higher potential risk categories (categories III, the Burdekin region was not exposed to category IV in 2015–16). These areas were smaller than the long-term areas (Table 3-4: 74% exposed to turbid waters, 1% to category I and 3% to category II). In 2015–16, it was estimated that:

- A total of 70% of the Burdekin coral reefs were exposed to turbid waters (Primary, Secondary and Tertiary waters combined), at least during one week of wet season. However, no corals were in the highest potential risk category (IV) from exposure and very few (0.02%) were in the exposure categories III.
- A total of 96% of the Burdekin seagrasses were exposed to turbid waters, at least during one week of wet season. However, no seagrasses were in the highest potential risk category (IV) from exposure, and only 10% were in exposure category III.
- These exposures indicate potential’ risk as exposure maps have not been yet validated against ecological health data to confirm the ecological consequences of the risk in 2015–16, the coral areas in the category III of potential risk were slightly smaller than the long-term areas (Table 3-4: 0.05%). These results were coherent with the characteristic of a relatively dry wet season.

Table 3-4: Areas (km^2) and percentages (%) of the Burdekin Region affected by different categories of exposure during the 2015–16 wet season *and* comparison with long-term values *(in brackets)*.

NRM		Total	Potential Risk category Lowest ----------------------- highest				Total exposed	Total non-exposed
Surface area	area	46,962	22,365 *(32,520)*	343 *(1,311)*	306 *(352)*	- *(399)*	23,014 *(34,581)*	23,948 *(12,381)*
	%	*100*	48 *(69)*	1 *(3)*	1 *(1)*	- *(1)*	49 *(74)*	51 *(26)*
Coral reefs	area	2,965	2,078 *(2,874)*	1 *(12)*	1 *(1)*	- *(-)*	2,081 *(2,887)*	885 *(78)*
	%	*100*	70 *(97)*	0.05 *(0.4)*	0.02 *(0.05)*	- *(-)*	70 *(97)*	30 *(3)*
Surveyed seagrass	area	669	509 *(269)*	69 *(228)*	67 *(55*	- *(96)*	645 *(648)*	24 *(21)*
	%	*100*	76 *(40)*	10 *(34)*	10 *(8)*	- *(14)*	96 *(97)*	4 *(3)*

Figure 3-44 and Figure 3-45 illustrate the changes in water quality and environmental conditions in the Burdekin region and focus on data collected by JCU. The 2015–16 wet season was characterised by low rainfall and consequent river discharge, resulting in river plumes that were not well developed and therefore the sampling sites did not receive a high riverine influence. Weekly river discharges in the 2015–16 sampling period were below the long-term mean weekly discharge value, except for weeks 10, but the location of the sample collected (restricted to colour class 5 and 6) did not allow describing water quality trends during this specific week. Maximum TSS, Chl-a and DIN values were sampled during week 19, in the colour class 3 (18.0 mg L^{-1}, 1.3 µg L^{-1} and 23 µg L^{-1}, respectively).

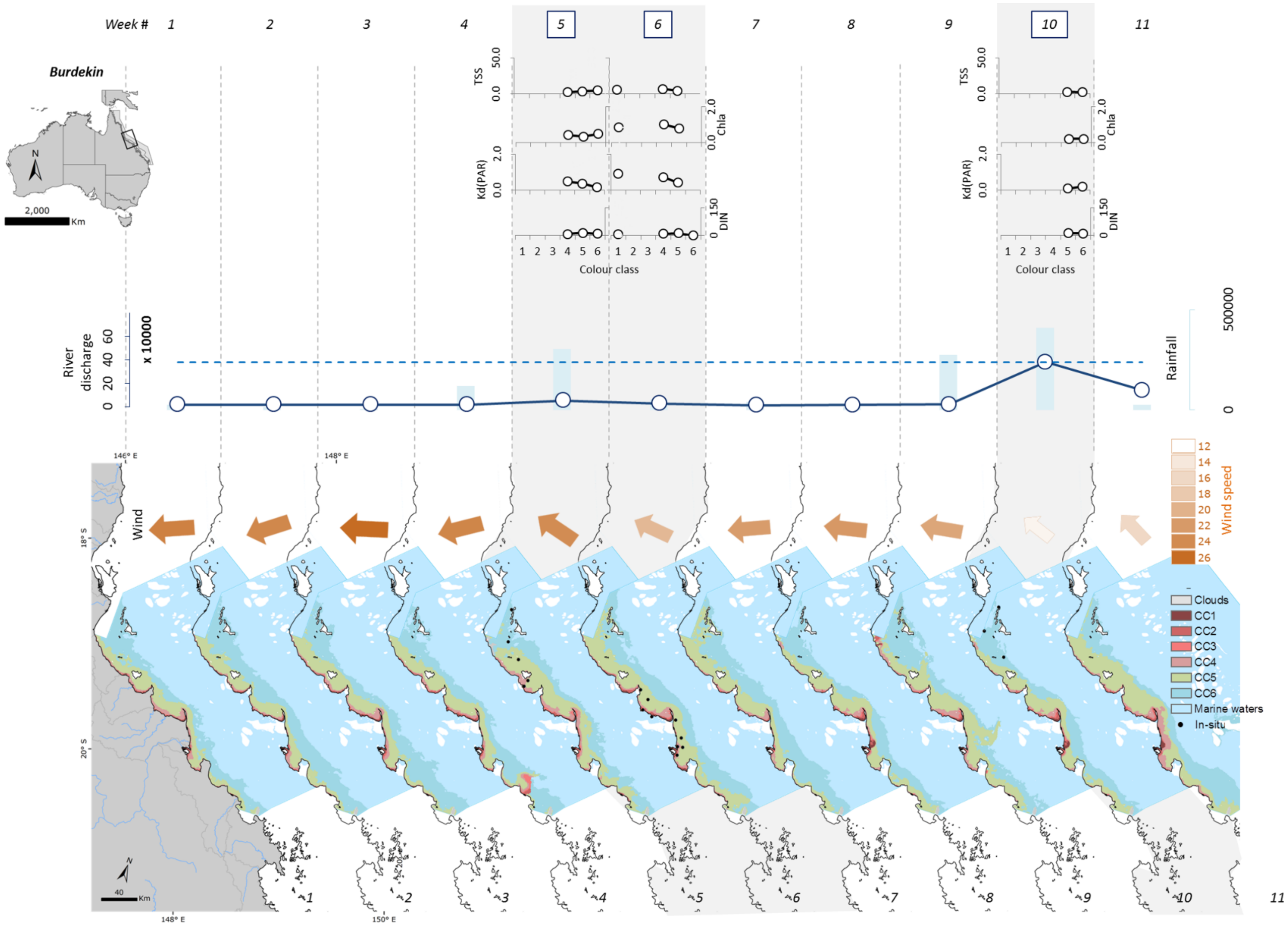

Figure 3-44: Panel of water quality and environmental characteristics in the Burdekin region throughout the 2015–16 wet season period: weeks 1 to 11. Details included in the panels include mean TSS (mg L^{-1}), Kd(PAR) (m^{-1}), Chl-a (µg L^{-1}) and DIN (µg L^{-1}) within each colour class; weekly river 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. The long-term mean weekly river discharge is indicated by a dotted blue line.

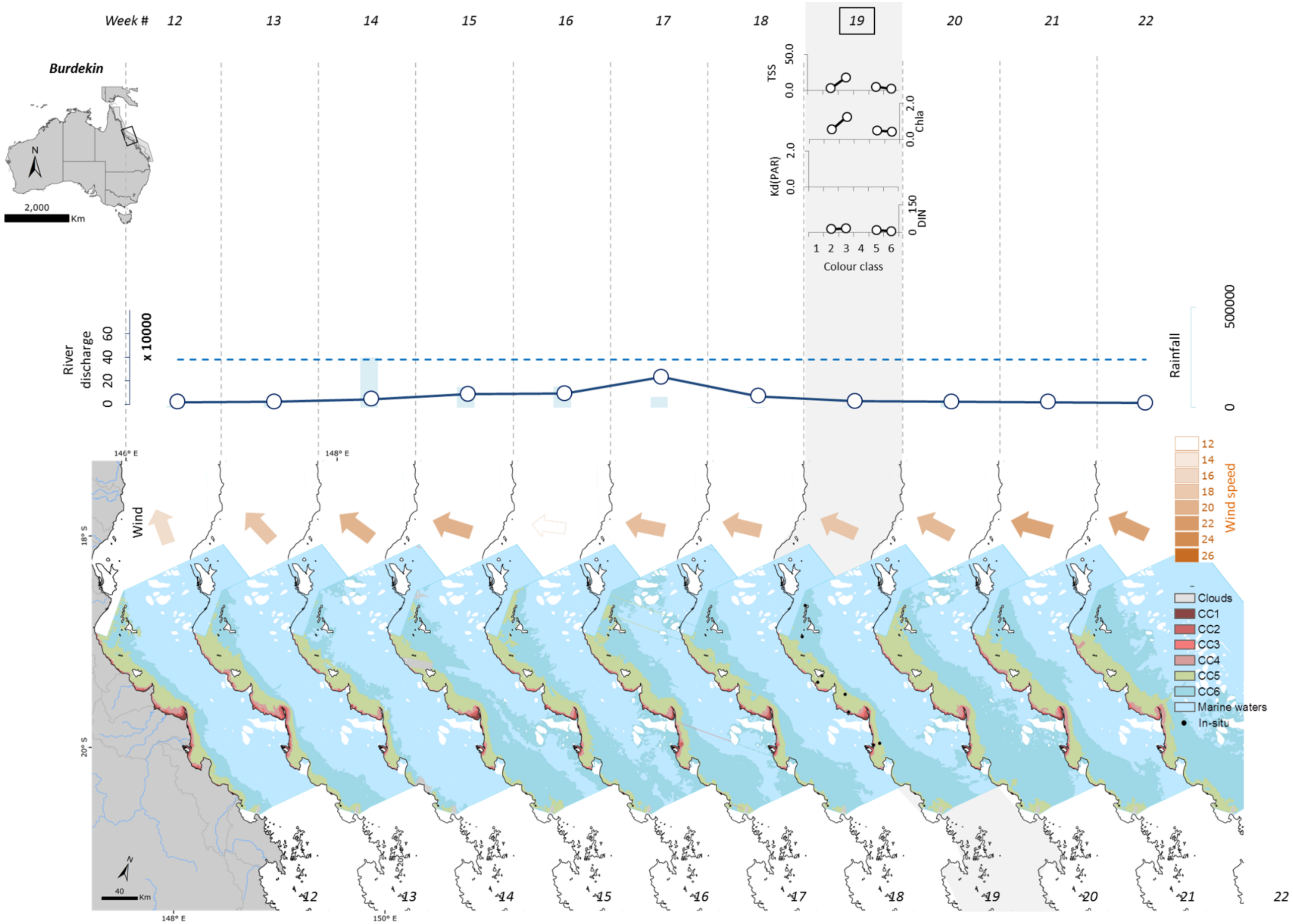

Figure 3-45: Panel of water quality and environmental characteristics in the Burdekin region throughout the 2015–16 wet season period: weeks 12 to 22. Details included in the panels include mean TSS (mg L^{-1}), Kd(PAR) (m^{-1}), Chl-a (µg L^{-1}) and DIN (µg L^{-1}) within each colour class; weekly 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. The long-term mean weekly river discharge is indicated by a dotted blue line.

3.4.5 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 runoff 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 (Brodie et al., 2003; GBRMPA 2012). 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 11 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 3-46).

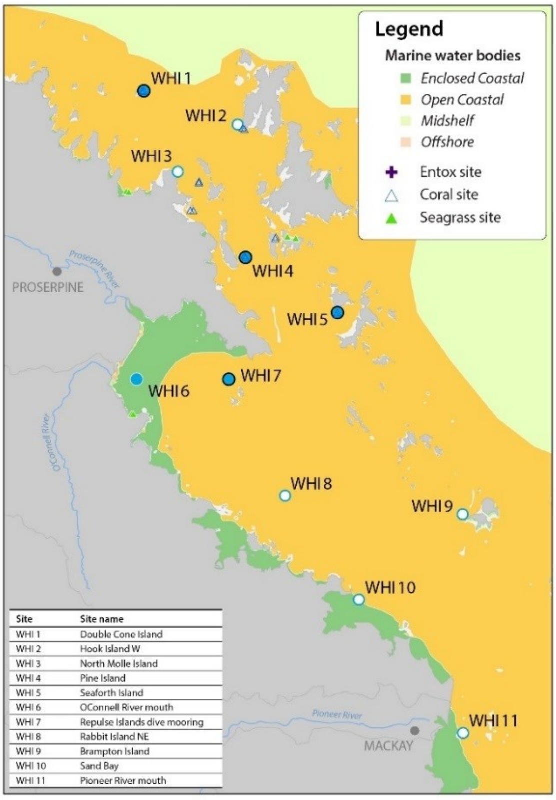

Figure 3-46: MMP sampling sites in the Mackay Whitsunday focus area, shown with the water body boundaries.

Over the period 2007 to 2013, annual discharge from the O'Connell and Pioneer Rivers was above median levels (Figure 3-47, Table D-1). Extreme floods (more than three 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. The combined annual discharge from the O'Connell, Proserpine and Pioneer Rivers during 2014-16 were below the long-term median flows (Figure 3-47). Peak daily discharge from these basins was also on the lower end over the 2006 to 2016 period (Figure 3-43).

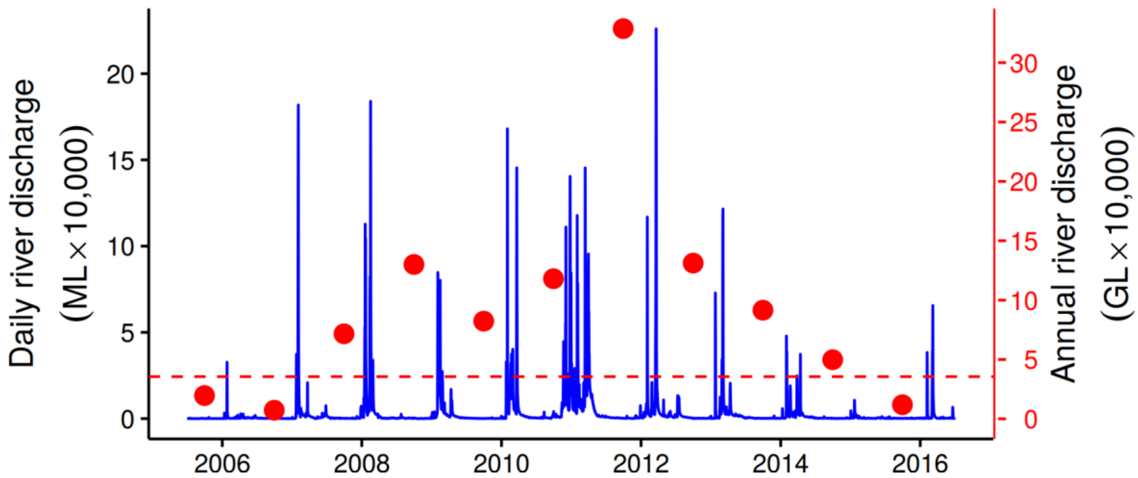

Figure 3-47: Combined discharge for the O'Connell (Stafford's Crossing gauge) and Pioneer (Dumbleton TW gauge) Rivers. Daily (blue) and water year (October to September, red) discharge is shown. Red dashed line represents the long-term median of the combined annual discharges. Please note as this is the combined discharge, high flows in one river will not necessarily be visible in the graph.

Only the O'Connell River is included in the hydrodynamic model and the estimated zone of influence is shown in Figure 3-48. The model shows a very limited zone of influence in 2015–16 and correlated is with the discharges well below the long-term median.

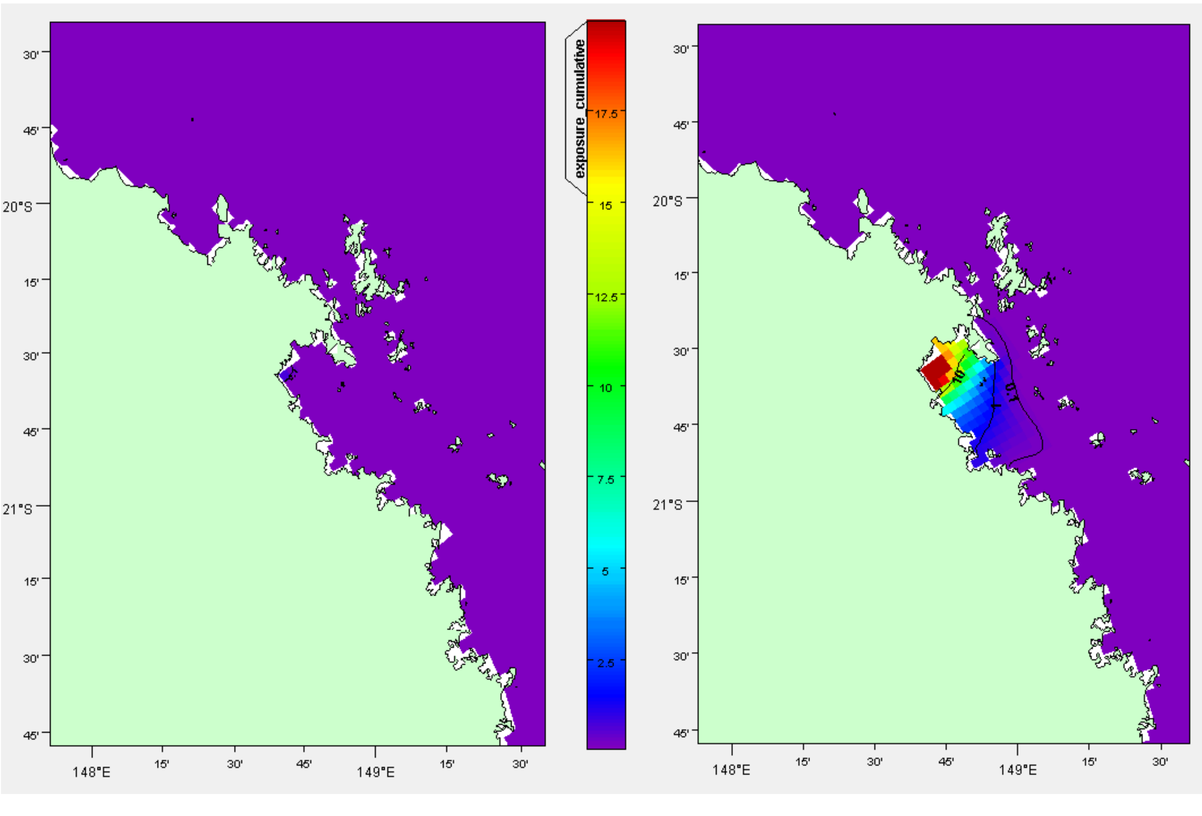

Figure 3-48: Cumulative exposure index for the O'Connell River in 2015–16 (left), with results for 2010–11 (right) shown for context. The colour bar indicates the calculated cumulative exposure (concentration × days) above 1% of the incoming concentration. The colour bar is capped at 20 Conc.Days. Contours show 0.1, 1.0 and 10.0 Conc.Days exposure levels.

The combined discharge and loads calculated for the 2015–16 water year from the Proserpine, O'Connell, Pioneer and Plane Basins were amongst the lowest over the past 10 years with only the previous 2014–15 year having lower discharge and loads in this period (Figure 3-49). Over the 10-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).

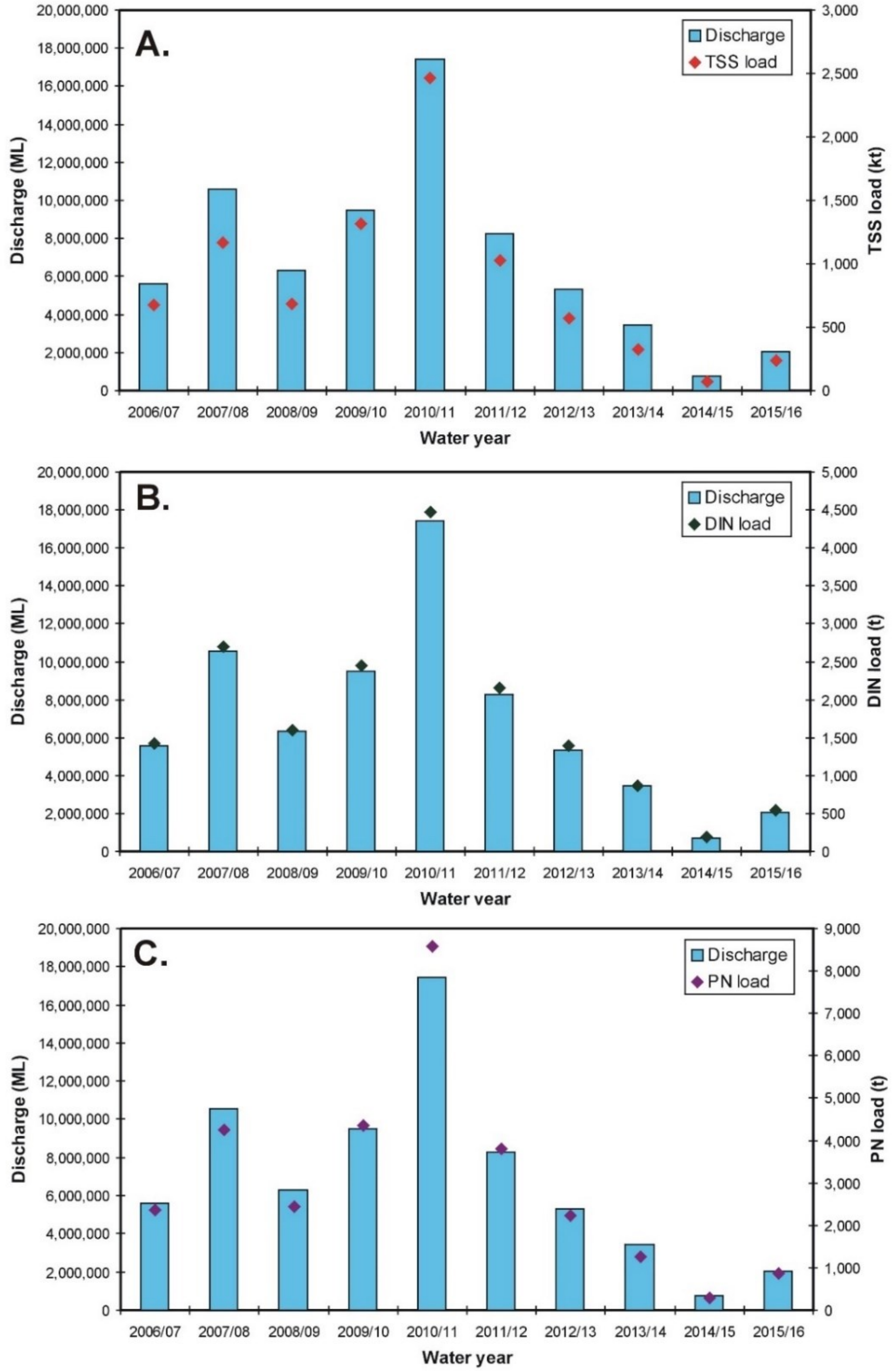

Figure 3-49: (A) Discharge and TSS, (B) DIN and (C) PN loads for the Proserpine, O'Connell, Pioneer and Plane Basins from 2006–07 to 2015–16. The loads reported here are a combination of 'best estimates' for each basin based on 'up-scaled discharge data from gauging stations, monitoring data (O'Connell 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.

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 3-50 shows the estimated DIN and TSS contributions for the Mackay Whitsunday region in 2010–11 and 2015–16. The panels show that the DIN mass in the Mackay Whitsunday region was influenced by the Fitzroy River in the large event of 2010–11 (~28%), and contributed almost 50% of the TSS mass in the 2010-–11. Figure 3-14 also shows that the Mackay Whitsunday Rivers can also influence the Burdekin Region.

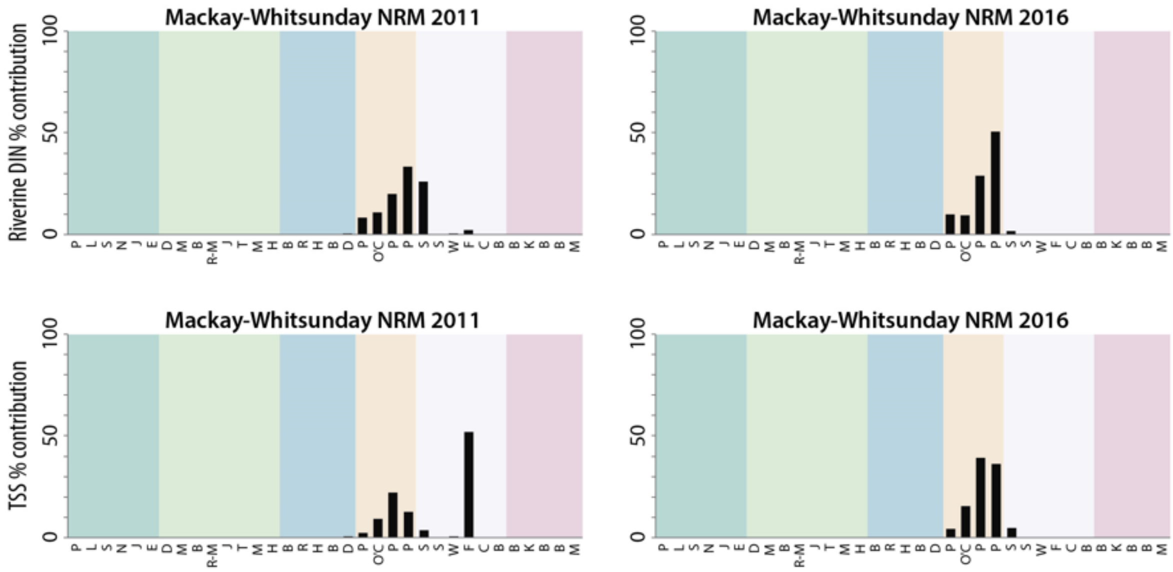

Figure 3-50: River contributions (x-axis, fully labelled in Figure 3-14) to the (top) DIN and (bottom) TSS mass to the Mackay Whitsunday NRM region. Shading groups rivers in the same NRM region: Cape York – dark green, Wet Tropics – light green, Burdekin – blue, Mackay Whitsunday – orange, Fitzroy – pink, Burnett Mary - red. The left panel show data for the 2010–11 water year (1 October to 30 September), and right panel for the 2015–16 water year.

Ambient water quality

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.

The long-term trend showed a decline since 2008 reaching “moderate” rating, which was the same obtained by the new AIMS/JCU index (Figure 3-51).

The Chl-a trend line remained relatively stable over the monitoring period with a slight declining trend although concentrations remain above the annual guideline (Figure 3-51b). Instrumental Chl-a records showed more pronounced fluctuations but generally followed the same trend as the manual sampling data (Figure 3-51b). Turbidity showed peaks in 2011 and 2014, with values above the guideline (Figure 3-51e). The trend-lines for both TSS and Secchi depth only showed minor changes, with slight decreases in TSS and corresponding increases in Secchi depth (Figure 3-51f, g). The trend line for TSS has remained at values around the guideline, while Secchi depth has been consistently non-compliant with the guideline (Figure 3-51f, 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 guideline values in 2015–16 (Figure 3-51h, i).

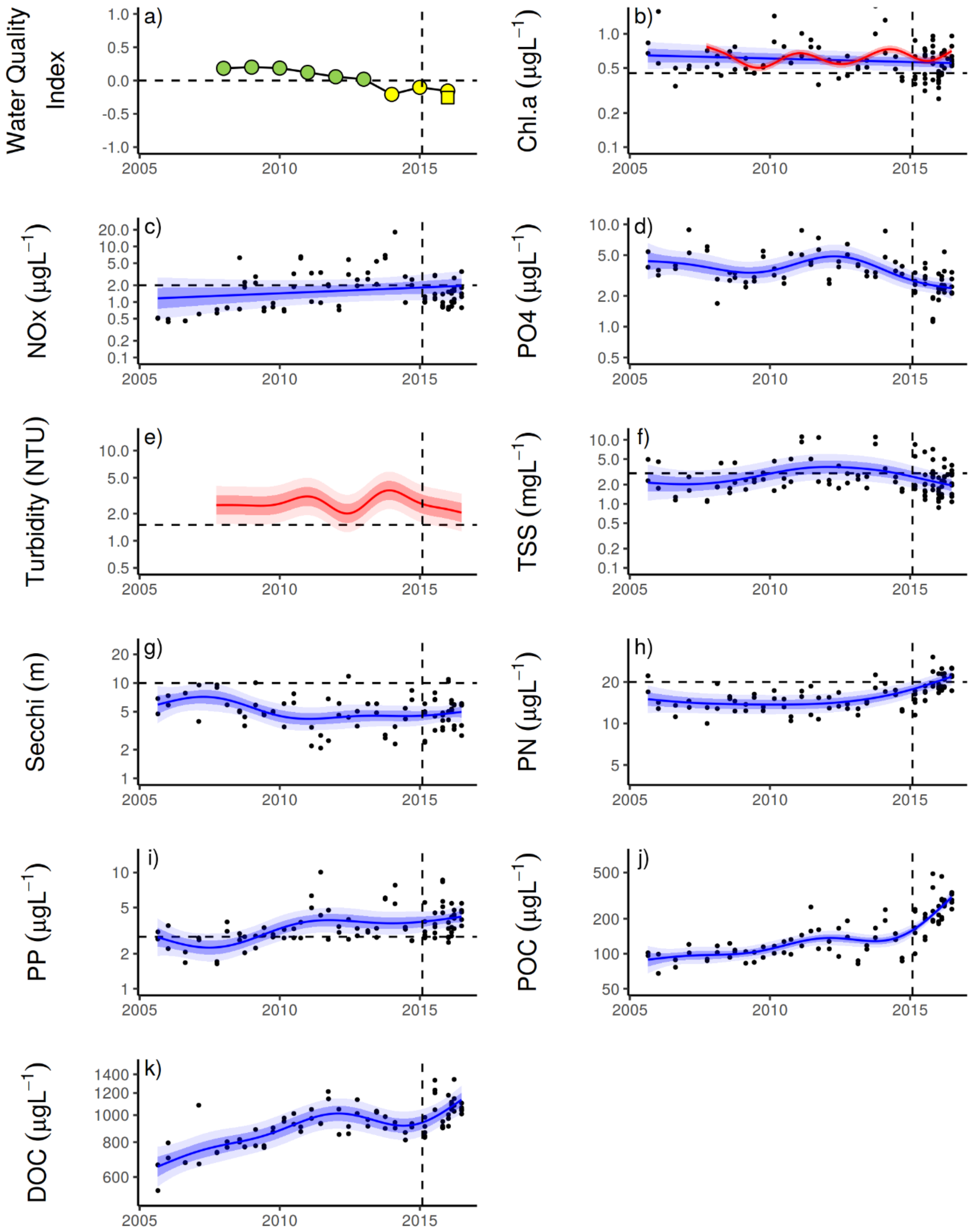

Figure 3-51: Temporal trends in water quality for the Mackay Whitsunday focus-region. a) water quality index, b) Chl-a, c) nitrate/nitrite, d) phosphate, e) turbidity, f) TSS, g) Secchi depth, h) PN, i) PP, j) POC and k) DOC. Water quality index colour coding: dark green – 'very good'; light green – 'good'; yellow – 'moderate; orange – 'poor'; red – 'very poor'. Note that in 2015–16 a separate score for the data collected by both AIMS and JCU are shown as a single point in Figure 3-42a, 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 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.

The concentrations of dissolved oxidised nitrogen (NO_x) showed a minor increase over the monitoring period with the trend-line approaching values above the guideline (Figure 3-51c). Phosphate (PO_4) concentrations have decreased since the beginning of the monitoring period (Figure 3-51d).

The concentrations of POC have increased markedly since 2015, while the DOC concentrations have shown a continued increase over the whole monitoring period (Figure 3-51j, k).

To examine if our data is similar with results obtained from the eReefs model we compared both the salinity values from our two moorings (Pine and Repulse Island) and water quality samples collected throughout the region (Appendix E, Figure E3 and E4). For both salinity and Chl-a, the eReefs model covers the major events found in the MMP data fairly well, however the inconsistency was larger between the model and the MMP data for the TSS, Secchi depth and NOx data (Appendix E, Figure E3 and E4).

Mackay Whitsunday region: mapping wet season conditions and flood events

As described in Section 2.6, 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 during the wet season, including high flow periods, is used to characterise and validate these products. This data are presented in Figure 3-52 and in a panel of weekly characteristics throughout the 22 week wet season period (Figure 3-53 and Figure 3-54). Details included in the panels includes: 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 3-53 (Top) presents the frequency of turbid waters (combined Primary, Secondary and Tertiary water types), the frequency of Primary, Secondary and Tertiary wet season water types and the exposure map in the 2015–16 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 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 (2003–2016), Figure 3-52 (Bottom) and Table 3-5 (numbers in brackets).

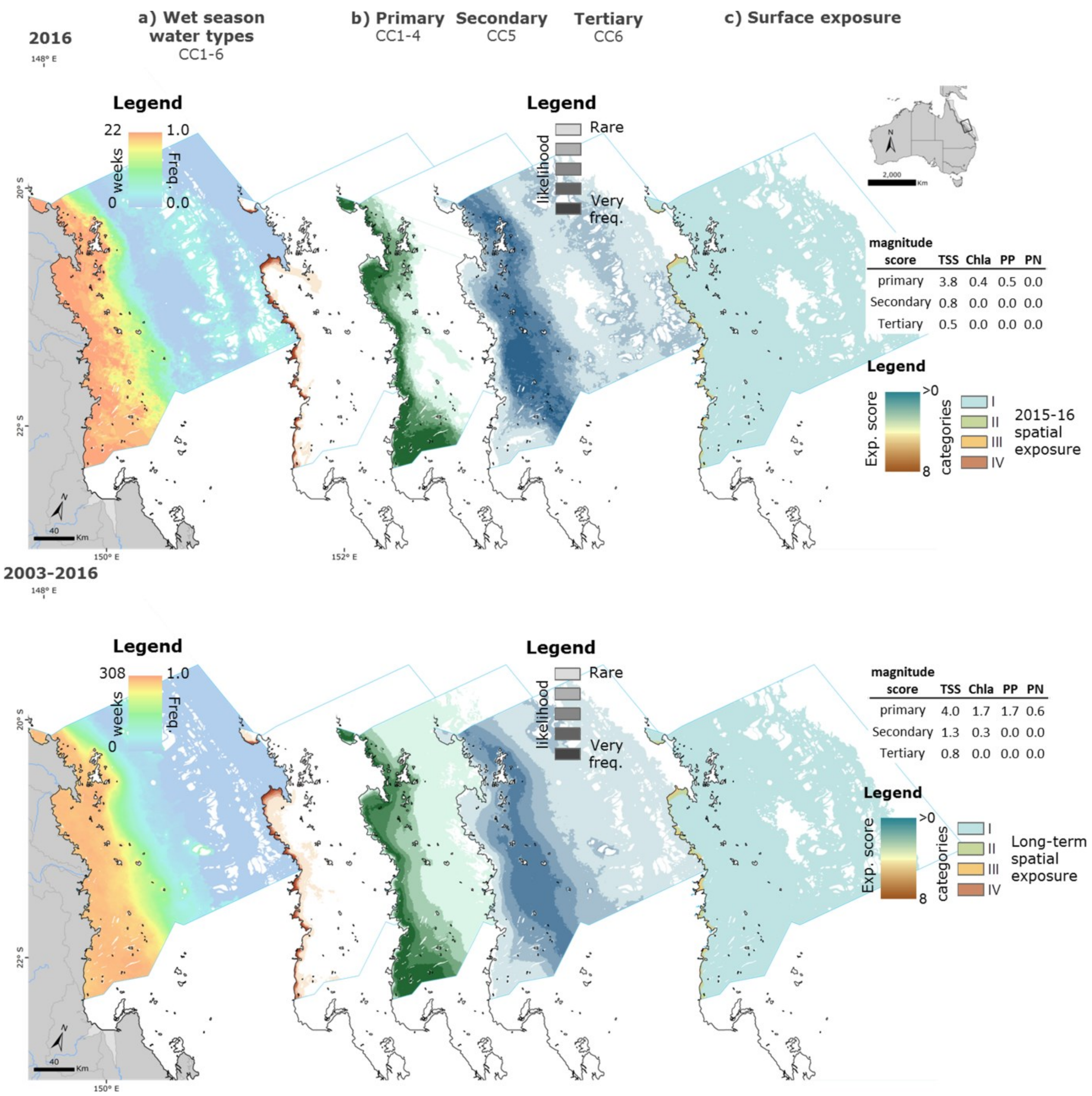

Figure 3-52: Maps showing the a) frequency of turbid waters (combined Primary, Secondary and Tertiary water types), b) the frequency of Primary, Secondary and Tertiary wet season water types and c) the exposure maps for the Mackay Whitsunday region in the long-term (bottom) and 2015–16 wet season (top).

In 2015–16, the Mackay Whitsunday region was most affected by the lowest exposure categories (categories I and II), in agreement to the long-term trends. Approximately 80% of the total area of the Burdekin Region was exposed to turbid waters (combined Primary, Secondary and Tertiary water types), at least during one week of the wet season. However, only 0.4% of the Mackay Whitsunday region was exposed to the higher potential risk categories (categories III, the Mackay Whitsunday region was not exposed to category IV in 2015–16). These areas were smaller than the long-term areas (Table 3-5: 86% exposed to turbid waters, 0.5% to category I and 0.5% to category II). In 2015–16, it was estimated that:

- A total of 94% of Mackay Whitsunday coral reefs were influenced by turbid waters (Primary, Secondary and Tertiary waters combined), at least during one week of wet season. However, no corals were in the highest potential risk category (IV) from exposure and only a very small area of reefs (<1% of the area) were in the exposure categories III.

- A total of 83% of the Mackay Whitsunday seagrasses were exposed to turbid waters, at least during one week of wet season. However, no seagrasses were in the highest potential risk category (IV) from exposure and only 8% were in exposure category III.
- These exposures indicate potential' risk as 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 category III of potential risk were smaller than long-term (Table 3-5: 0.1% of reefs and 11% of seagrasses exposed to category III). These results were logical with the characteristic of a relatively dry wet season.

Table 3-5: Areas (km^2) and percentages (%) of the Mackay Whitsunday Region affected by different categories of exposure during the 2015–16 wet season and comparison with long-term values (in brackets).

NRM		**Total**	**Potential Risk category** **Lowest ----------------------- highest**				**Total exposed**	**Total non-exposed**
Surface area	area	48,945	38,526 *(40,852)*	324 *(693)*	185 *(225)*	- *(241)*	39,035 *(42,011)*	9,911 *(6,934)*
	%	*100*	79 *(83)*	1 *(1)*	0.4 *(0.5)*	- *(0.5)*	80 *(86)*	20 *(14)*
Coral reefs	area	3,225	3,042 *(3,081)*	4 *(21)*	1 *(2)*	- *(1)*	3,047 *(3,105)*	178 *(121)*
	%	*100*	94 *(96)*	0.1 *(0.7)*	0.04 *(0.1)*	- *(0.02)*	94 *(96)*	6 *(4)*
Surveyed seagrass	area	311	186 *(146)*	48 *(44)*	23 *(35)*	- *(34)*	257 *(259)*	54 *(52)*
	%	*100*	60 *(47)*	16 *(14)*	8 *(11)*	- *(11)*	83 *(83)*	17 *(17)*

Figure 3-53 and Figure 3-54 illustrate the changes in water quality and environmental conditions in the Mackay Whitsunday region and focus on data collected by JCU. The 2015–16 wet season was characterised by low rainfall and consequent river discharge, resulting in river plumes that were not well developed and therefore the sampling sites did not receive a high riverine influence. Weekly river discharges in the 2015–16 sampling period were below the long-term mean weekly discharge value, except for weeks 10, 14 and 15, but samples were only collected during week 15, in colour classes 3 and 4; and did not allow describing water quality trends during the higher river flow events. Maximum TSS and DIN sampled were 17 µg L^{-1} in colour class 4 and 24 µg L^{-1}in colour class 3, respectively.

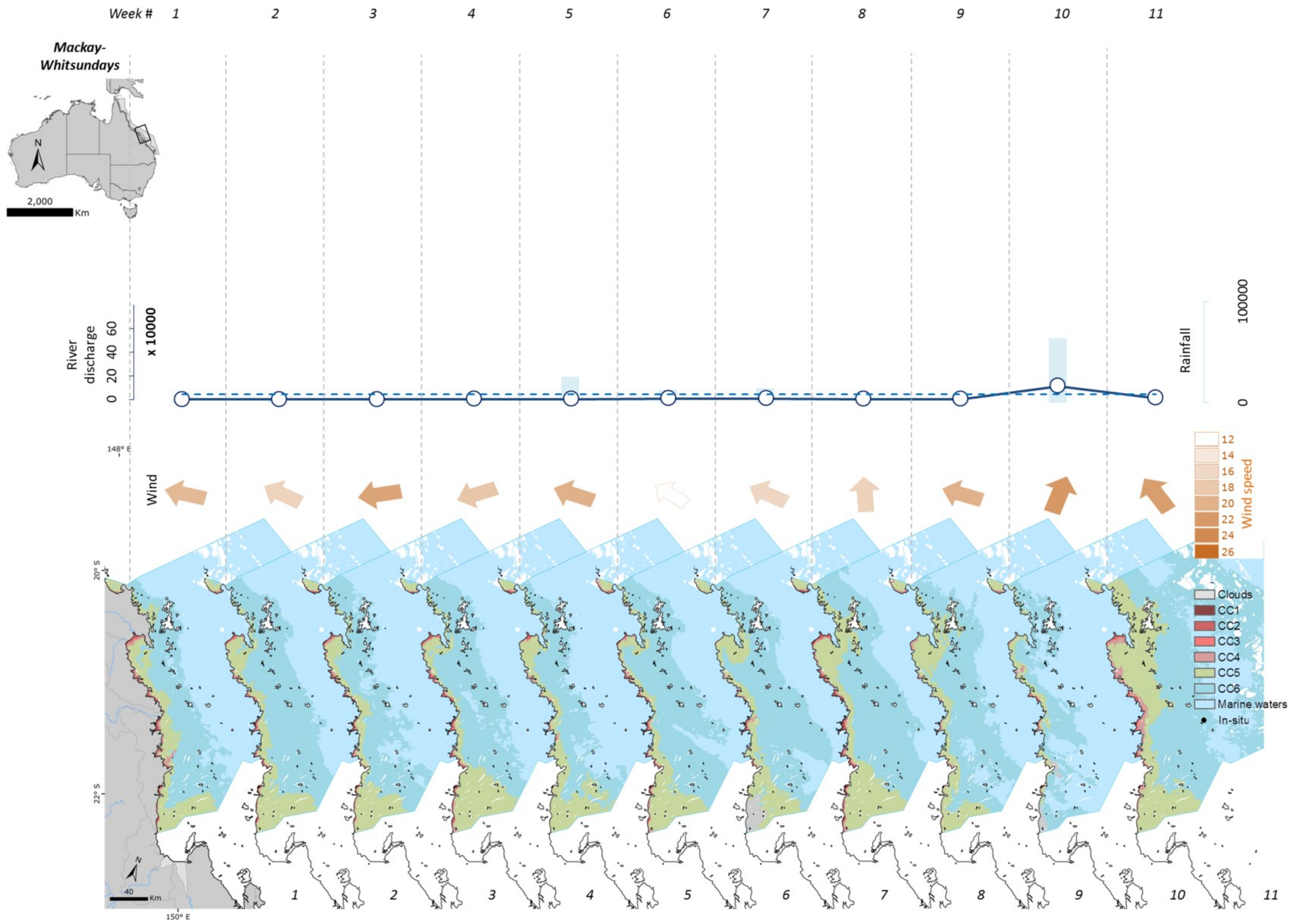

Figure 3-53: Panel of water quality and environmental characteristics in the Mackay Whitsunday region throughout the 2015–16 wet season period: weeks 1 to 11. Details included in the panels: mean TSS (mg L^{-1}), Kd(PAR) (m^{-1}), Chl-a (µg L^{-1}) and DIN (µg L^{-1}) within each colour class; weekly 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. The long-term mean weekly river discharge is indicated by a dotted blue line.

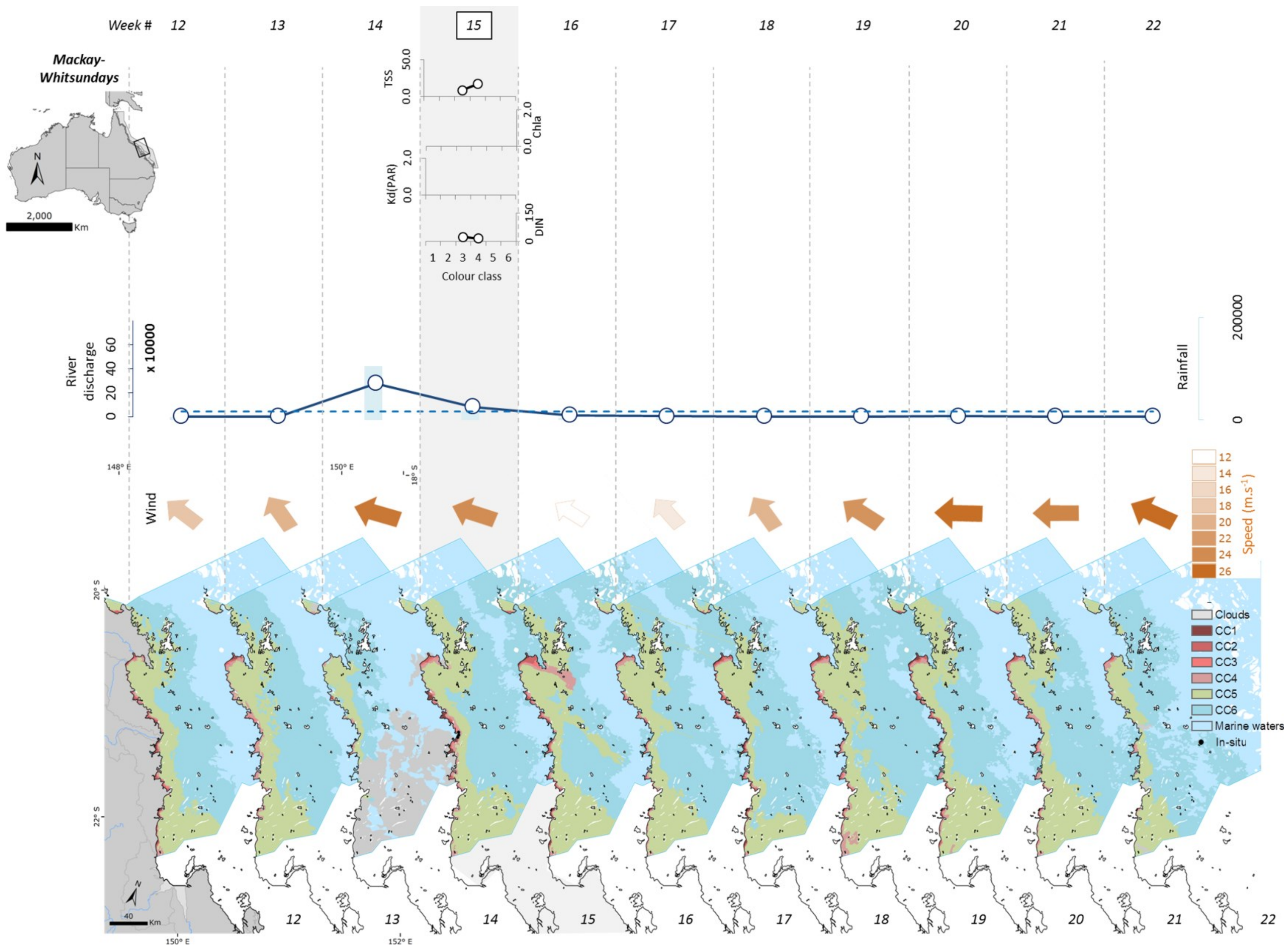

Figure 3-54: Panel of water quality and environmental characteristics in the Mackay Whitsunday region throughout the 2015–16 wet season period: weeks 12 to 22. Details included in the panels: mean TSS (mg L^{-1}), Kd(PAR) (m^{-1}), Chl-a (µg L^{-1}) and DIN (µg L^{-1}) within each colour class; weekly 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. The long-term mean weekly river discharge is indicated by a dotted blue line.

3.5 Report Card water quality metric 2015–16

In the past, the Reef Plan Report Card included a Water Quality Metric based on remote sensing data for Chl-a and TSS concentrations. The metric is currently being revised as part of a project under the National Environmental Science Program to address issues with data confidence in some regions and the sensitivity of the metric to annual variations and will be reported separately in 2017.

4. Discussion

Local environmental conditions, such as water quality, clearly 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 concentrations.

4.1 Water quality characteristics in 2015–16

The 2015–16 wet season had lower discharge and pollutant loads relative to previous years of monitoring since 2006–07 for all of the focus regions, apart from 2014–15 that was similar. This has had an important influence on the wet-season conditions and hence to the contribution to overall water quality in the GBR. The ambient conditions are more variable and more difficult to correlate directly to the relatively low river influence.

The main findings for each NRM region are highlighted below.

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 minor fluctuations over the monitoring period with no clear trend.
- The concentrations of dissolved oxidised nitrogen (NOx) have in some sub-regions remained stable while in others it peaked in previous years and are now slightly reducing in concentration
- Dissolved organic carbon (DOC) concentrations increased over the course of the monitoring period.
- Secchi depth is variable and shows a decline at some sites, and an increase at others; however, generally, levels throughout the period continue to not meet the guideline

Wet season water quality

- The 2015–16 wet season was characterised by low rainfall and consequent river discharge, resulting in river plumes that were not well developed and therefore the sampling sites did not receive a high riverine influence. Weekly river discharges were below the long-term mean weekly discharge value, except for two weeks toward the end of the season (week 15 and 16). An increase in water quality concentrations was observed following these two weeks, with TSS concentrations reaching 43 mg L^{-1} in the colour class 3. This is 18 times the wet season TSS guidelines for the open coastal and midshelf waters. The guideline however, is a seasonal mean and the ecological effect of the acute concentration peak is not known. The mean seasonal TSS concentrations measured across the Primary, Secondary and Tertiary water types were 11.5 mg L^{-1}, 4.2 mg L^{-1} and 2.6 mg. L^{-1}, i.e. about 4.8, 1.7 and 1.5 times the wet season TSS guidelines, respectively (Figure 3-9). The Kd(PAR) and DIN peak values reached 2 m^{-1} and 147 µg L^{-1} in the colour class 3 during week 16.

- The wet season exposure mapping showed that the Wet Tropic 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 56% of the total area of the region was exposed to turbid waters (combined Primary, Secondary and Tertiary water types s) at least during one week of the wet season. However, only 0.5% of the Wet Tropic region was exposed to the higher potential risk categories (categories III, the Wet Tropics region was not exposed to category IV in 2015–16).
- The loading maps showed relatively low influence from TSS and DIN loading for 2015–16, which was comparable to the previous two years.

Burdekin

Ambient water quality

- The long-term Water Quality index calculated for the sites in the Burdekin region has remained more or less stable with a score of ‘good’ or ‘very good’. By contrast, the combined AIMS/JCU index shows a moderate score for this region.
- Chl, TSS, PN and PP concentrations have been relatively stable over the whole monitoring period around, or just above or below GBR water quality guidelines
- The concentrations of NOx increased at the beginning of the monitoring program and have until 2015 remained at levels close to or above the Queensland guideline.
- Dissolved organic carbon (DOC) concentrations increased over the course of the monitoring period.
- Secchi depth remained stable and has not met the guideline values over the whole sampling period.

Wet season water quality

- The 2015–16 wet season was characterised by low rainfall and consequent river discharge, resulting in river plumes that were not well developed and therefore the sampling sites did not receive a high riverine influence. Weekly river discharges in the 2015–16 sampling period were below the long-term mean weekly discharge value, except for week 10.
- The 2015–16 wet season exposure mapping showed that the Burdekin region was most affected by the lowest exposure categories (categories I and II), in agreement to the long-term trends. Approximately 49% of the total area of the Burdekin Region was exposed to turbid waters (combined Primary, Secondary and Tertiary water types), at least during one week of the wet season. However, only 1% of the Burdekin region was exposed to the higher potential risk categories (categories III, the Burdekin region was not exposed to category IV in 2015–16). The loading maps showed relatively low influence from TSS and DIN loading for 2015–16, which was comparable to the previous two 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 monitoring maintaining a ‘moderate’ index score for the third consecutive year. A similar score was found for the combined AIMS/JCU index.

- Chl-a showed slight declining trend although concentrations remain above the annual guideline.
- Concentrations of PN and PP have increased over the sampling period, with both being above guideline values in 2015–16. The concentrations of NOx increased slightly over the monitoring period, with the trend-line approaching Queensland guideline values.
- The DOC concentrations showed a steep continued increase over the monitoring period.
- Combined, the turbidity, TSS and Secchi depth data indicate that the water clarity in the Mackay Whitsunday region has decreased

Wet season water quality

- The 2015–16 wet season was characterised by low rainfall and consequent river discharge, resulting in river plumes that were not well developed and therefore the sampling sites did not receive a high riverine influence. Weekly river discharges in the 2015–16 sampling period were below the long-term mean weekly discharge value, except for weeks 10, 14 and 15.
- The 2015–16 wet season exposure mapping showed that the Mackay Whitsunday region was most affected by the lowest exposure categories (categories I and II), in agreement to the long-term trends. Approximately 80% of the total area of the Mackay Whitsunday Region was exposed to turbid waters (combined Primary, Secondary and Tertiary water types), at least during one week of the wet season. However, only 0.4% of the Mackay Whitsunday region was exposed to the higher potential risk categories (categories III, the Mackay Whitsunday region was not exposed to category IV in 2015–16). The loading maps showed relatively low influence from TSS and DIN loading for 2015–16, which was comparable to the previous two years.

4.2 Long-term changes in water quality

Previous work has demonstrated that in order 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 10 years of continuous sampling there is no evidence for an overall change in the water quality of the GBR lagoon, although interannual differences, largely correlated with river discharge, are clearly 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 but also confounded by other influences. These complications result in continued uncertainty about the controlling factors in the cycling of key water quality variables (e.g. nitrogen) in the GBR. Therefore, to improve our ability to better manage and understand the impact of land management improvements on the marine water quality, improved process knowledge is required on the carbon, nitrogen and phosphorus cycling on land, in rivers/lakes and in the marine system. Such knowledge will be pivotal for effective support of policy developments and provide confidence that a management policy has provided a sufficient improvement in the water quality.

The results for 2015–16 followed typical patterns of water quality in the inshore GBR which generally shows minor gradients away from river mouths, with slightly elevated levels of most indicators closest to the coast. 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 biological transformation processes (see Schaffelke et al., 2013 and references therein). Such gradients and processes are a part of the natural GBR ecosystem, albeit under somewhat 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., 2012a) between years and locations. Most variation was explained by temporal factors (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 10 years 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 notable changes 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 e.g. sediments.

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 catchment improvements and end-of-river loads have been acknowledged (e.g. Darnell et al., 2012) and lags between the river loads and marine improvements are also expected.

This year the water quality index was calculated in two different ways, with these index's showing slightly different scores in most regions. We furthermore in some of the ambient WQ variables detected an increased variability over the last years. Whether these differences are due to real changes or simply linked with a different sampling design, more frequent sampling during the wet season and more sites further inshore, is currently not possible to conclude.

Over the monitoring period, an increase in the dissolved organic carbon (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, though not necessarily mutually exclusive, explanations: either the coral and plankton communities have increased primary production or they are directing more of their production towards DOC release or there is an enhanced export from the catchment area.

A large fraction 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. Thornton, 2014; Church et al., 2002). As slightly more inorganic nitrogen is available for growth in some regions (measured increase in NO_X concentrations) and phosphate is present at non-limiting levels, it suggests that nutrient stress might not be a likely cause of the increased DOC levels. 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).

Globally it has been recognised that DOC loads from catchments to coastal waters 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.

These complications highlight the importance of maintaining and further developing a range of monitoring 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 within the GBR lagoon while the ambient water quality monitoring during relatively calm weather show that the influence of previous plumes is not evident (i.e. the calm weather monitoring do 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). The sediment resuspension influence is not captured by the ambient grab sample monitoring. Hence two 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 water flushing removes the influences of the plankton. Second, and more likely, 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).

5. Conclusions

After 10 years of continuous sampling it is not clear whether there has been measurable change in the water quality of the GBR lagoon.

This report has presented the combined results of the ambient and flood response inshore water quality monitoring program, including some refined methods for the remote sensing products. When interpreting the long-term trends in water quality it is important to keep in mind that the change in sampling strategy in 2014, with more frequent sampling during the wet season and more sites further inshore, will by itself influence the long-term trend, presenting challenges for the detection of improvement or decline in the water quality conditions. The calculation of the Water Quality Metric for both datasets highlights the importance of this influence.

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.

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 2015–16. Overall, the frequency and extent of river plumes were constrained compared to previous years. 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 incorporation of the DIN and TSS loading 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, in some cases contributing almost half of the estimated loading (TSS from the Burdekin River into the Wet Tropics NRM region in 2010–11). 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 new 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 this year 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. 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: DOC-CDOM relationships in the Great Barrier Reef Lagoon

Christian Lønborg and Cátia Carreira

A-1 Scope

The concentration of dissolved organic carbon (DOC) has increased over the last years in the Great Barrier Reef (GBR) Lagoon. Therefore, in this case study, the objective was to determine whether coloured dissolved organic matter (CDOM), a cheaper and easier method with potential remote sensing application, could be used to trace DOC concentrations in the GBR Lagoon.

Case study abbreviations: a_{254} - CDOM absorption coefficient at 254 nm; a_{275}- CDOM absorption coefficient at 275 nm; a_{340} - CDOM absorption coefficient at 340 nm; a_{350} - CDOM absorption coefficient at 350 nm; a_{365} - CDOM absorption coefficient at 365 nm; a_{440} - CDOM absorption coefficient at 440 nm; CDOM - Coloured dissolved organic matter; CTD - Conductivity-temperature-depth; DOC - Dissolved organic carbon; DOM - Dissolved organic matter; MMP - Marine Monitoring Program.

A-2 Introduction

Dissolved organic carbon (DOC) is the carbon part of the dissolved organic matter (DOM) pool containing 97% of all the ocean organic carbon and, therefore, is a major part of ocean biogeochemical cycles (Hedges, 2002). In coastal waters, a large fraction of DOM is coloured (Harvey and Boran, 1981). This coloured fraction of DOM (CDOM) (also called 'chromophoric DOM', yellow substances, gelbstoff, or 'coloured dissolved organic carbon') (Kirk 1994) gives the water a characteristic brownish colour (McKee et al. 2002) and together with mineral/organic particles and phytoplankton controls the colour and optical properties of coastal waters (Bowers et al., 2004). CDOM absorbs strongly in the UV and blue area of the light spectrum with the absorption coefficient decreasing exponentially with increasing wavelength reaching almost zero in the red region (Blough and Vecchio, 2002). DOM in coastal waters, such as the GBR Lagoon, is influenced by terrestrial inputs from rivers and runoff, but *in-situ* production can also occur (Blough and Vecchio, 2002; Carder et al., 1989; Del Vecchio and Blough, 2004). A decrease in CDOM concentration is often observed with distance from land due to dilution (Stedmon and Markager 2003) and degradation mainly from solar radiation (e.g. Nelson et al., 2004). Due to the diversity of production and degradation pathways, the chemical composition of CDOM is complex resulting in different absorption properties, with the overall absorption spectrum representing the sum of the different absorption peaks. The relationship between DOC and CDOM absorption has been investigated in a variety of coastal systems (e.g. Blough and Vecchio, 2002), demonstrating that DOC concentrations potentially can be estimated through measurement of CDOM absorption. This approach provides several advantages compared with traditional DOC measurements as CDOM can be measured cheaply (~$2), rapidly (minutes), *in-situ* and can potentially be coupled with remote sensing.

In this case study, data from the AIMS database were used to test if CDOM could be used to trace DOC concentrations in the Marine Monitoring Program (MMP) study area of the GBR. If successful, this could be combined with remote sensing in the future to understand sources, large scale variability and longer term trends in DOC concentrations.

A-3 Materials and methods

Sample collection - Full-depth continuous conductivity-temperature-depth (CTD) profiles were recorded (Seabird SBE19Plus) at each sampling site before sample collection. The CTD salinity was calibrated with water samples collected with the Niskin bottles and analysed in the base laboratory with a Portasal Model 8410A. Following the CTD cast, Niskin bottle samples were collected at 2 depths for the analysis of dissolved organic carbon (DOC) and coloured dissolved organic matter (CDOM). Sub-samples for DOC were collected in duplicate by immediately filtering sample water through a 0.45 µm filter cartridge (Sartorius MiniSart) into acid-washed plastic containers. The samples were preserved by adding 100 µL of AR-grade HCl and stored in the dark at 4°C until analysis. The CDOM samples were collected by filtrations through a 0.2 µm filter (Pall-Acropak supor Membrane) and stored in acid-washed amber glass bottles in the dark at 4°C until analysis.

Sample measurements - The DOC concentrations were measured by high temperature combustion (720ºC) using a Shimadzu TOC-L carbon analyser. Three to five replicate injections of 150 µL were performed per sample. Concentrations were determined by subtracting a Milli-Q blank and dividing by the slope of a daily standard curve made from potassium hydrogen phthalate and glycine.

Absorption spectra of CDOM samples were measured on a Shimadzu UV-1800 Spectrophotometer equipped with a 10 cm quartz cells using Milli-Q water as a blank. Before analysis, samples were allowed to warm to room temperature. The absorption spectrum was measured between 240 and 650 nm and the absorption at different wavelengths was used to test if they related with the DOC concentrations. The absorption coefficients at each of these wavelengths were calculated using the equation:

$$A_\lambda = 2.303 A_\lambda / L$$

where, A_λ is the absorbance measured at the wavelength. The factor 2.303 converts from base 10 to base e logarithms and the denominator L is the cell path length in metres. Previous studies have used several different CDOM absorption wavelengths as a measure of CDOM concentration to give a quantitative measure of the amounts and differences in the CDOM pool. The choice of wavelength is arbitrary, so in this study we used wavelengths (254 (A_{254}), 275 (A_{275}), 340 (A_{340}), 350 (A_{350}), 365 (A_{365}) and 440 (A_{440}) nm) which has been used in previous studies to test if these correlated with the DOC concentrations (Blough and Del Vecchio 2002). Regression analyses were performed using the best–fit between the two variables X and Y obtained by regression model II as described in Sokal and Rohlf (1995). Prior to regressions, normality was checked and the confidence level was set at 95%, with all statistical analyses conducted in Statistica 6.0.

A-4 Results and discussion

A total of 349 pairs of concurrent measurements of CDOM absorption and DOC concentrations were compiled to test if CDOM absorption measurements can be used to trace DOC concentrations in the Great Barrier Reef (GBR) lagoon.

Figure A-1 shows the span in CDOM absorbance found during the sampling program, with CDOM absorption coefficients at for example 254 nm (A_{254}) varying between 0.3 and 10.6 m^{-1}. The mixing (either conservative or non-conservative) behaviour of DOC and CDOM was investigated by plotting these measurements against salinity (Figure A-2). A conservative mixing assumes that the chemical properties and variation in source and end-member is known as a function of time (Loder and Reichard, 1981). If DOC and CDOM behave conservatively during mixing of freshwater and marine water, their distributions would be purely controlled by the physical mixing of two end-members causing their levels to vary linearly with salinity. However, many of the data points deviated from the calculated mixing line, suggesting their levels are not controlled only by mixing (Figure A-2). This deviation could be due to 1) the presence of multiple riverine and marine sources with varying DOC and CDOM properties contributing to levels measured, and 2) production and degradation of CDOM and DOC along the salinity gradient. These variable mixing behaviours are in agreement with studies conducted in other regions of the world e.g. the Gulf of Mexico and Baltic Sea (Asmala et al., 2012; Gao and Zepp, 1998).

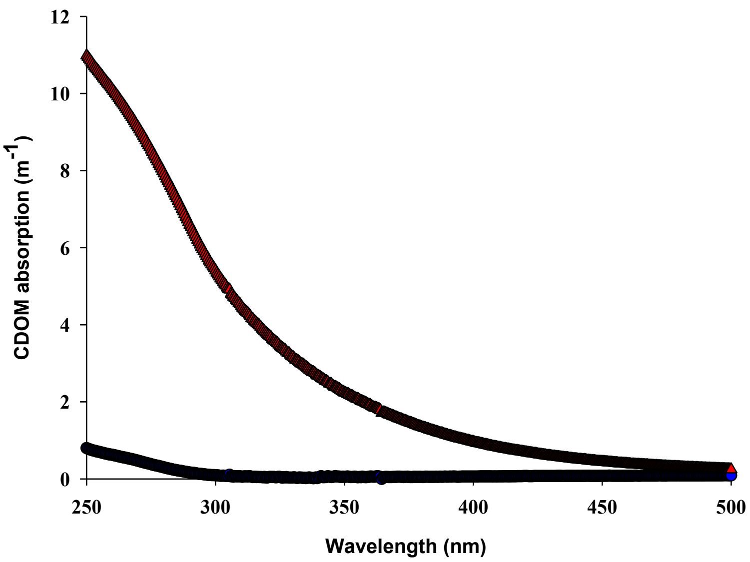

Figure A-1. Light absorption by the coloured fraction of DOM: Example of CDOM absorption spectra from inshore part (red, top) of the Great Barrier Reef Lagoon and offshore waters (blue, bottom).

A salinity of 35 is considered the level where terrestrial input has a minimal impact on salinity levels. A wide range of salinities (25 to 37 ppt) were found, including the hypersaline water (salinity above 35 ppt) which has been reported previously for the GBR during the dry season (Wolanski, 1994). The measured range of DOC concentrations, (64 to 202 µmol L^{-1}) spanned 3-fold over the salinity range from 25 to 37 ppt. In our dataset, it was clear that the CDOM absorption at 254 nm (A_{254}) showed the highest values at lower salinity, and generally decreased to an average value of 1.57 ± 0.63 m^{-1} at salinity 35, resembling the distribution of DOC (Figure A-2a and A-2b).

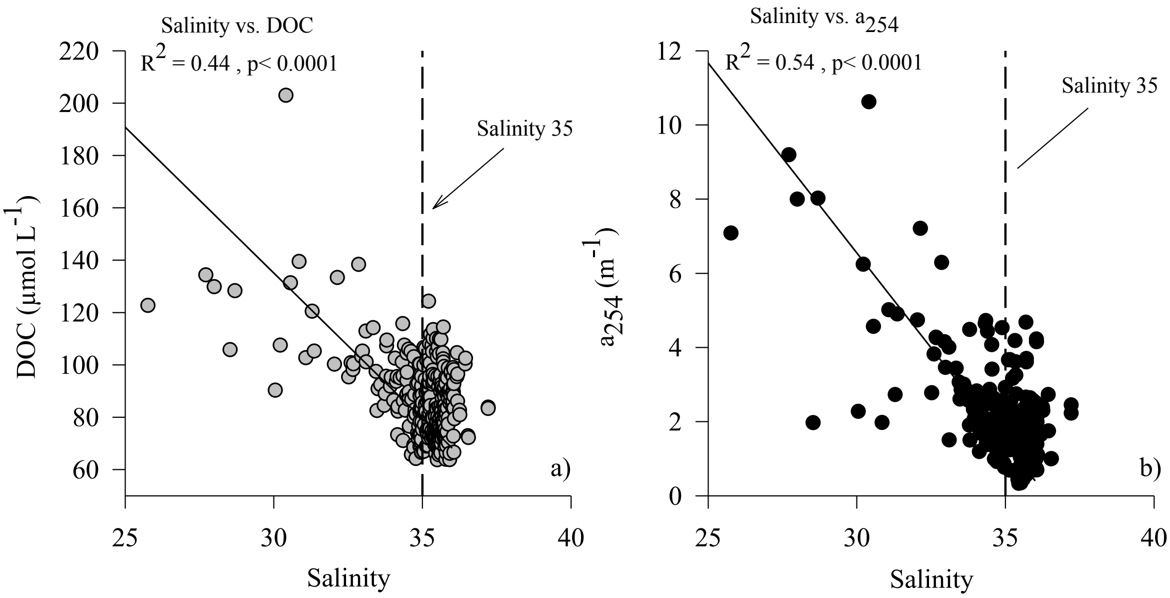

Figure A-2. Relationships between a) salinity and dissolved organic carbon (DOC) and an example of b) salinity and the coloured dissolved organic matter (CDOM) absorption coefficient here at 254 nm (a_{254}). The solid lines represent the conservative mixing line obtained by model II regression and the dashed line indicates salinity 35. R^2 = coefficient of determination, p = significant level.

DOC and A_{254} did not correlate significantly with salinity when samples with a salinity above 35 ppt were included, indicating that below salinity 35 ppt samples are influenced by terrestrial inputs while at higher salinities this influence was less pronounced (Figure A-2a and A-2b).

Therefore, in this study, a salinity of 35 ppt was used as the boundary between terrestrial influenced water and open ocean water.

A linear regression approach was used to test if individual CDOM absorption coefficients could be used to estimate DOC concentrations. As highlighted in Figure A-3 the regression models showed that different CDOM wavelengths had variable strengths in predicting the DOC levels. Our analysis demonstrates that the strongest correlation between CDOM absorption and DOC concentrations were in the wavelength area between 254 and 275 nm. This is in the UV-C range (250 and 270 nm) of the light spectrum which is the region where terrestrial and aromatic compounds strongly absorb (Sulzberger and Durisch-Kaiser, 2009). The higher R^2 values and significance levels of the relationship between DOC and CDOM absorption below 365 nm, could be explained by the greater sunlight degradation of CDOM observed at wavelengths above 400 nm, thus decreasing the strength of the DOC and CDOM relationship at wavelengths above 365 nm (Osburn et al., 2009). It could also be explained by the presence of multiple riverine and marine sources with different DOC and CDOM content and spatial/temporal variations in the sinks.

Remote sensing detects in the range 400 to 700 nm and they have successfully been used in other coastal waters to follow the CDOM spatial and temporal variability. In this study, strong relationships were found between DOC and CDOM below the remote-sensing detectable range (400 to 700 nm), suggesting that this tool cannot directly be used to follow DOC concentration changes in the GBR lagoon.

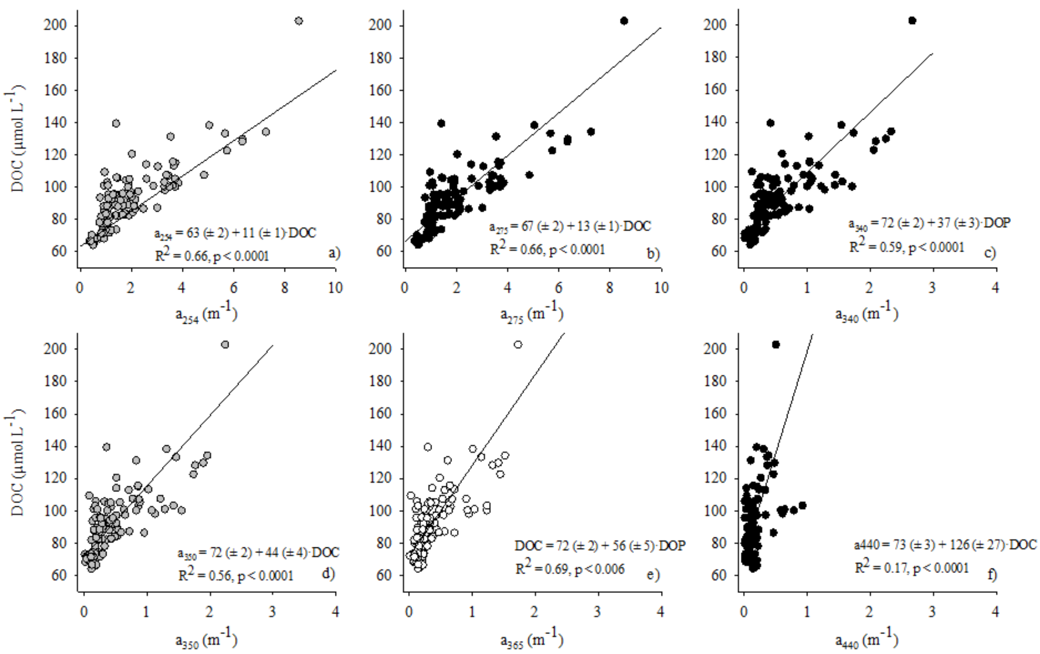

Figure A-3. Relationships between the coloured dissolved organic matter (CDOM) absorption coefficients at different wavelengths (a_{254}, a_{275}, a_{340}, a_{350}, a_{365} and a_{440}) and dissolved organic carbon (DOC). Solid lines represent the corresponding regression. R^2 = coefficient of determination, p = significant level. These relationships only include waters with salinity below 35 ppt.

Table A-1. The slope and intercept (± standard error), R^2, adjusted R2, P values and the standard error of estimates for the linear regressions.

Relationships	Slope (± SE)	Intercept (± SE)	R^2	adj. R^2	p value	Standard Error of Estimate
A_{254} vs. DOC	8.8 ± 0.6	69 ± 2	0.65	0.65	<0.0001	11.9196
A_{275} vs. DOC	10.8 ± 0.7	72 ± 2	0.66	0.66	<0.0001	11.8311
A_{340} vs. DOC	28.5 ± 2.3	77 ± 2	0.59	0.59	<0.0001	13.0193
A_{350} vs. DOC	32.7 ± 2.8	78 ± 2	0.56	0.56	<0.0001	13.4524
A_{365} vs. DOC	41.2 ± 3.7	78 ± 2	0.53	0.53	<0.0001	13.8496
A_{375} vs. DOC	46.3 ± 4.4	78 ± 2	0.50	0.50	<0.0001	14.2806
A_{440} vs. DOC	51.5 ± 11.8	85 ± 3	0.17	0.16	<0.0001	18.5342

A5 Conclusion

- At salinities below 35 ppt, the CDOM absorption at wavelengths between 254 and 275 showed the best capability to predict DOC concentrations.
- A future study should use samples covering a larger temporal and spatial range to test if these relationships (DOC vs a_{254} and DOC vs a_{275}) are valid for the whole GBR.

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

- CDOM is a cheaper (~$2)/faster (minutes) measure, which in the GBR can be used to trace DOC concentrations in waters with salinities below 35 ppt.
- The obtained relationships cannot be applied to detect DOC using remote sensing, as this technique does not capture the CDOM wavelengths able to predict DOC levels.

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Appendix B. Case study: Testing pesticide modelling in the GBR marine environment to inform development of a pesticide metric

Stephen Lewis, Dieter Tracey, Hemerson Tonin, Eduardo da Silva and Rachael Smith

B-1 Introduction

While the photosystem-II (PS-II) herbicides have collectively been identified as key pollutant under the Australian and Queensland Government's Water Quality Protection Plan for the Great Barrier Reef (GBR) (Reef Plan, 2013), their inter-annual influence on GBR water quality is not reported within the annual Report Cards. By comparison, the influence of sediment and nutrients are reported as metrics of total suspended solid (TSS) and chlorophyll-a (Chl-a) concentrations as measured via satellite imagery. In that regard, the spatial areas where exceedance of the water quality guidelines for TSS and Chl-a are compiled and additional calculations are made to produce a final score/ranking in terms of an A (very good), B (good), C (moderate), D (poor) and E (very poor) framework. The PS-II herbicides (or any pesticides) cannot be directly measured or inferred from satellite remote sensing data as concentrations in the GBR are not a direct function of colour dissolved organic matter (CDOM), but rather a function of the end-of-river concentration, the volume of river discharge, the antecedent concentrations in the lagoon (i.e. from previous discharge), the compound half-life and the lateral and vertical mixing of freshwaters in the GBR.

Previous risk assessments for PS-II herbicides in the GBR have continued to improve over the past decade and have gone from assessments of individual herbicides (Lewis et al., 2009) to examining 'normalised additive' PS-II herbicide concentrations (Kennedy et al., 2012; Lewis et al., 2012; Smith et al., 2012) to using CDOM-salinity relationships and end-of-river pesticide concentrations to examine the spatial risk (Lewis et al., 2013). Recent refinements to the normalisation of PS-II herbicides through toxic factors (Smith et al., 2016), improved water quality guideline values for ecosystem protection (DSITI, 2017) and improvements to the hydrodynamic modelling through the e-Reefs framework allow for the 'next generation' of herbicide risk assessments to be performed. This case study incorporates these latest refinements to demonstrate an approach to better quantify the spatial risk of PS-II herbicides in the GBR which can then be incorporated into a metric evaluating the regional water quality condition of pesticides in the GBR lagoon.

The specific objective of this case study was to examine the potential application of the e-Reefs hydrodynamic model coupled with available measured end-of-river PS-II herbicide data to produce an exposure/risk map highlighting areas of the GBR lagoon where exceedance of a PS-II herbicide water quality guideline occurred. In that regard, this case study represents a 'proof-of-application' methodological approach examining one water year rather than a GBR-wide exposure/risk metric that covers multiple years.

B-2 Methods

Using pesticide monitoring data collected from 14 catchments as part of the GBR Catchment Loads Monitoring Program, the raw concentration data for PS-II herbicides (ametryn, atrazine, diuron, hexazinone and tebuthiuron) for the 2013–14 water year (Oct 1 to Sept 30) were converted to an additive PS-II herbicide concentration (diuron-equivalent) using the toxic equivalency factors in Smith et al. (2017). Data were then sorted to highlight the periods where the additive concentrations exceeded the proposed water quality guideline for diuron (0.08 $\mu g.L^{-1}$) for protecting 99% of species (PC99 – protective concentration for 99% of species) (DSITI, 2017). Note that the diuron PC99 for the GBR is currently the subject of further examination where it is yet to be decided on the most appropriate value to adopt given the differences between the diuron freshwater high reliability (0.08 $\mu g\ L^{-1}$) and the diuron marine low reliability (0.39 $\mu g\ L^{-1}$) proposed guideline values (DSITI, in review). Here, the more conservative value is adopted. The rivers where the diuron guideline value was not exceeded were discarded from further analysis as, since the concentrations were below guideline values at the end-of-river site they will never exceed the guideline value upon seawater mixing (and further dilution). From this analysis the Mulgrave, Tully, Herbert and Pioneer Rivers were selected for further examination using the hydrodynamic model. Most commonly, the additive PSII herbicide (diuron equivalent) concentrations exceeded the diuron guideline value over a

4-5 day period (with some exceptions). In that regard, a 4-5 day period was chosen for each of these four rivers where the additive PS-II herbicide concentrations exceeded the diuron guideline value and where sufficient discharge occurred which would result in a sizable flood plume offshore.

The e-Reefs hydrodynamic model was then run for each of the selected rivers for each selected 4-5 day period using the dilution tracer (i.e. the tracer is ‘released’ into the end-of-river with a value of 1 and modelled offshore until the value becomes 0.01 – 1% of the original value). Hence this assumes conservative mixing of the PS-II herbicides in the GBR lagoon which is supported by the available monitoring data (e.g. Lewis et al., 2009; C. Gallen, unpublished data) and that PS-II herbicides are predominantly transported in the dissolved phase (Davis et al., 2012; Packett, 2013). To take into account the antecedent herbicide concentrations in the lagoon, day 1 concentrations at the river mouth mixing into the lagoon with a seawater endmember concentration of ‘0’ were modelled. The concentration of this tracer was then modelled over the following four days with no new tracer (i.e. 0 value) being released from the river into the GBR lagoon to calculate the influence of the contribution of this day over this period. Day 2 concentrations were then modelled to take into account the residual concentrations in the GBR lagoon from the day 1 input as well as the ‘new’ concentration released into the GBR on that day. This approach was continued for days 3, 4 and 5. This approach allows the risk of additive PS-II herbicides to be assessed to take into account antecedent concentrations from previous discharge as well as examine the 3D section (lateral and vertical) of the water column where guidelines would be exceeded (see schematic diagram in Figure B-1).

The mapping outputs examined the maximum PS-II herbicide concentration off each river (i.e. acute effects) as well as the 3-day mean concentration (i.e. chronic 72 h effects). The pixel size for the e-Reefs model of the GBR lagoon is represented by a 500 m by 500 m grid area and so the PS-II herbicide concentrations represent an average concentration for each pixel. Hence, there would be areas within a pixel that may have much higher (or lower) concentrations than the reported average value. It is noted that the vertical mixing outputs are not shown in the analysis.

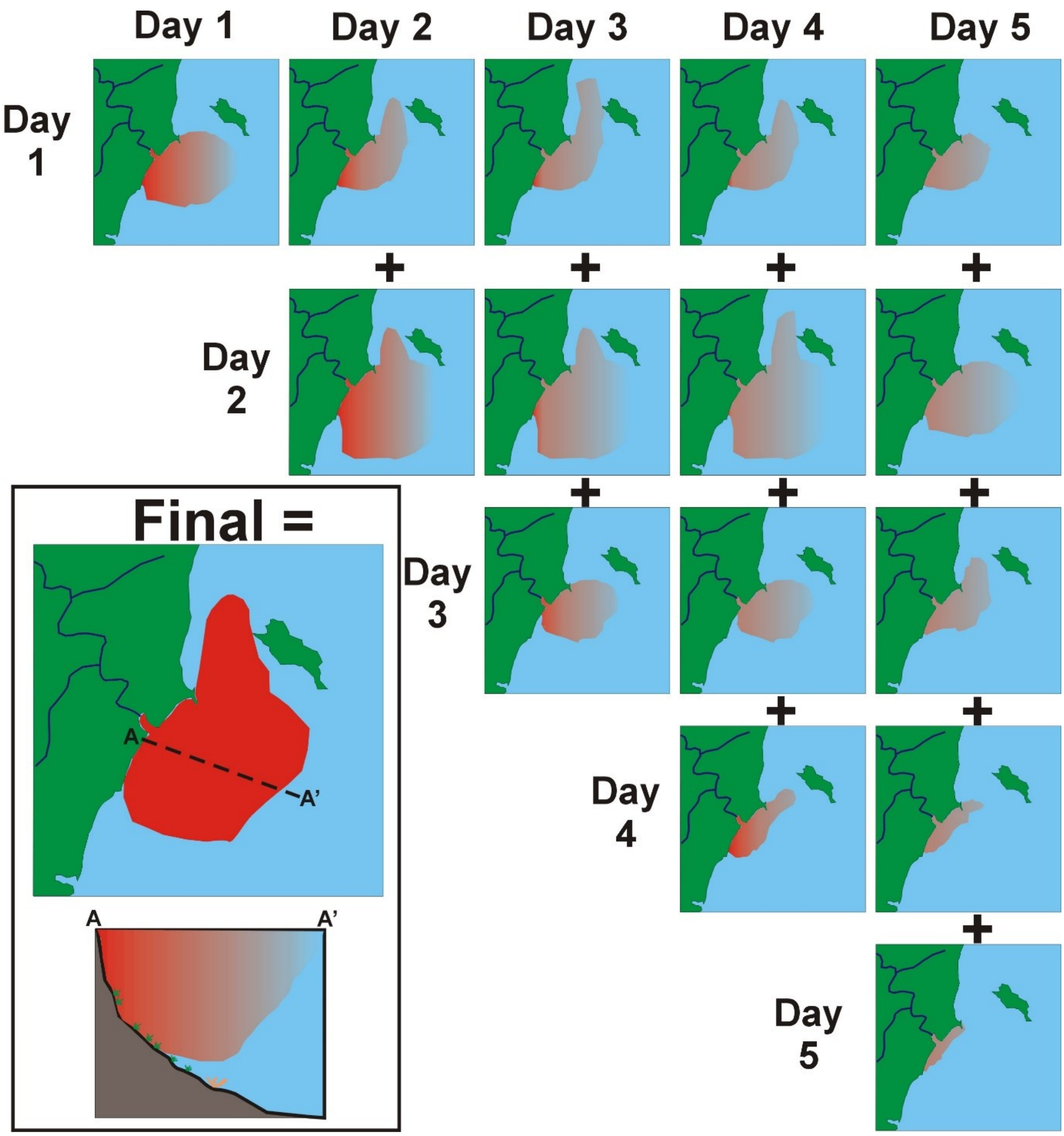

Figure B-1. Schematic diagram to summarise the methods used to generate spatial risk maps from each region. Each map represents the PS-II herbicide concentrations in the GBR lagoon with the final product (map) outlining the total area where exceedance of the GBR water quality guidelines has occurred both laterally and vertically through the water column.

3. Results and discussion

Based on the modelled outputs, the data show that the additive PS-II herbicide concentrations did not exceed the proposed diuron guideline value (freshwater PC99) in any pixel offshore from the mouths of the Russell-Mulgrave, Tully, Herbert and Pioneer Rivers in the Great Barrier Reef lagoon in the 2013/14 water year (Figure B-2 to Figure B-5, based on the 4-5 day event examined in this case study. However, given that the additive PS-II herbicide concentrations did exceed the diuron guideline value at the end-of-system catchment monitoring sites of all these rivers during this time (note that the sampling sites on the Tully, Mulgrave and Herbert Rivers do not capture the full agricultural area where herbicides are applied and so the actual end-of-river concentration may be underestimated), the diuron guideline value may have been exceeded in part of the pixel (500 m) at the mouth and river estuary. The periods targeted were 'first flush' events where PS-II concentrations were highest, although the daily discharge was much lower than the largest event of the season which occurred later on in the year (Figure B-6). However, the additive PS-II herbicide concentrations in these larger events were below the diuron guideline value and so the period of most risk during this particular water year was targeted. In that regard, it would be useful to examine periods where the first flush event of the season also coincided with the larger river flows. Previous monitoring data show periods (i.e. 2004/05) where in the Mackay Whitsunday region a much larger area of the GBR lagoon would have exceeded guidelines (e.g. see Lewis et al., 2009, 2012) and hence the end 'score' at least for this region in that year would be depreciated. Unfortunately, the e-Reefs hydrodynamic model does not go back to this period and so a 'validation' between model predictions and monitoring data cannot be performed at this stage. Furthermore, smaller streams discharging into the lagoon that are not modelled by e-Reefs (e.g. Sandy Creek, Barratta Creek) would also increase the area of PS-II herbicide exposure in the GBR coastal zone. This is a clear limitation in the analysis, although there are currently no options to resolve this issue.

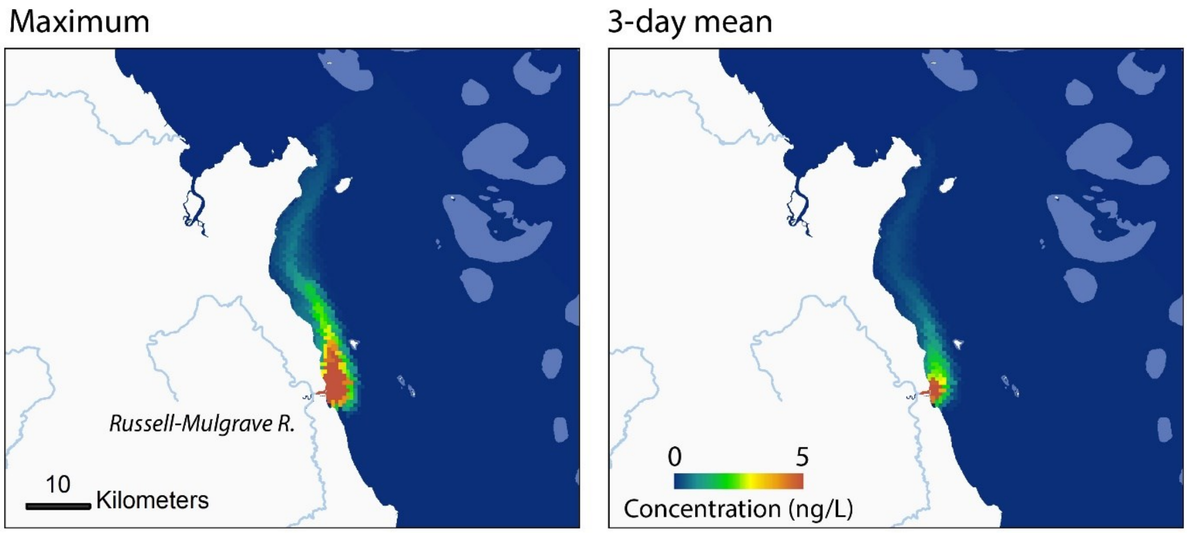

Figure B-2. Modelled additive PS-II herbicide concentrations offshore from the Russell-Mulgrave River including maximum and 3-day mean concentration for the period in the 2013/14 water year coinciding where the highest concentrations were measured.

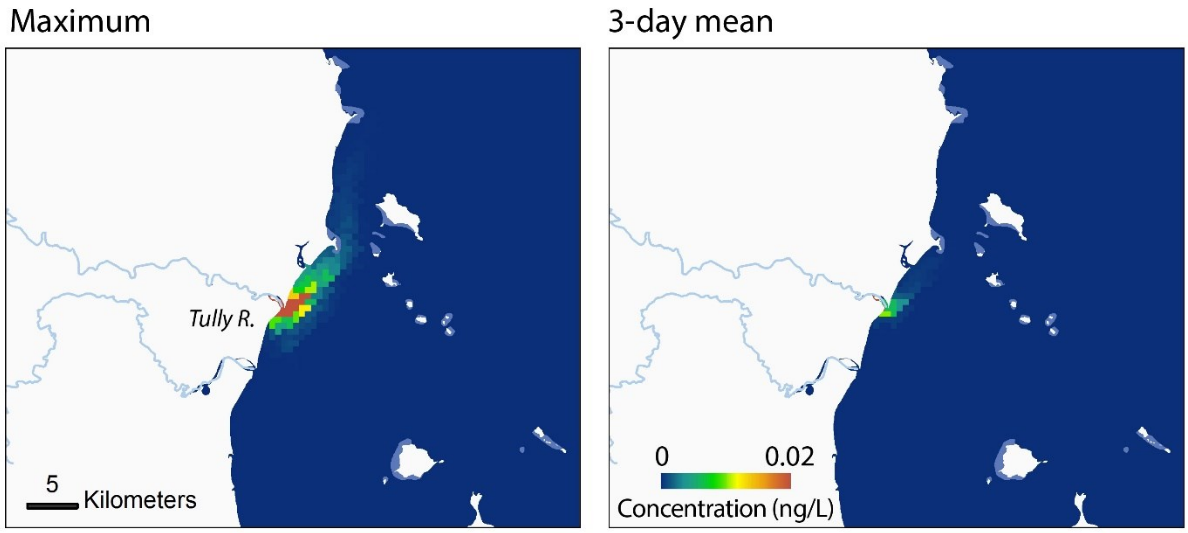

Figure B-3. Modelled additive PS-II herbicide concentrations offshore from the Tully River including maximum and 3-day mean concentration for the period in the 2013/14 water year coinciding where the highest concentrations were measured.

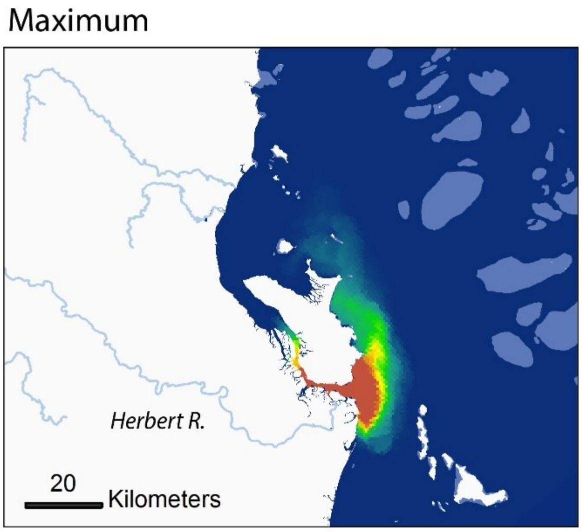

Figure B-4. Modelled additive PS-II herbicide concentrations offshore from the Herbert River including maximum and 3-day mean concentration for the period in the 2013/14 water year coinciding where the highest concentrations were measured.

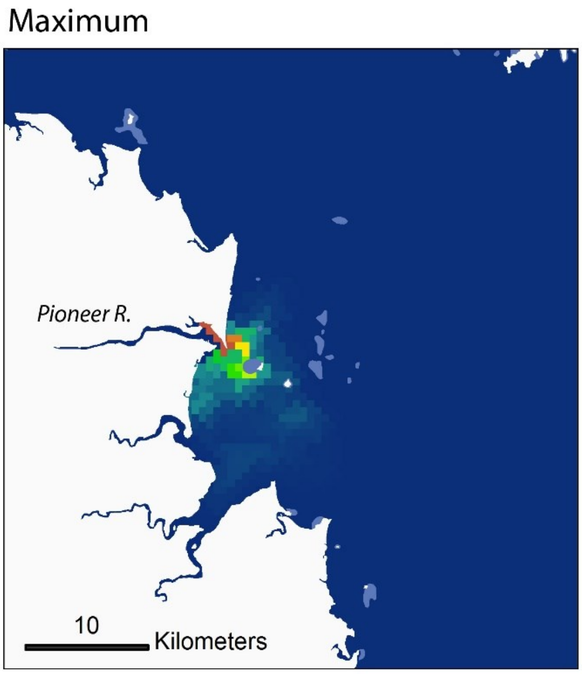

Figure B-5. Modelled additive PS-II herbicide concentrations offshore from the Pioneer River including maximum and 3-day mean concentration for the period in the 2013/14 water year coinciding where the highest concentrations were measured. We note that this model only examines the Pioneer River and does not include the streams to the south of the river such as Bakers or Sandy Creek. Monitoring at these sites suggest that additive PS-II herbicide concentrations would also exceed guideline values at the mouth of these streams and hence concentrations would extend further south if all streams could be modelled.

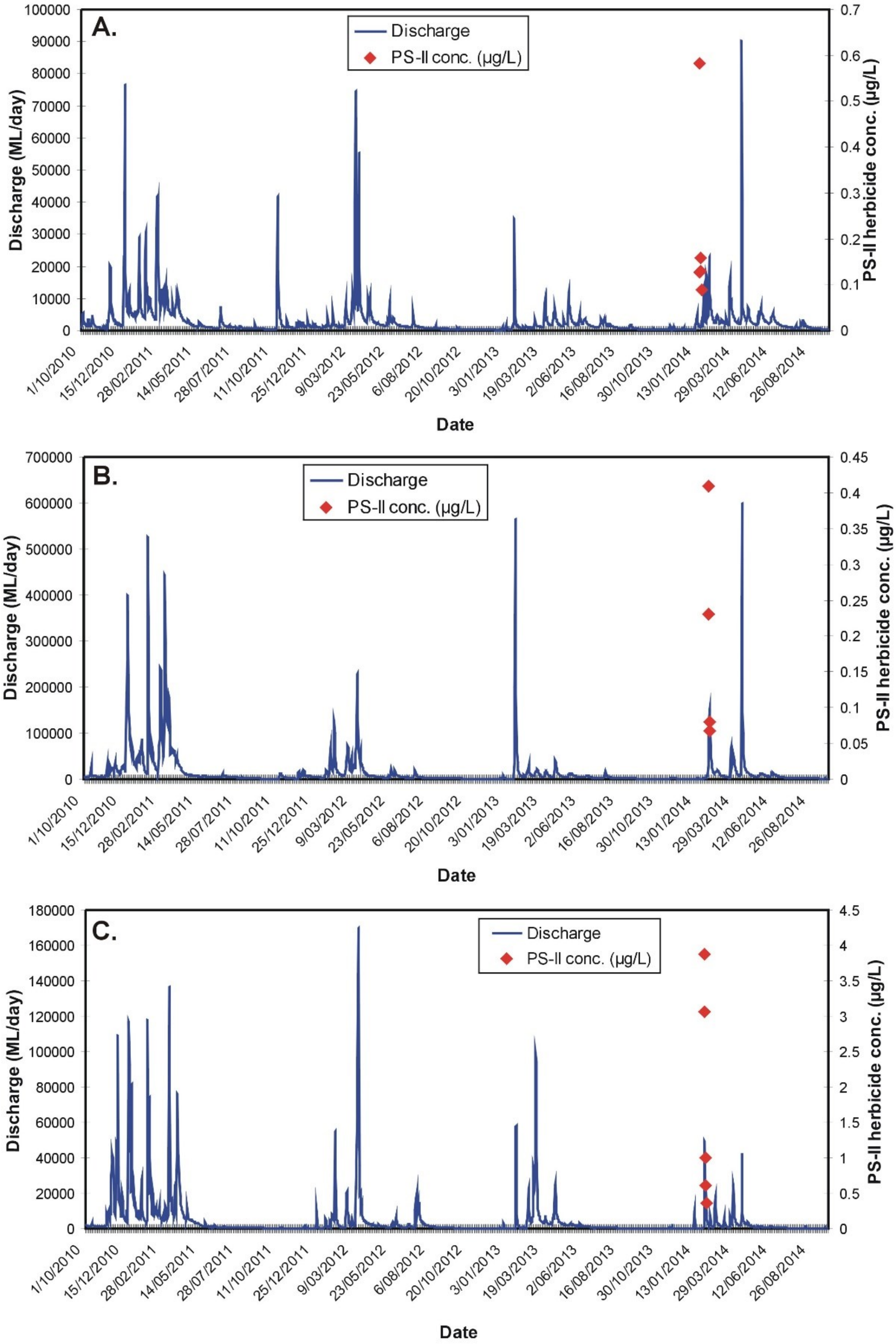

Figure B-6. Daily discharge in ML over 4 water years (2010/11 to 2013/14) highlighting the PS-II herbicide concentrations over 4–5-day periods where the model was run for the Russell-Mulgrave River (A) Using Mulgrave River at Peets Bridge gauge, (B) Herbert River and (C) Pioneer River (C). Note that no daily discharge data were available for the Tully River for the 2013/14 water year.

The assessment of the five (5) day additive PS-II herbicide concentration (plotted as maximum values and three-day mean concentrations) using the hydrodynamic model was a tedious exercise where the daily concentrations exported at the mouth of the river could not be altered and hence it was necessary to produce a number of maps which then needed to be combined and further analysed. The CSIRO e-Reefs team have the capacity to do this analysis by changing the daily concentration and so this option should be explored in the future as longer time periods and additional rivers can then be covered. In that regard, the model could be validated using passive samplers which commonly provide ‘mean herbicide concentrations’ over 1-2 month deployment periods as well as grab samples taken during flood plumes. Note that a combination of end-of-catchment modelling and monitoring (where available) data would be required to examine herbicide exposure and risk for all 35 basins of the GBR catchment area. Furthermore the model only covers ~15 of the major rivers of the GBR and so some of the smaller streams which have very high herbicide concentrations but lower discharge (e.g. Sandy Creek, Barratta Creek) would not be considered in the model.

Our approach highlights a possible way forward to determine herbicide exposure and risk in the GBR using a combination of daily monitoring/modelling data with a hydrodynamic model. However, further discussions would be needed through an expert panel to decide how the metric would be constructed including what constitutes an A, B, C, D and E rating. In that regard, there are two likely scenarios to consider, which include: (1) applying similar metric rules for exceedance of TSS and Chl-a guideline values or (2) a multiple species-Potentially Affected Fraction (ms-PAF) type framework to examine areas where >20%, 10-20%, 5-10%, 1-5% and <1% of species would be affected. Both scenarios could transfer directly into an A-E rating and there are pros and cons for both methods. The guideline exceedance metric is the most simplistic approach and quite straightforward to communicate and would form a consistent approach with the other metrics for TSS and Chl-a. Furthermore, concentrations measured in the GBR lagoon are commonly at the lower range where effects to biological productivity may be expected but not in the range which would result in high order to catastrophic effects such as immediate coral bleaching or organism mortality. However, this approach does not account for the complexity of the influences of multiple pulses of herbicide exposure over a wet season where the productivity of the ecosystem may not recover in between exposure periods. In that regard, the ms-PAF approach can account for this influence of multiple exposures and provide an overall rating for each pixel based on not only the percentage of species affected but also the compromised functioning of the ecosystem.

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Appendix C. Case study: A framework for defining coastal water quality target concentrations for ecosystem conservation in the Great Barrier Reef using empirical light attenuation models

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This case study is currently being prepared as a manuscript; Petus et al. (in prep), and is summarised below for this Annual Report. A full version of the draft paper is available from the JCU project team on request.

Executive summary

- This study used empirical light attenuation models to estimate water quality target concentrations to sustain sufficient light levels for conservation of marine ecosystem exposed to flood river plumes in the Great Barrier Reef (GBR), Australia.
- It modelled the relationship between regional data on light attenuation (Kd(PAR)) and concentrations of optically active water components (OAC), including coloured dissolved organic matter (CDOM), chlorophyll-a (Chl-a) and suspended particulate matter (SPM), collected *in-situ* in river plume waters of the GBR.
- Linear empirical models for Kd(PAR) as a function of SPM, Chl-a and CDOM were fitted to the data collected in the Wet Tropics region of the GBR and showed that all three OAC (CDOM, Chl-a and SPM) contributed to the light attenuation ($r^2 = 0.5$, $p < 0.01$) in the Wet Tropics plume waters.
- The accuracy of the Kd(PAR) prediction increased when the data were clustered into homogeneous plume water bodies, defined by their satellite-derived water colour. SPM and CDOM were the only contributors to light attenuation in the most inshore, turbid region of the river plume (brownish plume, $r^2 = 0.8$, $p < 0.01$), whereas all OACs contributed to light attenuation in the mid-water plumes (greenish plume, $r^2 = 0.5$, $p < 0.01$).
- Empirical models developed in this study were used to translate regional light guidelines into water quality target concentrations. Preliminary results showed that a 90th percentile SPM concentration of 7 mg L^{-1} should be maintained in Wet Tropics plume waters to sustain favourable light levels for Wet Tropics coral and seagrass ecosystems exposed to brownish and greenish plume water bodies during the wet season.
- A preliminary evaluation of the applicability of the empirical algorithms developed to the Dry Tropics region of the GBR was also investigated, but more data will be needed to confidently conclude (not presented in the case study).
- These results contribute to innovative approaches developed to improve land-sea management strategies in the GBR and propose an innovative framework to set ecologically-relevant water quality targets.
- Additional data will be used to further validate the light attenuation models and target concentrations, which can also be incorporated into wider catchment modelling efforts, such as being linked to end-of-river target pollutant loads required to improve coastal water quality.

C-1 Objectives

There is no management action that can directly control the light attenuation in water per se. However, as Kd(PAR) is linked to the content of the water, it is possible to develop empirical models able to quantitatively relate Kd(PAR) to OAC concentrations that can be influenced using best practice land management systems. The mineral SPM supply to the GBR originates mainly from erosion within the watershed and can be controlled, for example, by managing grazing through improved pasture cover and remediation of gullies and streambanks (e.g., Brodie et al., 2012, 2013; Thornburn et al., 2013, Waterhouse et al., 2017). The organic component of the SPM and Chl-a concentrations can be managed by limiting the load of particulate and dissolved nutrients, which can cause the phytoplankton population to decline and the water clarity to improve. This can be achieved, for example, by better managing fertiliser use (e.g. rate, placement and timing of application) in intensive cropping including sugarcane and banana cropping lands (e.g., Brodie et al., 2012, 2013; Thornburn et al., 2013, Waters et al., 2014). Conversely, there is no action that can directly manage the attenuation effects by the seawater (absorption and backscattering effects) and by the CDOM (absorption effect), resulting from the dissolution of any coloured substance into seawater (Abdelrhman, 2016). To maintain sufficient light levels for GBR coral and seagrass ecosystems, management actions should thus focus on reducing the amount of SPM and Chl-a measured in the lagoon in order to comply with relevant light guidelines for ecosystem conservation.

This study aims to develop a reproducible framework to estimate water quality target concentrations for conservation of marine photosynthetic ecosystem exposed to river plumes from simple empirical light attenuation models. In the proposed framework several steps are required (Figure C-1): (i) PAR profiles and CDOM, Chl-a and SPM concentrations are measured in-situ, (ii) the studied marine waters (in this study the Wet Tropics plume waters) are clustered into homogeneous water bodies; (iii) the relationship between Kd(PAR) and OAC concentrations as well as the relative contributions of each OAC to Kd(PAR) variability across the distinct water bodies are empirically modelled and; (iv) the empirical light attenuation models developed are used in combination with published Kd(PAR) guidelines for ecosystem conservation (in this study the GBR coral reefs and seagrasses) to define SPM and Chl-a target concentrations able to support seagrass and coral communities exposed to the distinct plume water bodies. This study focused on the Wet Tropics marine region of the GBR, and data collected during the wet season (November to April), when river floods and resuspension drive the variations in light attenuation (Fabricius et al., 2014, 2016) and high pollutant loads in river floods present the highest water quality risk to marine ecosystems (Davis et al., 2016; Devlin et al., 2015; Waterhouse et al., 2017).

C-2 Material and Methods

Water quality measurements

Depth profiles of PAR, Secchi Disk Depth (SDD), plus supporting CDOM and/or Chl-a, and/or SPM measurements (OAC measurements) were collected in the GBR during five wet seasons (as part of the river plume monitoring program of the Australian Government Reef Program - Marine Monitoring Program (MMP).

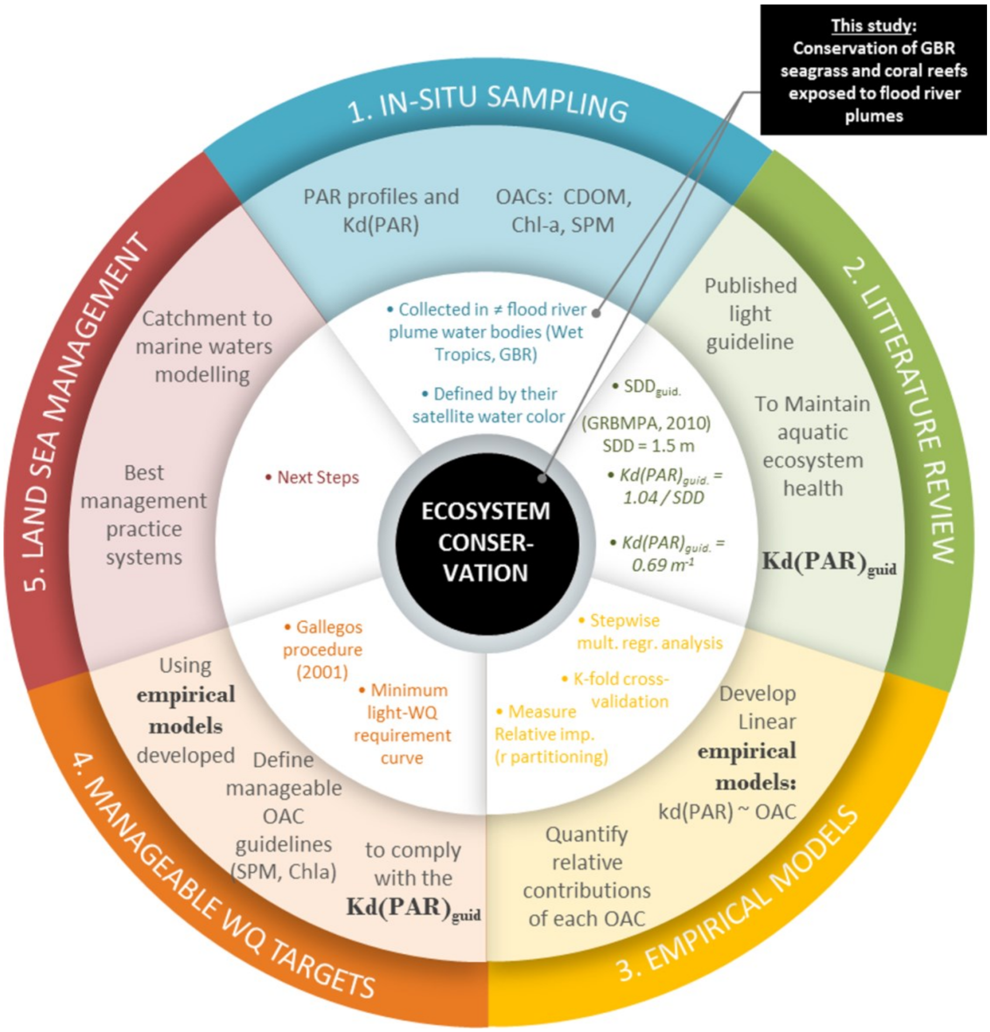

Figure C-1. Stressor-based objective framework developed in this study to conserve ecosystems exposed to river flood plumes in the GBR. This framework aims to define coastal water quality target concentrations for seagrass and coral reef conservation in the Great Barrier Reef (Australia) using empirical light attenuation models.

The number of samples (n) collected was 465 in the Wet Tropics region where frequent rainfall events lead to frequent runoff to coastal environments. A smaller number of samples were collected in the Dry Tropics regions, where major flood events can occur at intervals of years (Burdekin: n=55, Fitzroy: n=3 and Burnett-Mary: n = 65, no samples were collected in the Mackay Whitsundays region). In this study, samples were grouped into two groups: (i) 'Wet Tropics' refers to samples collected in the Wet Tropics region and (ii) 'Dry Tropics' to samples collected in Dry Tropics catchments (Burdekin, Fitzroy and Burnett-Mary regions). Secchi disk depth was measured using a standard Secchi Disk at a number of Wet Tropics sampling sites (n = 130) (GBRMPA, 2010).

Plume water bodies

The method in Álvarez-Romero et al. (2013) was used to produce weekly colour class maps for the wet season 2011 to 2015. The colour class category corresponding to the location of each in-situ water quality sample and the week of its acquisition was then extracted using the raster package (Hijmans et al., 2015) with the bilinear method in R 3.1 (R Development Core Team, 2015).

Kd(PAR) guideline for GBR seagrass and coral reefs conservation

We used the general SDD minimum guideline values defined by the GBR Marine Park Authority (GBRMPA) to define the guideline Kd(PAR) value (Figure C-1, step 2). The general SDD minimum guideline value is a set of guideline values defined to maintain coral reef and seagrass ecosystem health in the GBR (GBRMPA, 2010). The SDD guideline values for the enclosed GBR marine areas (SDD = 1.5 m) was converted to Kd(PAR) using a locally adjusted regression (Poole & Atkins, 1929) between SDD and Kd(PAR) measurements collected in the Wet Tropics (Eq. C-1 and Figure C-2).

Kd(PAR)guid = 1.04 / SDD ; Kd(PAR)guid = 0.69 m^{-1} Eq. C-1

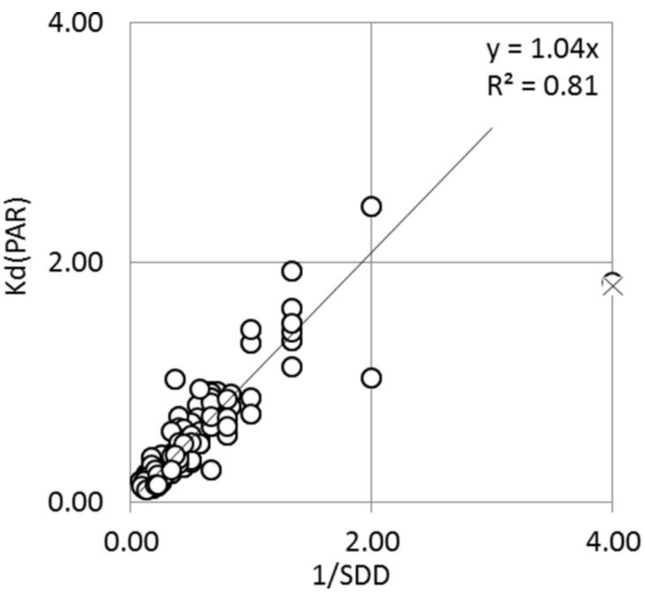

Figure C-2: Locally adjusted regression (Poole and Atkins, 1929) between SDD and Kd(PAR) measurements collected in the Wet Tropics (Eq. 5): Kd(PAR) = 1.04 / SDD.

Empirical model predicting Kd(PAR)

We adopted a simple, non-spectral, linear empirical approach similar to Equation (11) presented in Devlin et al. (2009) or to Equation (3) in Xu et al. (2005) (Eq. C-2 and C-3, and Figure C-1, step 3).

$$K_d = k_w^* + k_{spm}^* SPM + k_{chla}^* Chla + k_{cdom}^* CDOM \quad \text{Eq. C-2}$$

Where k_w^* refer to the effects of water, and k_{cdom}^*, k_{spm}^*, k_{chla}^* to the effect of CDOM, Chl-a and SPM, respectively.

$$K_d(PAR) = a + bSPM + cCHLA + dCDOM \quad \text{Eq. C-3}$$

The linear empirical models developed were chosen so that they provided good empirical explanations of variation in Kd(PAR) and the model parameters (a, b, c and d) cannot be explained in terms of any particular optical meaning.

Linear empirical models between Kd(PAR) and concentrations of OACs (hereafter empirical light models) were fitted by step-wise multiple regression analysis in order to determine the best combinations of the OACs (i.e., using all, a combination or a single OAC as explanatory variable(s)) to predict Kd(PAR) (Figure C-1, step 3). The Wet Tropics dataset was the most data-rich and was used to build the empirical light models.

Performances of the empirical light models were evaluated using a k-fold cross validation measure (CVM). The k-fold method randomly removes k-folds for the testing set and models the remaining (training set) data. It calculates the cross validation residual sum of squares which is a corrected measure of prediction error averaged across all folds, with lower values indicating greater accuracy. In this study we used the commonly accepted 10-fold application (Harrell, 1998). Measures of relative importance for each respective OAC (IOAC) in the best (i.e., using all, a combination or a single OAC as explanatory variable(s)) linear predictive models were computed (R2 partitioned by averaging over orders, Lindemann et al., 1980) (Figure C-1). This function provides a decomposition of the model explained variance into non-negative contributions.

Translation of Kd(PAR) guideline into target water quality concentrations

The procedure adapted from Gallegos (1994, 2001) was used to estimate SPM and Chl-a target concentrations able to sustain sufficient light levels for conservation of seagrass and coral reef exposed to river plumes in the GBR. This procedure includes three general steps (Figure C-1, Step 4): (i) a published Kd(PAR) threshold value to maintain ecosystem health is selected (in this study, Kd(PAR) = 0.69 m-1, see section 2.3); (ii) the curves of OAC values to comply with the Kd(PAR) guideline are calculated using the empirical light models developed (hereafter “minimum light-water quality requirement curve”) and; (iii) these curves are used to define management trajectories and to calculate target water quality concentrations

Gallegos’ method (1994, 2001) was defined for Kd(PAR) modelled with two OACs. In this study, when more than two OACs contributed to Kd(PAR), i.e., when SPM, Chl-a and CDOM all significantly contributed to the light attenuation, a background value for the OAC that contributed the least to light attenuation was set as its long-term median value. All OAC data measured in-situ and the long-term 90th percentile (P90OAC) of each plume water type were plotted and were compared to the minimum light-water quality requirement curve. If the P90 of one of OAC’s pair falls on the right side of the minimum light-water quality requirement curve, then P90OAC for either one or both OACs must be reduced (‘management trajectory’) to comply with target P90OAC concentrations that encounter the light-water quality requirement curve. The wet season SPM and Chl-a target concentrations (measured as P90 concentrations) were determined analytically by solving the empirical regressions developed.

C-3 Results

Empirical light models predicting light attenuation

All OACs contributed significantly to the prediction of light attenuation in the full plume dataset (Table C-1, r^2 =0.5, CVM = 0.12) and the SPM and CDOM had the greatest relative importance (Figure C-3, ISPM= 0.6, ICDOM= 0.3 and IChl-a= 0.1). In the GBR, colour classes 1 to 4 are usually grouped together, under the term “Primary” waters (e.g., Devlin et al., 2015). In this study empirical light models performed better when they were fitted to data grouped into [CC1, CC2 and CC3] (hereafter brownish plume) and [CC4 and CC5] (hereafter greenish plume), respectively (Table C-1).

It showed that SPM and CDOM are significant explanatory variables in the brownish plumes (ISPM = 0.7 and ICDOM = 0.3). In the greenish plume, all OAC were contributing, with the SPM and Chl-a the most important contributors (ISPM= 0.7, IChl-a= 0.2 and ICDOM= 0.1). Finally, only CDOM was contributing to the light attenuation in the CC6, but this was not significant (Table C-1). This analysis resulted in three significant ($p< 0.01$) empirical light models available to define wet season SPM and Chl-a target concentrations in Wet Tropics river plumes (Table C-1): the full plume model (Eq. C-4, r^2 = 0.5, CVM=0.12), the brownish plume model (Eq. C-5, r^2 = 0.8, CVM=0.14) and the greenish plume model (Eq. C-6, r^2=0.5, CMV=0.05):

Full plume (CC1-CC6): Kd(PAR) = -0.0137 + 0.0545 SPM + 0.0750 Chl-a + 0.3667 CDOM Eq. C-4

Brownish plume (CC1-3): Kd(PAR) = -0.1315 + 0.0746 SPM + 0.2563 CDOM Eq. C-5

Greenish plume (CC4-5): Kd(PAR) = 0.038 + 0.049 SPM + 0.118 Chla + 0.189 CDOM Eq. C-6

Table C-1: Coefficient of determination (r^2), p values and k-fold cross validation measure (CVM) of the empirical light models. n indicates the number of rows available to fit the model, nc. indicate the OAC variables not contributing to Kd(PAR). Significance for each variable is indicated as: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '-' 1 '.' not significant ns.

Name	Colour classes	n	r^2	p value	Intercept	SPM	Chl-a	CDOM	CVM
Full plume	CC1 - CC6	320	*0.5*	***	.	***	***	***	0.12
Primary [*a]	CC1 - CC4	138	*0.6*	***		***	nc.	***	0.13
Secondary [*a]	CC5	150	0.3	***	.	***	**	nc.	0.07
Tertiary [*a]	CC6	32	*0.2*	*ns*	***			*	0.01
Brownish	**CC1 - CC3**	**47**	***0.8***	***		***	**nc.**	***	**0.14**
Greenish	**CC4 - CC5**	**241**	**0.5**	***		***	***	**	**0.05**

*[*a] Devlin et al., 2015*

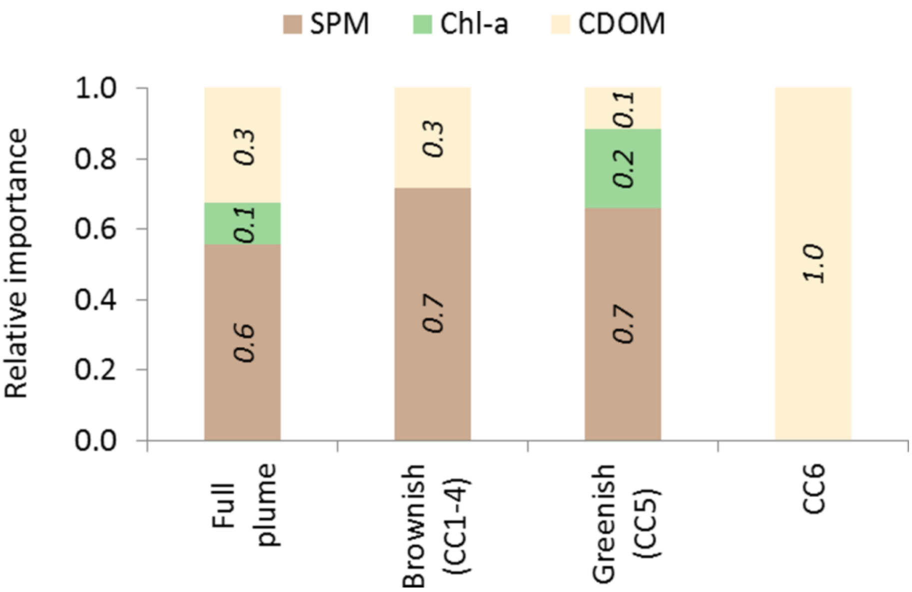

Figure C-3: Relative importance of each selected explanatory variables in (full plume) and across Wet Tropics river plume water bodies (brownish and greenish plume waters).

Translation of Kd(PAR) guideline into water quality targets

The brownish and greenish plume empirical light models developed for the Wet Tropics plume waters (Eq. C-5 and Eq. C-6) were used in combination with $Kd(PAR)_{guid}$ = 0.69 m^{-1} in order to calculate the minimum light-water quality requirement curve for each respective plume water body (Figure C-4). In the brownish plume waters off the Wet Tropics, both SPM and CDOM are significant explanatory variables to the light attenuation (Table C-1 and Figure C-3) and long-term 90th percentile concentrations of SPM and CDOM measured *in-situ* are the highest of all the optical water bodies ($P90_{SPM}$ = 13.40 mg L^{-1} and $P90_{CDOM}$ = 1.21 m^{-1}). The minimum light-water quality requirement curve for the brownish plume waters was calculated using back-transformation of Eq. C-5 (i.e., SPM = ($Kd(PAR)_{guid}$ + 0.1315 - 0.2563 CDOM) / 0.0746) and CDOM values were varied over their natural range of variation (>0 to 2 m^{-1} in the brownish plume waters) (Figure C-4a).

In the greenish plume waters of the Wet Tropics, all OACs are significant explanatory variables to the light attenuation, but CDOM has lower relative importance (Table C-1 and Figure C-3). A background CDOM value was set using the long-term median CDOM concentration recorded in the greenish plume waters of the Wet Tropic region ($CDOM_{back}$ = 0.64 m^{-1}). The Chl-a concentration was varied over its natural range of concentration (>0 to 5 µg L^{-1} in the greenish waters) and back-transformation of Eq. C-6 (i.e., SPM = ($Kd(PAR)_{guid}$ -0.038 -0.118 Chla -0.189 $CDOM_{back}$) / 0.049) was used to calculate the corresponding SPM values and the minimum light-water quality requirement curve for the greenish waters (Figure C-4b).

The minimum light-water quality requirement curves calculated indicated that reduction from an *in-situ* $P90_{SPM}$ concentration of 13.4 mg L^{-1} (long-term P90 concertation measured *in-situ*) to a target $P90_{SPM}$ concentration of 6.9 mg L^{-1} (49% reduction) would be needed to ensure that 90% of the samples measured in the Wet Tropics brownish plume waters comply with the $Kd(PAR)_{guid}$ of 0.69 m^{-1} (Figure C-4a). In the greenish plume waters, reductions from an *in-situ* $P90_{SPM}$ of 11.0 mg L^{-1} to a target $P90_{SPM}$ concentration of 6.8 mg L^{-1} (38% reduction) or, alternatively, reduction from *in-situ* $P90_{Chla}$ of 1.7 µg L^{-1} to trace concentrations (100% reduction) were calculated (Figure C-4b).

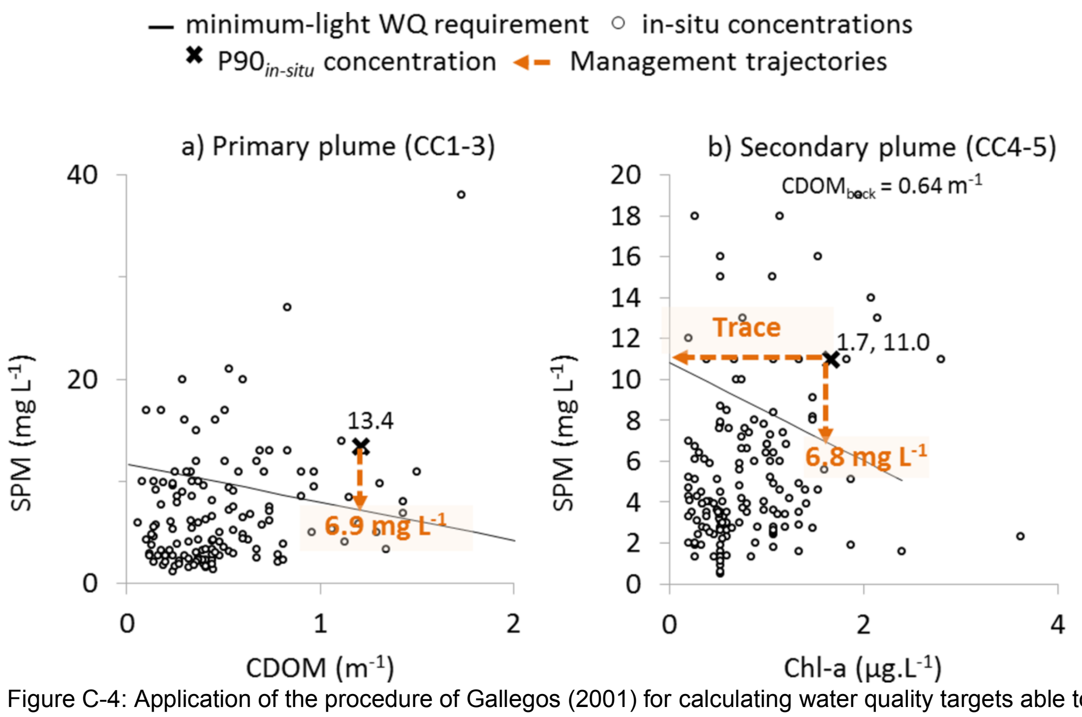

Figure C-4: Application of the procedure of Gallegos (2001) for calculating water quality targets able to support GBR marine ecosystems exposed to the brownish and greenish plume waters in the Wet Tropics.

C-4 Discussion: A framework to estimate water quality target concentrations for marine ecosystem conservation from simple empirical light models

This study demonstrated that Kd(PAR) can be predicted in the river plume waters off the Wet Tropics region using linear empirical light models for Kd(PAR) as a function of SPM, Chl-a and CDOM. It should be emphasised that the major purpose of this study was not to provide a complete analysis of the components of Kd(PAR) (IOPs and angular distribution of the light field in the water), but rather to provide simple empirical models that identify the main OACs driving light attenuation across GBR plume waters, and thus provide managers information on priorities for improving water quality from the GBR catchments.

Using all data collected in the Wet Tropics plume waters, 50% of the variability in Kd(PAR) was captured (Table C-1) and the order of importance of contributors to light attenuation from highest to lowest was SPM, CDOM, and Chl-a (Figure C-3). The relative contributions of each OAC varied locally across the distinct optical water bodies existing in the Wet Tropics river plumes and the accuracy of the Kd(PAR) prediction increased when the data were clustered by water bodies with similar surface water colour (r^2 up to 0.8 in the brownish plume waters). These results reiterated the optical complexity of the coastal and river plume waters of the GBR (Cherukuru, 2016; Oubelkheir et al., 2013, 2014) and the importance to group waters with similar optical traits to develop adapted models when modelling highly variable coastal waters (Moore et al., 2009; Vantrepotte et al., 2012).

The method used in this study to derive wet season SPM and Chl-a (modified from Gallegos, 1994, 2001) relies on the fact that the empirical light models developed between Kd(PAR) and SPM and/or CDOM and/or Chl-a concentrations give analytical expressions for combinations of water quality values that will result in a particular value of Kd(PAR), and can thus be used to translate published Kd(PAR) guideline into SPM and Chl-a target concentrations. Light reduction guidelines for seagrass have been derived using experimental approaches (Chartrand et al., 2016; Collier et al., 2016a, 2016b) but have focused on short-term impacts of light reduction rather than long-term exposure to degraded light environments.

In the GBR, many seagrasses occur in the inshore region of the GBR (Carter et al., 2016), close to the sources of SPM and Chl-a, and this study used the GBR SDD guidelines for the GBR enclosed waters (GBRMPA, 2010). This guideline is a mean annual water clarity minimum and is, to our knowledge, the only 'long-term' guideline available to define Kd(PAR) guidelines to maintain GBR seagrass and coral health exposed to declining water quality. A locally adjusted regression was used to relate Kd(PAR) to the inverse of SSD (Kd(PAR) = 1.04 / SDD, Poole & Atkins, 1929, Zhang et al., 2012); with the empirical coefficient a = 1.04 (Eq. 5) similar to the typical coefficient found for turbid waters (a = 1.3; e.g. Koenings and Edmundson, 1991).

High pollutant loads in river floods and associated pollutant concentrations measured in the GBR lagoon represent the highest water quality risk or worst-case scenario to marine ecosystems (Davis et al., 2016; Waterhouse et al., 2017). Wet season SPM and Chl-a target concentrations were therefore established through a conservative approach, *i.e.,* by using the long-term 90^{th} percentile which represents a concentration such that 90% of the observations are equal to or less than this value. However, mid-range scenarios could also be built by considering the long-term average concentrations to define the minimum light-water quality requirement curves and wet season SPM and Chl-a target concentrations.

A preliminary target P90 concentration of 7 mg L^{-1} for SPM was calculated for the Wet Tropics brownish and greenish plume waters, which corresponds to reductions of 49% and 38%, respectively of the $P90_{SPM}$ concentrations currently measured in the Wet Tropics river plumes (Figure C-4). Alternatively, a reduction of 100% of the $P90_{Chl\text{-}a}$ concentration in the greenish plume waters (i.e., to trace or null concentration) was calculated; but is impossible to reach as a management objective.

C-5 Future work

Work is required to improve our understanding of the frequency, duration (number of continuous days and weeks) and consequences of exposure of seagrass and coral ecosystems to the distinct plume water bodies, and to develop Kd(PAR) guidelines accordingly. The number of continuous days or weeks a particular ecosystem was in contact with particular water bodies, is available through the processing of daily MODIS true colour data and will be analysed in future work. Furthermore, it is likely that deepwater seagrasses and coral reefs, which occur predominantly in the mid and outer GBR (e.g. Coles et al., 2009) will have higher light requirement than species of seagrass which typically grow in shallower waters and are more regularly exposed to brownish plume water types. Characteristics such as the sensitivity and resilience of particular seagrass or coral communities, for example associated with their natural levels of exposure to pollutants, are additional parameters that must be considered when defining ecologically relevant water quality targets as different species assemblages will respond differently to the same exposure to reduced light levels (e.g., Collier et al., 2016b). In the future, a better definition of Kd(PAR) thresholds for coral reefs and seagrass through ongoing monitoring and assessment will improve the ability to define ecologically relevant SPM and Chl-a target concentrations (e.g., Brodie et al., 2013; Waterhouse et al., 2017).

In the future, thresholds, models and targets will be adapted and improved with continual validation and reduced uncertainty and it will be then possible to incorporate these results in catchment modelling scenarios to estimate the long-term annual load reductions and applied management actions needed to comply with the defined SPM and Chl-a target concentrations (Figure C-1, step 5). Results will be compared to current targets set by the Australian and Queensland Government's Reef Water Quality Protection Plan (Queensland and Australian Government, 2013) that at least aims for a 20% reduction in anthropogenic end-of-catchment loads of sediment and particulate nutrients and a 50% reduction of anthropogenic DIN loads in priority GBR areas toward 2018. The optical model developed in this study could furthermore be coupled with load models to predict future scenarios for water clarity in the GBR and optical models could also be adjusted to assess coupled targets for Kd(PAR) in terms of a combination of reduction in SPM and Chl-a loads.

The light availability in the GBR lagoon has been defined as one of the priority pressures to monitor in order to better understand cumulative impacts of stressors on local ecosystems and better inform management decisions (Uthicke et al., 2016). This study works toward this objective by providing information on manageable pressures as well as a simple and reproducible method that can improve the resilience of the inshore GBR. The framework can be used for other marine regions of the GBR and worldwide given that sufficient in-situ data are available and that the empirical relationships are regionally adjusted following the processes proposed in this study

6. References

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Appendix D: Water quality monitoring methods

D-1 Direct water sample collection, preparation and analyses

At all AIMS sites each of the 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 (Sea Tech, 25 cm, 660 nm) for concurrent chlorophyll-a and turbidity measurements. 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 to three depths through the water column with Niskin bottles. Sub-samples taken from the Niskin bottles were analysed for chlorophyll-a, total suspended solids and the following species of dissolved and particulate nutrients and carbon:

- 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 organic 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 later 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 room temperature until analysis.

Dissolved Inorganic nutrients (NH_4, NO_2, NO_3, PO_4, $Si(OH)_4$) 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 are 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 orthophthal-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.

Dissolved organic carbon (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 extract Chl-a concentrations were determined spectrophotometrically using the wavelengths and equation specified by Jeffrey and Humphrey (1975).

The particulate organic carbon (POC) and particulate nitrogen (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 IRGA and total bound Nitrogen (TNb, as nitrogen oxides) was quantified by chemiluminescence. The analyses were standardised using certified reference materials.

Particulate phosphorus (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.

D-2 Autonomous Water Quality Loggers

Instrumental 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 year round 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 which 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 (Conductivity-Temperature-Depth) 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 be fitted with additional sensors such as fluorometers, transmissometers or PAR (Photosynthetically Available Radiation) sensors. Annual calibrations of the profiler instrumentation are carried out by specialised laboratories, such as CSIRO CMAR in Hobart, or Sea-Bird Electronics and WET Labs 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 hr prior to use. 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 11.2V, and the CTD memory is cleared prior to a trip.

Pre-deployment of the CTD profiler on board the boat, the CTD is secured to the boat cable. Tygon tubing is removed from the CTD to allow flush water to drain from the C-T cell, and protective caps 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 filled with water.

Post deployment, when on board 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 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.

D-4 Comparison with GBR Water Quality Guideline values

The Water Quality Guidelines for the Great Barrier Reef Marine Park (GBRMPA, 2010) provides a useful framework to interpret the water quality values obtained at the twenty 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 guidelines values applied at each site can be found in Table E-10.

The relevant GVs from Queensland Water Quality Guidelines (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 (De'ath and Fabricius, 2010) 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	$\mu g\ L^{-1}$	2.0	2.0	0.45	0.45	0.45	0.45	0.40	0.40
Particulate nitrogen	$\mu g\ L^{-1}$	n/a	n/a	20.0	20.0	20.0	20.0	17.0	17.0
Particulate phosphorus	$\mu g\ L^{-1}$	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	$\mu g\ L^{-1}$	10.0	3.0	2.0	3.0	2.0	2.0	2.0	2.0
PO_4^Qld	$\mu g\ L^{-1}$	5.0	6.0	4.0	6.0	4.0	6.0	4.0	5.0

** The turbidity trigger value for opens coastal and midshelf 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, GBRMPA 2010, DERM 2009) for the following water quality constituents: chlorophyll-a (Chl-a), particulate nitrogen (PN), particulate phosphorus (PP), total suspended solids (TSS), Secchi depth, oxidised nitrogen (NO_x) and phosphate (PO_4).

Daily averages of the chlorophyll fluorescence and turbidity levels measured 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 (Chl-a a, TSS, Secchi depth, turbidity, NO_x, PN, PP) on a region or sub-region level. The Wet Tropics 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 the 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 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 current Paddock to Reef Report Cards (e.g., Anon. 2013), water quality assessments are based only 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. 2013). 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 (nutrients, dissolved and suspended organic matter, suspended particulates etc.) 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 had 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 in Schaffelke et al., (2012b) 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. Total suspended solids (TSS) concentration, in water samples; Secchi depth; and turbidity measurements by FLNTUSB instruments, where available.
2. Chlorophyll-a (Chl-a) concentration in water samples;
3. Particulate nitrogen (PN) concentrations in water samples;
4. Particulate phosphorus (PP) concentrations in water samples;
5. Dissolved oxidised nitrogen (NOx) concentrations in water samples; for this variable only Queensland guideline were available.

The six 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 for 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. Chlorophyll 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). In this year's report we have included NOx in our index calculation even though only Queensland guideline 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 the significant changes that we have observed in the NOx concentrations over the course of the monitoring program. Despite these significant limitations we believe it to be more valuable to include these measurements than not at all considering the increased NOx concentrations. It has to be emphasised that it is pivotal for the reliability of the index to establish GBRMPA guideline for NOx (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 potential useful variables such as total nitrogen and phosphorus.

Steps in the calculation of the index:

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

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, respectively, signify a doubling and a halving 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 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, SS 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, NOx, Chla and the combined turbidity ratio;

6. 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. < -0.33to -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 GBRMPA guidelines (guidelines values are now site specific and pertain to a more complex assortment of seasonal and annual means and median) well as modifications to sampling design and the addition of JCU observations. Consequently, in addition to the above procedure (used with the previous GBRMPA 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, SS 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, NOx, 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. < -0.33to -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, 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 Table E-10.

D-7 Validation and analysis of wet season water quality and exposure maps

The analysis of the water quality parameters sampled in flood plume waters are quite descriptive, and their main objective is to characterise the plume maps, i.e., to provide the range of the water quality parameters expected for each wet season water type (either the six wet season colour classes maps or for the Primary, Secondary and Tertiary water types). Once this characterisation is complete, the wet season maps can be used to estimate transport of land-based pollutants (see, e.g. Section 2.8 in this report) and also for the exposure maps (see for example Section 3.3 in this report). The wet season maps characterisation is attained by data extraction, when match-ups between sampled date and the corresponding weekly wet season water type maps are performed at site location basis. Match-ups were performed using *extract* in the raster package (Hijmans et al., 2015) with bilinear interpolation method in R 3.2.4, which interpolates from the values of the four nearest raster cells (R Development Core Team, 2015).

Table D-2: Summary of statistical analysis techniques exploring spatial and temporal variation applied to the water quality parameters sampled within the wet 2014–15 wet season.

Statistical approach	Data set used and method	Outcome
Match-ups *in-situ* data and season water type	Data extracted with bilinear interpolation.	Range of *in-situ* water quality concentrations within each wet season water type.

D-8 Mapping of river plumes using classification into 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 both the extent and frequency of river plume exposure on GBR ecosystems. Ocean colour imagery provides synoptic-scale information regarding the movement and composition of river plumes. Thus, in the past seven 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 river plumes in GBR waters (e.g., Bainbridge et al., 2012; Brodie et al.; 2010; Devlin et al.; 2012a, b; Schroeder et al., 2012).

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

The wet season water types are produced using MODIS true colour imagery reclassified to six distinct colour classes defined by their colour properties. The wet season water types are regrouped into three water types (Primary, Secondary and Tertiary) characterised by different concentrations of optically active components (TSS, colour dissolved organic matter and chlorophyll-a [Chl-a]) which control the colour of the water and influence the light attenuation, and different pollutant concentrations:

• Primary water type (colour classes 1 to 4): Corresponds to the brownish to brownish-green very turbid water masses. These waters are with high nutrient and phytoplankton concentrations, but are also enriched in TSS and dissolved organic matter and have reduced light levels. They are typical for near-shore areas or inshore regions of river plumes.

• Secondary water type (colour class 5): Corresponds to the greenish to greenish-blue turbid water masses (intermediate turbidity) and are typical of coastal waters dominated by algae, but also with some dissolved matter and some fine sediment present. Relatively high nutrient availability and increased light levels due to sedimentation favour an increased coastal productivity in this water type. This water type is typical for the coastal waters or the mid-region of river plumes.

• Tertiary water type (colour class 6): Transitional, greenish-blue water mass with slightly above ambient turbidity and nutrient concentrations. This water type is typical for areas towards the open sea or offshore regions of river plumes.

Within GBR river plumes (from the inshore to the offshore boundary of river plumes), the water types are characterised by varying salinity levels, spectral properties and colours summarised in Table D-3, and different water quality concentrations (Devlin et al., 2012a, Álvarez-Romero et al., 2013 and Petus et al., 2014b).

- The Primary water type presents very high turbidity, low salinity (0 to 10 ppt; Devlin et al., 2010), and very high values of CDOM and total suspended solids (TSS). Turbidity levels limit light penetration in Primary waters, inhibiting primary production and limiting Chl-a concentration.
- The Secondary water type is characterised by intermediate salinity, elevated CDOM concentrations, and reduced TSS due to sedimentation of the coarser particles (Bainbridge et al., 2012). In this water type (middle salinity range: 10 to 25 ppt; Devlin et al., 2010), the phytoplankton growth is prompted by the increased light (due to lower TSS) and high nutrient availability delivered by the river plume.
- The Tertiary water type occupies the external region of the river plume. It exhibits no or low TSS associated with the river plume, and above-ambient concentrations of Chl-a and CDOM. This water type can be described as being the transition between Secondary water

and marine ambient water, and have salinity lower than the marine waters (typically defined by salinity ≥ 35 ppt; e.g. Pinet, 2000).

Supervised classification using spectral signatures

Daily MODIS Level-0 data are acquired from the NASA Ocean Colour website (http://oceancolour.gsfc.nasa.gov) and converted into true colour images with a spatial resolution of about 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, tertiary) corresponding to the three wet season water types defined by Devlin and Schaffelke (2009) and Devlin et al. (2012a).

Production of weekly wet season water type maps

The sediment-dominated waters or primary water type are defined as corresponding to Greenish-brown waters, i.e.., colour classes 1 to 4 of Álvarez-Romero et al., (2013). The Chl-a-dominated waters or secondary water type is defined as corresponding to the greenish waters (i.e., colour class 5 from Álvarez-Romero et al., 2013) and the tertiary water type is defined as corresponding to the Bluish green waters, i.e., colour class 6 of Álvarez-Romero et al., (2013) (see Table D3). The ”turbid waters” are defined as the combination of the Primary; Secondary and Tertiary plume water surfaces.

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).

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 (hereafter wet season frequency maps). Pixel (or cell) values of these maps range from 1 to 22 (normalised value of 0.45 – 1); 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 overlayed in ArcGIS to create multi-annual (2003-2015) normalised frequency composites of occurrence of plume s (hereafter multi-annual frequency maps). An improved cloud mask was developed this year and applied to the 2015–16 and 2010–11 satellite products (weekly wet season water type composites, frequency and exposure maps) (Figure D-1). It allows distinguishing cloudy areas and marine waters that were previously both classified as “no plume” waters. The whole suite of satellite data (2002–03 to 2015–16) will be reprocessed with this new mask and reported in 2017–18.

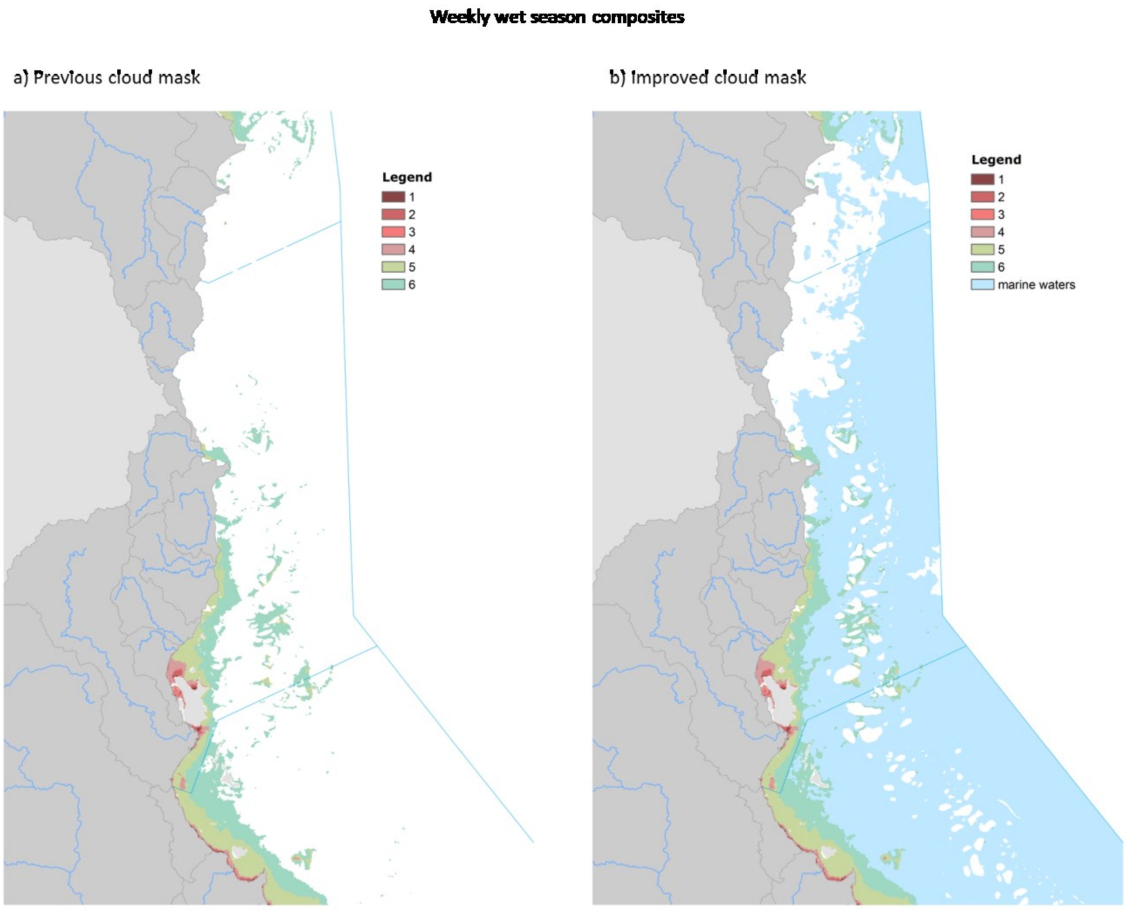

Figure D-1: Illustration of the new cloud mask implemented for the 2015–16 wet season.

Water quality concentrations in river plumes

Additional information on plume water quality can be extracted from these wet season water type maps by reporting the characteristics of the corresponding in-situ wet season water quality data with the wet season colour class or water type frequency values. Several land-sourced pollutants are investigated through match-ups between *in-situ* data and the six plume colour class maps, including the dissolved inorganic nitrogen (DIN), dissolved inorganic phosphorus (DIP), TSS, Chl-a, Kd and CDOM. Comparisons between weekly wet season water composites (Primary, Secondary and Tertiary,) and *in-situ* physical and water quality measurements collected during the wet seasons 2007 to 2013 as part of the GBR Marine Monitoring Program were performed. *In-situ* values were assigned to each weekly wet season water type (colour classes 1 to 6) based on their location, and the data extraction was done on a weekly basis, i.e. the smallest temporal resolution of the plume maps. Mean values and standard deviations were calculated.

Table D-3: Plume water types as described in Devlin et al. (2012a), Álvarez-Romero et al. (2013) and Petus et al. (2014b) and detailing the water quality and optical properties (e.g., Clarke et al.,1970; Morel and Prieur,1977; Froidefond et al., 2002; McClain, 2009), and the mean TSS, Chl-a and Kd(PAR) that define the plume characteristics within each plume type concentrations (modified from Devlin et al., 2013b).

Colour classes	Type	Description	Colour properties
1 to 4	**Primary**	Characterised by high values of CDOM and TSS, with TSS concentrations dropping out rapidly as the heavier particulate material flocculates and settles to the sea floor (Devlin and Brodie, 2005; Brodie and Waterhouse, 2009). High turbidity levels limit the light in these low salinity waters	Greenish-brown to beige waters: Usually with high nutrient and phytoplankton concentrations, but also increased sediment and dissolved organic matter. Typical for near-shore areas and tidal flats. Sediment particles are highly reflective in the red to infra-red wavelengths of the light spectrum. Sediment-dominated waters have a distinctive brown/beige colour, depending upon the concentration and mineral composition of the sediments.
5	**Secondary**	Characterised by elevated CDOM with reduced TSS due to sedimentation. In this region, the increased light in comparison to primary condition (but still under marine ambient conditions) and nutrient availability prompt phytoplankton growth measured by elevated Chl-a concentrations.	Greenish waters: often coastal waters which usually display increased nutrient and phytoplankton levels, but also contain minerals and dissolved organic material. Due to this green pigment, chlorophyll /phytoplankton preferentially absorb the red and blue portions of the light spectrum (for photosynthesis) and reflect green light. Chl-a-dominated waters will appear from blue-green to green, depending upon the type and density of the phytoplankton population.
6	**Tertiary**	Offshore region of the plume that exhibits no or low TSS that has originated from the flood plume and above ambient concentrations of Chl-a and CDOM. This region can be described as being the transition between secondary water type and marine ambient conditions.	Bluish green waters: The colour is still dominated by algae, but also dissolved matter and some sediment may be present. Typical for areas towards the open sea.
Full extent of the plume = Primary + Secondary + Tertiary			

D-9 Estimating the level of exposure to flood plumes of GBR ecosystems (coral reefs and seagrass meadows) and validation of numerical hydrodynamics modelling of flood plumes

The wet season water type maps and frequency maps (see Section 3.3) 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.

Petus et al. (2014a) proposed “*a framework to produce river plume risk maps for seagrass and coral ecosystems based on a simplified risk matrix assuming that ecological responses will increase linearly with the pollutant concentrations and frequency of river plume exposure*”. This framework used MODIS Level-2 satellite data processed by the NASA algorithms implemented in the SeaWiFS Data Analysis System (SeaDAS, Baith et al., 2001). MODIS data were used to characterize external boundaries of river plumes and different wet season water types or aggregation of wet season water types, within GBR river plumes using supervised classification of the MODIS Level 2 data and a combination of CDOM, Chl-a and TSS (estimated from two remote sensing proxies) threshold values. In the previous MMP reports, it was decided to work with river plume products derived from MODIS true colour satellite data (Álvarez-Romero et al., 2013) instead of the L2 to progress the risk framework proposed in Petus et al. (2014a).

Petus et al. (2014b) assumed that the magnitude of risk for the GBR seagrass beds and coral reefs from river plume exposure will increase from the Tertiary waters to the Primary core of river plumes. Classification of surface waters into Primary, Secondary, and Tertiary water types can thus provide a mechanism to cluster cumulative WQ stressors into three (ecologically relevant) broad categories of potential risk magnitude. At the multi-annual scale, the changes in the frequency of occurrence of these surface water types help understanding the likelihood of the different categories of potential risk magnitude. Annual maps of frequency of Primary, Secondary, and Tertiary water types in the GBR lagoon summarise the combined likelihood and magnitude of the potential river plume risk over a defined period of time. In combination with ecosystem maps, these maps provide the basis to assess potential ecological consequences imposed by different levels and frequency of exposure to land-sourced pollutants in river plumes (i.e. magnitude of risk).

Thus, in summary, the potential risk of a particular ecosystem (e.g. in the GBR, seagrass meadows or coral reefs) to be detrimentally affected by a particular stressor (in this case land-sourced pollutants associated with river plumes) can be assessed by evaluating (Figure D-2):

- The likelihood of the risk, i.e., how likely a particular stressor is to happen. This can be estimated by calculating the frequency of occurrence of river plumes or specific plume wet season water type;
- The magnitude of the risk, i.e., in river plume risk analysis, the intensity quantified as concentration, level or load of pollutant discharge through the river plume; and
- The ecological consequences of the risk, i.e., the extent of the ecological impact for a particular ecosystem given a combination of magnitude and likelihood of occurrence of the stressor.

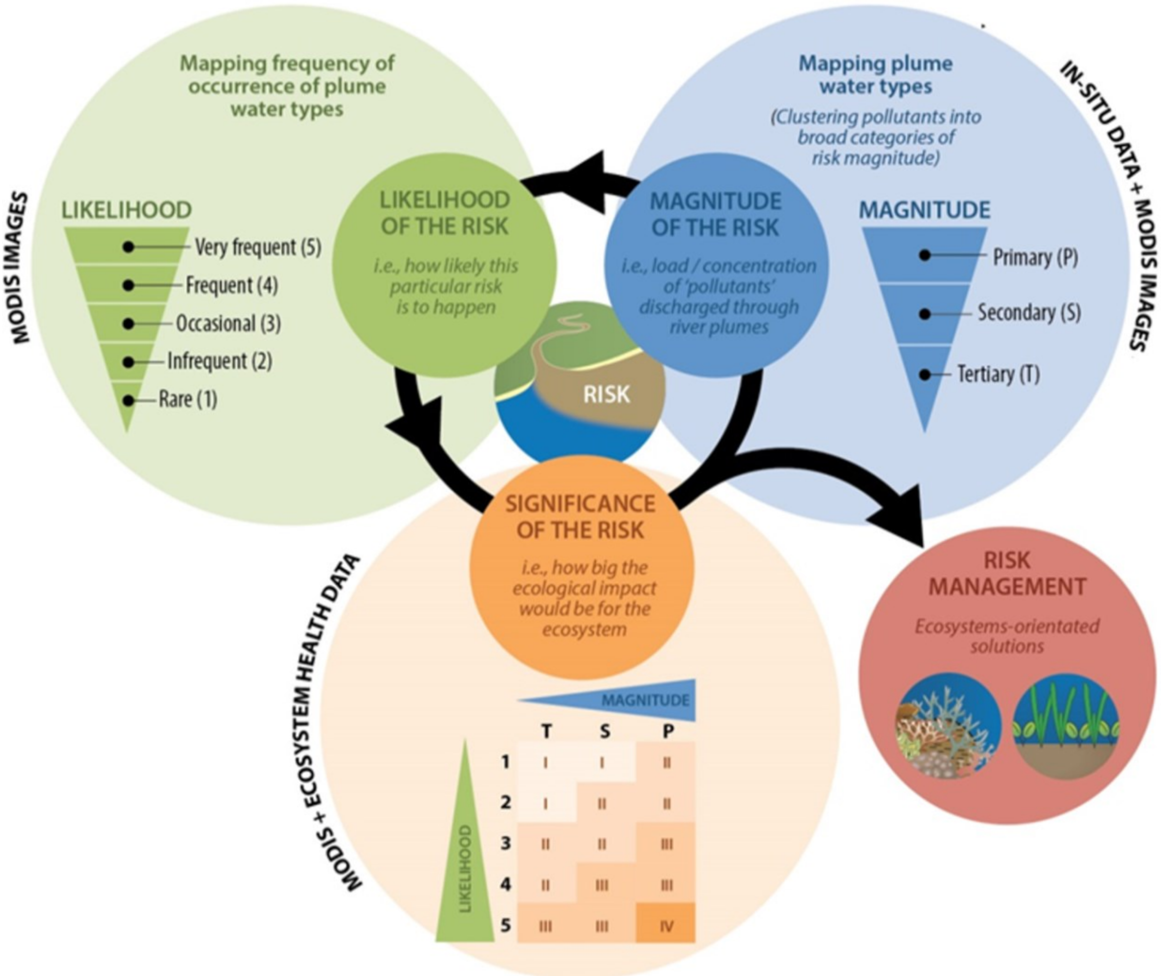

Figure D-2: Conceptual scheme of the risk framework proposed in Petus et al. (2014a).

In the GBR river plume risk framework, the potential 'risk' corresponds to an exposure to land-sourced pollutants concentrated in river plume waters (Figure D-2). 'The magnitude of the risk' correspond to the intensity quantified as concentration, level or load of pollutant discharged through the river plume and mapped through the Primary, Secondary, Tertiary water types. The 'likelihood of the risk' can be estimated by calculating the frequency of occurrence of river plumes or specific wet season water type. The potential risk from river plume exposure for GBR ecosystems is finally ranked (I to IV) assuming that ecological consequences will increase linearly with the pollutant concentrations and frequency of river plume exposure (Figure D-3).

The annual Primary, Secondary and Tertiary frequency maps (see Section 3.3, produced through methods described in Appendix D-8) are grouped into frequency levels or likelihood levels (rare to very frequent) based on Table D-4. An annual "potential" risk maps was produced for the wet season 2014–15. Each 2014–15 likelihood map (Primary, Secondary and Tertiary) is attributed a "potential" risk level (I to IV) using the simplified risk matrix (Figure A1-2). The three reclassified wet season water type maps are finally combined to create an annual river plume potential risk map. The maximum potential risk category value of each cell/likelihood map is selected to keep the highest potential risk level (Figure D-3). An 8-pixel Majority Filter (two times), the Boundary Clean function of ArcGIS and manual cleaning of the maps are used to smooth the final results. The term 'potential' is used as risk maps have not been yet validated against ecological health data to confirm the ecological consequences of the risk, i.e., the potential risk ranking Figure D-3 (I, II, III, IV) given a combination of magnitude and likelihood is, at this stage, theoretical.

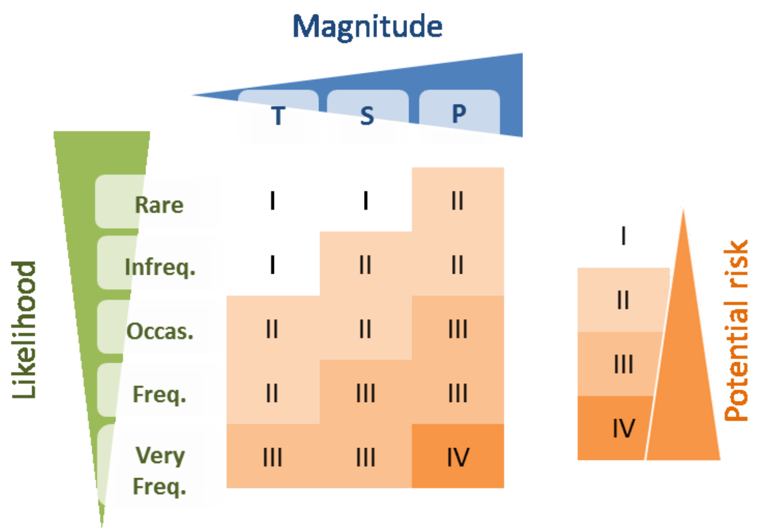

Figure D-3: Potential risk matrix in function of the magnitude and the likelihood of the river plume risk. Potential risk categories I, II, III, IV (modified from Petus et al., 2014b).

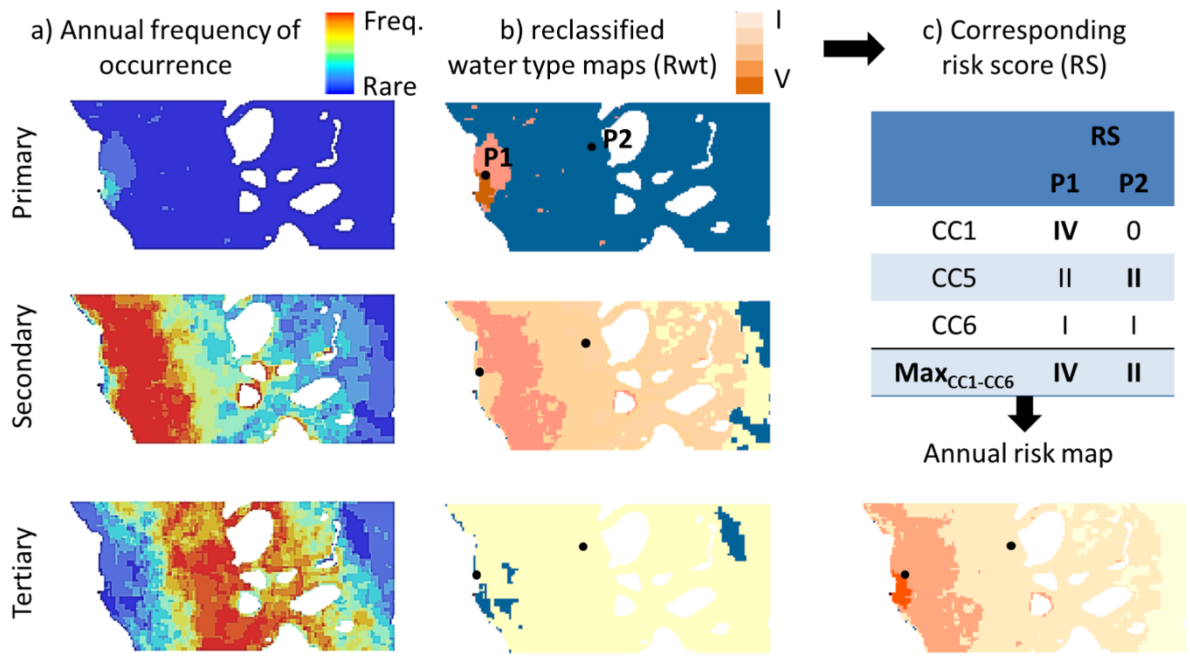

Figure D-4: Theoretical example of the production of an annual potential risk map and the results for two pixels (P1 and P2) in the GBR at a river mouth, their classification and final potential risk classification.

Table D-4: 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 has been developed (modified from Petus et al., 2016), where the 'potential risk' corresponds to an exposure to above guideline concentrations of land-sourced pollutant during high flow 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, 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:

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

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

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

With $water\ type$: the Primary, secondary or Tertiary wet season water types, $[Poll.]_{water\ type}$: the wet season or long-term mean TSS, Chl-a, PN or PP concentration measured in each respective wet season water types and $guideline$ 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 he 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:

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

Finally, the overall exposure score (ranging from 0 to 8) are categorised into four equal potential risk categories ([>0-2] = cat. I, [2-4] = cat. II, [4-6] = cat III and [6-8] = 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):

$$Chla\_exp_{Primary} = \frac{1.7-0.63}{0.63} \times frequency_{water\ type\ (0-1, cell-specific)}$$

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

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

The total exposure for Chl:

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

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-5 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.

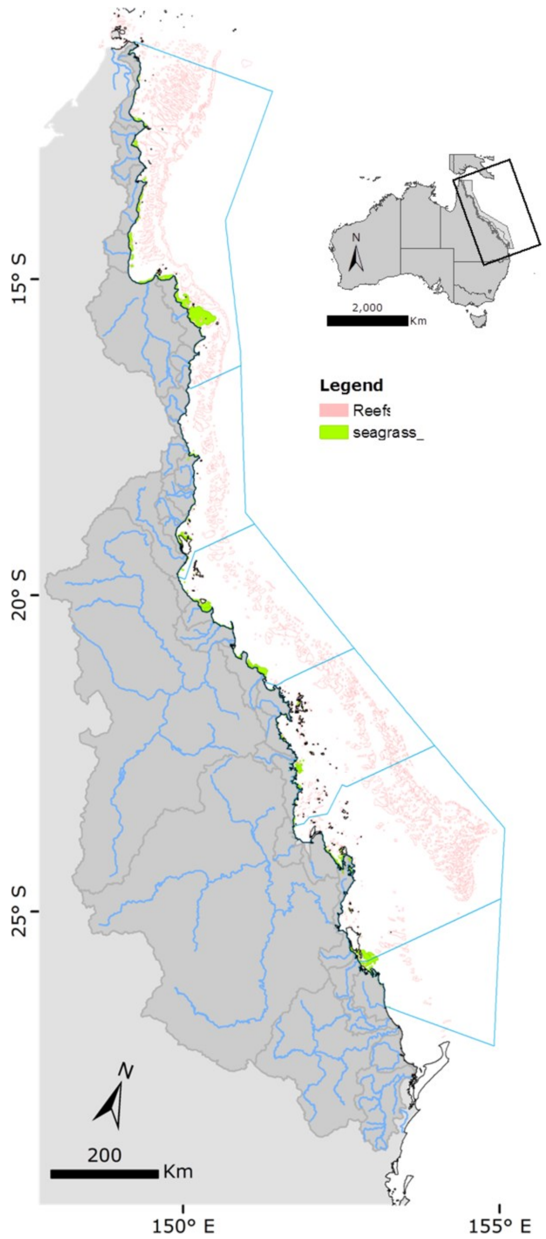

Figure D-5. Marine boundaries used for the GBR Marine Park, each NRM region and the coral reefs and seagrass ecosystems. Coral reef and NRM layers derived from GBRMPA, supplied 2013. Seagrass layer is a composite of surveys conducted by DAF.

D-10 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 Great Barrier Reef (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 Natural Resources Management (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 work 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 Álvarez-Romero et al. (2013), combines *in-situ* data from the Marine Monitoring Program, Moderate Resolution Imaging Spectroradiometer (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 (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 A1-6 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, like those produced for the GBR (see Remote Sensing section in this report), 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 x 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.

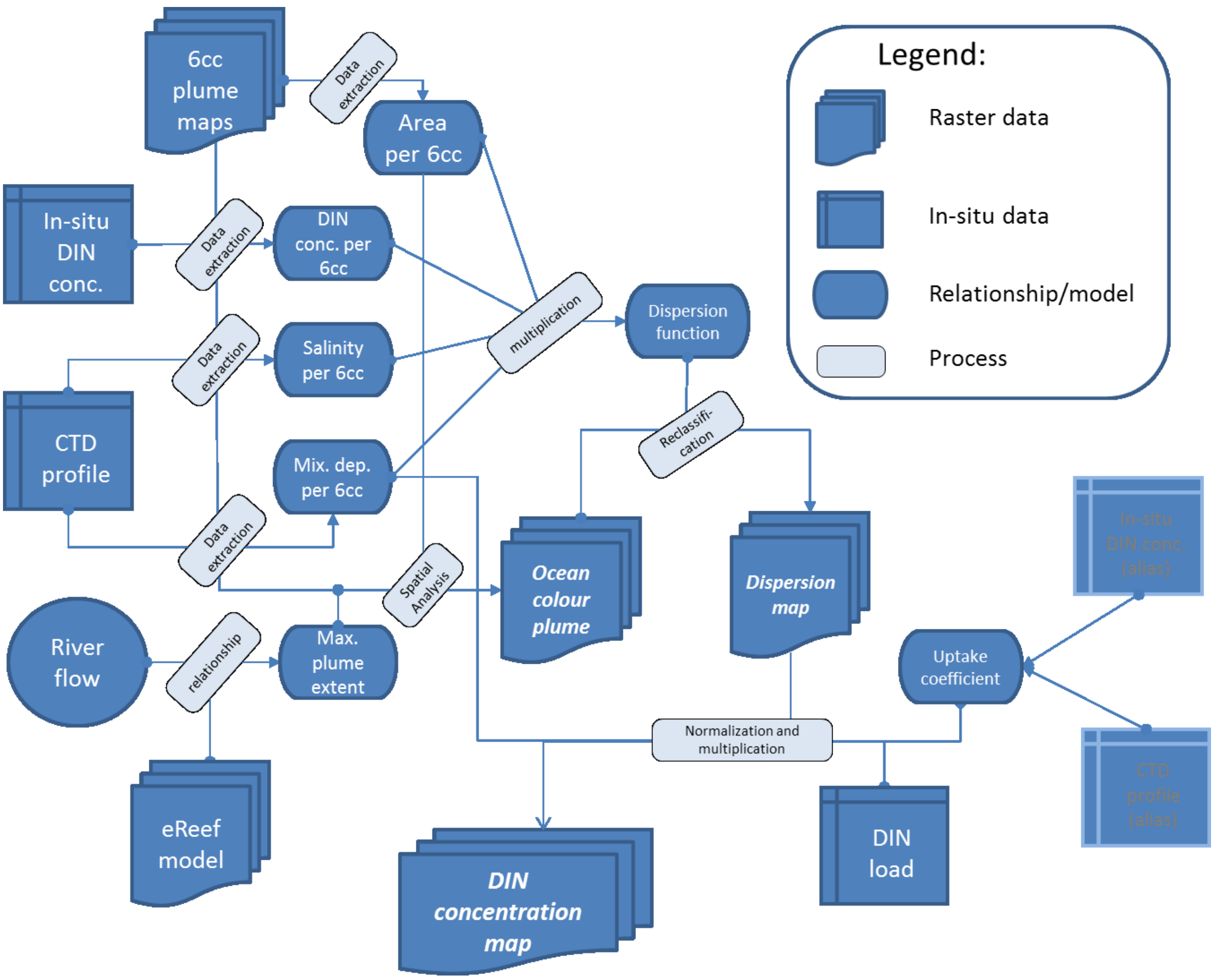

Figure D-6. Conceptual model for DIN concentration load mapping. See text for explanation.

(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, see Remote Sensing section of this report), 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., 2007a). 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 plume types from the inner class to the outer classes (see river plume maps in the Remote Sensing section of this report).

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-7) 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).

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

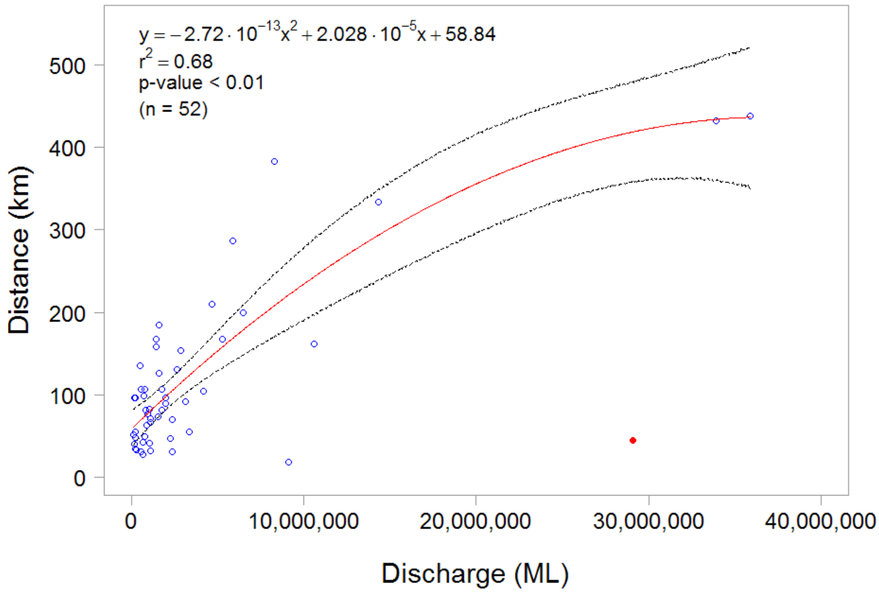

Figure D-7. Relationship between river discharge (million litres, ML) and distance (km) between river mouth and the outer edge of tracer plume as obtained from the eReefs hydrodynamic model for the GBR. Dashed lines stand for CI 95%. Red dot stands for point excluded from the regression model.

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-5).

Table D-5: 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) Conductivity-Temperature-Depth (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-8).

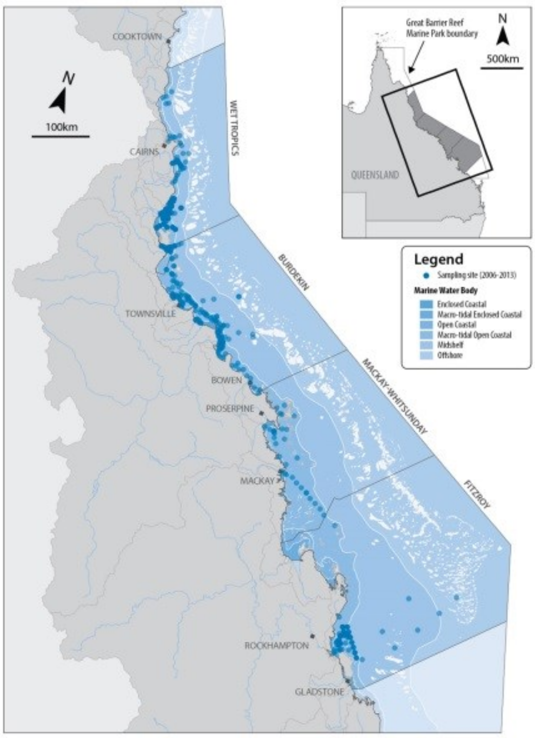

Figure D-8. The Great Barrier Reef Marine Park (Queensland, Australia), boundaries of the Natural Resource Management (NRM) regions, and the sampling sites (colour density indicates recurrent sampling) included for validation.

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, so 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:

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

where SAL_{max} and SAL_{min} stands 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-9. 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-8). Further work (and monitoring data) is needed to develop regionally specific pollutant dispersion models.

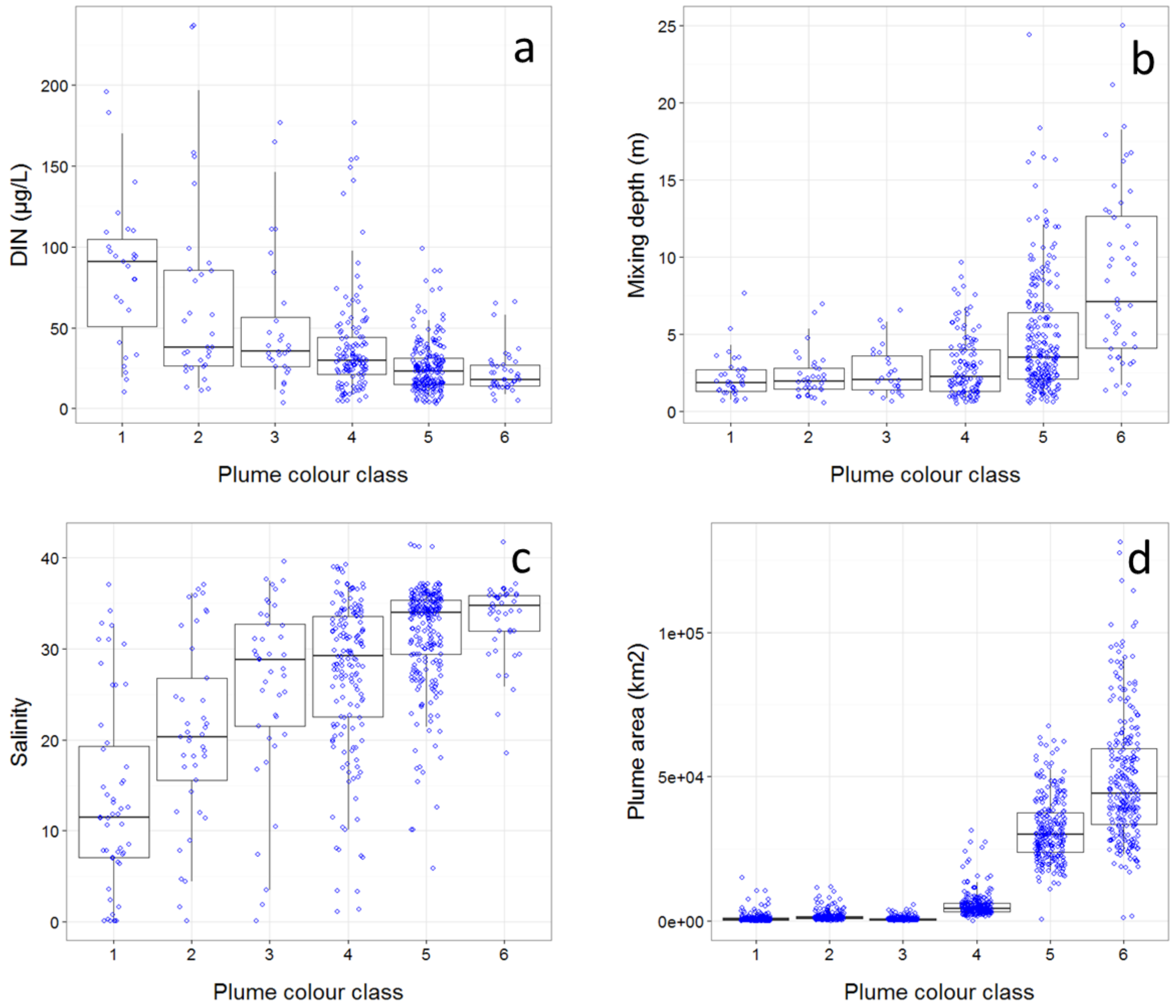

Figure D-9. In-situ DIN concentration (a), depth of the mixing layer (b), superficial salinity (c) and plume area (d) per colour class, measured over 13 wet seasons (December to April inclusive) from 2002/03 to 2014/15. Boxplot presents the median (dark black line), 25^{th} and 75^{th} percentile values (rectangle) and 5^{th} and 95^{th} 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-10. 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.

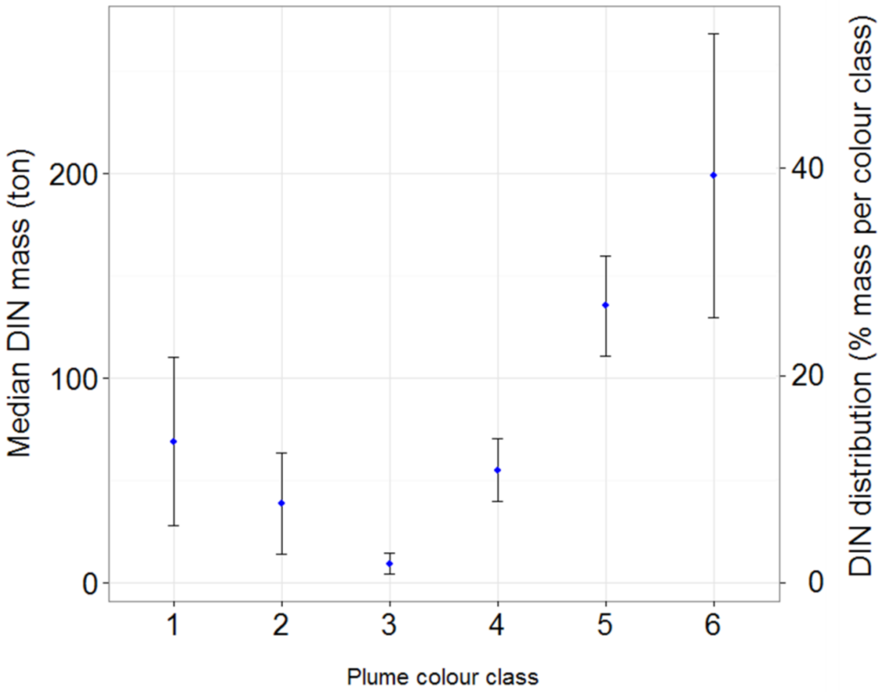

Figure D-10. Median DIN mass and percent contribution across the six-colour class. Error bars represent 95%CI (see text for explanation).

Therefore, the values of 1 to 6 in the ocean colour plumes (raster file) are converted into DIN mass, as per Figure D-10. Values of 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-11, which shows an exponential DIN decay.

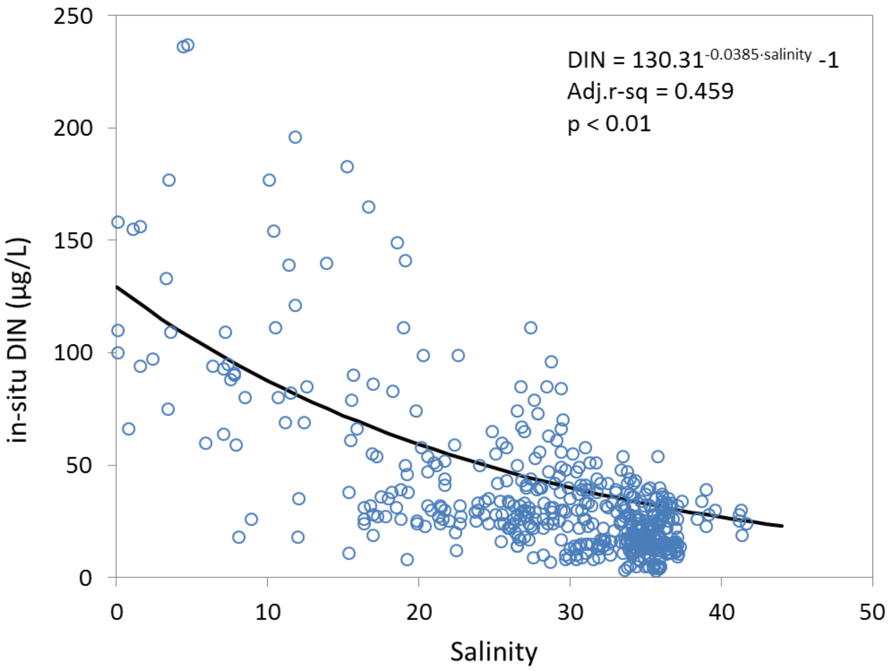

Figure D-11. Relationship between in-situ DIN concentration (µg/L) and salinity opportunistically measured at the surface in river plume waters over the GBR lagoon (2002–2003 to 2014–2015 wet season) under river discharge > 75th percentile (see text for explanation).

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 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-12. 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*.

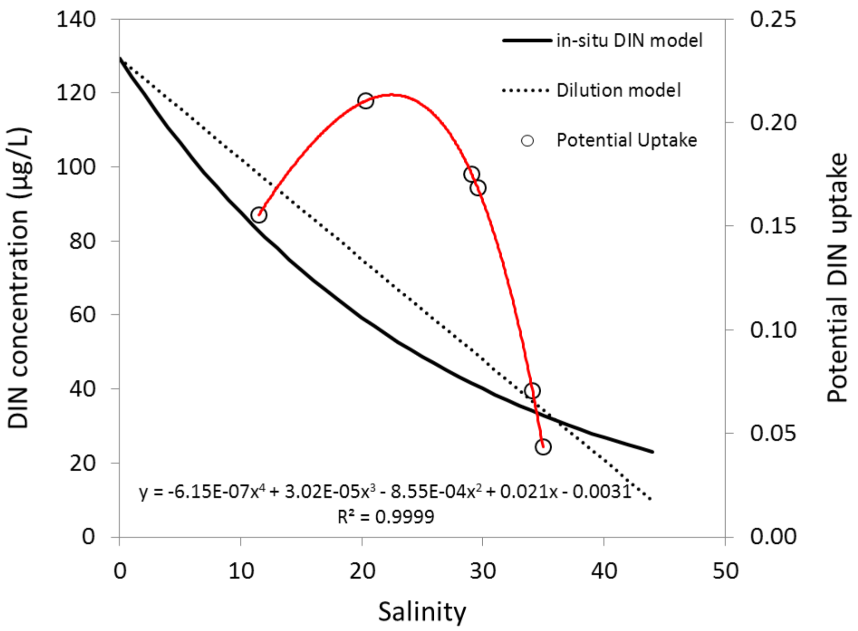

Figure D-12. Potential DIN uptake (red line) derived from the ratio between in-situ DIN concentration x salinity (black solid line, as in Figure D-11) and the theoretical dilution model (black dashed line, derived from Eq. 4).

(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 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 which 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-8) where modelled DIN load and basin discharge data were available for the 14 years are presented in Table D-6 and D-7, respectively. The pre-development DIN loads were calculated using an AMC of 50 $\mu g.L^{-1}$ for most regions which is based on monitoring data from pristine locations within the GBR catchment area. A higher DIN AMC (up to 100 $\mu g.L^{-1}$) was applied for the drier southern catchments which 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-6: End-of-catchment DIN loads (t/year) from 2003 to 2016 water years (from October 2002 to September 2016).

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
Jacky Jacky Creek	69	127	116	354	76	79	76	184	237	91	99	190	75	32
Olive Pascoe River	87	159	144	443	95	99	95	230	296	114	124	237	94	39
Lockhart River	55	101	91	280	60	63	60	146	187	72	79	150	59	25
Stewart River	22	68	29	141	50	29	33	55	109	31	26	66	15	16
Normanby River	18	492	67	489	216	411	266	386	648	112	227	399	170	180
Jeannie River	1	61	12	89	22	47	29	64	75	28	19	50	38	42
Endeavour River	1	75	15	109	26	58	35	79	92	34	23	61	47	51
Daintree River	20	221	75	193	120	150	120	232	361	220	153	470	170	149
Mossman River	82	182	119	204	118	108	77	99	111	85	66	106	32	69
Barron River	6	48	19	38	21	79	38	24	92	37	14	29	17	12
Russell-Mulgrave	280	970	434	760	597	707	549	534	1,199	822	437	711	443	242
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
Tully River	165	393	264	441	471	361	413	328	710	434	341	432	211	333
Murray River	124	293	197	329	352	270	308	245	530	324	255	323	158	273
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
Black River	8	35	21	41	107	139	230	115	267	140	35	79	3	24
Ross River	5	39	15	29	93	110	159	100	167	106	22	94	0	2
Haughton River	87	190	264	312	610	776	1,210	524	1,030	749	209	235	42	114
Burdekin River	477	353	1,312	350	1,296	2,006	1,798	1,303	2,600	1,200	800	130	150	280
Don River	22	31	58	27	108	287	171	99	560	143	103	58	31	18
Proserpine River	49	64	152	168	394	930	503	483	880	317	310	304	46	76
O'Connell River	52	54	170	201	411	573	427	732	1,312	622	236	199	42	68
Pioneer River	22	5	43	16	226	347	230	363	836	361	268	146	30	140
Plane Creek	112	24	167	15	391	854	443	878	1,441	855	584	221	71	250
Styx River	83	30	6	3	1	54	24	89	171	59	266	48	82	25
Shoalwater Creek	95	35	7	3	1	61	27	101	194	67	303	55	93	29
Water Park Creek	55	7	24	13	29	140	55	160	272	83	290	163	113	103
Fitzroy River	674	382	363	135	176	1,580	367	2,060	3,900	950	920	150	470	680
Calliope River	98	36	7	3	1	63	28	104	200	69	312	57	96	30
Boyne River	24	9	1	1	0	19	5	31	53	26	29	4	10	4
Baffle Creek	112	41	7	6	1	91	23	149	256	124	142	19	50	18
Kolan River	100	15	0	0	0	31	1	87	234	92	243	14	64	33
Burrum River	37	70	6	12	2	17	10	19	34	35	27	19	45	100
Burnett River	114	49	30	15	7	4	5	225	1,884	129	1,516	44	171	76
Mary River	167	153	61	56	87	300	209	378	1,221	608	1,072	83	231	67

Table D-7: Total wet season river discharge (ML) from 2003 to 2016 water years (from October 2002 to September 2016).

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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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

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-13: .

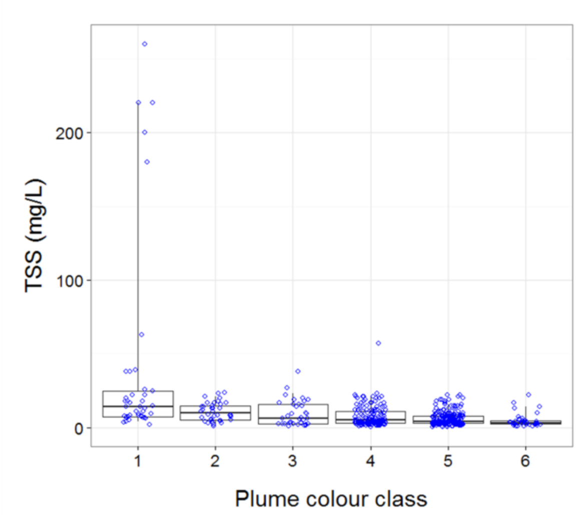

Figure D-13: In-situ TSS per colour class, measured over 13 wet seasons (c.a., December to April inclusive) from 2002/03 to 2014/15 wet season.
Boxplot presents the median (dark black line), 25th and 75th percentile values (rectangle) and 5th and 95th percentile values (vertical lines). Nudge was applied 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-9. , 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 which 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 (Joo et al., 2012; Turner et al., 2012, 2013; Garzon-Garcia et al., 2015; Wallace et al., 2015, 2016). 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 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-8.

Table D-8: End-of-catchment TSS loads (kt/year) from 2003 to 2015 water years (from October, 2002 to September, 2016).

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
Jacky Jacky Creek	28	51	46	142	30	32	31	74	95	36	40	76	30	13
Olive Pascoe River	35	64	58	177	38	40	38	92	118	46	50	95	37	16
Lockhart River	22	40	37	112	24	25	24	58	75	29	31	60	24	10
Stewart River	9	27	12	56	20	12	13	22	44	12	10	26	6	6
Normanby River	8	482	57	479	206	401	256	376	638	102	217	389	160	170
Jeannie River	0	24	5	36	9	19	12	26	30	11	7	20	15	17
Endeavour River	1	75	15	109	26	58	35	79	92	34	23	61	47	51
Daintree River	16	172	59	151	86	105	77	146	197	120	84	257	93	81
Mossman River	37	78	52	88	57	63	50	77	97	74	58	93	28	61
Barron River	25	209	84	164	91	353	170	110	423	170	66	133	76	37
Russell-Mulgrave	48	163	76	135	106	140	107	111	225	154	82	133	83	45
Johnstone River	181	251	316	590	515	462	603	424	937	548	342	504	241	353
Tully River	52	118	79	130	142	115	129	107	223	103	100	130	80	88
Murray River	13	62	21	89	68	64	95	48	213	103	50	77	18	49
Herbert River	79	379	154	458	457	383	1,077	363	1,313	478	333	448	112	198
Black River	15	64	39	75	195	253	419	209	486	255	64	143	6	44
Ross River	7	48	19	37	116	138	199	125	209	132	28	118	0	2
Haughton River	28	59	85	98	200	276	381	171	359	261	73	82	15	272
Burdekin River	755	384	4,338	884	7,195	14,806	10,855	1,938	6,200	3,300	2,500	220	700	700
Don River	40	50	90	38	153	427	227	134	784	201	145	81	43	25
Proserpine River	10	13	32	35	82	194	105	101	183	66	64	63	10	16
O'Connell River	39	40	127	150	308	430	320	549	984	466	177	150	32	51
Pioneer River	16	4	32	12	156	255	112	374	820	210	130	35	4	44
Plane Creek	37	8	56	5	130	285	148	293	480	285	195	74	24	83
Styx River	108	40	8	4	1	70	31	115	222	77	346	63	106	33
Shoalwater Creek	57	21	4	2	1	37	16	61	116	40	182	33	56	17
Water Park Creek	33	4	15	8	18	84	33	96	163	50	174	98	68	62
Fitzroy River	1,800	600	250	140	425	4,530	404	3,564	7,000	1,300	2,500	52	900	670
Calliope River	88	32	7	3	1	57	25	94	180	62	281	51	86	27
Boyne River	8	3	0	0	0	7	2	11	19	9	10	1	4	1
Baffle Creek	256	94	16	13	2	208	52	341	584	284	325	44	114	41
Kolan River	43	7	0	0	0	13	1	38	101	40	105	6	28	14
Burrum River	80	34	21	11	5	3	4	158	1,319	90	1,061	31	119	53
Burnett River	12	23	2	4	1	6	3	6	11	12	9	6	15	33
Mary River	286	263	104	96	149	515	358	647	2,093	1,042	1,837	143	396	115

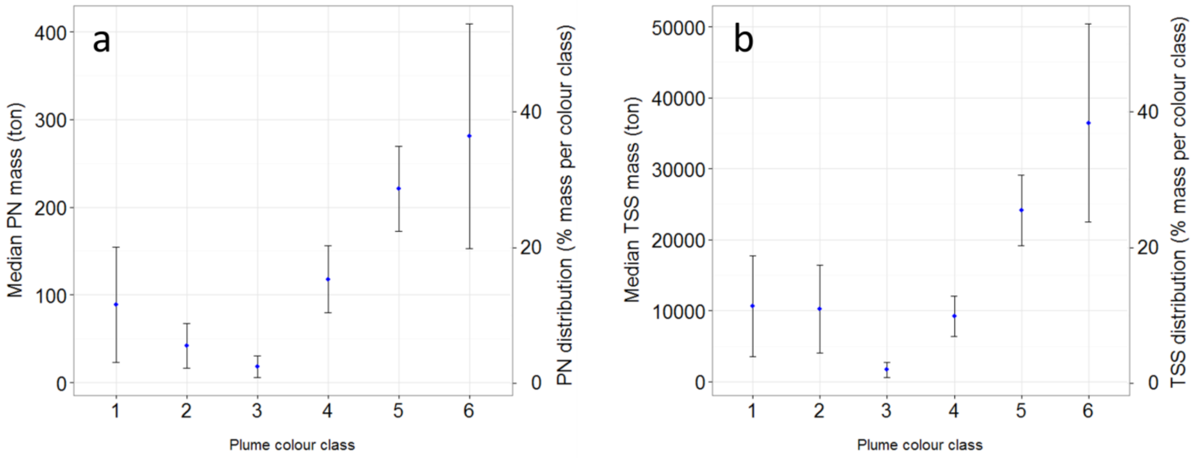

Figure D-14: Median mass of particulate nitrogen (a) and TSS (b), and percent contribution across the six-colour class. Error bars stand for 95%CI (see text for explanation).

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-9. 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 plume 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 whole plume extent. After classes 2-3, the plume waters experience reduction of suspended sediment and consequently light conditions improve, favouring primary production and DIN consumption (Bainbridge et al., 2012; Devlin et al., 2012a, 2012b; Devlin and Brodie, 2005). Therefore, the behaviour presented by *in-situ* DIN concentration through the river plume accounts for those processes.

Other processes that may affect DIN concentrations in plume waters can be nitrogen fixation by (cyano-) bacteria (*Trichodesmium*) and upwelling of nutrient-enriched deep water from the Coral Sea (Furnas et al., 2011). However, land runoff is the largest source of new nutrients to the inshore 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 whole 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-9. a), the largest mass of DIN is in colour class 6 (more than 35%, Figure D-10.). This is due to the large volume of colour class 6 compared to the other colour classes (Figure D-9. 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-8 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-8: 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-15:) 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.

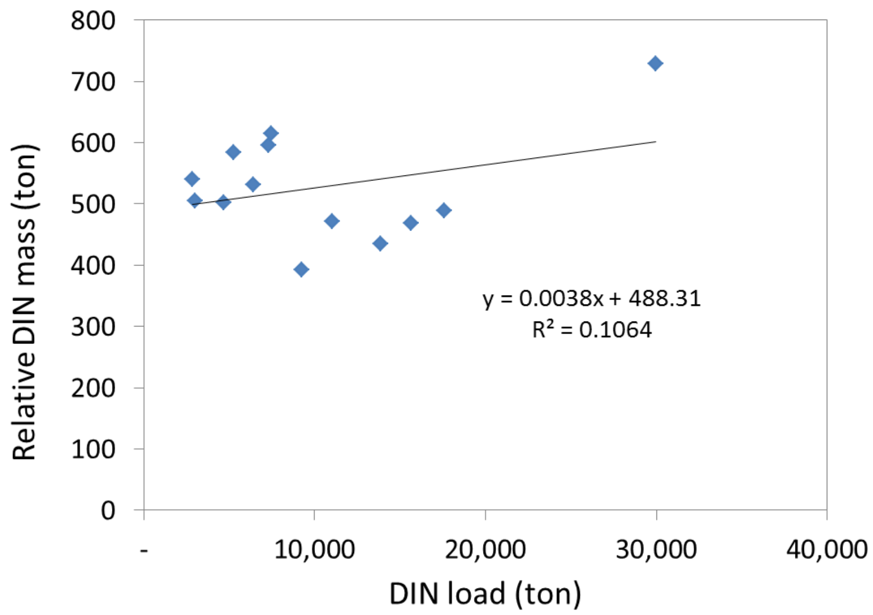

Figure D-15: Relationship between DIN load (tonnes) against the relative DIN mass (tonnes) in plume waters (see text for explanation).

Moreover, 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., 2007b). 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. Indeed, 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).

Although dispersion load maps were produced for TSS and particulate nitrogen (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-11 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 which 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, but 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 three-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,

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

and $\text{Conc}_{threshold}$ is the 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.

Appendix D References

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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 2016 water year are incomplete (to August 2016). 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)	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Wet Tropics	Daintree (108002A)	727,872	0.1*	0.2***	2.0	0.7	1.7	1.0	1.2	0.9	1.7	2.3	1.3	0.9	3.2	1.1	0.9
	Barron (110001D)	529,091	0.3	0.2	1.8	0.7	1.4	0.8	3.0	1.5	0.9	3.6	1.5	0.5	1.1	0.7	0.3
	Mulgrave (111007A)	728,917	0.3***	0.5	1.6	0.6	1.3***	1.0	1.3	1.0	1.0	2.1	1.5	0.7	1.3	0.8	0.5
	Russell (111101D)	995,142	0.4	0.6	1.4	1.0	1.3	1.3	1.1	1.2	1.3	1.7	1.3	0.8	1.3	0.7	1.0
	North Johnstone (112004A)	1,764,742	0.4	0.5	1.3	0.8	1.2	1.2	1.1	1.1	1.0	2.0	1.7	0.8	1.2	0.2	0.7
	South Johnstone (112101B)	850,463	0.4*	0.4	0.5	0.6	1.2	1.0	0.9	1.2	0.8	1.8	1.1	0.6	0.9	0.5	0.7
	Tully (113006A)	2,944,018	0.4	0.5	1.1	0.7	1.2	1.3	1.1	1.2	1.0	2.1	1.2	1.0	1.2	0.0	0.8
	Herbert (116001E/F)	3,041,440	0.3	0.2	1.1	0.4	1.3	1.3	1.1	3.1	1.0	3.8	1.4	1.0	1.3	0.3	0.6
Burdekin	Burdekin (120006B)	5,312,986	0.8	0.4	0.3	0.8	0.4	1.8	5.2	5.5	1.5	6.6	2.9	0.6	0.3	0.2	0.3
Mackay Whitsunday	O'Connell (124001B)	150,788	0.6	0.2	0.2*	0.5***	0.6	1.1	1.7	1.3	2.2	3.9	1.9	0.7	0.6	0.1	0.3
	Pioneer (125007A)	355,584	0.6	0.3	0.1	0.6	0.2	2.0	3.7	2.3	3.3	9.2	3.7	2.6	1.4	0.3	1.2
Fitzroy	Fitzroy (130005A)	3,071,435	0.2	0.8	0.4**	0.3**	0.2*	0.3	4.0	0.7	3.8	12.4	2.6	2.8	0.5	0.9	1.1

Table E-2: Summary statistics for direct water sampling data from inshore lagoon sites from June 2015 to June 2016. 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	DirectionOfFailure	Location	Annual	Dry	Wet
Wet Tropics	Cape Tribulation	DIN (µgL⁻¹)	3	0.87	0.73	0.65	0.67	1.03	1.19					
		DOC (mgL⁻¹)	3	846.79	854.47	815.89	828.75	866.36	872.31					
		DON (µgL⁻¹)	3	92.87	90.58	43.19	58.99	126.29	144.14					
		DOP (µgL⁻¹)	3	4.17	4.02	3.13	3.43	4.88	5.30					
		Chla (µgL⁻¹)	3	0.31	0.31	0.14	0.20	0.43	0.49	H	Mean	0.45		
		NOx (µgL⁻¹)	3	0.48	0.63	0.19	0.34	0.65	0.65	H	Median	0.35		
		PN (µgL⁻¹)	3	10.79	11.33	9.22	9.92	11.77	11.99	H	Mean	20.00		
		PO4 (µgL⁻¹)	3	1.69	1.77	1.17	1.37	2.02	2.15	H	Median	2.00		
		PP (µgL⁻¹)	3	2.25	2.19	1.87	1.98	2.51	2.67	H	Mean	2.80		
		Secchi (m)	3	6.83	6.00	6.00	6.00	7.50	8.25	L	Mean	10.00		
		TSS (mgL⁻¹)	3	1.03	1.02	0.88	0.93	1.12	1.17	H	Mean	2.00		
	Port Douglas	DIN (µgL⁻¹)	3	0.52	0.32	0.28	0.29	0.70	0.89					
		DOC (mgL⁻¹)	3	854.75	864.44	801.77	822.66	888.78	900.94					
		DON (µgL⁻¹)	3	96.89	90.23	41.45	57.71	134.74	157.00					
		DOP (µgL⁻¹)	3	4.28	3.78	3.63	3.68	4.79	5.29					
		Chla (µgL⁻¹)	3	0.35	0.31	0.22	0.25	0.44	0.50	H	Median	0.30	0.32	0.63
		NOx (µgL⁻¹)	3	0.18	0.14	0.14	0.14	0.21	0.24	H	Median	0.31		
		PN (µgL⁻¹)	3	10.54	10.61	9.64	9.96	11.12	11.38	H	Median	14.00	16.00	25.00
		PO4 (µgL⁻¹)	3	1.44	1.42	0.60	0.88	2.00	2.29	H	Median	2.00		
		PP (µgL⁻¹)	3	2.32	2.27	2.23	2.25	2.38	2.44	H	Median	2.00	2.30	3.30
		Secchi (m)	3	7.33	7.00	6.10	6.40	8.20	8.80	L	Median	13.00		
		TSS (mgL⁻¹)	3	1.73	2.09	0.93	1.32	2.21	2.27	H	Median	1.20	1.60	2.40
	Double	DIN (µgL⁻¹)	3	0.28	0.31	0.22	0.25	0.32	0.33					
		DOC (mgL⁻¹)	3	840.08	850.90	807.22	821.78	860.54	865.36					
		DON (µgL⁻¹)	3	90.44	93.95	45.98	61.97	119.61	132.44					
		DOP (µgL⁻¹)	3	4.01	3.77	3.18	3.38	4.59	5.00					

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOfFailure	Location	Annual	Dry	Wet
		Chla (µgL⁻¹)	3	0.38	0.38	0.35	0.36	0.40	0.41	H	Median	0.30	0.32	0.63
		NOx (µgL⁻¹)	3	0.20	0.14	0.14	0.14	0.25	0.30	H	Median	0.31		
		PN (µgL⁻¹)	3	10.46	10.24	9.93	10.04	10.84	11.15	H	Median	14.00	16.00	25.00
		PO4 (µgL⁻¹)	3	1.66	1.42	1.41	1.41	1.86	2.08	H	Median	2.00		
		PP (µgL⁻¹)	3	6.08	2.73	2.54	2.60	8.89	11.98	H	Median	2.00	2.30	3.30
		Secchi (m)	3	5.50	5.50	4.15	4.60	6.40	6.85	L	Median	13.00		
		TSS (mgL⁻¹)	3	1.02	0.95	0.80	0.85	1.18	1.29	H	Median	1.20	1.60	2.40
	Green	DIN (µgL⁻¹)	3	1.16	0.47	0.29	0.35	1.83	2.51					
	Green	DOC (mgL⁻¹)	3	859.42	837.02	816.86	823.58	890.78	917.65					
	Green	DON (µgL⁻¹)	3	86.56	67.17	50.24	55.88	113.36	136.46					
	Green	DOP (µgL⁻¹)	3	4.29	3.97	3.77	3.84	4.67	5.02					
	Green	Chla (µgL⁻¹)	3	0.25	0.25	0.13	0.17	0.33	0.37	H	Median	0.30	0.32	0.63
	Green	NOx (µgL⁻¹)	3	0.44	0.20	0.15	0.16	0.67	0.90	H	Median	0.31		
	Green	PN (µgL⁻¹)	3	10.54	10.64	9.40	9.81	11.30	11.63	H	Median	14.00	16.00	25.00
	Green	PO4 (µgL⁻¹)	3	1.52	1.40	1.11	1.21	1.80	2.00	H	Median	2.00		
	Green	PP (µgL⁻¹)	3	1.81	1.76	1.59	1.64	1.96	2.06	H	Median	2.00	2.30	3.30
	Green	Secchi (m)	3	9.33	9.50	6.35	7.40	11.30	12.20	L	Median	13.00		
	Green	TSS (mgL⁻¹)	3	0.98	0.52	0.16	0.28	1.58	2.12	H	Median	1.20	1.60	2.40
	Yorkey's Knob	DIN (µgL⁻¹)	3	0.75	0.37	0.30	0.32	1.10	1.46					
	Yorkey's Knob	DOC (mgL⁻¹)	3	855.76	845.45	843.41	844.09	865.36	875.32					
	Yorkey's Knob	DON (µgL⁻¹)	3	83.64	74.70	46.49	55.89	109.60	127.06					
	Yorkey's Knob	DOP (µgL⁻¹)	3	4.63	3.54	3.07	3.23	5.82	6.96					
	Yorkey's Knob	Chla (µgL⁻¹)	3	0.48	0.52	0.41	0.45	0.52	0.53	H	Mean	0.45		
	Yorkey's Knob	NOx (µgL⁻¹)	3	0.28	0.29	0.16	0.20	0.37	0.40	H	Median	0.35		
	Yorkey's Knob	PN (µgL⁻¹)	3	13.75	13.88	12.90	13.22	14.30	14.50	H	Mean	20.00		
	Yorkey's Knob	PO4 (µgL⁻¹)	3	1.97	1.96	1.90	1.92	2.01	2.04	H	Median	2.00		
	Yorkey's Knob	PP (µgL⁻¹)	3	4.00	3.75	3.69	3.71	4.23	4.47	H	Mean	2.80		
	Yorkey's Knob	Secchi (m)	3	3.00	3.00	2.55	2.70	3.30	3.45	L	Mean	10.00		
	Yorkey's Knob	TSS (mgL⁻¹)	3	2.55	2.57	2.33	2.41	2.70	2.77	H	Mean	2.00		

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOfFailure	Location	Annual	Dry	Wet
	Fairlead Buoy	DIN (µgL⁻¹)	3	1.34	1.34	0.54	0.81	1.87	2.13					
		DOC (mgL⁻¹)	3	863.41	866.76	853.98	858.24	869.24	870.48					
		DON (µgL⁻¹)	3	77.15	77.15	53.31	61.26	93.04	100.99					
		DOP (µgL⁻¹)	3	4.30	4.43	3.97	4.13	4.50	4.53					
		Chla (µgL⁻¹)	3	0.52	0.57	0.38	0.44	0.60	0.62	H	Mean	0.45		
		NOx (µgL⁻¹)	3	0.41	0.41	0.23	0.29	0.53	0.60	H	Median	0.35		
		PN (µgL⁻¹)	3	14.42	14.45	13.55	13.85	14.99	15.26	H	Mean	20.00		
		PO4 (µgL⁻¹)	3	2.26	2.06	1.47	1.67	2.82	3.19	H	Median	2.00		
		PP (µgL⁻¹)	3	4.12	4.13	3.86	3.95	4.30	4.38	H	Mean	2.80		
		Secchi (m)	3	2.83	2.50	2.50	2.50	3.10	3.40	L	Mean	10.00		
		TSS (mgL⁻¹)	3	2.75	2.90	2.46	2.61	2.93	2.95	H	Mean	2.00		
	Fitzroy West	DIN (µgL⁻¹)	5	2.16	2.16	2.16	2.16	2.16	2.16					
		DOC (mgL⁻¹)	5	910.17	904.24	801.57	810.60	1007.36	1027.06					
		DON (µgL⁻¹)	5	92.08	84.09	53.88	69.50	111.46	141.46					
		DOP (µgL⁻¹)	5	5.58	5.64	4.45	4.57	6.61	6.63					
		Chla (µgL⁻¹)	5	0.30	0.27	0.15	0.16	0.42	0.50	H	Mean	0.45		
		NOx (µgL⁻¹)	5	0.88	0.59	0.42	0.48	1.17	1.75	H	Median	0.35		
		PN (µgL⁻¹)	5	16.03	15.65	12.64	13.70	18.21	19.96	H	Mean	20.00		
		PO4 (µgL⁻¹)	5	1.71	1.73	1.14	1.45	1.98	2.25	H	Median	2.00		
		PP (µgL⁻¹)	5	2.03	2.17	1.50	1.77	2.34	2.36	H	Mean	2.80		
		Secchi (m)	5	10.62	11.75	7.17	9.20	12.50	12.50	L	Mean	10.00		
		TSS (mgL⁻¹)	5	0.54	0.52	0.37	0.44	0.59	0.80	H	Mean	2.00		
	RM3	DIN (µgL⁻¹)	4	2.16	2.16	2.16	2.16	2.16	2.16					
		DOC (mgL⁻¹)	4	970.81	943.28	879.97	904.99	1025.62	1100.18					
		DON (µgL⁻¹)	4	90.29	99.50	44.15	61.43	122.84	123.54					
		DOP (µgL⁻¹)	4	5.59	5.65	3.81	4.76	6.44	7.27					
		Chla (µgL⁻¹)	4	0.38	0.31	0.14	0.16	0.57	0.72	H	Median	0.30	0.32	0.63

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOfFailure	Location	Annual	Dry	Wet
		NOx (µgL⁻¹)	4	1.32	1.16	0.23	0.51	2.07	2.65	H	Median	0.31		
		PN (µgL⁻¹)	4	18.60	16.59	12.44	12.47	23.93	27.60	H	Median	14.00	16.00	25.00
		PO4 (µgL⁻¹)	4	1.84	2.06	1.25	1.67	2.10	2.13	H	Median	2.00		
		PP (µgL⁻¹)	4	2.61	2.50	1.98	2.12	3.06	3.39	H	Median	2.00	2.30	3.30
		Secchi (m)	4	12.50	13.00	9.30	10.20	15.00	15.00	L	Median	13.00		
		TSS (mgL⁻¹)	4	0.67	0.63	0.45	0.49	0.84	0.96	H	Median	1.20	1.60	2.40
	High West	DIN (µgL⁻¹)	6	3.14	3.14	3.14	3.14	3.14	3.14					
		DOC (mgL⁻¹)	6	964.69	936.62	868.53	880.62	1037.54	1100.15					
		DON (µgL⁻¹)	6	94.89	88.68	44.73	64.92	122.38	153.74					
		DOP (µgL⁻¹)	6	5.98	5.40	3.81	4.37	7.36	8.97					
		Chla (µgL⁻¹)	6	0.48	0.33	0.26	0.32	0.78	0.83	H	Mean	0.45		
		NOx (µgL⁻¹)	6	3.86	1.68	0.77	1.03	5.82	10.01	H	Median	0.35		
		PN (µgL⁻¹)	6	20.88	16.88	14.28	15.64	24.52	33.08	H	Mean	20.00		
		PO4 (µgL⁻¹)	6	2.27	2.12	0.83	1.31	3.17	3.94	H	Median	2.00		
		PP (µgL⁻¹)	6	4.01	3.33	3.22	3.27	4.47	5.75	H	Mean	2.80		
		Secchi (m)	6	7.62	6.75	5.22	5.90	9.00	11.25	L	Mean	10.00		
		TSS (mgL⁻¹)	6	1.93	1.10	0.82	0.86	2.16	4.70	H	Mean	2.00		
	Russell Mulgrave Mouth Mooring	DIN (µgL⁻¹)	4	NaN										
		DOC (mgL⁻¹)	4	1022.64	1009.82	891.43	930.13	1110.02	1171.81					
		DON (µgL⁻¹)	4	90.04	109.81	38.23	74.07	113.93	114.18					
		DOP (µgL⁻¹)	4	6.76	5.81	5.32	5.44	7.71	9.55					
		Chla (µgL⁻¹)	4	0.46	0.43	0.33	0.36	0.55	0.65	H	Mean	0.45		
		NOx (µgL⁻¹)	4	0.61	0.56	0.14	0.14	1.06	1.15	H	Median	0.35		
		PN (µgL⁻¹)	4	17.17	16.68	13.89	14.59	19.55	21.12	H	Mean	20.00		
		PO4 (µgL⁻¹)	4	1.72	1.79	0.99	1.30	2.16	2.34	H	Median	2.00		
		PP (µgL⁻¹)	4	4.59	3.99	3.13	3.40	5.54	6.87	H	Mean	2.80		

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOfFailure	Location	Annual	Dry	Wet
		Secchi (m)	4	4.75	4.75	2.30	3.20	6.30	7.20	L	Mean	10.00		
		TSS (mgL⁻¹)	4	1.96	1.84	1.15	1.17	2.71	2.94	H	Mean	2.00		
	Franklands West	DIN (µgL⁻¹)	6	0.47	0.47	0.47	0.47	0.47	0.47					
		DOC (mgL⁻¹)	6	927.55	900.49	831.34	842.62	1001.66	1061.65					
		DON (µgL⁻¹)	6	98.50	108.67	41.19	74.78	126.28	141.56					
		DOP (µgL⁻¹)	6	8.02	5.12	4.44	4.65	10.24	15.67					
		Chla (µgL⁻¹)	6	0.28	0.25	0.18	0.19	0.35	0.44	H	Median	0.30	0.32	0.63
		NOx (µgL⁻¹)	6	0.64	0.14	0.14	0.14	0.94	1.85	H	Median	0.31		
		PN (µgL⁻¹)	6	19.64	15.19	10.82	11.23	26.27	34.69	H	Median	14.00	16.00	25.00
		PO4 (µgL⁻¹)	6	1.38	1.43	0.93	1.02	1.76	1.76	H	Median	2.00		
		PP (µgL⁻¹)	6	2.34	2.42	1.65	2.01	2.71	2.92	H	Median	2.00	2.30	3.30
		Secchi (m)	6	10.33	10.00	8.65	9.10	11.50	12.25	L	Median	13.00		
		TSS (mgL⁻¹)	6	0.52	0.48	0.37	0.44	0.68	0.69	H	Median	1.20	1.60	2.40
	Clump Point East	DIN (µgL⁻¹)	3	NaN										
		DOC (mgL⁻¹)	3	1075.98	1112.35	992.89	1032.71	1126.52	1133.60					
		DON (µgL⁻¹)	3	86.08	85.70	27.94	47.19	124.90	144.50					
		DOP (µgL⁻¹)	3	6.84	6.25	5.48	5.73	7.82	8.61					
		Chla (µgL⁻¹)	3	0.26	0.22	0.16	0.18	0.33	0.38	H	Median	0.30	0.32	0.63
		NOx (µgL⁻¹)	3	0.53	0.35	0.16	0.22	0.81	1.04	H	Median	0.31		
		PN (µgL⁻¹)	3	18.30	17.07	12.77	14.21	22.15	24.69	H	Median	14.00	16.00	25.00
		PO4 (µgL⁻¹)	3	1.90	1.62	1.30	1.41	2.33	2.69	H	Median	2.00		
		PP (µgL⁻¹)	3	1.85	1.77	1.58	1.65	2.04	2.17	H	Median	2.00	2.30	3.30
		Secchi (m)	3	17.50	16.00	14.20	14.80	19.90	21.85	L	Median	13.00		
		TSS (mgL⁻¹)	3	0.31	0.24	0.22	0.22	0.39	0.46	H	Median	1.20	1.60	2.40
	Dunk North	DIN (µgL⁻¹)	3	NaN										
		DOC (mgL⁻¹)	3	1035.78	1045.50	933.89	971.09	1102.42	1130.87					
		DON (µgL⁻¹)	3	95.57	90.74	37.80	55.45	134.73	156.72					
		DOP (µgL⁻¹)	3	7.18	6.64	5.80	6.08	8.17	8.93					
		Chla (µgL⁻¹)	3	0.40	0.44	0.26	0.32	0.48	0.50	H	Mean	0.45		

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOfFailure	Location	Annual	Dry	Wet
		NOx (µgL⁻¹)	3	0.40	0.14	0.14	0.14	0.60	0.84	H	Median	0.35		
		PN (µgL⁻¹)	3	21.35	21.40	21.02	21.15	21.56	21.64	H	Mean	20.00		
		PO4 (µgL⁻¹)	3	1.71	1.34	1.18	1.23	2.12	2.51	H	Median	2.00		
		PP (µgL⁻¹)	3	3.80	3.12	3.10	3.10	4.35	4.97	H	Mean	2.80		
		Secchi (m)	3	7.17	7.50	6.15	6.60	7.80	7.95	L	Mean	10.00		
		TSS (mgL⁻¹)	3	0.97	1.00	0.47	0.64	1.30	1.46	H	Mean	2.00		
	Dunk South	DIN (µgL⁻¹)	3	NaN										
		DOC (mgL⁻¹)	3	1047.38	1050.20	888.90	942.67	1152.65	1203.88					
		DON (µgL⁻¹)	3	104.31	115.61	39.14	64.63	146.25	161.58					
		DOP (µgL⁻¹)	3	7.60	6.19	5.78	5.91	9.01	10.42					
		Chla (µgL⁻¹)	3	0.43	0.46	0.27	0.33	0.54	0.57	H	Mean	0.45		
		NOx (µgL⁻¹)	3	0.59	0.26	0.15	0.19	0.93	1.27	H	Median	0.35		
		PN (µgL⁻¹)	3	18.27	17.51	14.48	15.49	20.90	22.60	H	Mean	20.00		
		PO4 (µgL⁻¹)	3	1.83	1.79	1.08	1.32	2.34	2.62	H	Median	2.00		
		PP (µgL⁻¹)	3	2.68	2.70	2.21	2.37	2.99	3.14	H	Mean	2.80		
		Secchi (m)	3	9.50	8.50	8.50	8.50	10.30	11.20	L	Mean	10.00		
		TSS (mgL⁻¹)	3	0.61	0.72	0.41	0.51	0.73	0.74	H	Mean	2.00		
	Between Tam O'Shanter and Timana	DIN (µgL⁻¹)	3	NaN										
		DOC (mgL⁻¹)	3	1149.29	1049.75	1038.67	1042.36	1236.32	1329.60					
		DON (µgL⁻¹)	3	66.96	76.77	41.55	53.29	82.59	85.50					
		DOP (µgL⁻¹)	3	8.54	6.14	5.87	5.96	10.64	12.89					
		Chla (µgL⁻¹)	3	0.37	0.31	0.28	0.29	0.43	0.50	H	Mean	0.45		
		NOx (µgL⁻¹)	3	0.45	0.18	0.14	0.16	0.69	0.95	H	Median	0.35		
		PN (µgL⁻¹)	3	17.93	16.26	10.47	12.40	23.13	26.57	H	Mean	20.00		
		PO4 (µgL⁻¹)	3	1.69	1.51	1.25	1.34	2.00	2.24	H	Median	2.00		
		PP (µgL⁻¹)	3	3.21	3.33	2.73	2.93	3.51	3.60	H	Mean	2.80		
		Secchi (m)	3	6.00	5.00	4.55	4.70	7.10	8.15	L	Mean	10.00		

						Quantiles				Guidelines				
Region	**Site**	**Measure**	**N**	**Mean**	**Median**	**Q5**	**Q20**	**Q80**	**Q95**	**DirectionOfFailure**	**Location**	**Annual**	**Dry**	**Wet**
		TSS (mgL⁻¹)	3	0.88	0.91	0.45	0.60	1.17	1.30	H	Mean	2.00		
	Bedarra	DIN (µgL⁻¹)	3	NaN										
	Bedarra	DOC (mgL⁻¹)	3	1049.11	1018.09	919.01	952.04	1139.97	1200.91					
	Bedarra	DON (µgL⁻¹)	3	68.46	76.56	39.72	52.00	86.54	91.53					
	Bedarra	DOP (µgL⁻¹)	3	8.08	5.68	5.59	5.62	10.07	12.26					
	Bedarra	Chla (µgL⁻¹)	3	0.35	0.37	0.23	0.28	0.43	0.46	H	Mean	0.45		
	Bedarra	NOx (µgL⁻¹)	3	1.76	1.27	0.25	0.59	2.82	3.60	H	Median	0.35		
	Bedarra	PN (µgL⁻¹)	3	17.21	16.81	9.91	12.21	22.14	24.80	H	Mean	20.00		
	Bedarra	PO4 (µgL⁻¹)	3	1.83	1.75	1.48	1.57	2.06	2.22	H	Median	2.00		
	Bedarra	PP (µgL⁻¹)	3	2.74	2.71	2.43	2.53	2.94	3.06	H	Mean	2.80		
	Bedarra	Secchi (m)	3	7.17	7.00	5.65	6.10	8.20	8.80	L	Mean	10.00		
	Bedarra	TSS (mgL⁻¹)	3	0.75	0.54	0.45	0.48	0.97	1.19	H	Mean	2.00		
	Tully Mouth Mooring	DIN (µgL⁻¹)	3	NaN										
	Tully Mouth Mooring	DOC (mgL⁻¹)	3	1151.70	1092.38	1048.79	1063.32	1228.22	1296.14					
	Tully Mouth Mooring	DON (µgL⁻¹)	3	85.84	87.51	40.29	56.03	115.99	130.23					
	Tully Mouth Mooring	DOP (µgL⁻¹)	3	8.84	7.41	6.14	6.57	10.83	12.54					
	Tully Mouth Mooring	Chla (µgL⁻¹)	3	0.50	0.52	0.30	0.37	0.63	0.69	H	Median	1.10	0.32	0.63
	Tully Mouth Mooring	NOx (µgL⁻¹)	3	1.12	0.32	0.16	0.21	1.87	2.65	H	Median	3.00		
	Tully Mouth Mooring	PO4 (µgL⁻¹)	3	1.75	1.92	1.28	1.50	2.04	2.10	H	Median	3.00		
	Tully Mouth Mooring	Secchi (m)	3	4.83	4.50	3.15	3.60	6.00	6.75	L	Median	1.60		
	Tully Mouth Mooring	TSS (mgL⁻¹)	3	1.71	1.99	1.09	1.39	2.08	2.13	H	Median	5.00	1.60	2.40
Burdekin	Palms West	DIN (µgL⁻¹)	5	NaN										
Burdekin	Palms West	DOC (mgL⁻¹)	5	1067.39	1095.97	992.04	1026.68	1113.82	1122.74					
Burdekin	Palms West	DON (µgL⁻¹)	5	85.30	104.82	37.34	59.83	114.67	119.59					
Burdekin	Palms West	DOP (µgL⁻¹)	5	5.92	5.33	5.27	5.29	6.43	6.98					
Burdekin	Palms West	Chla (µgL⁻¹)	5	0.56	0.59	0.34	0.50	0.65	0.70	H	Median	0.35	0.32	0.63
Burdekin	Palms West	NOx (µgL⁻¹)	5	1.48	0.76	0.20	0.39	2.43	3.27	H	Median	0.28		
Burdekin	Palms West	PN (µgL⁻¹)	5	20.85	22.39	18.17	19.58	22.43	22.45	H	Median	12.00	16.00	25.00

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOfFailure	Location	Annual	Dry	Wet
		PO4 (µgL⁻¹)	5	1.37	1.38	1.02	1.14	1.61	1.73	H	Median	1.00		
		PP (µgL⁻¹)	5	2.41	2.21	2.04	2.10	2.69	2.93	H	Median	2.20	2.30	3.30
		Secchi (m)	5	8.00	6.00	5.10	5.40	10.20	12.30	L	Mean	10.00		
		TSS (mgL⁻¹)	5	0.85	0.49	0.30	0.42	1.37	1.68	H	Median	1.20	1.60	2.40
	Pandora	DIN (µgL⁻¹)	5	NaN										
		DOC (mgL⁻¹)	5	1175.44	1210.95	1077.37	1121.90	1236.08	1248.65					
		DON (µgL⁻¹)	5	95.91	75.62	46.00	55.87	131.89	160.02					
		DOP (µgL⁻¹)	5	6.11	7.03	4.12	5.09	7.32	7.46					
		Chla (µgL⁻¹)	5	0.40	0.35	0.28	0.33	0.51	0.55	H	Median	0.35	0.32	0.63
		NOx (µgL⁻¹)	5	0.56	0.27	0.15	0.19	0.87	1.17	H	Median	0.28		
		PN (µgL⁻¹)	5	19.54	19.54	19.01	19.19	19.89	20.06	H	Median	12.00	16.00	25.00
		PO4 (µgL⁻¹)	5	1.16	1.19	0.89	0.99	1.34	1.42	H	Median	1.00		
		PP (µgL⁻¹)	5	3.02	2.77	2.75	2.76	3.24	3.47	H	Median	2.20	2.30	3.30
		Secchi (m)	5	5.67	6.00	5.10	5.40	6.00	6.00	L	Mean	10.00		
		TSS (mgL⁻¹)	5	0.98	1.04	0.53	0.84	1.20	1.27	H	Median	1.20	1.60	2.40
	Magnetic	DIN (µgL⁻¹)	5	NaN										
		DOC (mgL⁻¹)	5	1148.38	1199.06	1051.86	1100.93	1205.96	1209.41					
		DON (µgL⁻¹)	5	75.45	52.42	46.22	48.29	98.01	120.81					
		DOP (µgL⁻¹)	5	6.29	6.79	4.56	5.30	7.37	7.67					
		Chla (µgL⁻¹)	5	0.57	0.55	0.28	0.35	0.79	0.88	H	Median	0.59	0.32	0.63
		NOx (µgL⁻¹)	5	1.49	0.86	0.79	0.82	2.04	2.63	H	Median	0.28		
		PN (µgL⁻¹)	5	24.48	24.15	20.38	21.64	27.26	28.81	H	Median	17.00	16.00	25.00
		PO4 (µgL⁻¹)	5	1.40	1.38	1.22	1.28	1.51	1.58	H	Median	1.00		
		PP (µgL⁻¹)	5	3.70	3.84	3.22	3.42	4.00	4.08	H	Mean	2.80		
		Secchi (m)	5	5.17	4.50	3.15	3.60	6.60	7.65	L	Median	4.00		
		TSS (mgL⁻¹)	5	1.54	1.65	0.81	0.87	2.12	2.27	H	Median	1.90	1.60	2.40
	Haughton	DIN (µgL⁻¹)	3	NaN										
		DOC (mgL⁻¹)	3	1188.25	1163.95	1069.93	1101.27	1270.37	1323.58					
		DON (µgL⁻¹)	3	108.11	117.48	69.20	85.29	132.79	140.45					

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOfFailure	Location	Annual	Dry	Wet
		DOP (µgL⁻¹)	3	5.58	5.88	5.01	5.30	5.92	5.94					
		Chla (µgL⁻¹)	3	0.44	0.45	0.35	0.39	0.50	0.53	H	Mean	0.45		
		NOx (µgL⁻¹)	3	0.37	0.20	0.15	0.17	0.54	0.70	H	Median	1.00		
		PN (µgL⁻¹)	3	14.05	14.15	13.49	13.71	14.41	14.54	H	Median	13.00	16.00	25.00
		PO4 (µgL⁻¹)	3	0.82	0.80	0.59	0.66	0.97	1.05	H	Median	2.00		
		PP (µgL⁻¹)	3	2.78	2.80	2.30	2.47	3.09	3.24	H	Median	2.10	2.30	3.30
		Secchi (m)	3	8.00	8.00	6.20	6.80	9.20	9.80	L	Mean	10.00		
		TSS (mgL⁻¹)	3	1.20	1.10	0.89	0.96	1.43	1.59	H	Median	1.20	1.60	2.40
	Yongala	DIN (µgL⁻¹)	7	NaN										
	Yongala	DOC (mgL⁻¹)	7	1039.91	994.82	857.49	915.67	1191.15	1257.85					
	Yongala	DON (µgL⁻¹)	7	116.54	113.27	65.99	79.21	148.46	170.63					
	Yongala	DOP (µgL⁻¹)	7	5.11	4.76	4.03	4.56	5.98	6.28					
	Yongala	Chla (µgL⁻¹)	7	0.23	0.25	0.11	0.17	0.28	0.33	H	Median	0.33	0.32	0.63
	Yongala	NOx (µgL⁻¹)	7	0.97	0.36	0.14	0.16	1.31	2.81	H	Median	0.28		
	Yongala	PN (µgL⁻¹)	7	10.69	10.53	7.45	9.45	12.38	13.58	H	Median	14.00	16.00	25.00
	Yongala	PO4 (µgL⁻¹)	7	1.24	1.26	0.75	0.98	1.49	1.58	H	Median	1.00		
	Yongala	PP (µgL⁻¹)	7	1.55	1.49	1.14	1.31	1.80	2.14	H	Median	2.00	2.30	3.30
	Yongala	Secchi (m)	7	14.83	14.00	11.25	12.00	19.00	19.00	L	Mean	10.00		
	Yongala	TSS (mgL⁻¹)	7	0.30	0.33	0.05	0.16	0.45	0.47	H	Median	0.80	1.60	2.40
	Burdekin Mouth Mooring	DIN (µgL⁻¹)	3	NaN										
	Burdekin Mouth Mooring	DOC (mgL⁻¹)	3	1194.94	1208.90	1143.14	1165.06	1227.62	1236.98					
	Burdekin Mouth Mooring	DON (µgL⁻¹)	3	122.53	109.82	64.71	79.75	162.77	189.24					
	Burdekin Mouth Mooring	DOP (µgL⁻¹)	3	5.54	5.69	4.51	4.90	6.20	6.46					
	Burdekin Mouth Mooring	Chla (µgL⁻¹)	3	0.87	0.92	0.74	0.80	0.95	0.96	H	Median	1.00	0.32	0.63
	Burdekin Mouth Mooring	NOx (µgL⁻¹)	3	0.73	0.67	0.26	0.40	1.05	1.24	H	Median	4.00		
	Burdekin Mouth Mooring	PO4 (µgL⁻¹)	3	1.56	1.42	1.12	1.22	1.87	2.10	H	Median	1.00		
	Burdekin Mouth Mooring	Secchi (m)	3	3.33	3.50	2.15	2.60	4.10	4.40	L	Median	1.50		
	Burdekin Mouth Mooring	TSS (mgL⁻¹)	3	2.30	1.55	1.28	1.38	3.08	3.84	H	Median	2.00	1.60	2.40
	Double Cone	DIN (µgL⁻¹)	6	NaN										

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOfFailure	Location	Annual	Dry	Wet
Mackay Whitsunday		DOC (mgL⁻¹)	6	1011.63	1073.69	816.27	948.07	1098.24	1121.88					
		DON (µgL⁻¹)	6	83.75	65.80	50.23	56.59	108.20	137.91					
		DOP (µgL⁻¹)	6	5.82	5.62	4.25	4.60	7.31	7.32					
		Chla (µgL⁻¹)	6	0.42	0.43	0.23	0.25	0.59	0.60	H	Median	0.36	0.32	0.63
		NOx (µgL⁻¹)	6	1.08	1.07	0.23	0.48	1.80	1.84	H	Median	1.00		
		PN (µgL⁻¹)	6	23.34	19.71	18.69	19.19	23.68	35.42	H	Mean	14.00		
		PO4 (µgL⁻¹)	6	1.94	1.90	1.21	1.28	2.50	2.81	H	Median	1.00		
		PP (µgL⁻¹)	6	3.37	3.56	2.73	2.86	3.73	3.96	H	Median	2.30	2.30	3.30
		Secchi (m)	6	5.10	5.50	4.00	4.00	6.00	6.00	L	Mean	10.00		
		TSS (mgL⁻¹)	6	1.40	1.41	0.77	0.86	1.67	2.14	H	Median	1.40	1.60	2.40
	Pine	DIN (µgL⁻¹)	8	NaN										
		DOC (mgL⁻¹)	8	946.96	979.46	806.92	886.27	1030.37	1031.77					
		DON (µgL⁻¹)	8	79.68	60.18	44.19	51.22	110.29	132.51					
		DOP (µgL⁻¹)	8	5.95	6.03	4.43	5.19	7.04	7.08					
		Chla (µgL⁻¹)	8	0.57	0.52	0.38	0.43	0.66	0.91	H	Median	0.36	0.32	0.63
		NOx (µgL⁻¹)	8	2.29	1.34	0.26	0.45	4.06	5.32	H	Median	1.00		
		PN (µgL⁻¹)	8	18.59	17.91	17.42	17.51	19.77	20.37	H	Mean	14.00		
		PO4 (µgL⁻¹)	8	2.03	2.20	0.62	1.08	3.02	3.24	H	Median	1.00		
		PP (µgL⁻¹)	8	3.29	3.36	2.68	2.76	3.60	4.06	H	Median	2.30	2.30	3.30
		Secchi (m)	8	5.90	6.00	3.40	4.60	7.00	8.50	L	Mean	10.00		
		TSS (mgL⁻¹)	8	1.90	1.75	0.81	1.04	2.80	3.08	H	Median	1.40	1.60	2.40
	Seaforth	DIN (µgL⁻¹)	8	NaN										
		DOC (mgL⁻¹)	8	984.04	959.83	860.96	931.63	1077.07	1090.70					
		DON (µgL⁻¹)	8	85.17	63.96	43.20	50.27	115.40	153.05					
		DOP (µgL⁻¹)	8	5.03	5.32	3.10	3.32	5.94	7.50					
		Chla (µgL⁻¹)	8	0.54	0.50	0.28	0.37	0.65	0.91	H	Median	0.36	0.32	0.63
		NOx (µgL⁻¹)	8	1.42	1.23	0.39	0.61	1.87	2.98	H	Median	1.00		

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOfFailure	Location	Annual	Dry	Wet
		PN (µgL⁻¹)	8	20.15	20.34	18.11	18.81	21.42	22.05	H	Mean	14.00		
		PO4 (µgL⁻¹)	8	2.18	2.27	1.34	1.53	2.86	2.92	H	Median	1.00		
		PP (µgL⁻¹)	8	3.79	3.88	2.70	3.24	4.36	4.77	H	Median	2.30	2.30	3.30
		Secchi (m)	8	4.80	5.00	3.20	3.80	6.00	6.00	L	Mean	10.00		
		TSS (mgL⁻¹)	8	2.13	1.97	0.99	1.18	3.01	3.69	H	Median	1.40	1.60	2.40
	Repulse	DIN (µgL⁻¹)	8	NaN										
	O'Connell Mouth	DIN (µgL⁻¹)	5	NaN										
	Repulse	DOC (mgL⁻¹)	8	1105.67	1085.30	898.12	976.73	1187.80	1380.41					
	O'Connell Mouth	DOC (mgL⁻¹)	5	1370.64	1340.74	1021.48	1073.17	1506.70	1911.11					
	Repulse	DON (µgL⁻¹)	8	131.62	98.43	58.66	82.32	201.21	217.47					
	O'Connell Mouth	DON (µgL⁻¹)	5	116.16	121.72	76.20	97.74	141.38	143.78					
	Repulse	DOP (µgL⁻¹)	8	6.57	5.97	5.14	5.39	7.03	9.35					
	O'Connell Mouth	DOP (µgL⁻¹)	5	6.65	5.57	4.54	5.12	8.00	10.00					
	Repulse	Chla (µgL⁻¹)	8	0.76	0.69	0.51	0.58	0.94	1.18	H	Mean	0.45		
	O'Connell Mouth	Chla (µgL⁻¹)	5	0.78	0.92	0.26	0.54	1.02	1.18	H	Median	1.30	0.32	0.63
	Repulse	NOx (µgL⁻¹)	8	1.79	0.58	0.16	0.20	3.14	4.89	H	Median	0.25		
	O'Connell Mouth	NOx (µgL⁻¹)	5	0.83	0.14	0.14	0.14	1.49	2.25	H	Median	4.00		
	Repulse	PN (µgL⁻¹)	8	26.01	28.29	19.97	20.12	30.23	31.45	H	Median	18.00	16.00	25.00
	Repulse	PO4 (µgL⁻¹)	8	2.68	2.73	0.68	1.49	4.16	4.36	H	Median	2.00		
	O'Connell Mouth	PO4 (µgL⁻¹)	5	3.71	3.35	0.88	2.24	5.62	6.48	H	Median	3.00		
	Repulse	PP (µgL⁻¹)	8	5.33	5.14	3.70	4.31	6.15	7.34	H	Median	2.10	2.30	3.30
	Repulse	Secchi (m)	8	4.10	4.50	2.70	3.30	5.00	5.00	L	Mean	10.00		
	O'Connell Mouth	Secchi (m)	5	4.70	5.00	2.20	2.80	6.00	7.50	L	Median	1.60		
	Repulse	TSS (mgL⁻¹)	8	4.17	3.90	1.53	2.24	5.55	7.48	H	Median	1.60	1.60	2.40
	O'Connell Mouth	TSS (mgL⁻¹)	5	1.70	2.09	0.45	1.19	2.36	2.43	H	Median	5.00	1.60	2.40

Table E-3: Summary statistics for direct water sampling data from inshore lagoon sites from August 2005 to June 2016. 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	DirectionOfFailure	Location	Annual	Dry	Wet
Wet Tropics	Cape Tribulation	DIN (µgL⁻¹)	30	1.49	1.47	0.57	0.66	1.77	2.46					
		DOC (mgL⁻¹)	30	832.59	862.08	629.20	730.18	914.37	987.38					
		DON (µgL⁻¹)	30	78.34	80.92	40.02	58.59	94.01	109.42					
		DOP (µgL⁻¹)	30	4.70	4.23	1.62	2.42	6.03	7.91					
		Chla (µgL⁻¹)	30	0.41	0.40	0.22	0.28	0.53	0.71	H	Mean	0.45		
		NOx (µgL⁻¹)	30	0.76	0.65	0.01	0.25	1.32	1.52	H	Median	0.35		
		PN (µgL⁻¹)	30	12.53	12.06	9.14	10.25	14.09	18.41	H	Mean	20.00		
		PO4 (µgL⁻¹)	30	2.42	2.28	0.50	1.58	3.26	3.63	H	Median	2.00		
		PP (µgL⁻¹)	30	2.79	2.55	1.87	2.04	3.37	4.37	H	Mean	2.80		
		Secchi (m)	30	6.76	6.25	3.17	5.00	9.30	11.00	L	Mean	10.00		
		TSS (mgL⁻¹)	30	1.52	1.24	0.61	0.84	1.86	3.25	H	Mean	2.00		
	Port Douglas	DIN (µgL⁻¹)	31	1.17	0.90	0.20	0.58	1.53	3.09					
		DOC (mgL⁻¹)	31	814.12	816.78	642.55	732.42	895.00	983.88					
		DON (µgL⁻¹)	31	75.32	72.88	36.27	53.13	94.94	124.24					
		DOP (µgL⁻¹)	31	4.17	3.56	1.82	2.22	4.82	7.01					
		Chla (µgL⁻¹)	31	0.38	0.34	0.22	0.26	0.45	0.68	H	Median	0.30	0.32	0.63
		NOx (µgL⁻¹)	31	0.75	0.46	0.01	0.14	1.23	1.63	H	Median	0.31		
		PN (µgL⁻¹)	31	12.41	12.11	9.26	10.61	14.13	17.07	H	Median	14.00	16.00	25.00
		PO4 (µgL⁻¹)	31	2.26	2.24	0.52	1.42	3.12	3.69	H	Median	2.00		
		PP (µgL⁻¹)	31	2.52	2.44	1.51	2.16	2.99	3.59	H	Median	2.00	2.30	3.30
		Secchi (m)	31	6.44	6.00	3.25	4.50	9.00	10.50	L	Median	13.00		
		TSS (mgL⁻¹)	31	1.45	1.53	0.66	0.91	1.88	2.27	H	Median	1.20	1.60	2.40
	Double	DIN (µgL⁻¹)	30	1.06	0.67	0.08	0.25	1.72	2.66					
		DOC (mgL⁻¹)	30	813.73	797.15	674.97	723.36	909.06	989.77					
		DON (µgL⁻¹)	30	77.40	75.50	39.26	60.50	94.71	114.95					

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOfFailure	Location	Annual	Dry	Wet
		DOP (µgL⁻¹)	30	4.75	3.94	2.45	2.97	5.45	7.87					
		Chla (µgL⁻¹)	30	0.39	0.36	0.19	0.28	0.51	0.60	H	Median	0.30	0.32	0.63
		NOx (µgL⁻¹)	30	0.69	0.31	0.01	0.06	1.24	2.04	H	Median	0.31		
		PN (µgL⁻¹)	30	11.50	11.57	8.11	9.85	13.05	13.90	H	Median	14.00	16.00	25.00
		PO4 (µgL⁻¹)	30	2.08	2.05	0.49	1.20	2.77	4.03	H	Median	2.00		
		PP (µgL⁻¹)	30	2.74	2.40	1.56	1.93	2.95	3.48	H	Median	2.00	2.30	3.30
		Secchi (m)	30	7.16	6.50	3.20	4.00	10.00	13.80	L	Median	13.00		
		TSS (mgL⁻¹)	30	1.22	1.14	0.54	0.92	1.40	2.02	H	Median	1.20	1.60	2.40
	Green	DIN (µgL⁻¹)	31	1.55	1.44	0.29	0.54	2.25	3.74					
		DOC (mgL⁻¹)	31	797.41	814.62	602.71	702.45	883.46	933.08					
		DON (µgL⁻¹)	31	75.94	73.52	44.27	57.13	93.80	106.17					
		DOP (µgL⁻¹)	31	5.05	4.30	2.26	2.79	7.03	8.91					
		Chla (µgL⁻¹)	31	0.29	0.24	0.12	0.14	0.38	0.68	H	Median	0.30	0.32	0.63
		NOx (µgL⁻¹)	31	0.91	0.71	0.10	0.33	1.57	2.19	H	Median	0.31		
		PN (µgL⁻¹)	31	9.97	9.86	7.46	8.31	11.43	12.72	H	Median	14.00	16.00	25.00
		PO4 (µgL⁻¹)	31	2.11	2.04	1.10	1.47	2.79	3.46	H	Median	2.00		
		PP (µgL⁻¹)	31	1.66	1.62	0.92	1.15	2.09	2.51	H	Median	2.00	2.30	3.30
		Secchi (m)	31	11.84	12.00	5.00	8.00	15.00	18.50	L	Median	13.00		
		TSS (mgL⁻¹)	31	0.53	0.40	0.10	0.17	0.82	1.35	H	Median	1.20	1.60	2.40
	Yorkey's Knob	DIN (µgL⁻¹)	31	1.36	1.04	0.20	0.60	1.95	2.90					
		DOC (mgL⁻¹)	31	841.11	843.19	628.62	745.36	930.95	1078.05					
		DON (µgL⁻¹)	31	74.59	74.26	38.35	55.20	93.62	108.04					
		DOP (µgL⁻¹)	31	5.14	4.46	1.95	2.94	6.69	10.61					
		Chla (µgL⁻¹)	31	0.60	0.53	0.33	0.42	0.73	1.06	H	Mean	0.45		
		NOx (µgL⁻¹)	31	0.84	0.51	0.01	0.22	1.42	2.40	H	Median	0.35		
		PN (µgL⁻¹)	31	16.06	15.13	12.09	12.81	18.27	23.16	H	Mean	20.00		
		PO4 (µgL⁻¹)	31	2.13	1.98	0.65	1.28	3.03	3.98	H	Median	2.00		
		PP (µgL⁻¹)	31	4.07	3.82	2.80	3.29	4.55	5.72	H	Mean	2.80		

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOfFailure	Location	Annual	Dry	Wet
		Secchi (m)	31	3.61	3.00	2.00	2.50	5.00	6.75	L	Mean	10.00		
		TSS (mgL⁻¹)	31	3.06	2.52	1.36	1.91	4.02	6.51	H	Mean	2.00		
	Fairlead Buoy	DIN (µgL⁻¹)	31	1.46	1.29	0.40	0.56	2.38	2.89					
		DOC (mgL⁻¹)	31	844.13	866.76	648.79	747.35	932.82	1010.83					
		DON (µgL⁻¹)	31	76.49	75.33	37.34	56.46	92.29	105.28					
		DOP (µgL⁻¹)	31	4.97	4.26	1.53	3.02	5.60	9.44					
		Chla (µgL⁻¹)	31	0.60	0.50	0.32	0.38	0.71	1.16	H	Mean	0.45		
		NOx (µgL⁻¹)	31	0.70	0.48	0.01	0.09	1.29	1.75	H	Median	0.35		
		PN (µgL⁻¹)	31	16.33	15.59	11.23	13.88	19.12	22.21	H	Mean	20.00		
		PO4 (µgL⁻¹)	31	2.19	2.26	0.59	1.27	2.86	3.95	H	Median	2.00		
		PP (µgL⁻¹)	31	4.56	4.30	2.49	3.11	5.46	7.75	H	Mean	2.80		
		Secchi (m)	31	3.30	3.00	1.50	2.00	4.10	6.87	L	Mean	10.00		
		TSS (mgL⁻¹)	31	4.12	2.89	0.75	1.85	6.18	10.90	H	Mean	2.00		
	Fitzroy West	DIN (µgL⁻¹)	36	3.06	2.32	0.69	1.31	3.85	8.32					
		DOC (mgL⁻¹)	36	828.95	819.08	622.00	695.77	907.21	1034.12					
		DON (µgL⁻¹)	36	76.58	74.19	40.02	52.27	92.18	119.68					
		DOP (µgL⁻¹)	36	5.01	4.69	0.96	2.27	6.49	7.80					
		Chla (µgL⁻¹)	36	0.32	0.33	0.14	0.18	0.41	0.57	H	Mean	0.45		
		NOx (µgL⁻¹)	36	1.79	1.71	0.16	0.50	2.48	5.01	H	Median	0.35		
		PN (µgL⁻¹)	36	11.84	10.89	7.31	9.74	13.76	18.21	H	Mean	20.00		
		PO4 (µgL⁻¹)	36	2.40	2.34	0.86	1.47	3.28	4.38	H	Median	2.00		
		PP (µgL⁻¹)	36	2.03	1.96	1.33	1.59	2.38	3.07	H	Mean	2.80		
		Secchi (m)	36	9.05	9.00	5.05	7.00	11.00	12.75	L	Mean	10.00		
		TSS (mgL⁻¹)	36	0.87	0.75	0.27	0.49	1.18	1.70	H	Mean	2.00		
	RM3	DIN (µgL⁻¹)	6	2.16	2.16	2.16	2.16	2.16	2.16					
		DOC (mgL⁻¹)	6	995.26	943.28	884.16	921.74	1125.04	1156.22					

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOfFailure	Location	Annual	Dry	Wet
		DON (µgL⁻¹)	6	81.65	73.49	43.42	58.52	122.21	123.38					
		DOP (µgL⁻¹)	6	5.23	5.44	3.56	3.72	5.71	7.09					
		Chla (µgL⁻¹)	6	0.40	0.38	0.14	0.18	0.59	0.72	H	Median	0.30	0.32	0.63
		NOx (µgL⁻¹)	6	1.16	1.06	0.18	0.28	1.56	2.52	H	Median	0.31		
		PN (µgL⁻¹)	6	20.44	17.61	12.44	12.49	28.82	32.47	H	Median	14.00	16.00	25.00
		PO4 (µgL⁻¹)	6	2.33	2.06	1.27	1.74	2.14	4.20	H	Median	2.00		
		PP (µgL⁻¹)	6	2.69	2.50	1.94	1.97	3.50	3.69	H	Median	2.00	2.30	3.30
		Secchi (m)	6	11.00	10.00	8.00	8.00	15.00	15.00	L	Median	13.00		
		TSS (mgL⁻¹)	6	0.75	0.75	0.46	0.53	1.00	1.04	H	Median	1.20	1.60	2.40
	High West	DIN (µgL⁻¹)	37	2.95	2.38	0.74	1.36	3.85	5.80					
		DOC (mgL⁻¹)	37	866.49	867.03	648.54	728.92	978.21	1116.42					
		DON (µgL⁻¹)	37	78.67	79.56	44.30	58.29	94.50	105.29					
		DOP (µgL⁻¹)	37	4.98	4.71	1.94	2.45	6.66	8.51					
		Chla (µgL⁻¹)	37	0.47	0.36	0.25	0.27	0.74	1.02	H	Mean	0.45		
		NOx (µgL⁻¹)	37	2.28	1.50	0.19	0.68	2.69	8.13	H	Median	0.35		
		PN (µgL⁻¹)	37	13.90	12.35	8.81	10.95	16.76	21.26	H	Mean	20.00		
		PO4 (µgL⁻¹)	37	2.30	2.18	0.94	1.37	3.05	4.61	H	Median	2.00		
		PP (µgL⁻¹)	37	2.81	2.51	1.77	2.18	3.40	4.28	H	Mean	2.80		
		Secchi (m)	37	6.60	6.50	2.50	4.00	9.00	12.00	L	Mean	10.00		
		TSS (mgL⁻¹)	37	1.44	1.04	0.43	0.77	2.15	3.23	H	Mean	2.00		
	Russell Mulgrave Mouth Mooring	DIN (µgL⁻¹)	8	23.06	23.06	23.06	23.06	23.06	23.06					
		DOC (mgL⁻¹)	8	1061.75	1055.10	904.33	980.31	1168.10	1216.87					
		DON (µgL⁻¹)	8	78.55	79.72	28.58	42.34	112.14	114.10					
		DOP (µgL⁻¹)	8	5.32	5.28	1.72	4.67	5.97	8.93					
		Chla (µgL⁻¹)	8	0.67	0.56	0.34	0.42	0.89	1.24	H	Mean	0.45		
		NOx (µgL⁻¹)	8	8.23	1.18	0.14	0.31	16.73	28.22	H	Median	0.35		
		PN (µgL⁻¹)	8	20.81	21.64	14.12	15.80	24.89	28.11	H	Mean	20.00		

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOfFailure	Location	Annual	Dry	Wet
		PO4 (µgL⁻¹)	8	2.19	2.00	0.95	1.19	3.09	3.85	H	Median	2.00		
		PP (µgL⁻¹)	8	5.23	4.38	3.22	3.78	7.02	7.83	H	Mean	2.80		
		Secchi (m)	8	3.97	3.75	1.19	2.40	5.50	6.80	L	Mean	10.00		
		TSS (mgL⁻¹)	8	3.02	2.76	0.92	1.16	4.70	6.21	H	Mean	2.00		
	Franklands West	DIN (µgL⁻¹)	38	1.83	1.82	0.85	1.00	2.53	2.90					
		DOC (mgL⁻¹)	38	821.03	846.30	650.34	717.92	867.90	994.99					
		DON (µgL⁻¹)	38	78.14	77.14	42.41	62.15	94.25	110.62					
		DOP (µgL⁻¹)	38	5.13	4.46	1.28	2.89	6.66	12.33					
		Chla (µgL⁻¹)	38	0.34	0.30	0.17	0.19	0.44	0.70	H	Median	0.30	0.32	0.63
		NOx (µgL⁻¹)	38	1.10	0.91	0.09	0.44	2.06	2.31	H	Median	0.31		
		PN (µgL⁻¹)	38	12.98	10.89	8.08	9.64	14.89	25.23	H	Median	14.00	16.00	25.00
		PO4 (µgL⁻¹)	38	2.20	2.15	0.86	1.29	3.03	3.30	H	Median	2.00		
		PP (µgL⁻¹)	38	2.09	2.10	1.25	1.58	2.53	3.06	H	Median	2.00	2.30	3.30
		Secchi (m)	38	9.43	9.00	5.00	6.00	12.60	13.00	L	Median	13.00		
		TSS (mgL⁻¹)	38	0.70	0.59	0.18	0.39	0.98	1.47	H	Median	1.20	1.60	2.40
	Clump Point East	DIN (µgL⁻¹)	6	NaN										
		DOC (mgL⁻¹)	6	999.28	985.13	877.97	909.67	1112.35	1130.06					
		DON (µgL⁻¹)	6	77.43	70.46	32.50	65.44	85.70	134.70					
		DOP (µgL⁻¹)	6	4.86	4.46	2.11	3.43	6.25	8.22					
		Chla (µgL⁻¹)	6	0.25	0.26	0.13	0.16	0.30	0.38	H	Median	0.30	0.32	0.63
		NOx (µgL⁻¹)	6	0.76	0.84	0.19	0.35	1.15	1.24	H	Median	0.31		
		PN (µgL⁻¹)	6	17.91	17.51	13.36	16.56	18.02	23.66	H	Median	14.00	16.00	25.00
		PO4 (µgL⁻¹)	6	1.81	1.72	1.30	1.41	1.93	2.59	H	Median	2.00		
		PP (µgL⁻¹)	6	1.97	2.05	1.61	1.77	2.20	2.21	H	Median	2.00	2.30	3.30
		Secchi (m)	6	14.08	13.00	9.50	11.00	16.00	20.88	L	Median	13.00		
		TSS (mgL⁻¹)	6	0.40	0.34	0.22	0.24	0.49	0.69	H	Median	1.20	1.60	2.40
	Dunk North	DIN (µgL⁻¹)	36	2.65	2.02	0.36	1.19	3.27	7.54					
		DOC (mgL⁻¹)	36	921.32	897.53	712.31	803.71	1035.92	1235.36					
		DON (µgL⁻¹)	36	81.37	76.02	39.20	66.20	97.20	116.67					

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOfFailure	Location	Annual	Dry	Wet
		DOP (µgL⁻¹)	36	5.06	4.60	2.12	2.69	6.54	9.32					
		Chla (µgL⁻¹)	36	0.53	0.42	0.18	0.24	0.61	1.44	H	Mean	0.45		
		NOx (µgL⁻¹)	36	1.52	0.96	0.01	0.14	1.63	5.31	H	Median	0.35		
		PN (µgL⁻¹)	36	16.04	14.30	9.83	11.99	20.64	23.92	H	Mean	20.00		
		PO4 (µgL⁻¹)	36	2.10	2.19	0.69	1.31	2.76	3.27	H	Median	2.00		
		PP (µgL⁻¹)	36	3.41	3.09	1.77	2.34	4.40	5.92	H	Mean	2.80		
		Secchi (m)	36	5.14	5.00	2.55	3.36	6.50	8.45	L	Mean	10.00		
		TSS (mgL⁻¹)	36	2.18	1.37	0.47	1.01	2.36	5.63	H	Mean	2.00		
	Dunk South	DIN (µgL⁻¹)	6	NaN										
		DOC (mgL⁻¹)	6	1012.71	1001.85	885.84	930.41	1050.20	1178.27					
		DON (µgL⁻¹)	6	89.11	78.27	39.28	65.18	115.61	153.92					
		DOP (µgL⁻¹)	6	5.36	4.87	2.46	3.12	6.19	9.71					
		Chla (µgL⁻¹)	6	0.45	0.43	0.26	0.31	0.58	0.66	H	Mean	0.45		
		NOx (µgL⁻¹)	6	0.59	0.36	0.17	0.26	1.01	1.29	H	Median	0.35		
		PN (µgL⁻¹)	6	18.78	18.37	14.98	17.51	21.15	22.66	H	Mean	20.00		
		PO4 (µgL⁻¹)	6	1.80	1.79	1.10	1.42	2.12	2.56	H	Median	2.00		
		PP (µgL⁻¹)	6	2.93	2.95	2.18	2.26	3.40	3.75	H	Mean	2.80		
		Secchi (m)	6	7.75	8.00	4.88	6.00	8.50	10.75	L	Mean	10.00		
		TSS (mgL⁻¹)	6	1.15	1.02	0.46	0.72	1.88	1.89	H	Mean	2.00		
	Between Tam O'Shanter and Timana	DIN (µgL⁻¹)	6	NaN										
		DOC (mgL⁻¹)	6	1140.28	1093.00	951.86	1037.44	1334.23	1354.08					
		DON (µgL⁻¹)	6	74.42	79.68	45.34	68.45	86.47	92.55					
		DOP (µgL⁻¹)	6	6.02	5.37	2.56	3.32	6.14	11.77					
		Chla (µgL⁻¹)	6	0.56	0.41	0.26	0.27	0.87	1.06	H	Mean	0.45		
		NOx (µgL⁻¹)	6	1.86	0.80	0.15	0.18	1.04	6.43	H	Median	0.35		
		PN (µgL⁻¹)	6	23.64	20.51	11.44	16.26	27.71	42.17	H	Mean	20.00		

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOfFailure	Location	Annual	Dry	Wet
		PO4 (µgL⁻¹)	6	1.83	1.84	1.30	1.51	2.25	2.30	H	Median	2.00		
		PP (µgL⁻¹)	6	4.64	3.55	2.83	3.33	4.64	8.74	H	Mean	2.80		
		Secchi (m)	6	4.83	4.75	1.88	4.50	5.50	7.75	L	Mean	10.00		
		TSS (mgL⁻¹)	6	3.18	1.30	0.53	0.91	1.35	10.70	H	Mean	2.00		
	Bedarra	DIN (µgL⁻¹)	6	NaN										
		DOC (mgL⁻¹)	6	1031.71	1026.78	918.48	949.90	1057.54	1180.31					
		DON (µgL⁻¹)	6	76.07	80.60	44.11	69.56	93.19	95.91					
		DOP (µgL⁻¹)	6	6.03	5.01	3.44	4.30	5.68	11.16					
		Chla (µgL⁻¹)	6	0.42	0.42	0.24	0.31	0.54	0.61	H	Mean	0.45		
		NOx (µgL⁻¹)	6	1.28	0.93	0.23	0.49	1.34	3.23	H	Median	0.35		
		PN (µgL⁻¹)	6	22.72	24.30	11.06	16.81	27.84	32.44	H	Mean	20.00		
		PO4 (µgL⁻¹)	6	1.80	1.76	1.46	1.49	2.03	2.21	H	Median	2.00		
		PP (µgL⁻¹)	6	3.66	3.39	2.48	2.71	4.14	5.47	H	Mean	2.80		
		Secchi (m)	6	6.00	6.25	2.12	5.50	8.00	8.75	L	Mean	10.00		
		TSS (mgL⁻¹)	6	1.66	0.78	0.47	0.54	1.26	4.96	H	Mean	2.00		
	Tully Mouth Mooring	DIN (µgL⁻¹)	8	28.13	28.13	28.13	28.13	28.13	28.13					
		DOC (mgL⁻¹)	8	1187.46	1097.07	1053.68	1079.60	1332.36	1344.26					
		DON (µgL⁻¹)	8	82.61	82.24	46.48	74.52	87.10	120.74					
		DOP (µgL⁻¹)	8	6.34	6.00	3.07	4.28	7.25	11.40					
		Chla (µgL⁻¹)	8	0.79	0.63	0.31	0.43	1.23	1.40	H	Median	1.10	0.32	0.63
		NOx (µgL⁻¹)	8	7.94	1.86	0.19	0.62	19.32	24.57	H	Median	3.00		
		PO4 (µgL⁻¹)	8	1.90	1.92	1.30	1.56	2.11	2.48	H	Median	3.00		
		Secchi (m)	8	3.29	3.00	0.65	1.30	4.50	6.25	L	Median	1.60		
		TSS (mgL⁻¹)	8	6.56	2.70	1.01	1.43	9.59	18.89	H	Median	5.00	1.60	2.40
Burdekin	Palms West	DIN (µgL⁻¹)	36	2.66	1.70	0.65	1.17	3.02	8.38					
		DOC (mgL⁻¹)	36	844.40	855.60	654.25	736.13	934.21	1062.96					
		DON (µgL⁻¹)	36	76.51	77.33	30.26	59.30	96.93	112.21					

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOfFailure	Location	Annual	Dry	Wet
		DOP (µgL⁻¹)	36	5.27	5.19	1.82	2.91	6.22	7.17					
		Chla (µgL⁻¹)	36	0.41	0.37	0.17	0.23	0.59	0.77	H	Median	0.35	0.32	0.63
		NOx (µgL⁻¹)	36	1.47	1.00	0.13	0.50	2.26	3.06	H	Median	0.28		
		PN (µgL⁻¹)	36	12.83	11.37	8.12	9.31	15.12	22.42	H	Median	12.00	16.00	25.00
		PO4 (µgL⁻¹)	36	2.36	2.22	0.84	1.43	3.06	3.85	H	Median	1.00		
		PP (µgL⁻¹)	36	2.17	2.04	1.33	1.55	2.59	3.47	H	Median	2.20	2.30	3.30
		Secchi (m)	36	8.55	8.75	4.00	6.00	10.00	14.55	L	Mean	10.00		
		TSS (mgL⁻¹)	36	0.85	0.67	0.23	0.40	1.24	1.99	H	Median	1.20	1.60	2.40
	Pandora	DIN (µgL⁻¹)	39	3.12	2.62	0.61	1.52	5.31	6.70					
		DOC (mgL⁻¹)	39	885.49	871.74	669.53	758.00	992.40	1225.61					
		DON (µgL⁻¹)	39	81.32	79.62	40.84	69.67	94.57	106.21					
		DOP (µgL⁻¹)	39	4.91	4.61	1.12	2.14	6.86	7.95					
		Chla (µgL⁻¹)	39	0.39	0.34	0.15	0.25	0.56	0.80	H	Median	0.35	0.32	0.63
		NOx (µgL⁻¹)	39	1.91	1.40	0.01	0.33	3.59	5.26	H	Median	0.28		
		PN (µgL⁻¹)	39	13.38	12.52	9.28	10.20	17.38	19.16	H	Median	12.00	16.00	25.00
		PO4 (µgL⁻¹)	39	2.56	2.56	1.04	1.45	3.28	3.88	H	Median	1.00		
		PP (µgL⁻¹)	39	2.66	2.41	1.68	1.90	3.25	4.18	H	Median	2.20	2.30	3.30
		Secchi (m)	39	6.69	6.00	3.32	4.50	9.00	11.45	L	Mean	10.00		
		TSS (mgL⁻¹)	39	1.25	1.02	0.28	0.62	1.48	2.93	H	Median	1.20	1.60	2.40
	Magnetic	DIN (µgL⁻¹)	40	4.97	3.18	0.82	1.41	8.93	11.40					
		DOC (mgL⁻¹)	40	943.16	942.88	707.05	803.45	1043.30	1230.92					
		DON (µgL⁻¹)	40	81.05	85.70	39.48	54.66	102.37	110.93					
		DOP (µgL⁻¹)	40	5.10	4.73	1.37	3.15	7.22	8.60					
		Chla (µgL⁻¹)	40	0.59	0.51	0.25	0.32	0.76	0.98	H	Median	0.59	0.32	0.63
		NOx (µgL⁻¹)	40	2.99	2.00	0.08	0.71	4.86	8.49	H	Median	0.28		
		PN (µgL⁻¹)	40	17.36	16.41	11.14	12.79	19.81	29.58	H	Median	17.00	16.00	25.00
		PO4 (µgL⁻¹)	40	3.15	2.90	1.24	2.04	4.08	5.23	H	Median	1.00		
		PP (µgL⁻¹)	40	3.69	3.52	1.85	2.47	4.36	6.21	H	Mean	2.80		
		Secchi (m)	40	4.41	4.00	2.00	2.55	5.90	8.22	L	Median	4.00		

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOfFailure	Location	Annual	Dry	Wet
		TSS (mgL^{-1})	40	2.15	1.59	0.55	0.90	2.95	4.32	H	Median	1.90	1.60	2.40
	Haughton	DIN (µgL^{-1})	6	NaN										
		DOC (mgL^{-1})	6	1121.41	1075.10	1035.83	1037.78	1163.95	1296.97					
		DON (µgL^{-1})	6	106.70	114.80	67.51	78.55	125.21	138.55					
		DOP (µgL^{-1})	6	5.09	5.40	3.75	4.21	5.95	5.99					
		Chla (µgL^{-1})	6	0.45	0.43	0.25	0.34	0.53	0.68	H	Mean	0.45		
		NOx (µgL^{-1})	6	0.52	0.59	0.16	0.20	0.76	0.82	H	Median	1.00		
		PN (µgL^{-1})	6	15.84	14.37	12.48	13.42	17.31	21.88	H	Median	13.00	16.00	25.00
		PO4 (µgL^{-1})	6	1.22	1.26	0.63	0.80	1.55	1.78	H	Median	2.00		
		PP (µgL^{-1})	6	3.03	3.04	2.29	2.41	3.69	3.73	H	Median	2.10	2.30	3.30
		Secchi (m)	6	6.42	5.75	4.50	4.50	8.00	9.50	L	Mean	10.00		
		TSS (mgL^{-1})	6	1.35	1.27	0.86	0.86	1.65	2.06	H	Median	1.20	1.60	2.40
	Yongala	DIN (µgL^{-1})	12	NaN										
		DOC (mgL^{-1})	12	1037.91	1009.80	877.56	936.29	1125.93	1239.74					
		DON (µgL^{-1})	12	109.61	108.28	68.18	87.61	125.03	164.54					
		DOP (µgL^{-1})	12	5.01	5.17	3.27	3.95	6.06	6.21					
		Chla (µgL^{-1})	12	0.21	0.21	0.09	0.13	0.28	0.33	H	Median	0.33	0.32	0.63
		NOx (µgL^{-1})	12	0.80	0.40	0.14	0.20	1.18	2.29	H	Median	0.28		
		PN (µgL^{-1})	12	10.81	10.81	7.91	9.45	12.38	13.53	H	Median	14.00	16.00	25.00
		PO4 (µgL^{-1})	12	1.31	1.44	0.52	0.98	1.59	1.90	H	Median	1.00		
		PP (µgL^{-1})	12	1.49	1.46	1.02	1.21	1.80	2.07	H	Median	2.00	2.30	3.30
		Secchi (m)	12	15.41	13.00	11.50	12.00	19.00	22.00	L	Mean	10.00		
		TSS (mgL^{-1})	12	0.26	0.28	0.01	0.10	0.44	0.46	H	Median	0.80	1.60	2.40
	Burdekin Mouth Mooring	DIN (µgL^{-1})	6	NaN										
		DOC (mgL^{-1})	6	1195.99	1204.73	1106.33	1135.83	1240.10	1280.54					
		DON (µgL^{-1})	6	107.03	94.00	66.42	86.61	109.82	176.00					
		DOP (µgL^{-1})	6	5.02	5.14	2.68	4.38	6.55	6.75					
		Chla (µgL^{-1})	6	1.02	0.82	0.41	0.57	0.97	2.17	H	Median	1.00	0.32	0.63
		NOx (µgL^{-1})	6	1.09	0.99	0.16	0.22	1.87	2.23	H	Median	4.00		

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOfFailure	Location	Annual	Dry	Wet
		PO4 (µgL⁻¹)	6	1.80	1.79	1.16	1.38	2.33	2.37	H	Median	1.00		
		Secchi (m)	6	3.50	3.75	2.12	2.50	4.50	4.50	L	Median	1.50		
		TSS (mgL⁻¹)	6	2.13	1.69	1.23	1.25	2.80	3.77	H	Median	2.00	1.60	2.40
Mackay Whitsunday	Double Cone	DIN (µgL⁻¹)	36	2.75	1.73	0.85	1.05	3.25	8.78					
		DOC (mgL⁻¹)	36	842.06	846.48	615.58	720.59	984.82	1082.53					
		DON (µgL⁻¹)	36	77.23	73.77	46.35	58.30	84.77	122.61					
		DOP (µgL⁻¹)	36	5.06	4.15	2.05	3.37	5.66	9.48					
		Chla (µgL⁻¹)	36	0.46	0.43	0.16	0.25	0.59	0.95	H	Median	0.36	0.32	0.63
		NOx (µgL⁻¹)	36	1.48	1.05	0.06	0.51	1.83	4.15	H	Median	1.00		
		PN (µgL⁻¹)	36	14.54	12.63	8.85	10.99	18.21	20.23	H	Mean	14.00		
		PO4 (µgL⁻¹)	36	3.00	2.96	1.26	1.92	3.85	4.82	H	Median	1.00		
		PP (µgL⁻¹)	36	2.75	2.61	1.47	1.89	3.43	4.56	H	Median	2.30	2.30	3.30
		Secchi (m)	36	6.21	6.00	3.50	4.00	7.00	10.75	L	Mean	10.00		
		TSS (mgL⁻¹)	36	1.54	1.26	0.50	0.85	2.20	3.23	H	Median	1.40	1.60	2.40
	Pine	DIN (µgL⁻¹)	37	6.17	3.31	0.80	1.57	8.34	24.46					
		DOC (mgL⁻¹)	37	844.78	818.57	621.55	747.15	977.42	1030.84					
		DON (µgL⁻¹)	37	82.47	79.35	48.29	59.17	98.31	128.74					
		DOP (µgL⁻¹)	37	5.01	4.17	1.86	3.45	6.71	8.32					
		Chla (µgL⁻¹)	37	0.58	0.54	0.36	0.45	0.73	0.89	H	Median	0.36	0.32	0.63
		NOx (µgL⁻¹)	37	3.38	1.52	0.17	0.50	4.58	12.72	H	Median	1.00		
		PN (µgL⁻¹)	37	14.30	13.59	10.03	11.40	17.48	19.63	H	Mean	14.00		
		PO4 (µgL⁻¹)	37	3.68	3.32	1.56	2.53	4.86	6.49	H	Median	1.00		
		PP (µgL⁻¹)	37	3.20	2.82	1.97	2.36	3.58	6.31	H	Median	2.30	2.30	3.30
		Secchi (m)	37	5.23	5.00	1.50	3.00	7.00	9.00	L	Mean	10.00		
		TSS (mgL⁻¹)	37	3.09	2.23	0.91	1.24	3.96	8.83	H	Median	1.40	1.60	2.40
	Seaforth	DIN (µgL⁻¹)	11	NaN										
		DOC (mgL⁻¹)	11	989.58	959.83	862.29	927.35	1083.68	1092.61					
		DON (µgL⁻¹)	11	82.54	63.96	44.38	53.85	100.91	146.77					

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOfFailure	Location	Annual	Dry	Wet
		DOP (µgL⁻¹)	11	5.08	5.32	3.13	3.57	6.00	7.45					
		Chla (µgL⁻¹)	11	0.53	0.48	0.29	0.43	0.63	0.85	H	Median	0.36	0.32	0.63
		NOx (µgL⁻¹)	11	1.52	1.50	0.43	0.80	1.92	2.95	H	Median	1.00		
		PN (µgL⁻¹)	11	17.80	19.05	10.91	15.11	21.04	21.94	H	Mean	14.00		
		PO4 (µgL⁻¹)	11	2.51	2.84	1.37	1.73	3.15	3.38	H	Median	1.00		
		PP (µgL⁻¹)	11	3.54	3.42	2.60	2.85	4.15	4.71	H	Median	2.30	2.30	3.30
		Secchi (m)	11	4.79	5.00	3.30	4.10	5.80	6.00	L	Mean	10.00		
		TSS (mgL⁻¹)	11	2.13	1.92	1.03	1.24	2.75	3.59	H	Median	1.40	1.60	2.40
	Repulse	DIN (µgL⁻¹)	11	NaN										
	O'Connell Mouth	DIN (µgL⁻¹)	7	NaN										
	Repulse	DOC (mgL⁻¹)	11	1096.70	1085.30	894.34	957.90	1186.22	1371.79					
	O'Connell Mouth	DOC (mgL⁻¹)	7	1332.84	1258.80	1030.09	1115.89	1365.67	1843.70					
	Repulse	DON (µgL⁻¹)	11	114.73	90.20	52.44	62.80	176.32	214.76					
	O'Connell Mouth	DON (µgL⁻¹)	7	107.84	104.93	72.11	82.42	136.80	143.38					
	Repulse	DOP (µgL⁻¹)	11	6.24	5.97	4.31	5.14	6.71	9.13					
	O'Connell Mouth	DOP (µgL⁻¹)	7	6.97	5.57	4.43	4.75	10.00	10.84					
	Repulse	Chla (µgL⁻¹)	11	0.76	0.66	0.44	0.56	1.01	1.25	H	Mean	0.45		
	O'Connell Mouth	Chla (µgL⁻¹)	7	0.81	0.92	0.20	0.35	1.18	1.40	H	Median	1.30	0.32	0.63
	Repulse	NOx (µgL⁻¹)	11	1.58	0.58	0.16	0.28	2.36	4.60	H	Median	0.25		
	O'Connell Mouth	NOx (µgL⁻¹)	7	0.98	0.51	0.14	0.14	2.01	2.41	H	Median	4.00		
	Repulse	PN (µgL⁻¹)	11	23.35	20.17	16.13	18.51	29.51	31.24	H	Median	18.00	16.00	25.00
		PO4 (µgL⁻¹)	11	3.06	3.73	0.82	1.95	4.24	4.38	H	Median	2.00		
	O'Connell Mouth	PO4 (µgL⁻¹)	7	4.16	5.14	1.10	2.83	5.37	6.35	H	Median	3.00		
	Repulse	PP (µgL⁻¹)	11	4.92	4.51	3.43	3.68	5.63	7.14	H	Median	2.10	2.30	3.30
		Secchi (m)	11	3.50	3.50	1.80	2.50	4.90	5.00	L	Mean	10.00		

						Quantiles				Guidelines				
Region	Site	Measure	N	Mean	Median	Q5	Q20	Q80	Q95	DirectionOfFailure	Location	Annual	Dry	Wet
	O'Connell Mouth	Secchi (m)	7	4.43	5.00	1.65	2.20	5.90	7.40	L	Median	1.60		
	Repulse	TSS (mgL^{-1})	11	4.41	3.50	1.58	1.79	5.72	9.14	H	Median	1.60	1.60	2.40
	O'Connell Mouth	TSS (mgL^{-1})	7	1.99	2.09	0.51	1.28	2.43	3.68	H	Median	5.00	1.60	2.40

Table E-4: 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 > GV	%d > 5 GV	N	Annual Mean	SE	Annual Median	%d > GV	%d > 5 GV	N	Annual Mean	SE	Annual Median	%d > GV	%d > 5 GV
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
	Repulse																		
	Seaforth																		

Table E-4 Continued

		Oct2010 - Sept2011						Oct2011 - Sept2012						Oct2012 - Sept2013					
Region	Reef	N	Annual Mean	SE	Annual Median	%d > GV	%d > 5 GV	N	Annual Mean	SE	Annual Median	%d > GV	%d > 5 GV	N	Annual Mean	SE	Annual Median	%d > GV	%d > 5 GV
Johnstone Russell Mulgrave	Fitzroy West	365	1.26	0.12	0.74	30.41	3.84	366	1.21	0.07	0.78	33.21	2.92	365	1.08	0.1	0.76	22.85	1.5
	Franklands West	365	1.14	0.15	0.54	42.74	3.56	366	0.88	0.07	0.54	41.26	1.91	365	0.96	0.06	0.67	60	1.1
	High West	365	1.56	0.15	0.82	36.71	5.48	366	1.08	0.08	0.64	24.04	2.19	365	1.55	0.1	0.93	43.01	4.93
	Russell Mulgrave Mouth Mooring																		
Tully Herbert	Dunk North	229	3.32	0.39	1.36	70.31	16.59	220	2.91	0.26	1.17	61.36	16.82	285	3.67	0.29	1.26	61.75	22.81
	Tully Mouth Mooring																		
Burdekin	Burdekin Mouth Mooring																		
	Magnetic	365	2.79	0.3	1.48	54.79	10.68	366	2.3	0.15	1.37	54.1	9.29	365	4	0.42	1.92	72.05	14.52
	Palms West	263	1.17	0.21	0.68	38.78	0.76	366	0.69	0.03	0.6	22.4	0.27	365	0.9	0.06	0.6	24.38	2.47
	Pandora	365	1.7	0.23	0.89	57.26	5.75	366	1.31	0.1	0.88	55.19	3.01	365	1.6	0.09	1.07	72.05	6.58
Mackay Whitsunday	Double Cone	332	1.47	0.05	1.27	57.83	0.9	366	1.31	0.04	1.05	46.72	0.27	365	1.75	0.07	1.31	60.27	1.64
	Repulse																		
	Seaforth																		

Table E-4 Continued

		Oct2013 - Sept2014						Oct2014 - Sept2015						Oct2015 - Sept2016					
Region	Reef	N	Annual Mean	SE	Annual Median	%d > GV	%d > 5 GV	N	Annual Mean	SE	Annual Median	%d > GV	%d > 5 GV	N	Annual Mean	SE	Annual Median	%d > GV	%d > 5 GV
Johnstone Russell Mulgrave	Fitzroy West	358	1.13	0.09	0.74	27.87	1.72	57	0.52	0.02	0.49	0.00	0.00	273	1.37	0.10	0.85	33.33	3.66
	Franklands West	358	0.97	0.07	0.61	51.12	1.12	59	0.69	0.08	0.53	30.51	0.00	273	1.18	0.07	0.92	86.73	1.77
	High West	213	1.27	0.14	0.77	27.7	3.29	226	1.51	0.10	1.00	50.00	4.42	273	1.10	0.06	0.80	32.23	1.10
	Russell Mulgrave Mouth Mooring							192	6.50	0.43	4.66	97.38	45.55	253	2.69	0.21	1.60	75.10	10.67
Tully Herbert	Dunk North	357	3.94	0.26	1.76	78.15	23.25	222	2.82	0.24	1.18	61.71	16.67	224	2.56	0.23	1.23	65.62	12.50
	Tully Mouth Mooring							217	5.13	0.35	3.24	40.74	32.41	122	3.74	0.26	3.01	35.25	18.85
Burdekin	Burdekin Mouth Mooring							194	4.25	0.23	3.44	40.93	28.50	241	5.02	0.34	3.22	40.66	35.27
	Magnetic	365	2.88	0.13	2.05	76.62	14.08	365	2.13	0.09	1.57	67.27	6.82	252	2.02	0.12	1.49	64.29	5.16
	Palms West	356	0.73	0.04	0.59	20.79	1.12	221	0.77	0.02	0.72	39.37	0.00	103	0.83	0.04	0.78	44.66	0.00
	Pandora	278	1.72	0.1	1.14	80.22	6.12	227	1.44	0.08	1.08	74.45	2.20	223	1.60	0.10	1.16	86.94	4.50
Mackay Whitsunday	Double Cone	365	1.96	0.09	1.51	70.11	3.91	332	1.42	0.11	1.06	47.59	1.51	217	1.38	0.06	1.06	48.39	0.46
	Repulse							82	4.10	0.31	3.36	78.05	23.17	188	4.44	0.22	3.44	82.45	31.91
	Seaforth							208	1.79	0.06	1.53	82.69	0.00	271	1.77	0.05	1.51	80.81	0.00

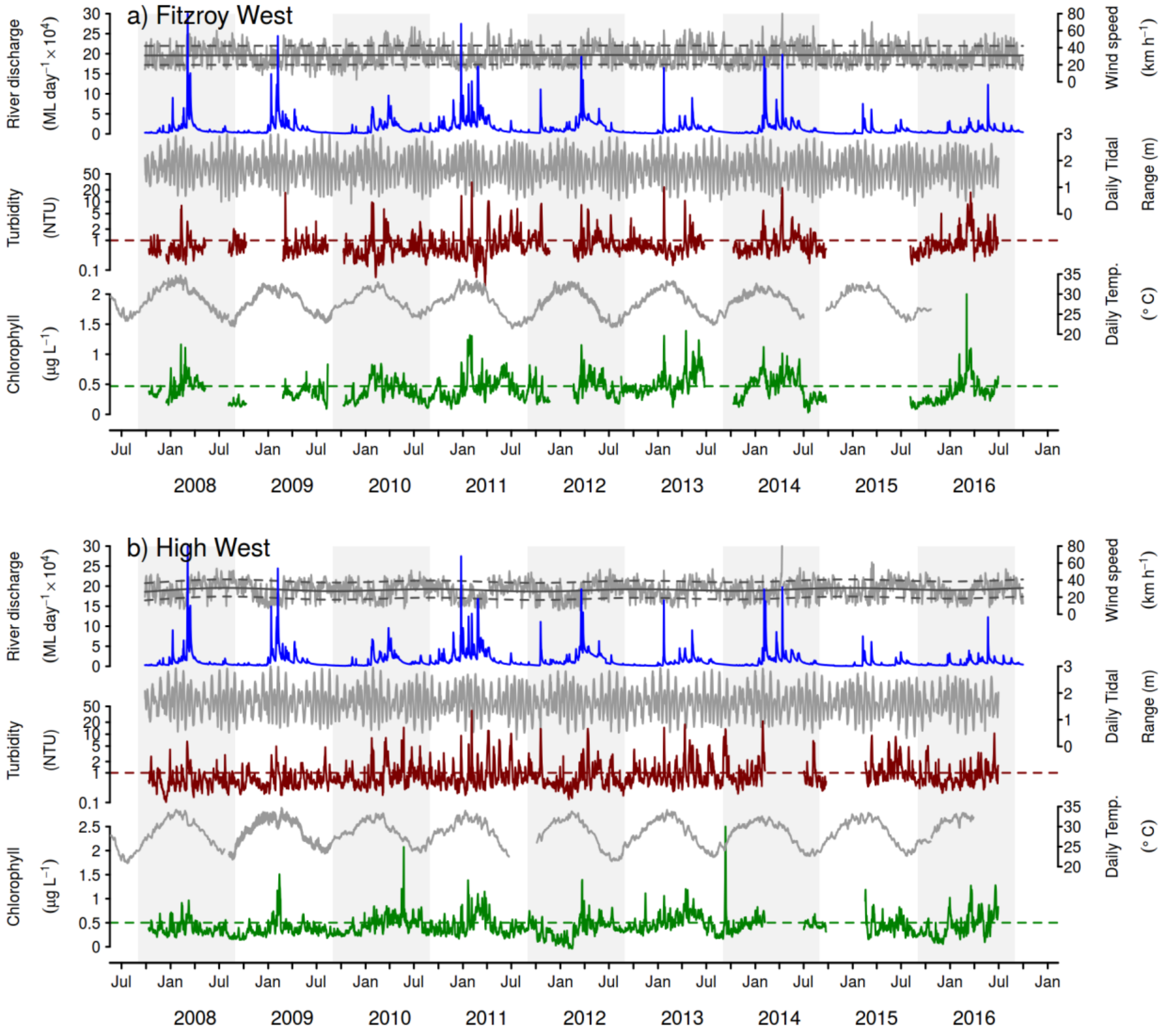


Figure E-1: Time series of daily means of chlorophyll (green line) and turbidity (red line) collected by ECO FLNTUSB instruments. Additional panels represent daily discharge from nearest rivers (blue line) and daily wind speeds (grey line) from the nearest weather stations. Horizontal green and red lines 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; a) Fitzroy West; b) High West.

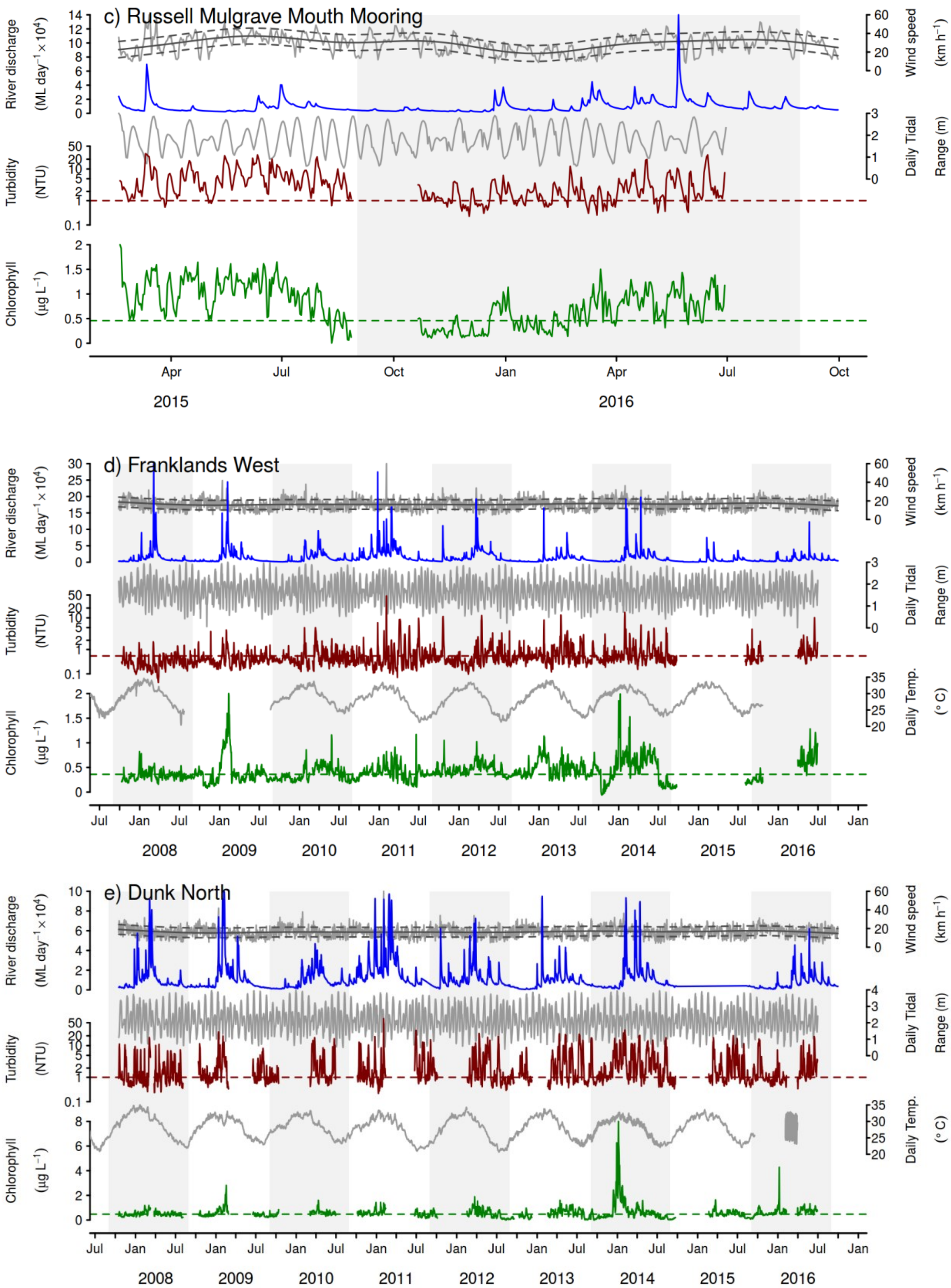


Figure E-1: Continued - c) Russell Mulgrave Mouth Mooring, d) Franklands West, e) Dunk North.

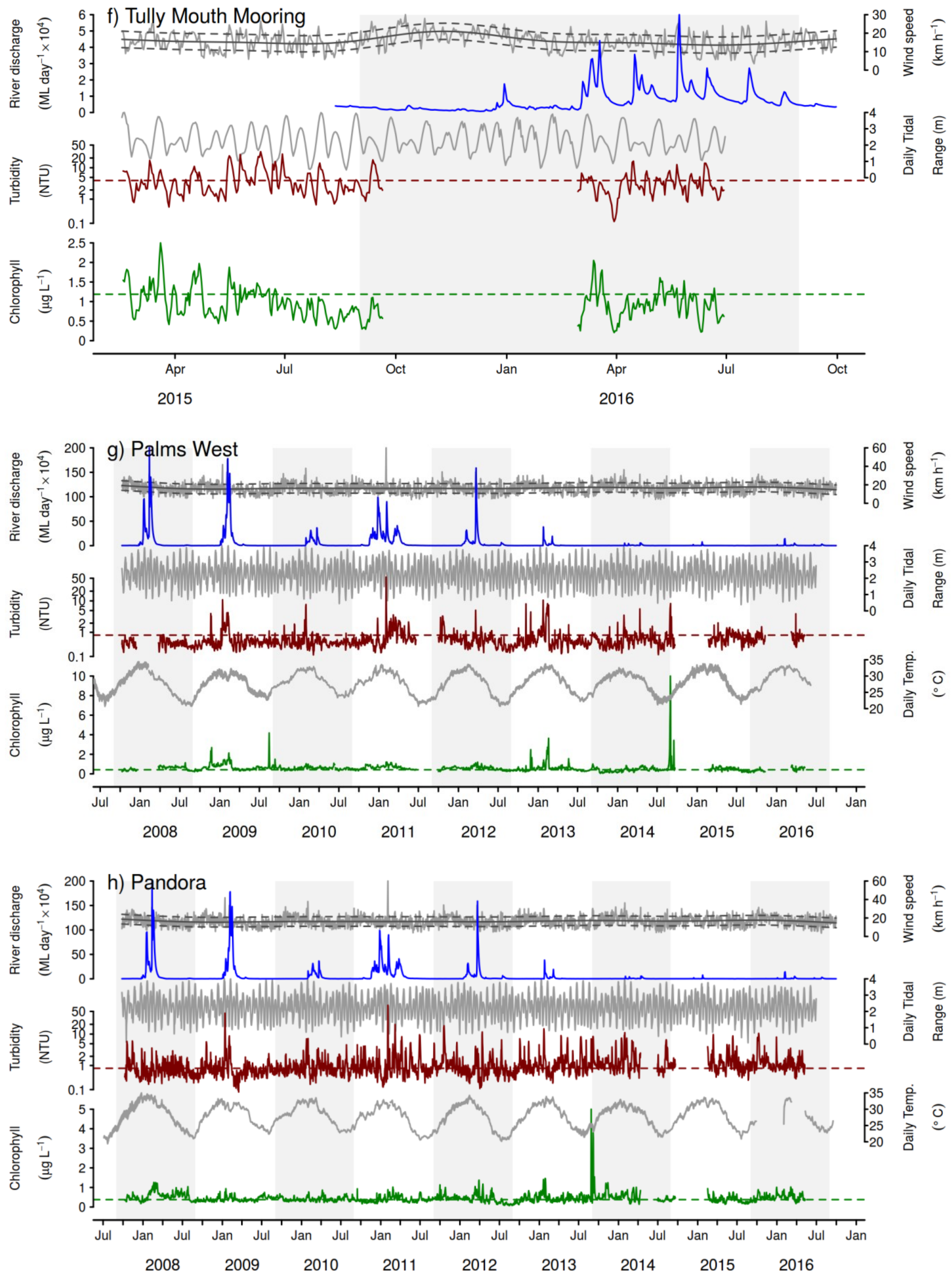


Figure E-1: Continued - f) Tully Mouth Mooring, g) Palms West, h) Pandora.

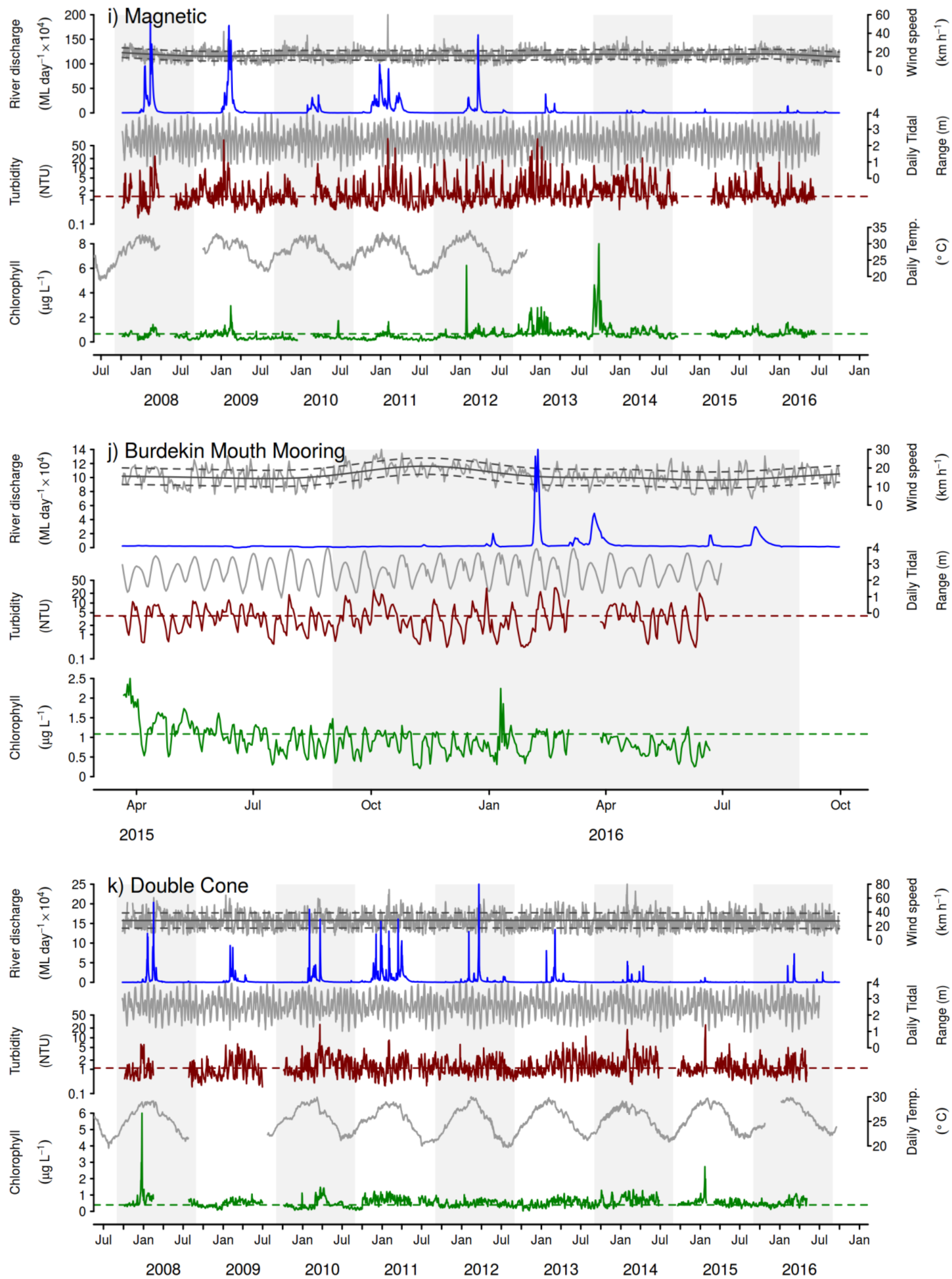


Figure E-1: Continued - i) Magnetic, j) Burdekin Mouth Mooring, k) Double Cone.

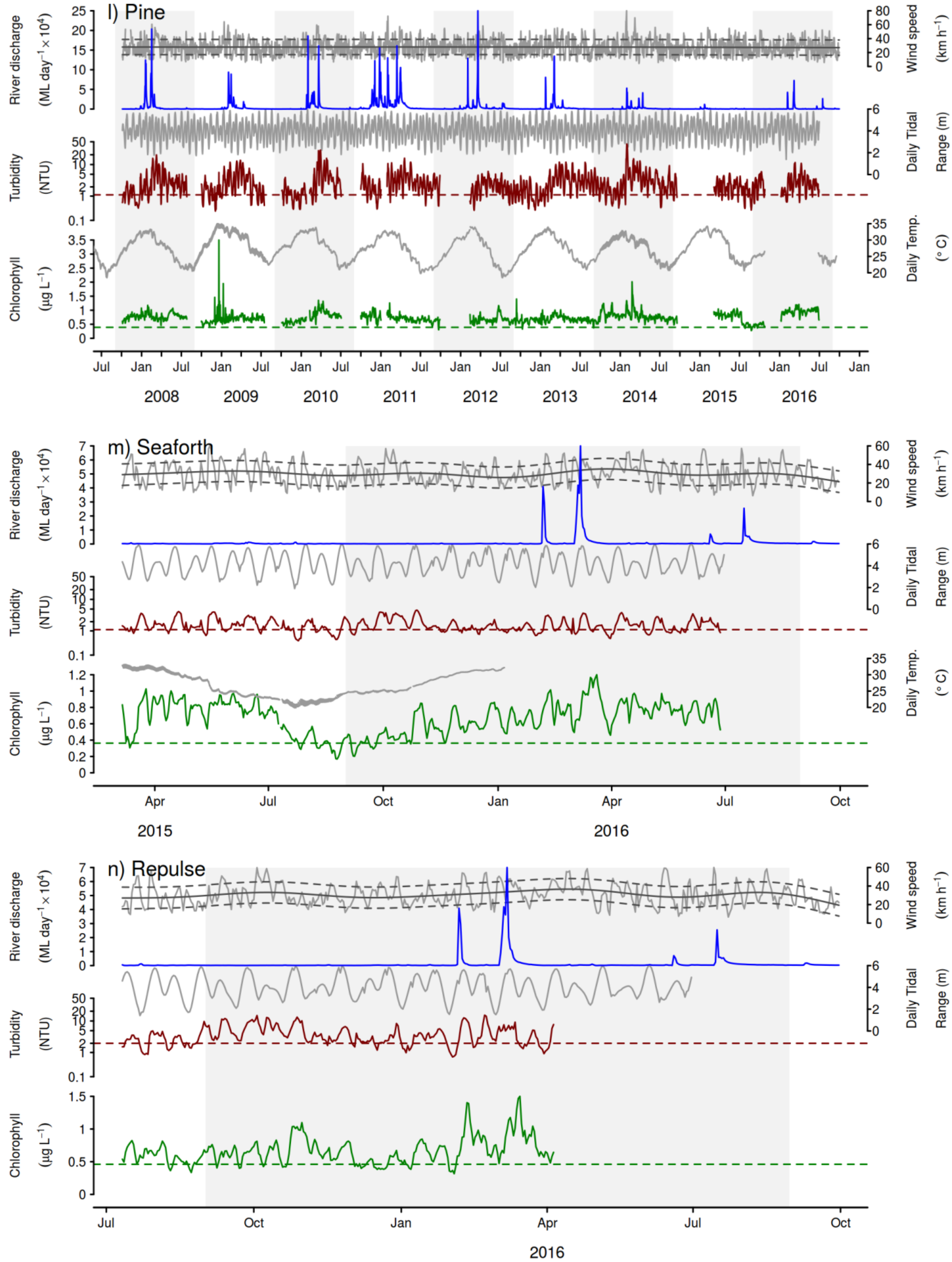


Figure E-1: Continued - L) Pine, j) Seaforth, k) Repulse.

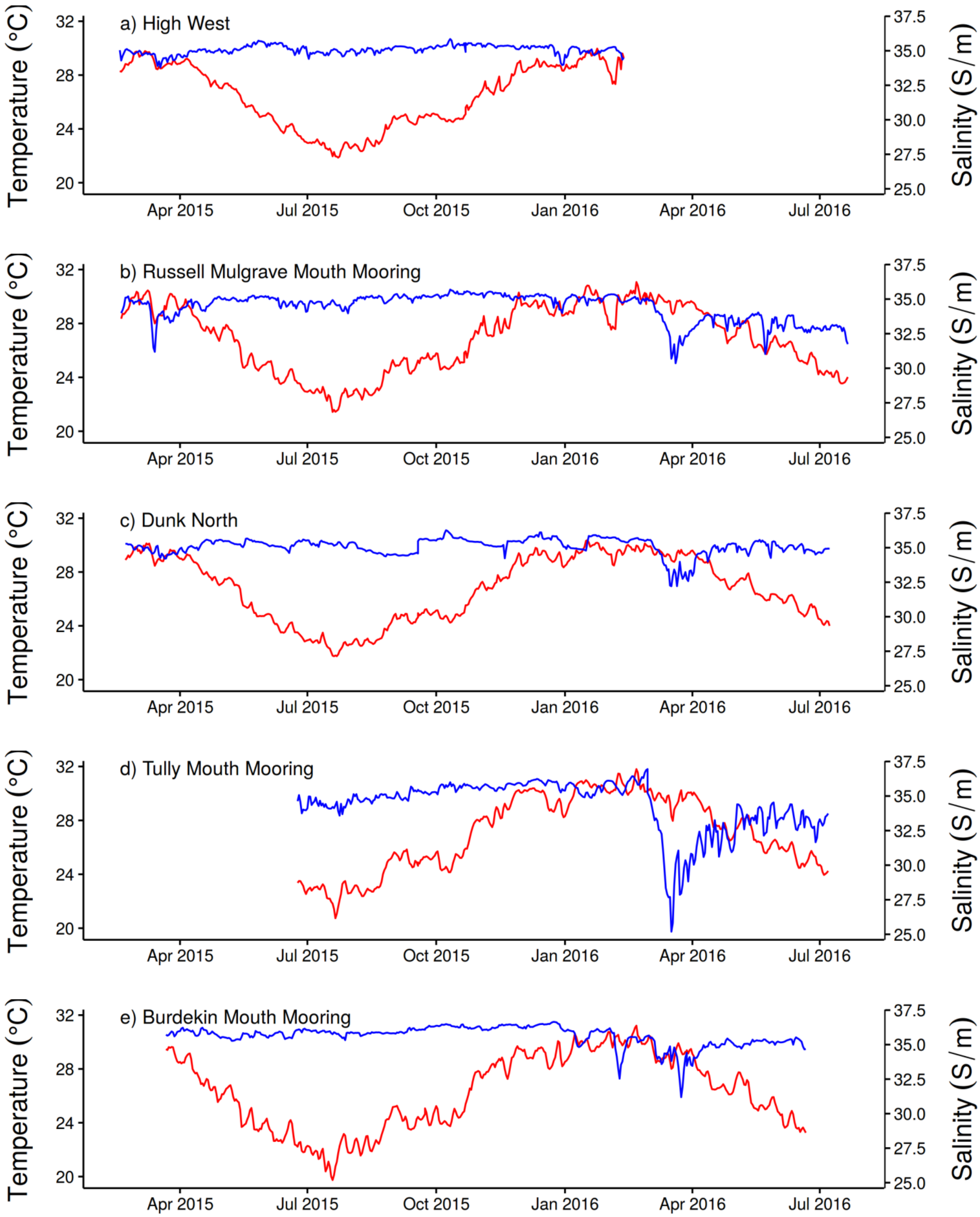


Figure E-2: Time series of daily means of temperature (red line) and salinity (blue line) derived from the Sea-Bird Electronics (SBE) CTD profilers. Plots represent locations of SBE CTD profilers; a) High West; b) Russel Mulgrave Mouth Mooring; c) Dunk North; d) Tully River Mouth Mooring; e) Burdekin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

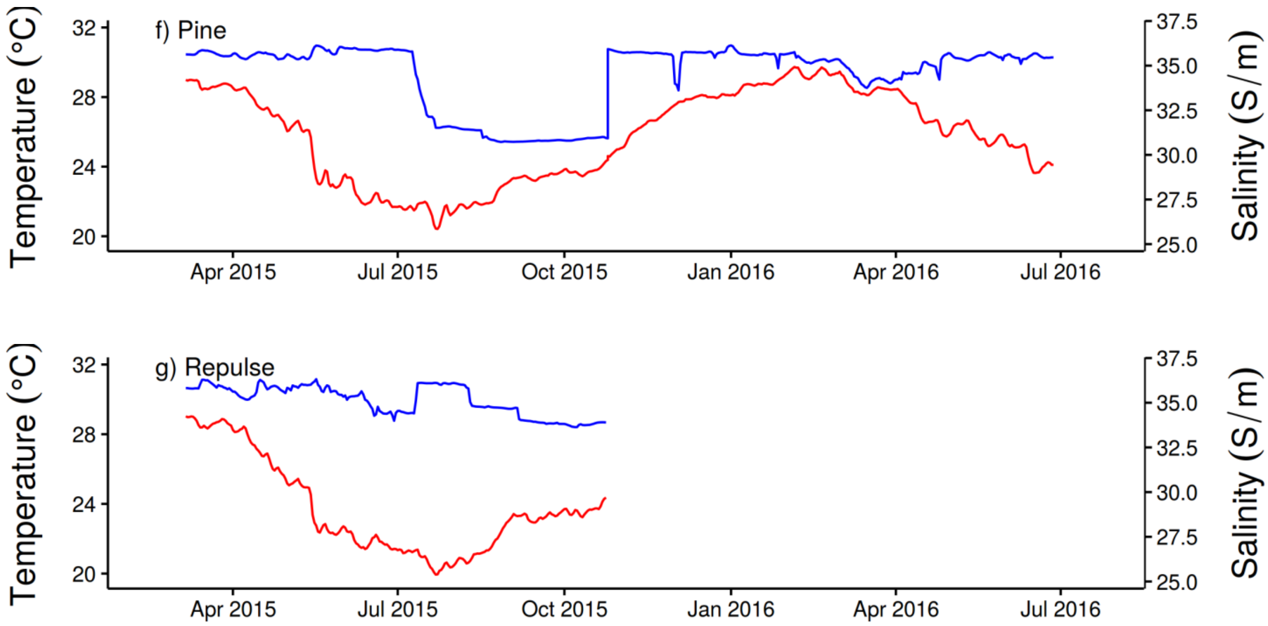


Figure E-2: Continued - f) Pine, g) Repulse.

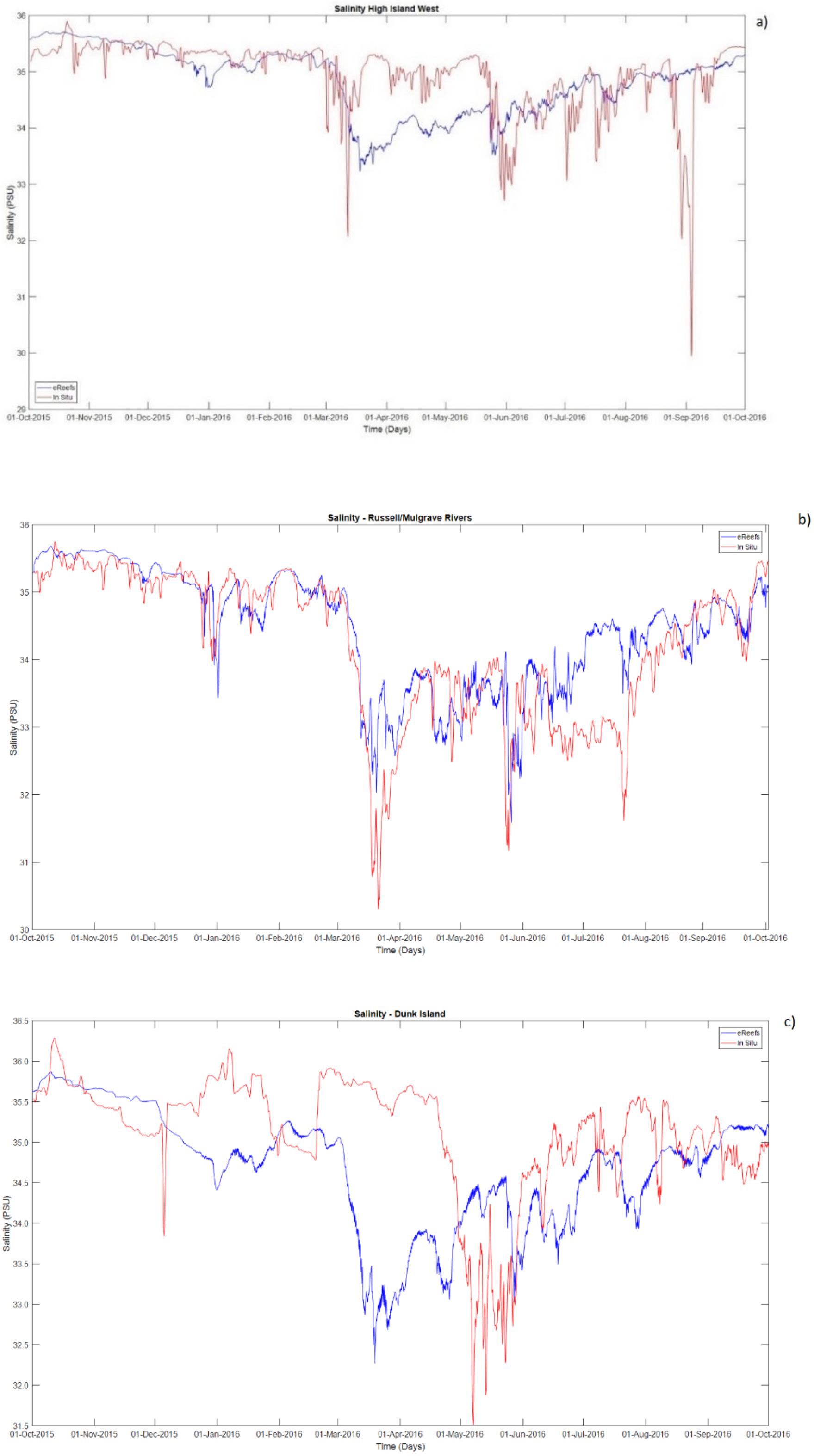
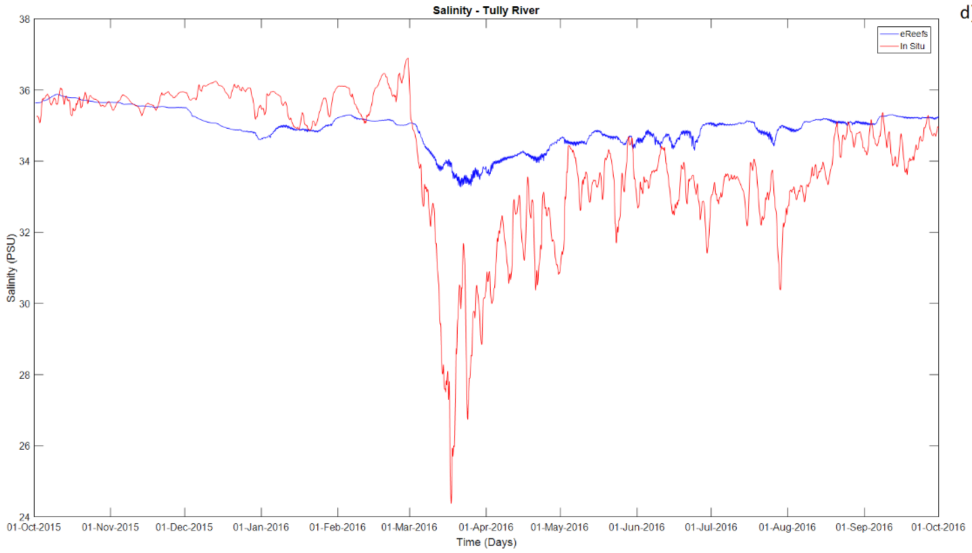
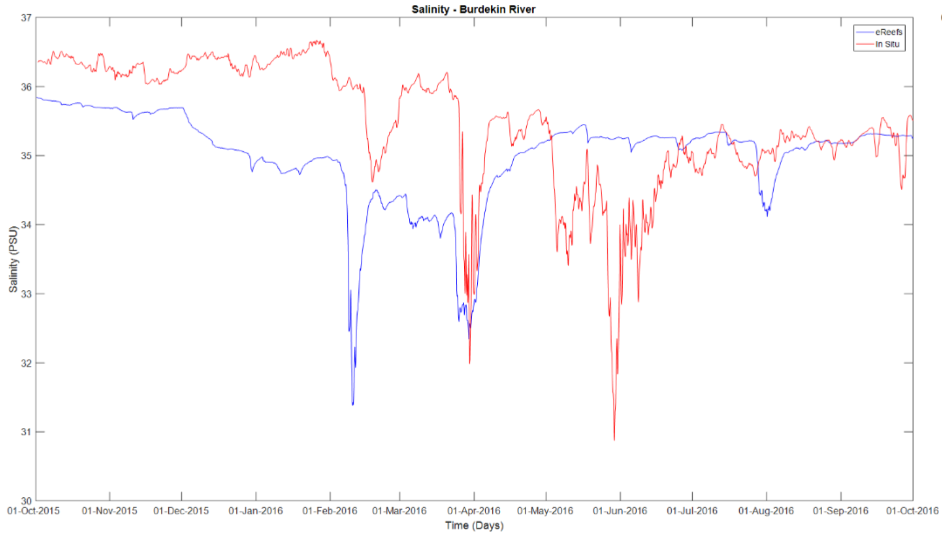


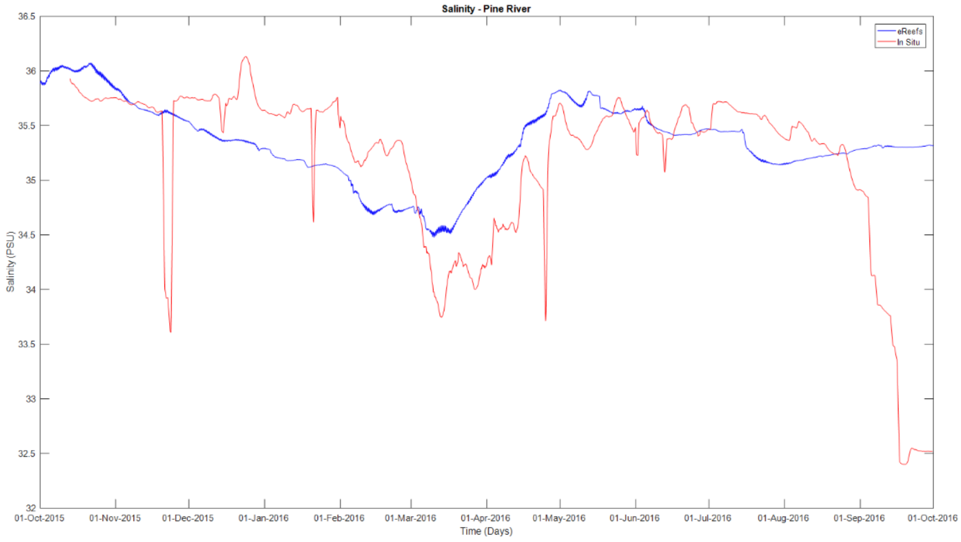
Figure E- 3: Time series of daily means of salinity determined by the mooring Sea-Bird Electronics (SBE) CTD profilers and eReefs model (blue line) with results from a) High West; b) Russel Mulgrave River mouth; c) Dunk North; d) Tully River mouth mooring; e) Burdekin mouth mooring; f) Pine, g) Repulse.


Salinity - Tully River
eReefs
In Situ
Salinity (PSU)
Time (Days)
01-Oct-2015
01-Nov-2015
01-Dec-2015
01-Jan-2016
01-Feb-2016
01-Mar-2016
01-Apr-2016
01-May-2016
01-Jun-2016
01-Jul-2016
01-Aug-2016
01-Sep-2016
01-Oct-2016

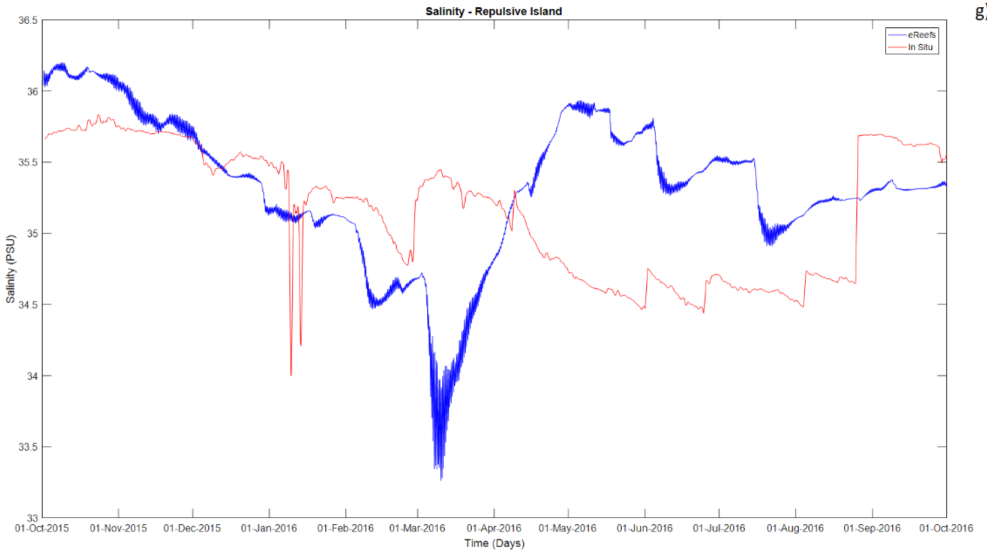
d)


Salinity - Burdekin River
eReefs
In Situ
Salinity (PSU)
Time (Days)
01-Oct-2015
01-Nov-2015
01-Dec-2015
01-Jan-2016
01-Feb-2016
01-Mar-2016
01-Apr-2016
01-May-2016
01-Jun-2016
01-Jul-2016
01-Aug-2016
01-Sep-2016
01-Oct-2016

e)


Salinity - Pine River
eReefs
In Situ
Salinity (PSU)
36.5
36
35.5
35
34.5
34
33.5
33
32.5
32
01-Oct-2015
01-Nov-2015
01-Dec-2015
01-Jan-2016
01-Feb-2016
01-Mar-2016
01-Apr-2016
01-May-2016
01-Jun-2016
01-Jul-2016
01-Aug-2016
01-Sep-2016
01-Oct-2016
Time (Days)

f)


Salinity - Repulsive Island
eReefs
In Situ
Salinity (PSU)
36.5
36
35.5
35
34.5
34
33.5
33
01-Oct-2015
01-Nov-2015
01-Dec-2015
01-Jan-2016
01-Feb-2016
01-Mar-2016
01-Apr-2016
01-May-2016
01-Jun-2016
01-Jul-2016
01-Aug-2016
01-Sep-2016
01-Oct-2016
Time (Days)

g)

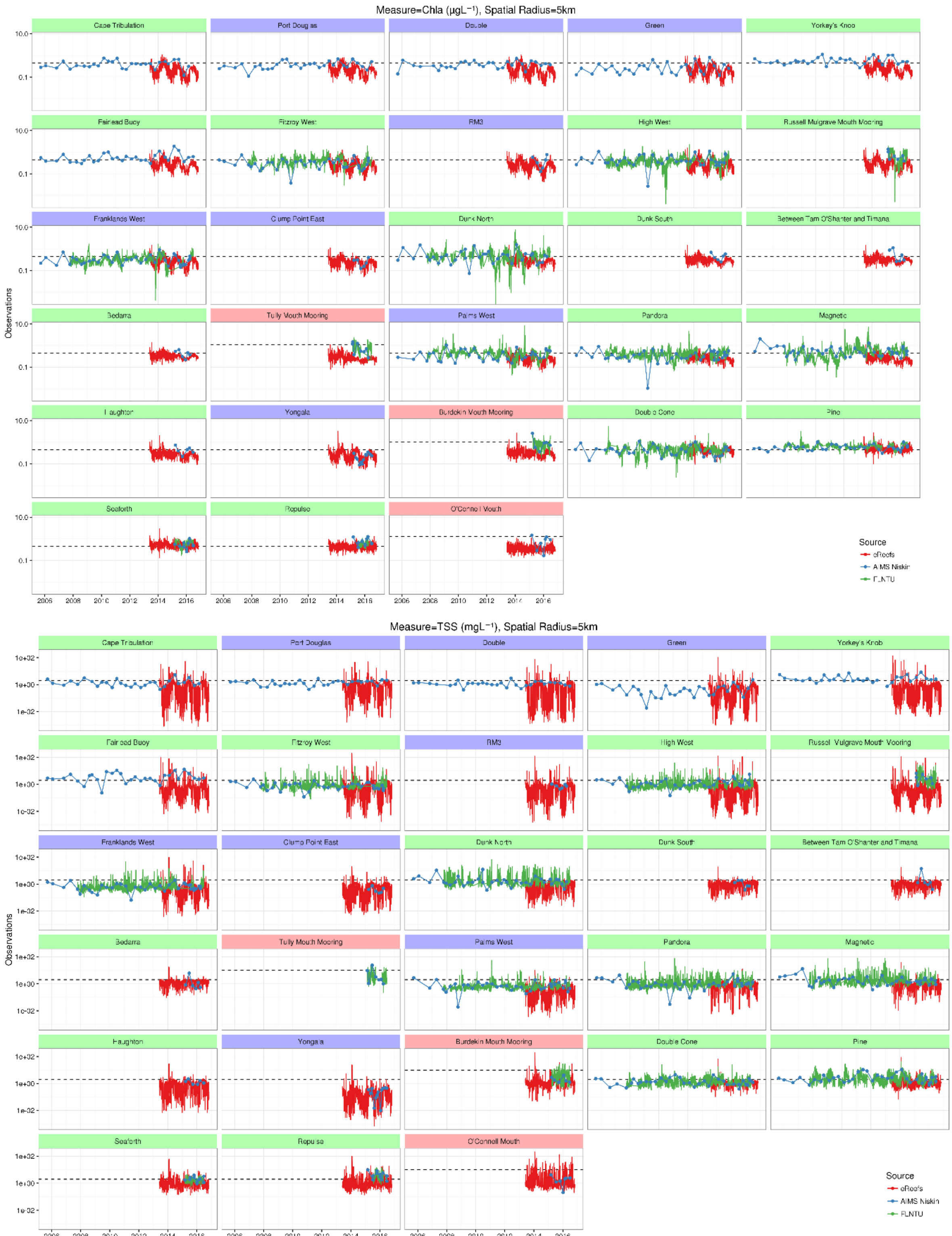


Figure E-4: Temporal patterns within 5km of each AIMS MMP sampling site for eReefs, AIMS in-situ and FLNTU logger (Chl-a and TSS only) sources. The data shown are Chl-a, TSS, Secchi depth and NO_X. Horizontal dashed line represents the guideline value. Please note the logarithmic scale on the Y-axis.


Measure=Secchi (m), Spatial Radius=5km
Cape Tribulation
Port Douglas
Double
Green
Yorkey's Knob
Fairlead Buoy
Fitzroy West
RM3
High West
Russell Mulgrave Mouth Mooring
Franklands West
Clump Point East
Dunk North
Dunk South
Between Tam O'Shanter and Timana
Bedarra
Tully Mouth Mooring
Palms West
Pandora
Magnetic
Haughton
Yongala
Burdekin Mouth Mooring
Double Cone
Pine
Seaforth
Repulse
O'Connell Mouth
Observations
Source
eReefs
AIMS Niskin
FLNTU

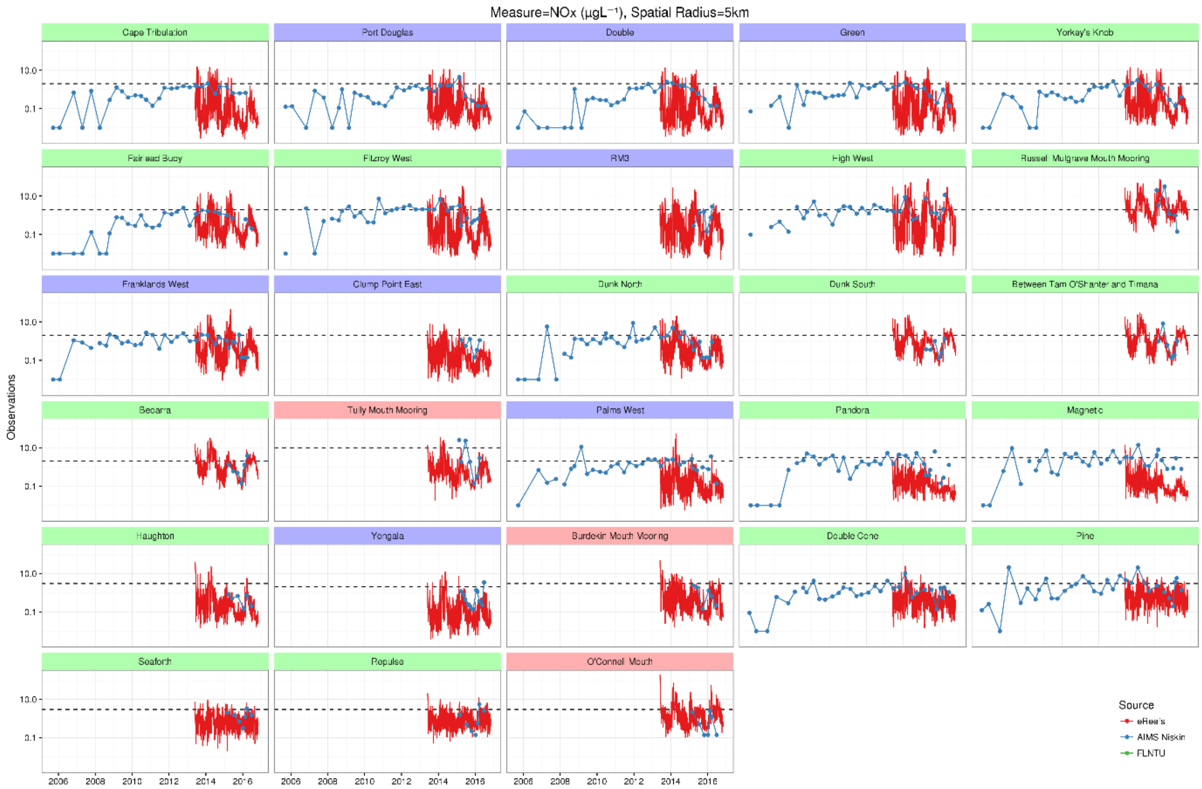

Measure=NOx (µgL⁻¹), Spatial Radius=5km
Cape Tribulation
Port Douglas
Double
Green
Yorkey's Knob
Fairlead Buoy
Fitzroy West
RM3
High West
Russell Mulgrave Mouth Mooring
Franklands West
Clump Point East
Dunk North
Dunk South
Between Tam O'Shanter and Timana
Bedarra
Tully Mouth Mooring
Palms West
Pandora
Magnetic
Haughton
Yongala
Burdekin Mouth Mooring
Double Cone
Pine
Seaforth
Repulse
O'Connell Mouth
Observations
Source
eReefs
AIMS Niskin
FLNTU

Table E- 5: 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})	Chl-a (µg L^{-1})	CDOM (m^{-1})	Kd (m^{-1})	DIN (µg L^{-1})	DIP (µg L^{-1})	PP (µg L^{-1})	PN (µg L^{-1})
GBR-wide	multi-annual	CC1	mean	33.04	2.37	1.71	1.09	67.78	8.80	25.42	89.53
			SD	60.45	3.16	1.21	0.90	46.43	6.14	41.69	106.15
			min	2.10	0.20	0.26	0.21	8.00	1.00	0.00	14.00
			max	260.00	17.93	6.03	4.28	196.00	29.00	167.00	573.00
			count	53.00	73.00	44.00	26.00	41.00	45.00	45.00	35.00
	2015-16	CC1	mean	5.70	0.84	nd.	0.90	9.00	5.00	0.00	29.26
			SD	0.10	0.30	nd.	0.23	1.00	1.00	0.00	14.63
			min	5.60	0.54	nd.	0.67	8.00	4.00	0.00	14.63
			max	5.80	1.14	nd.	1.13	10.00	6.00	0.00	43.89
			count	2.00	2.00	nd.	2.00	2.00	2.00	2.00	2.00
	multi-annual	CC2	mean	10.85	2.06	1.01	0.89	65.91	8.83	7.93	29.64
			SD	6.54	3.06	0.95	0.58	57.17	5.89	5.86	25.18
			min	1.00	0.20	0.04	0.18	11.00	2.00	0.00	1.00
			max	31.00	22.43	5.57	2.49	237.00	28.00	23.00	90.00
			count	51.00	57.00	50.00	27.00	43.00	40.00	43.00	36.00
	2015-16	CC2	mean	17.25	0.51	0.48	nd.	74.00	5.50	7.50	1.50
			SD	13.75	0.05	0.44	nd.	55.00	0.50	5.50	0.50
			min	3.50	0.46	0.04	nd.	19.00	5.00	2.00	1.00
			max	31.00	0.55	0.92	nd.	129.00	6.00	13.00	2.00
			count	2.00	2.00	2.00	nd.	2.00	2.00	2.00	2.00
	multi-annual	CC3	mean	12.51	1.91	0.78	0.82	50.40	8.62	7.59	36.80
			SD	12.77	2.57	0.97	0.59	48.19	5.69	6.43	35.25
			min	0.84	0.20	0.00	0.07	3.00	0.00	1.00	1.00
			max	70.00	15.00	4.77	2.61	218.00	20.00	32.00	134.00
			count	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00
	2015-16	CC3	mean	25.29	1.07	1.08	1.55	93.67	5.71	12.71	24.00
			SD	23.63	0.35	1.00	0.76	68.68	3.19	10.02	30.20
			min	3.90	0.58	0.05	0.85	23.00	2.00	2.00	2.00
			max	70.00	1.37	3.11	2.61	218.00	13.00	32.00	96.00
			count	7.00	3.00	6.00	3.00	6.00	7.00	7.00	7.00
	multi-annual	CC4	mean	7.06	1.36	0.55	0.72	40.49	8.75	5.13	34.46
			SD	6.26	1.21	0.61	0.52	40.41	5.64	4.53	34.69
			min	0.00	0.20	0.01	0.10	5.00	1.00	0.00	0.00
			max	57.00	9.08	4.15	2.89	357.00	23.00	27.00	268.00
			count	209.00	228.00	200.00	121.00	191.00	204.00	183.00	179.00
	2015-16	CC4	mean	7.08	0.88	0.42	0.68	36.25	5.45	2.60	16.15
			SD	4.24	0.47	0.40	0.56	39.93	1.99	2.22	24.73
			min	2.00	0.20	0.01	0.12	7.00	2.00	0.00	0.00
			max	18.00	1.66	1.31	2.39	148.00	10.00	11.00	112.00
			count	22.00	16.00	20.00	14.00	20.00	22.00	20.00	19.00
	multi-annual	P	mean	12.14	1.71	0.80	0.80	48.78	8.74	8.77	40.77
			SD	25.76	2.22	0.91	0.61	46.28	5.74	17.92	51.60
			min	0.00	0.20	0.00	0.07	3.00	0.00	0.00	0.00
			max	260.00	22.43	6.03	4.28	357.00	29.00	167.00	573.00
			count	363.00	413.00	338.00	199.00	317.00	336.00	312.00	294.00
	2015-16	P	mean	11.48	0.87	0.57	0.84	48.43	5.48	5.03	17.88
			SD	14.12	0.44	0.64	0.66	53.51	2.22	6.86	25.53
			min	2.00	0.20	0.01	0.12	7.00	2.00	0.00	0.00

			TSS (mg L-1)	Chl-a (µg L-1)	CDOM (m-1)	Kd (m-1)	DIN (µg L-1)	DIP (µg L-1)	PP (µg L-1)	PN (µg L-1)
		max	70.00	1.66	3.11	2.61	218.00	13.00	32.00	112.00
		count	33.00	23.00	28.00	19.00	30.00	33.00	31.00	30.00
multi-annual	S (or CC5)	mean	5.50	0.81	0.29	0.35	23.41	6.53	3.25	23.02
		SD	4.02	0.66	0.44	0.26	16.11	4.79	3.23	22.10
		min	0.40	0.02	0.00	0.03	3.00	1.00	0.00	0.00
		max	22.00	9.08	3.25	2.46	130.00	22.00	14.00	111.00
		count	368.00	419.00	339.00	261.00	392.00	392.00	378.00	391.00
2015-16	S (or CC5)	mean	4.18	0.57	0.11	0.30	13.15	3.76	1.33	15.31
		SD	2.34	0.36	0.12	0.16	7.86	1.28	1.77	18.87
		min	0.95	0.10	0.00	0.08	3.00	1.00	0.00	0.00
		max	12.00	2.18	0.55	0.86	39.00	8.00	12.00	78.69
		count	66.00	57.00	60.00	42.00	66.00	66.00	66.00	66.00
multi-annual	T (or CC6)	mean	4.41	0.39	0.13	0.16	19.29	5.29	2.33	18.33
		SD	3.78	0.52	0.20	0.08	10.93	4.25	2.39	19.46
		min	1.10	0.02	0.00	0.01	4.00	1.00	0.00	0.00
		max	19.00	5.34	1.38	0.63	66.00	20.00	11.00	84.00
		count	100.00	118.00	72.00	73.00	112.00	114.00	111.00	112.00
2015-16	T (or CC6)	mean	3.61	0.30	0.03	0.15	12.52	3.55	1.03	10.49
		SD	2.88	0.11	0.02	0.04	5.38	1.28	1.47	16.65
		min	1.30	0.10	0.00	0.09	4.00	2.00	0.00	0.00
		max	14.00	0.49	0.08	0.25	28.00	7.00	6.00	80.96
		count	33.00	33.00	30.00	26.00	33.00	33.00	32.00	33.00

Table E-6: Summary of water quality data collected in the Wet Tropics NRM 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 sampling of the MMP.

				TSS (mg L-1)	Chl-a (µg L-1)	CDOM (m-1)	Kd (m-1)	DIN (µg L-1)	DIP (µg L-1)	PP (µg L-1)	PN (µg L-1)
Wet Tropics	multi-annual	CC1	mean	10.72	1.38	1.02	1.42	43.20	5.10	7.33	53.20
			SD	7.50	1.31	0.53	1.03	40.18	2.66	9.37	40.80
			min	2.10	0.20	0.26	0.65	10.00	2.00	0.00	23.00
			max	38.00	6.14	1.82	4.28	140.00	9.00	32.00	167.00
			count	20.00	20.00	18.00	10.00	10.00	10.00	9.00	10.00
	2015-16	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	9.74	1.60	0.77	0.93	74.58	9.15	6.96	32.50
			SD	6.18	1.40	0.39	0.56	68.88	5.03	5.04	27.43
			min	2.30	0.20	0.10	0.18	11.00	2.00	0.00	2.00
			max	31.00	5.87	1.59	2.49	237.00	18.00	19.00	90.00
			count	35.00	35.00	35.00	23.00	26.00	26.00	25.00	24.00
	2015-16	CC2	mean	31.00	0.46	0.92	nd.	129.00	6.00	2.00	2.00
			SD	0.00	0.00	0.00	nd.	0.00	0.00	0.00	0.00
			min	31.00	0.46	0.92	nd.	129.00	6.00	2.00	2.00
			max	31.00	0.46	0.92	nd.	129.00	6.00	2.00	2.00
			count	1.00	1.00	1.00	nd.	1.00	1.00	1.00	1.00
	multi-annual	CC3	mean	12.60	1.46	0.67	0.88	64.41	8.77	6.60	37.35
			SD	15.26	1.84	0.61	0.64	59.51	5.07	7.51	38.32
			min	0.84	0.20	0.00	0.07	3.00	0.00	1.00	2.00

			TSS (mg L-1)	Chl-a (µg L-1)	CDOM (m-1)	Kd (m-1)	DIN (µg L-1)	DIP (µg L-1)	PP (µg L-1)	PN (µg L-1)
		max	70.00	10.15	3.11	2.61	218.00	19.00	32.00	134.00
		count	31.00	29.00	28.00	19.00	22.00	26.00	20.00	23.00
2015-16	CC3	mean	30.08	0.98	1.50	1.55	128.75	4.40	14.00	11.20
		SD	26.31	0.40	0.98	0.76	58.17	1.36	11.08	7.98
		min	3.90	0.58	0.58	0.85	75.00	2.00	2.00	2.00
		max	70.00	1.37	3.11	2.61	218.00	6.00	32.00	26.00
		count	5.00	2.00	4.00	3.00	4.00	5.00	5.00	5.00
multi-annual	CC4	mean	6.52	1.20	0.51	0.72	46.70	9.21	4.85	32.11
		SD	6.07	0.87	0.43	0.52	45.40	5.30	4.59	36.14
		min	0.00	0.20	0.01	0.12	5.00	1.00	0.00	0.00
		max	57.00	5.34	2.90	2.89	357.00	22.00	27.00	268.00
		count	167.00	170.00	160.00	107.00	137.00	144.00	131.00	138.00
2015-16	CC4	mean	6.24	0.91	0.46	0.69	42.00	5.17	2.67	10.82
		SD	3.01	0.48	0.42	0.61	42.70	2.01	2.33	10.32
		min	2.00	0.20	0.01	0.12	7.00	2.00	0.00	0.00
		max	14.00	1.66	1.31	2.39	148.00	10.00	11.00	37.00
		count	18.00	14.00	17.00	12.00	16.00	18.00	18.00	18.00
multi-annual	P	mean	8.04	1.30	0.61	0.81	52.24	8.95	5.45	33.86
		SD	8.22	1.15	0.48	0.61	51.69	5.22	5.44	36.04
		min	0.00	0.20	0.00	0.07	3.00	0.00	0.00	0.00
		max	70.00	10.15	3.11	4.28	357.00	22.00	32.00	268.00
		count	253.00	254.00	241.00	159.00	195.00	206.00	185.00	195.00
2015-16	P	mean	12.24	0.89	0.67	0.86	62.67	5.04	5.00	10.53
		SD	16.09	0.47	0.69	0.73	58.31	1.88	7.14	9.82
		min	2.00	0.20	0.01	0.12	7.00	2.00	0.00	0.00
		max	70.00	1.66	3.11	2.61	218.00	10.00	32.00	37.00
		count	24.00	17.00	22.00	15.00	21.00	24.00	24.00	24.00
multi-annual	S (or CC5)	mean	4.99	0.81	0.31	0.35	24.02	6.70	3.22	21.43
		SD	3.68	0.52	0.44	0.28	18.14	4.58	3.23	21.86
		min	0.40	0.02	0.00	0.09	3.00	1.00	0.00	0.00
		max	19.25	3.62	2.74	2.46	130.00	22.00	14.00	111.00
		count	260.00	284.00	246.00	202.00	254.00	262.00	248.00	255.00
2015-16	S (or CC5)	mean	4.11	0.57	0.12	0.28	13.19	3.69	1.42	9.04
		SD	2.43	0.31	0.13	0.14	8.49	1.37	1.94	8.39
		min	0.95	0.20	0.00	0.16	3.00	1.00	0.00	0.00
		max	12.00	1.60	0.55	0.86	39.00	8.00	12.00	41.00
		count	52.00	43.00	52.00	32.00	52.00	52.00	52.00	52.00
multi-annual	T (or CC6)	mean	4.50	0.45	0.14	0.16	19.58	5.64	2.06	16.50
		SD	3.60	0.57	0.21	0.08	12.08	4.60	2.15	17.46
		min	1.10	0.02	0.00	0.08	4.00	1.00	0.00	0.00
		max	17.00	5.34	1.38	0.63	66.00	20.00	11.00	73.00
		count	75.00	86.00	64.00	62.00	80.00	81.00	81.00	80.00
2015-16	T (or CC6)	mean	3.72	0.29	0.03	0.14	12.89	3.61	0.96	9.08
		SD	3.09	0.10	0.02	0.04	5.57	1.35	1.37	11.76
		min	1.30	0.10	0.00	0.09	4.00	2.00	0.00	0.00
		max	14.00	0.49	0.08	0.25	28.00	7.00	6.00	50.65
		count	28.00	28.00	25.00	23.00	28.00	28.00	27.00	28.00

Table E-7: Summary of water quality data collected in the Burdekin NRM 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 sampling of the MMP.

				TSS (mg L-1)	Chl-a (µg L-1)	CDOM (m-1)	Kd (m-1)	DIN (µg L-1)	DIP (µg L-1)	PP (µg L-1)	PN (µg L-1)
Burdekin	multi-annual	CC1	mean	99.72	0.96	2.05	0.64	65.47	11.67	51.13	112.57
			SD	100.93	0.58	1.02	0.37	36.54	6.90	62.72	146.82
			min	3.50	0.20	0.51	0.21	8.00	1.00	0.00	14.00
			max	260.00	2.00	3.48	1.47	110.00	29.00	167.00	573.00
			count	12.00	18.00	9.00	11.00	15.00	18.00	15.00	15.00
	2015-16	CC1	mean	5.70	0.84	nd.	0.90	9.00	5.00	0.00	29.26
			SD	0.10	0.30	nd.	0.23	1.00	1.00	0.00	14.63
			min	5.60	0.54	nd.	0.67	8.00	4.00	0.00	14.63
			max	5.80	1.14	nd.	1.13	10.00	6.00	0.00	43.89
			count	2.00	2.00	nd.	2.00	2.00	2.00	2.00	2.00
	multi-annual	CC2	mean	13.50	0.88	0.10	nd.	46.50	4.25	8.33	20.00
			SD	7.97	0.62	0.06	nd.	28.54	0.83	4.64	12.35
			min	3.50	0.20	0.04	nd.	19.00	3.00	2.00	1.00
			max	23.00	1.87	0.15	nd.	90.00	5.00	13.00	34.00
			count	3.00	4.00	2.00	nd.	4.00	4.00	3.00	4.00
	2015-16	CC2	mean	3.50	0.55	0.04	nd.	19.00	5.00	13.00	1.00
			SD	0.00	0.00	0.00	nd.	0.00	0.00	0.00	0.00
			min	3.50	0.55	0.04	nd.	19.00	5.00	13.00	1.00
			max	3.50	0.55	0.04	nd.	19.00	5.00	13.00	1.00
			count	1.00	1.00	1.00	nd.	1.00	1.00	1.00	1.00
	multi-annual	CC3	mean	9.54	0.95	0.06	0.44	18.25	3.50	7.25	29.50
			SD	5.55	0.36	0.01	0.00	6.50	1.66	6.46	35.77
			min	3.40	0.20	0.05	0.44	10.00	1.00	1.00	5.00
			max	18.00	1.30	0.07	0.44	26.00	5.00	18.00	91.00
			count	7.00	6.00	2.00	1.00	4.00	4.00	4.00	4.00
	2015-16	CC3	mean	18.00	1.25	0.05	nd.	23.00	5.00	4.00	16.00
			SD	0.00	0.00	0.00	nd.	0.00	0.00	0.00	0.00
			min	18.00	1.25	0.05	nd.	23.00	5.00	4.00	16.00
			max	18.00	1.25	0.05	nd.	23.00	5.00	4.00	16.00
			count	1.00	1.00	1.00	nd.	1.00	1.00	1.00	1.00
	multi-annual	CC4	mean	7.79	0.87	0.12	0.92	12.21	4.11	4.58	45.31
			SD	4.50	0.72	0.09	0.28	4.32	3.71	2.98	25.08
			min	2.30	0.20	0.03	0.49	5.00	1.00	0.00	7.00
			max	18.00	3.47	0.35	1.25	24.00	18.00	12.00	85.00
			count	18.00	16.00	8.00	5.00	19.00	19.00	19.00	16.00
	2015-16	CC4	mean	4.70	0.72	0.06	0.61	9.50	5.50	2.00	nd.
			SD	2.20	0.30	0.00	0.12	0.50	0.50	0.00	nd.
			min	2.50	0.42	0.06	0.49	9.00	5.00	2.00	nd.
			max	6.90	1.01	0.06	0.73	10.00	6.00	2.00	nd.
			count	2.00	2.00	1.00	2.00	2.00	2.00	2.00	nd.
	multi-annual	P	mean	36.11	0.92	0.94	0.71	35.07	7.09	22.15	66.96
			SD	69.37	0.62	1.17	0.36	34.24	6.26	43.99	100.29
			min	2.30	0.20	0.03	0.21	5.00	1.00	0.00	1.00
			max	260.00	3.47	3.48	1.47	110.00	29.00	167.00	573.00
			count	40.00	44.00	21.00	17.00	42.00	45.00	41.00	39.00
	2015-16	P	mean	7.05	0.82	0.05	0.75	13.17	5.17	3.50	18.88
			SD	5.11	0.33	0.01	0.24	5.70	0.69	4.46	15.59
			min	2.50	0.42	0.04	0.49	8.00	4.00	0.00	1.00

			TSS (mg L-1)	Chl-a (µg L-1)	CDOM (m-1)	Kd (m-1)	DIN (µg L-1)	DIP (µg L-1)	PP (µg L-1)	PN (µg L-1)
		max	18.00	1.25	0.06	1.13	23.00	6.00	13.00	43.89
		count	6.00	6.00	3.00	4.00	6.00	6.00	6.00	4.00
multi-annual	S (or CC5)	mean	5.46	0.64	0.13	0.35	17.15	3.67	2.53	28.91
		SD	2.85	0.43	0.12	0.19	6.74	2.73	2.84	23.12
		min	0.80	0.10	0.00	0.03	5.00	1.00	0.00	0.00
		max	12.00	2.94	0.53	0.83	42.00	14.00	11.00	100.00
		count	79.00	78.00	45.00	49.00	78.00	78.00	76.00	77.00
2015-16	S (or CC5)	mean	4.43	0.55	0.03	0.34	13.00	4.00	1.00	38.60
		SD	1.93	0.50	0.02	0.22	4.90	0.85	0.76	27.00
		min	2.60	0.10	0.00	0.08	8.00	3.00	0.00	1.00
		max	8.50	2.18	0.07	0.83	22.00	5.00	2.00	78.69
		count	14.00	14.00	8.00	10.00	14.00	14.00	14.00	14.00
multi-annual	T (or CC6)	mean	2.89	0.44	0.04	0.19	12.10	4.20	2.78	28.50
		SD	1.09	0.26	0.02	0.02	3.65	2.71	2.74	27.94
		min	1.50	0.20	0.00	0.16	4.00	1.00	0.00	1.00
		max	4.90	1.07	0.08	0.22	18.00	11.00	8.00	80.96
		count	9.00	9.00	7.00	4.00	10.00	10.00	9.00	10.00
2015-16	T (or CC6)	mean	3.02	0.36	0.02	0.19	10.40	3.20	1.40	18.39
		SD	1.00	0.12	0.01	0.03	3.50	0.75	1.85	31.33
		min	2.20	0.20	0.00	0.16	4.00	2.00	0.00	1.00
		max	4.90	0.49	0.04	0.22	14.00	4.00	5.00	80.96
		count	5.00	5.00	5.00	3.00	5.00	5.00	5.00	5.00

Table E-8: Summary of water quality data collected in the Mackay Whitsunday NRM region across the wet season colour classes (CC1, CC2, CC3, CC4, CC5, CC6) and water types (Primary, Secondary, Tertiary) as part of the JCU flood response sampling of the MMP.

Region				TSS (mg L-1)	Chl-a (µg L-1)	CDOM (m-1)	Kd (m-1)	DIN (µg L-1)	DIP (µg L-1)	PP (µg L-1)	PN (µg L-1)
Mackay Whitsundays	multi-annual	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.
	2015-16	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	3.35	0.67	0.24	nd.	28.50	12.50	7.00	15.00
			SD	2.35	0.40	0.17	nd.	6.50	6.50	2.00	10.00
			min	1.00	0.27	0.07	nd.	22.00	6.00	5.00	5.00
			max	5.70	1.07	0.41	nd.	35.00	19.00	9.00	25.00
			count	2.00	2.00	2.00	nd.	2.00	2.00	2.00	2.00
	2015-16	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	6.60	0.97	0.33	nd.	44.25	16.50	12.25	30.75
			SD	5.09	0.24	0.11	nd.	23.35	3.04	3.34	37.81
			min	1.40	0.80	0.15	nd.	24.00	13.00	8.00	4.00

			TSS (mg L^{-1})	Chl-a (µg L^{-1})	CDOM (m^{-1})	Kd (m^{-1})	DIN (µg L^{-1})	DIP (µg L^{-1})	PP (µg L^{-1})	PN (µg L^{-1})
		max	14.00	1.30	0.45	nd.	84.00	20.00	16.00	96.00
		count	4.00	3.00	4.00	nd.	4.00	4.00	4.00	4.00
2015-16	CC3	mean	8.60	nd.	0.45	nd.	24.00	13.00	15.00	96.00
		SD	0.00	nd.	0.00	nd.	0.00	0.00	0.00	0.00
		min	8.60	nd.	0.45	nd.	24.00	13.00	15.00	96.00
		max	8.60	nd.	0.45	nd.	24.00	13.00	15.00	96.00
		count	1.00	nd.	1.00	nd.	1.00	1.00	1.00	1.00
multi-annual	CC4	mean	5.65	1.47	0.20	nd.	26.75	13.71	7.67	29.67
		SD	6.59	1.53	0.14	nd.	7.40	4.03	2.87	38.35
		min	1.30	0.27	0.03	nd.	14.00	8.00	4.00	2.00
		max	18.00	4.81	0.44	nd.	39.00	20.00	11.00	112.00
		count	8.00	6.00	8.00	nd.	8.00	7.00	3.00	6.00
2015-16	CC4	mean	17.00	nd.	0.33	nd.	17.00	8.00	nd.	112.00
		SD	1.00	nd.	0.00	nd.	3.00	0.00	nd.	0.00
		min	16.00	nd.	0.33	nd.	14.00	8.00	nd.	112.00
		max	18.00	nd.	0.33	nd.	20.00	8.00	nd.	112.00
		count	2.00	nd.	2.00	nd.	2.00	2.00	nd.	1.00
multi-annual	P	mean	5.59	1.19	0.24	nd.	32.00	14.38	9.56	27.58
		SD	5.83	1.19	0.14	nd.	15.92	4.50	3.80	35.50
		min	1.00	0.27	0.03	nd.	14.00	6.00	4.00	2.00
		max	18.00	4.81	0.45	nd.	84.00	20.00	16.00	112.00
		count	14.00	11.00	14.00	nd.	14.00	13.00	9.00	12.00
2015-16	P	mean	14.20	nd.	0.37	nd.	19.33	9.67	15.00	104.00
		SD	4.04	nd.	0.06	nd.	4.11	2.36	0.00	8.00
		min	8.60	nd.	0.33	nd.	14.00	8.00	15.00	96.00
		max	18.00	nd.	0.45	nd.	24.00	13.00	15.00	112.00
		count	3.00	nd.	3.00	nd.	3.00	3.00	1.00	2.00
multi-annual	S (or CC5)	mean	10.15	1.29	0.12	nd.	28.15	7.64	6.85	14.57
		SD	5.76	0.46	0.04	nd.	7.48	3.79	3.35	8.57
		min	3.10	0.27	0.05	nd.	15.00	2.00	1.00	3.00
		max	19.00	2.38	0.20	nd.	43.00	14.00	13.00	28.00
		count	13.00	14.00	10.00	nd.	13.00	14.00	13.00	14.00
2015-16	S (or CC5)	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	T (or CC6)	mean	12.00	0.53	nd.	nd.	35.00	7.00	10.00	10.00
		SD	0.00	0.00	nd.	nd.	0.00	0.00	0.00	0.00
		min	12.00	0.53	nd.	nd.	35.00	7.00	10.00	10.00
		max	12.00	0.53	nd.	nd.	35.00	7.00	10.00	10.00
		count	1.00	1.00	nd.	nd.	1.00	1.00	1.00	1.00
2015-16	T (or CC6)	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.

Table E-9: Interim water quality index for each water quality sampling location in 2015–16, 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
		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
		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
		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
		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

						Annual			Dry Season			Wet Season			
Region	Subregion	Reef	Year	Measure	Stat.	GL	Mean	Median	GL	Mean	Median	GL	Mean	Median	Index
	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
		Fitzroy West	2015 - 2016	Chla (µgL⁻¹)	Median				0.32		0.14	0.63		0.33	0.96
			2015 - 2016	NOx (µgL⁻¹)	Median	0.35		0.59							-0.76
			2015 - 2016	Turbidity (NTU)	Median	1		0.85							0.23
			2015 - 2016	PN (µgL⁻¹)	Median				16		16.65	25		14.64	0.36
			2015 - 2016	PP (µgL⁻¹)	Median				2.3		2.33	3.3		2.01	0.35
			2015 - 2016	Secchi (m)	Mean	10	10.62								0.09
			2015 - 2016	TSS (mgL⁻¹)	Median				1.6		0.53	2.4		0.48	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
		RM3	2015 - 2016	Chla (µgL⁻¹)	Median				0.32		0.13	0.63		0.32	0.99
			2015 - 2016	NOx (µgL⁻¹)	Median	0.31		2.42							-1
			2015 - 2016	PN (µgL⁻¹)	Median				16		28.82	25		12.43	0.08
			2015 - 2016	PP (µgL⁻¹)	Median				2.3		2.25	3.3		1.93	0.4
			2015 - 2016	Secchi (m)	Median	13		10							-0.38
			2015 - 2016	TSS (mgL⁻¹)	Median				1.6		0.44	2.4		1.7	0.75
		RM4	2015 - 2016	Chla (µgL⁻¹)	Median							0.63		0.31	1
			2015 - 2016	NOx (µgL⁻¹)	Median	0.35		5							-1
			2015 - 2016	PN (µgL⁻¹)	Median							25		12	1
			2015 - 2016	PP (µgL⁻¹)	Median							3.3		2	0.72
			2015 - 2016	Secchi (m)	Mean	10	3.83								-1
			2015 - 2016	TSS (mgL⁻¹)	Median							2.4		3.65	-0.6
		High East	2015 - 2016	Chla (µgL⁻¹)	Median							0.63		0.36	0.81

						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	0.31		9							-1
			2015 - 2016	PN (µgL⁻¹)	Median							25		6	1
			2015 - 2016	PP (µgL⁻¹)	Median							3.3		0	1
			2015 - 2016	Secchi (m)	Median	13		3.75							-1
			2015 - 2016	TSS (mgL⁻¹)	Median							2.4		2.55	-0.09
		High West	2015 - 2016	Chla (µgL⁻¹)	Median				0.32		0.29	0.63		0.45	0.33
			2015 - 2016	NOx (µgL⁻¹)	Median	0.35		2.09							-1
			2015 - 2016	Turbidity (NTU)	Median	1		0.8							0.33
			2015 - 2016	PN (µgL⁻¹)	Median				16		16.85	25		15.37	0.31
			2015 - 2016	PP (µgL⁻¹)	Median				2.3		3.33	3.3		2	0.1
			2015 - 2016	Secchi (m)	Mean	10	5.86								-0.77
			2015 - 2016	TSS (mgL⁻¹)	Median				1.6		0.84	2.4		2.5	0.44
		Palmer Point	2015 - 2016	Chla (µgL⁻¹)	Median							0.63		0.41	0.62
			2015 - 2016	NOx (µgL⁻¹)	Median	0.35		11							-1
			2015 - 2016	PN (µgL⁻¹)	Median							25		10	1
			2015 - 2016	PP (µgL⁻¹)	Median							3.3		1	1
			2015 - 2016	Secchi (m)	Mean	10	3								-1
			2015 - 2016	TSS (mgL⁻¹)	Median							2.4		3.5	-0.54
		Normanby	2015 - 2016	Chla (µgL⁻¹)	Median							0.63		0.3	1
			2015 - 2016	NOx (µgL⁻¹)	Median	0.31		6							-1
			2015 - 2016	PN (µgL⁻¹)	Median							25		8	1
			2015 - 2016	PP (µgL⁻¹)	Median							3.3		1	1
			2015 - 2016	Secchi (m)	Median	13		5							-1
			2015 - 2016	TSS (mgL⁻¹)	Median							2.4		2.4	0
		Russell Mulgrave Mouth Mooring	2015 - 2016	Chla (µgL⁻¹)	Median				0.32		0.46	0.63		0.52	-0.13
			2015 - 2016	NOx (µgL⁻¹)	Median	0.35		8							-1
			2015 - 2016	Turbidity (NTU)	Median	1		1.61							-0.68
			2015 - 2016	PN (µgL⁻¹)	Median				16		21.64	25		10.09	0.28
			2015 - 2016	PP (µgL⁻¹)	Median				2.3		7.31	3.3		3.34	-0.51
			2015 - 2016	Secchi (m)	Mean	10	3.86								-1
			2015 - 2016	TSS (mgL⁻¹)	Median				1.6		2.5	2.4		3.16	-0.52

						Annual			Dry Season			Wet Season			
Region	Subregion	Reef	Year	Measure	Stat.	GL	Mean	Median	GL	Mean	Median	GL	Mean	Median	Index
		Franklands West	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.19	0.63		0.33	0.86
			2015 - 2016	NOx (µgL^{-1})	Median	0.31		2							-1
			2015 - 2016	Turbidity (NTU)	Median	0.6		0.92							-0.62
			2015 - 2016	PN (µgL^{-1})	Median				16		37.49	25		9.34	0
			2015 - 2016	PP (µgL^{-1})	Median				2.3		2.52	3.3		1.25	0.43
			2015 - 2016	Secchi (m)	Median	13		7.25							-0.84
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		0.42	2.4		0.95	1
		Russell Mulgrave Junction	2015 - 2016	Chla (µgL^{-1})	Median							0.63		0.52	0.29
			2015 - 2016	NOx (µgL^{-1})	Median	15		148							-1
			2015 - 2016	PN (µgL^{-1})	Median							25		31	-0.31
			2015 - 2016	PP (µgL^{-1})	Median							3.3		5	-0.6
			2015 - 2016	Secchi (m)	Median	1.5		1							-0.58
			2015 - 2016	TSS (mgL^{-1})	Median							2.4		4.4	-0.87
	Tully Herbert	King	2015 - 2016	Chla (µgL^{-1})	Median							0.63		0.46	0.45
			2015 - 2016	NOx (µgL^{-1})	Median	0.35		8							-1
			2015 - 2016	PN (µgL^{-1})	Median							25		13.1	0.93
			2015 - 2016	PP (µgL^{-1})	Median							3.3		1	1
			2015 - 2016	Secchi (m)	Mean	10	3.43								-1
			2015 - 2016	TSS (mgL^{-1})	Median							2.4		2.8	-0.22
		Clump Point East	2015 - 2016	Chla (µgL^{-1})	Median				0.32		1.93	0.63		0.29	0
			2015 - 2016	NOx (µgL^{-1})	Median	0.31		3.5							-1
			2015 - 2016	PN (µgL^{-1})	Median				16		74	25		9	0
			2015 - 2016	PP (µgL^{-1})	Median				2.3		7	3.3		1.56	0
			2015 - 2016	Secchi (m)	Median	13		10.5							-0.31
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		3.8	2.4		1.9	-0.33
		Dunk North	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.53	0.63		0.42	-0.07
			2015 - 2016	NOx (µgL^{-1})	Median	0.35		7.5							-1
			2015 - 2016	Turbidity (NTU)	Median	1		1.23							-0.29
			2015 - 2016	PN (µgL^{-1})	Median				16			25		11	1
			2015 - 2016	PP (µgL^{-1})	Median				2.3		0	3.3		2	0.86
			2015 - 2016	Secchi (m)	Mean	10	4.24								-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				1.6		5.4	2.4		3.2	-0.71
		Mission Beach South	2015 - 2016	Chla (µgL⁻¹)	Median				0.32		0.68	0.63		0.38	-0.14
			2015 - 2016	NOx (µgL⁻¹)	Median	0.35		12							-1
			2015 - 2016	PN (µgL⁻¹)	Median				16		17	25		5.39	0.46
			2015 - 2016	PP (µgL⁻¹)	Median				2.3		0	3.3		1.5	1
			2015 - 2016	Secchi (m)	Mean	10	1.5								-1
			2015 - 2016	TSS (mgL⁻¹)	Median				1.6		4.1	2.4		3.9	-0.85
		Dunk South	2015 - 2016	Chla (µgL⁻¹)	Median				0.32		1.12	0.63		0.46	-0.28
			2015 - 2016	NOx (µgL⁻¹)	Median	0.35		3							-1
			2015 - 2016	PN (µgL⁻¹)	Median				16		2	25		7.25	1
			2015 - 2016	PP (µgL⁻¹)	Median				2.3		0	3.3		2.43	0.72
			2015 - 2016	Secchi (m)	Mean	10	6.38								-0.65
			2015 - 2016	TSS (mgL⁻¹)	Median				1.6		4.9	2.4		3	-0.66
		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		9.5							-1
			2015 - 2016	PN (µgL⁻¹)	Median				16		20	25		9.83	0.34
			2015 - 2016	PP (µgL⁻¹)	Median				2.3		0	3.3		2.67	0.65
			2015 - 2016	Secchi (m)	Mean	10	2.81								-1
			2015 - 2016	TSS (mgL⁻¹)	Median				1.6		3.6	2.4		4	-0.87
		Hull Mouth	2015 - 2016	Chla (µgL⁻¹)	Median				0.32		0.84	0.63		0.85	-0.72
			2015 - 2016	NOx (µgL⁻¹)	Median	3		19							-1
			2015 - 2016	PN (µgL⁻¹)	Median				16		18	25		11.61	0.42
			2015 - 2016	PP (µgL⁻¹)	Median				2.3		5	3.3		2	-0.14
			2015 - 2016	Secchi (m)	Median	1.6		1.25							-0.36
			2015 - 2016	TSS (mgL⁻¹)	Median				1.6		8	2.4		6.25	-1
		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		34	25		5.5	0
			2015 - 2016	PP (µgL⁻¹)	Median				2.3		2	3.3		1	0.6
			2015 - 2016	Secchi (m)	Mean	10	4.16								-1
			2015 - 2016	TSS (mgL⁻¹)	Median				1.6		5.9	2.4		3.3	-0.73
		Tully	2015 - 2016	Chla (µgL⁻¹)	Median				0.32		0.31	0.63		0.52	0.16

						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		127							-1
			2015 - 2016	PN (µgL^{-1})	Median				16		28	25		20.16	-0.25
			2015 - 2016	PP (µgL^{-1})	Median				2.3		10	3.3		5.5	-0.87
			2015 - 2016	Secchi (m)	Median	1.5		1							-0.58
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		12	2.4		15.5	-1
		Tully Mouth Mooring	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.81	0.63		1.37	-1
			2015 - 2016	NOx (µgL^{-1})	Median	3		9.25							-1
			2015 - 2016	Turbidity (NTU)	Median	4		3.01							0.41
			2015 - 2016	PN (µgL^{-1})	Median				16		3	25		17.62	0.75
			2015 - 2016	PP (µgL^{-1})	Median				2.3		3	3.3		4.99	-0.49
			2015 - 2016	Secchi (m)	Median	1.6		1							-0.68
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		7.1	2.4		11.3	-1
		Triplets	2015 - 2016	Chla (µgL^{-1})	Median				0.32		2.3	0.63		0.36	-0.1
			2015 - 2016	NOx (µgL^{-1})	Median	0.35		8							-1
			2015 - 2016	PN (µgL^{-1})	Median				16		45	25		3	0
			2015 - 2016	PP (µgL^{-1})	Median				2.3		1	3.3		1	1
			2015 - 2016	Secchi (m)	Mean	10	3.25								-1
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		4.6	2.4		3.2	-0.71
Burdekin	Burdekin	Palms West	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.57	0.63		0.43	-0.15
			2015 - 2016	NOx (µgL^{-1})	Median	0.28		2							-1
			2015 - 2016	Turbidity (NTU)	Median	0.8		0.87							-0.12
			2015 - 2016	PN (µgL^{-1})	Median				16		22.45	25		15.04	0.12
			2015 - 2016	PP (µgL^{-1})	Median				2.3		3.01	3.3		1.98	0.17
			2015 - 2016	Secchi (m)	Mean	10	6.58								-0.6
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		0.36	2.4		2.09	0.6
		Pandora	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.46	0.63		0.37	0.12
			2015 - 2016	NOx (µgL^{-1})	Median	0.28		2							-1
			2015 - 2016	Turbidity (NTU)	Median	0.8		1.19							-0.58
			2015 - 2016	PN (µgL^{-1})	Median				16		20.12	25		12.69	0.32
			2015 - 2016	PP (µgL^{-1})	Median				2.3		3.55	3.3		1.62	0.19
			2015 - 2016	Secchi (m)	Mean	10	4.46								-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				1.6		0.86	2.4		2.92	0.31
		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
		Magnetic	2015 - 2016	Chla (μgL^{-1})	Median				0.32		0.47	0.63		0.54	-0.16
			2015 - 2016	NOx (μgL^{-1})	Median	0.28		5							-1
			2015 - 2016	Turbidity (NTU)	Median	1.3		1.44							-0.15
			2015 - 2016	PN (μgL^{-1})	Median				16		19.96	25		24.05	-0.13
			2015 - 2016	PP (μgL^{-1})	Median				2.3		4.11	3.3		3.07	-0.37
			2015 - 2016	Secchi (m)	Median	4		2.75							-0.54
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		1.27	2.4		3.9	-0.18
		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
			2015 - 2016	TSS (mgL^{-1})	Median							2.4		2.9	-0.27
		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		0.34	0.63		0.46	0.18
			2015 - 2016	NOx (μgL^{-1})	Median	1		2.47							-1
			2015 - 2016	PN (μgL^{-1})	Median				16		13.42	25		14.37	0.53
			2015 - 2016	PP (μgL^{-1})	Median				2.3		2.25	3.3		2.4	0.25
			2015 - 2016	Secchi (m)	Mean	10	6.67								-0.58
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		1.1	2.4		4.54	-0.19

						Annual			Dry Season			Wet Season			
Region	**Subregion**	**Reef**	**Year**	**Measure**	**Stat.**	**GL**	**Mean**	**Median**	**GL**	**Mean**	**Median**	**GL**	**Mean**	**Median**	**Index**
		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		9.29	25		12.13	0.89
			2015 - 2016	PP (µgL^{-1})	Median				2.3		1.35	3.3		1.69	0.87
			2015 - 2016	Secchi (m)	Mean	10	14.83								0.57
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		0.44	2.4		0.28	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
		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
		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
		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
		Burdekin Mouth Mooring	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.73	0.63		0.53	-0.38
			2015 - 2016	NOx (µgL^{-1})	Median	4		8.39							-1

						Annual			Dry Season			Wet Season			
Region	Subregion	Reef	Year	Measure	Stat.	GL	Mean	Median	GL	Mean	Median	GL	Mean	Median	Index
			2015 - 2016	Turbidity (NTU)	Median	4		3.17							0.34
			2015 - 2016	PN (µgL⁻¹)	Median				16			25		23.69	0.08
			2015 - 2016	PP (µgL⁻¹)	Median				2.3		4.05	3.3		1.49	0.09
			2015 - 2016	Secchi (m)	Median	1.5		2.75							0.87
			2015 - 2016	TSS (mgL⁻¹)	Median				1.6		1.25	2.4		3.29	-0.05
		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
		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
Mackay Whitsunday	Mackay Whitsunday	Double Cone	2015 - 2016	Chla (µgL⁻¹)	Median				0.32		0.42	0.63		0.43	0.08
			2015 - 2016	NOx (µgL⁻¹)	Median	1		1.07							-0.09
			2015 - 2016	Turbidity (NTU)	Median	1.1		1.06							0.06
			2015 - 2016	PN (µgL⁻¹)	Median				16		18.94	25		19.76	0.05
			2015 - 2016	PP (µgL⁻¹)	Median				2.3		3.8	3.3		2.91	-0.27
			2015 - 2016	Secchi (m)	Mean	10	5.1								-0.97
			2015 - 2016	TSS (mgL⁻¹)	Median				1.6		1.6	2.4		0.86	0.5
		Pine	2015 - 2016	Chla (µgL⁻¹)	Median				0.32		0.55	0.63		0.48	-0.19
			2015 - 2016	NOx (µgL⁻¹)	Median	1		1.34							-0.43
			2015 - 2016	Turbidity (NTU)	Median	1.1		2.42							-1
			2015 - 2016	PN (µgL⁻¹)	Median				16		17.65	25		19.57	0.11
			2015 - 2016	PP (µgL⁻¹)	Median				2.3		3.83	3.3		2.78	-0.24
			2015 - 2016	Secchi (m)	Mean	10	5.9								-0.76
			2015 - 2016	TSS (mgL⁻¹)	Median				1.6		2.42	2.4		1.06	0.2

						Annual			Dry Season			Wet Season			
Region	Subregion	Reef	Year	Measure	Stat.	GL	Mean	Median	GL	Mean	Median	GL	Mean	Median	Index
		Seaforth	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.5	0.63		0.48	-0.12
			2015 - 2016	NOx (µgL^{-1})	Median	1		1.23							-0.3
			2015 - 2016	Turbidity (NTU)	Median	1.1		1.51							-0.46
			2015 - 2016	PN (µgL^{-1})	Median				16		20.65	25		20.34	-0.04
			2015 - 2016	PP (µgL^{-1})	Median				2.3		4.39	3.3		3.42	-0.49
			2015 - 2016	Secchi (m)	Mean	10	4.8								-1
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		2.94	2.4		1.52	-0.11
		O'Connell Mouth	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.77	0.63		0.96	-0.81
			2015 - 2016	NOx (µgL^{-1})	Median	4		0.14							1
			2015 - 2016	PN (µgL^{-1})	Median				16		30.42	25		27.6	-0.53
			2015 - 2016	PP (µgL^{-1})	Median				2.3		6.92	3.3		5.64	-0.89
			2015 - 2016	Secchi (m)	Median	1.6		5							1
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		1.94	2.4		2.09	-0.04
		Repulse	2015 - 2016	Chla (µgL^{-1})	Median				0.32		0.69	0.63		0.79	-0.66
			2015 - 2016	NOx (µgL^{-1})	Median	0.25		0.58							-1
			2015 - 2016	Turbidity (NTU)	Mean	2	4.4								-1
			2015 - 2016	PN (µgL^{-1})	Median				16		25.88	25		28.29	-0.44
			2015 - 2016	PP (µgL^{-1})	Median				2.3		5.62	3.3		5.14	-0.82
			2015 - 2016	Secchi (m)	Mean	10	4.1								-1
			2015 - 2016	TSS (mgL^{-1})	Median				1.6		4.35	2.4		3.66	-0.8
		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
		Sand Bay 2	2015 - 2016	Chla (µgL^{-1})	Median							0.63			
			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

						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		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

Table E-10: 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.

REGION/ MMP Sites	Water area/type sched doc	Management intent /Level of protection	Indicators							
			Oxid N (µg/L)	Partic N (µg/L)	FRP (µg/L)	Partic P (µg/L)	Chl-a (µg/L)	Turb (NTU)	Secchi (m)	TSS (mg/L)
			Bold value = proposed single value for use in MMP comparisons. **ALL are median guidelines unless otherwise noted**							
All GBR marine sites	**Open coastal and midshelf waters (same all sites)**	**HEV**	**-**	**Dry: ≤16 (May-Oct) Wet:≤25 (Nov-Apr)**	**-**	**Dry: ≤2.3 (May-Oct) Wet: ≤3.3 (Nov-Apr)**	**Dry: ≤0.32 (May-Oct) Wet: ≤0.63 (Nov-Apr)**	**-**	**-**	**Dry: ≤1.6 (May-Oct) Wet: ≤2.4 (Nov-Apr)**
WET TROPICS										
C1, C6, C8, RM1, RM4, RM8, TUL1	**Open coastal waters Daintree/Mossman Barron Russell-Mulgrave Johnstone Tully-Murray**	**HEV/SD**	**≤0.35**	**≤20 (annual mean)**	**≤2**	**≤2.8 (annual mean)**	**≤0.45 (annual mean)**	**≤1**	**≥10 (annual mean)**	**≤2 (annual mean)**
RM9, RM10, TUL3, TUL4, TUL5, TUL6, TUL8, TUL9	**Open coastal waters Russell-Mulgrave Tully-Murray**	**SMD**	**≤0.35**	**≤20 (annual mean)**	**≤2**	**≤2.8 (annual mean)**	**≤0.45 (annual mean)**	**≤1**	**≥10 (annual mean)**	**≤2 (annual mean)**
C4, C5, C11 RM2, RM3, RM5, RM6, RM7 TUL2	**Midshelf waters Daintree-Mossman Russell-Mulgrave Tully-Murray Green Island**	**HEV**	**≤0.31**	**≤14**	**≤2**	**≤2.0**	**≤0.3**	**≤0.6**	**≥13**	**≤1.2**
RM12, TUL11	**Mid estuarine waters Russell-Mulgrave Tully-Murray**	**HEV/SD baseflow**	**≤15**	**–**	**≤3**	**–**	**≤2**	**≤5**	**≥1.5**	**≤7** [1]
TUL7, TUL10	**Lower estuary/ enclosed coastal waters Tully-Murray**	**MD baseflow**	**≤3**	**–**	**≤3**	**–**	**≤1.1**	**≤4**	**≥1.6**	**≤5** [1]
BUR1, BUR2	**Open coastal waters Herbert**	**HEV**	**≤0.28**	**≤12**	**≤1**	**≤2.2**	**≤0.35**	**≤0.8**	**≥10 (annual mean)**	**≤1.2**
BURDEKIN - BLACK AND ROSS										
BUR3	**Open coastal Black**	**SMD**	**≤0.28**	**≤20 (annual mean)**	**≤1**	**≤2.8 (annual mean)**	**≤0.45 (annual mean)**	**≤0.8**	**≥10 (annual mean)**	**≤2 (annual mean)**
BUR4	**Open coastal Ross River/Magnetic Island**	**SD**	**≤0.28**	**≤ 17**	**≤1**	**≤2.8 (annual mean)**	**<0.59**	**≤1.3**	**>4**	**≤1.9**

REGION/ MMP Sites	Water area/type sched doc	Management intent /Level of protection	Indicators							
			Oxid N (µg/L)	Partic N (µg/L)	FRP (µg/L)	Partic P (µg/L)	Chl-a (µg/L)	Turb (NTU)	Secchi (m)	TSS (mg/L)
			Bold value = proposed single value for use in MMP comparisons. **ALL are median guidelines unless otherwise noted**							
BUR5 (inside port)	**Open coastal Ross River/Magnetic Island**	**MD**	**≤0.5**	**≤20 (annual mean)**	**≤2**	**≤2.8 (annual mean)**	**<0.6**	**<3**	**≥3**	**<5**
BURDEKIN-DON-HAUGHTON										
BUR6, BUR7	**Open coastal – Bowling Green Bay**	**SD**	**≤1**	**≤ 13**	**≤2**	**≤2.1**	**≤0.45 (annual mean)**	**≤2 (annual mean)**	**≥10 (annual mean)**	**≤1.2**
BUR8, BUR9	**Enclosed coastal – Bowling Green Bay**	**SD**	**≤4**	-	**≤1**	-	**≤1**	**≤4**	**≥1.5**	**≤2**
BUR10	**Midshelf Burdekin-Haughton**	**HEV**	**≤0.28**	**≤14**	≤1	**≤2.0**	**≤0.33**	**≤0.5**	**≥10 (annual mean)**	**≤0.8**
BUR11, BUR12	**Open coastal- Lower Burdekin/ Haughton**	**SMD**	≤1	**≤20 (annual mean)**	**≤2**	**≤2.8 (annual mean)**	**≤0.45 (annual mean)**	**≤2**	**≥10 (annual mean)**	**≤2 (annual mean)**
BUR13, BUR14, BUR15	**Enclosed coastal – Lower Burdekin/ Haughton**	**SMD**	**≤4**	(nd)	**≤1**	(nd)	**≤1**	**≤4**	**≥1.5**	**≤2**
WHI1, WHI2, WHI3, WHI4, WHI5	**Open coastal - Proserpine, Whitsunday Isld, O'Connell**	**HEV**	**≤1**	**≤14**	**≤1**	**≤2.3**	**≤0.36**	**<1.1**	**≥10 (annual mean)**	**≤1.4**
WHI6	**Enclosed coastal - Proserpine, Whitsunday Isld, O'Connell**	**SD2381s**	**<4**	**-**	**<3**	**-**	**<1.3**	**≤4[4]**	**≥1.6[4]**	**≤5[4]**
WHI7, WHI10	**Open coastal - Proserpine, Whitsunday Isld, O'Connell**	**SD2381s**	**≤0.25**	**≤18**	**≤2**	**≤2.1**	**≤0.45 (annual mean)**	**≤2 (annual mean)**	**≥10 (annual mean)**	**≤1.6**
WHI8, WHI11	**Open coastal - Proserpine, Whitsunday Isld, O'Connell Pioneer and Plan Creek Basins**	**SMD**	≤1	**≤20 (annual mean)**	**≤2**	**≤2.8 (annual mean)**	**≤0.45 (annual mean)**	**≤2 (annual mean)**	**≥10 (annual mean)**	**≤2 (annual mean)**
WHI9	**Open coastal - Proserpine, Whitsunday Isld, O'Connell**	**HEV**	**≤0.25**	**≤18**	**≤2**	**≤2.1**	**≤0.45 (annual mean)**	**≤1 (annual mean)**	**≥10 (annual mean)**	**≤1.6**
WHI10.1, 10.2	**Open coastal – port subzone Pioneer and Plane Creek Basins**	**MD**	**≤1**	**≤20 (annual mean)**	**≤2**	**≤2.8 (annual mean)**	**≤0.45 (annual mean)**	**≤2 dry ≤12 wet (median)**	**≥10 (annual mean)**	**≤2 (annual mean)**

Appendix F. QA/QC Information

Method performance and QA/QC information for water quality monitoring activities

Information pertaining to quality control and assurance (QA/QC) generally includes the assessment of the limit of detection (LOD), measurements of accuracy (e.g. using reference materials to assess recovery of known amount of analyte) and precision (the repeated analyses of the same concentration of analyte to check for reproducibility).

Limits of detection

Limit 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: Limits of detection (LODs) for analyses of marine water quality parameters.

Parameter (analyte)	LOD
NO2	0.28 µg L^{-1}*
NO3+ NO2	0.28 µg L^{-1}*
NH4	0.84 µg L^{-1}*
NH4 by OPA	0.28 µg L^{-1}
TDN	0.28 µg L^{-1}*
PN	1.0 µg $filter^{-1}$
PO4	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.

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: Summary of coefficients of variation (CV, %) of replicate measurements (N) of a standard or reference material.

Parameter (analyte)	CV (%)	N
PN	10-15**	37-40
PP	8	7
DOC	2-3*	10-35
POC	7-11**	37-40
Chl-a	1	15
TSS	n/a***	
Salinity	<0.1	2-4

*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 2014/15.; ** two different reference materials used in each batch; ***n/a= no suitable standard material available for analysis of this parameter.

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	107-109	37-40
PP	85*	7
POC	105-109	37-40
Chl-a	102	15
TSS	n/a**	

Salinity	100	9

*PP: data are adjusted using a batch-specific efficiency factor (recovery); **n/a= no suitable reference material available for analysis of this parameter

Procedural blanks

Wet filter blanks (filter placed on filtration unit and wetted with filtered seawater, then further handled like samples) were prepared during the on-board sample preparation to measure contamination during the preparation procedure for PN, PP, POC and Chl-a. The instrument readings (or actual readings, in 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 2% of the measured values for Chl-a (Table F-5) 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 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 about 5% of the average sample filter weight (Table F-5). This value was included in the calculation of the amount of suspended solids 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 ($\mu g\ L^{-1}$)	TSS (mg filter^{-1})	POC (μg filter^{-1})
Average of blank readings	0.005	1.61	0.006	0.15	8.36
N of blank readings	39	19	23	22	19
Average of sample readings	0.103	5.61	0.48	1.43	44.31
N of sample readings	523	521	579	402	519
Average of blanks as % of average sample readings	4.7%	28.7%	1.1%	10.3%	18.9%

Validation by alternative methods

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 last year's (Thompson et al., 2013, 2014). Though these relationships are valid it should be remembered that the two variables are measures of two different things which 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.

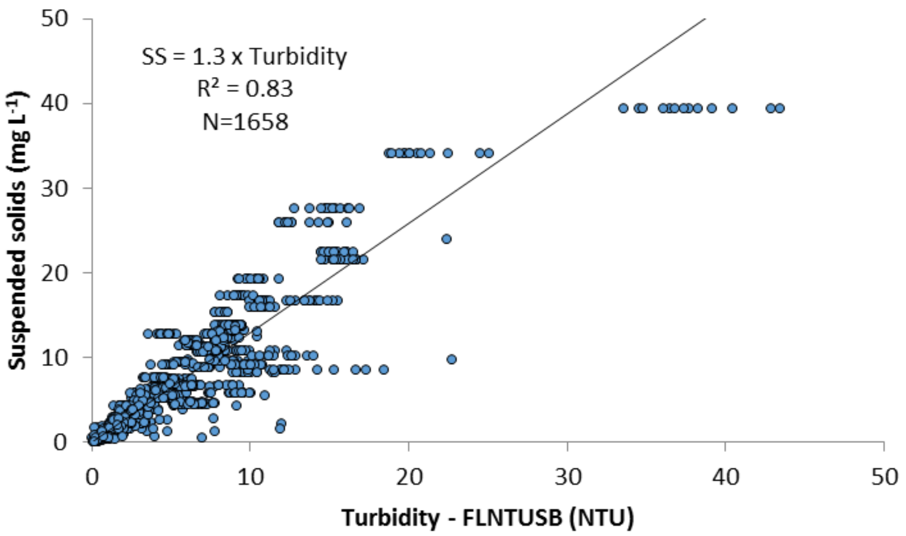


Figure F-1: Match-up of instrument readings of turbidity (NTU) from field deployments of WET Labs Eco FLNTUSB Combination Fluorometer and Turbidity Sensors with values from standard laboratory analysis of concurrently collected water samples.

Appendix G. An assessment of the feasibility of incorporating the MiniBAT in the Marine Monitoring Program

Christian Lønborg and Britta Schaffelke, Australian Institute of Marine Science.

Objective: Assess the feasibility of incorporating the MiniBAT in the Marine Monitoring Program.

Introduction

Towed devices have been used widely for marine surveys, as they provide a platform for data collection in three dimensions (Hains and Kennedy, 2002).

The MiniBAT (FC60 Automated undulating towed vehicle, OSII, United Kingdom) is a towed, light weight, computer controlled undulating vehicle, which can be equipped with a range of sensors to provide 3D extent of salinity and temperature. This vehicle is fitted with wings that allow it to undulate from the surface to near bottom, providing continuous water column profiling. On-board the research vessel, the electronics are connected to a GPS/Echosounder on the towing vessel to facilitate continuous positional data and bottom avoidance by the vehicle.

Methods

The MiniBAT trial for application in the Marine Monitoring Program (MMP) was conducted at four different locations in the GBR lagoon to test its feasibility under different depth ranges and physical conditions (Table G-1; Figure G-1).

Table G-1: The dates, region, and latitude/longitude position of transects.

Date	Region	Latitude	Longitude
27/02/2016	Cape Tribulation	-16.117	145.484
27/02/2016	Double Island	-16.665	145.707
28/02/2016	Russell Mulgrave	-17.201	145.986
29/02/2016	Tully river	-18.023	146.075

The device was towed behind the AIMS research vessel RV Cape Ferguson and the undulations covered the water column from near surface to 1 m above the seabed. In the present setup, the MiniBAT was fitted with a SBE 49 CTD probe, which measured salinity, temperature and depth continuously with readings being recorded on-board the vessel.

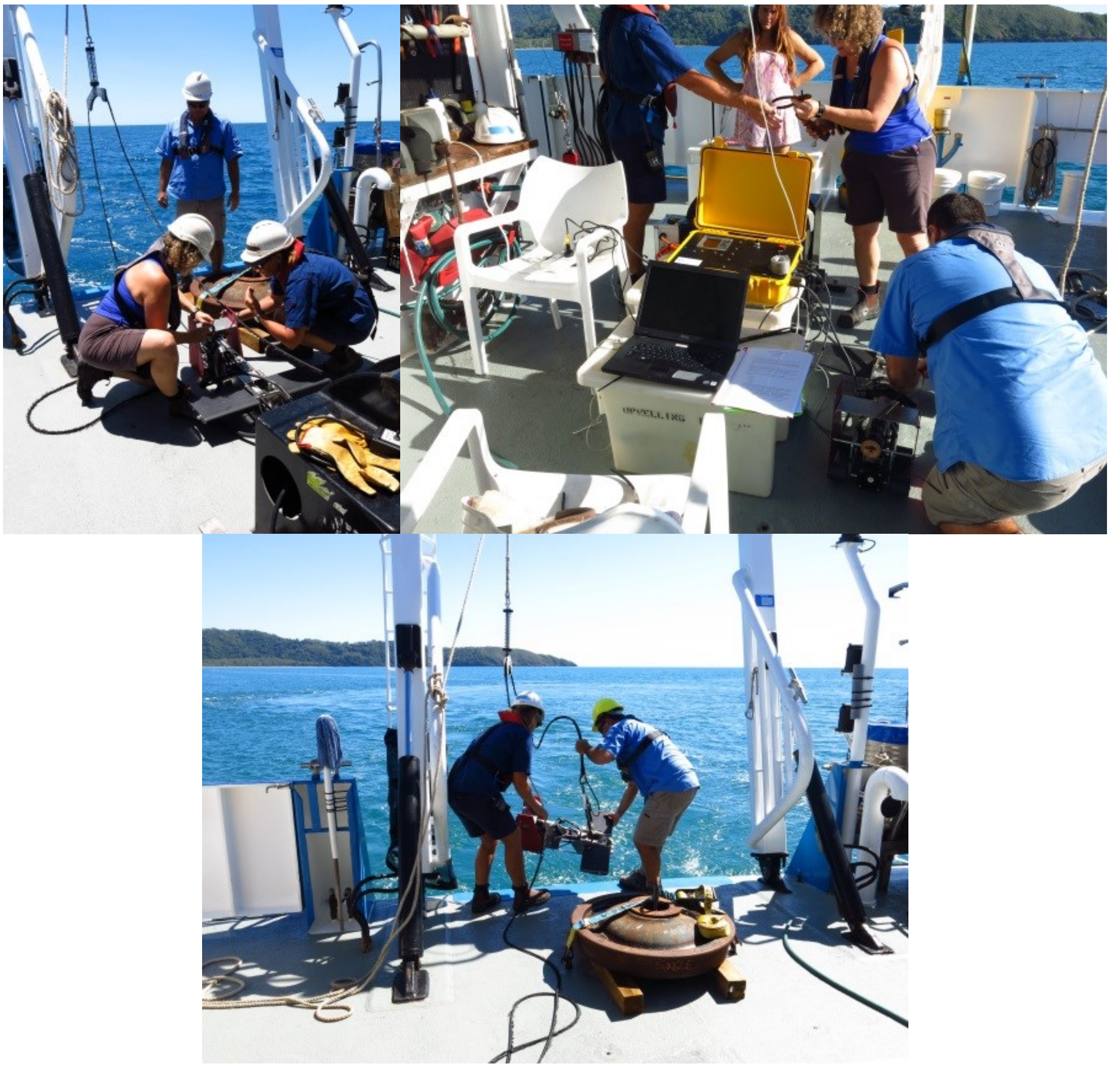


Figure G-1: Top left photo shows the setting up of the MiniBAT on board the vessel; Top right photo shows the computer and cable setup necessary for deployment; Bottom photo shows the deployment of the MiniBAT. Photos provided by AIMS.

Results

The data presented are from single transects in the different regions and each survey was completed within approximately one hour after deployment.

Overall the MiniBAT worked well with no major technical problems and useable data sets were acquired. However, during the deployment it became clear that due to its size and the technical equipment required to operate it (e.g. large winch, computer in water-proof housing), a larger research vessel, such as the AIMS RV Cape Ferguson, was necessary for its safe handling, deployment and retrieval (Figure G-1).

Salinity and temperature data showed only minor variations between depths and regions (Table G-2, Figures G-2 to G-5).

Table G-2: The minimum, maximum, average (± standard deviation) and the coefficient of variation (CV) of the salinity and temperature measured in the four different regions using the sensor mounted on the MiniBAT. The CV was calculated as the (standard deviation/mean) × 100.

Variable	Region	Cape Tribulation	Double Island	Russell Mulgrave	Tully River
Salinity	Min	32.19	30.51	24.58	34.51
	Max	35.15	35.14	35.08	35.3
	Avg (± St dev)	34.81 (± 0.32)	35.04 (± 0.11)	34.94 (± 0.26)	35.20 (± 0.12)
	C.V.	0.92	0.30	0.73	0.34
Temperature	Min	30.04	29.6	29.28	29.84
	Max	30.81	30.58	30.5	30.3
	Avg (± St dev)	30.27 (± 0.14)	29.85 (± 0.22)	29.55 (± 0.19)	30.02 (± 0.05)
	C.V.	0.46	0.73	0.65	0.16

The salinity and temperature contour plots obtained from the MiniBAT in February 2016 along the four transects are shown in Figures G-2 to G-5.

In all cases the water column was relatively well mixed resulting in minimal differences in salinity and temperature between the surface and bottom readings.

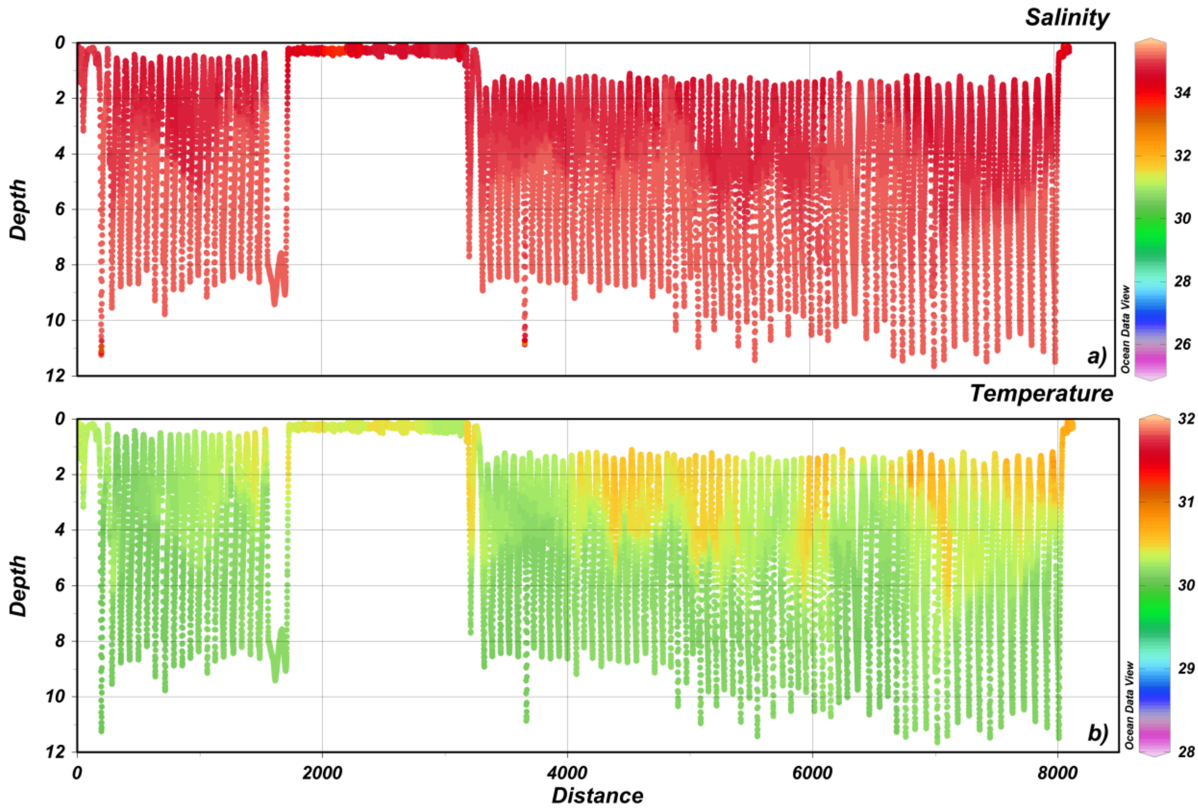


Figure G-2: MiniBAT depth profiles of a) salinity and b) temperature along a transect near Cape Tribulation. Note that the distance reported is arbitrary.

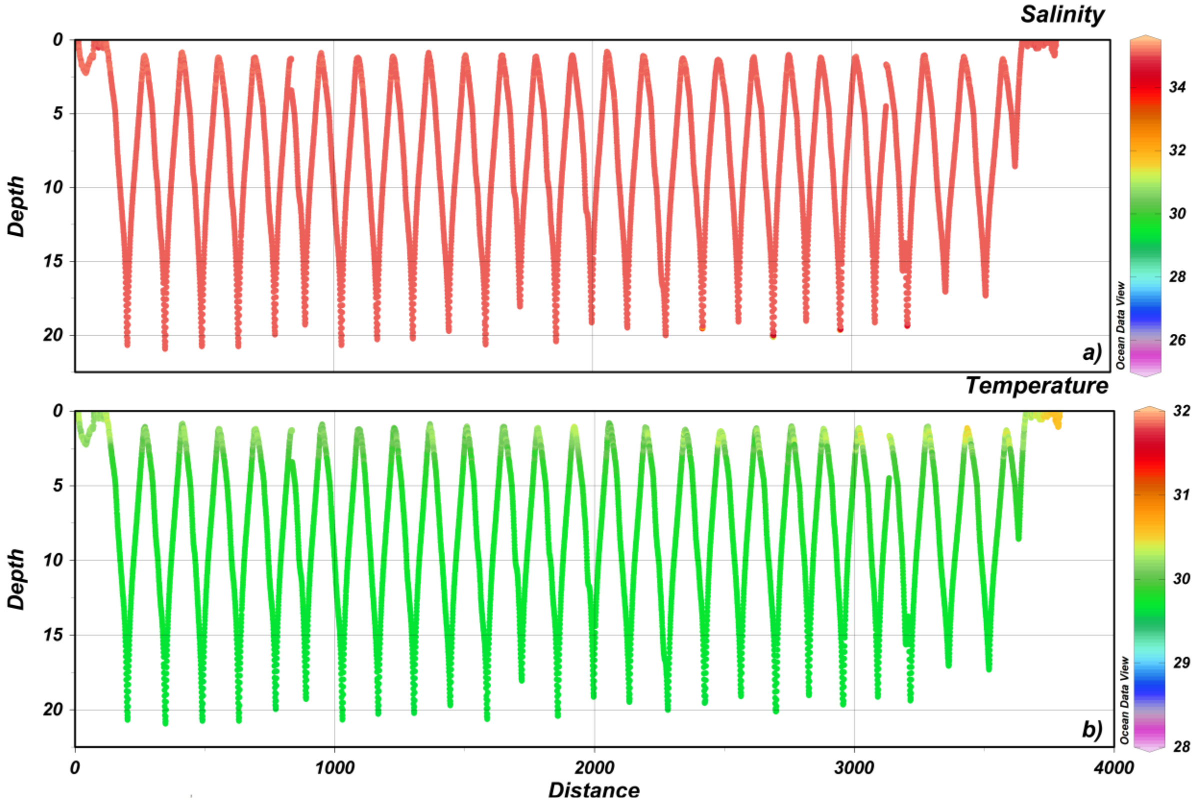


Figure G-3: MiniBAT depth profiles of a) salinity and b) temperature along a transect near Double Island. Note that the distance reported is arbitrary.

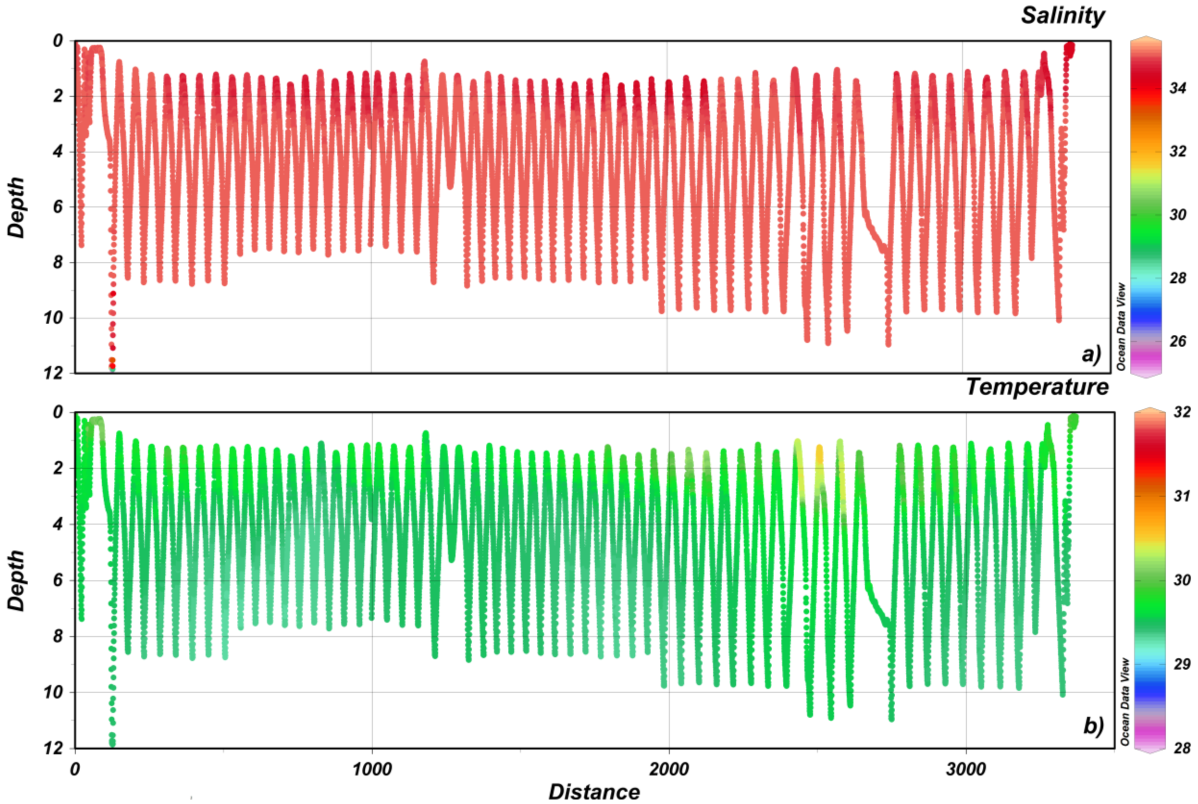


Figure G-4: MiniBAT depth profiles of a) salinity and b) temperature along a transect near Russell Mulgrave. Note that the distance reported is arbitrary.

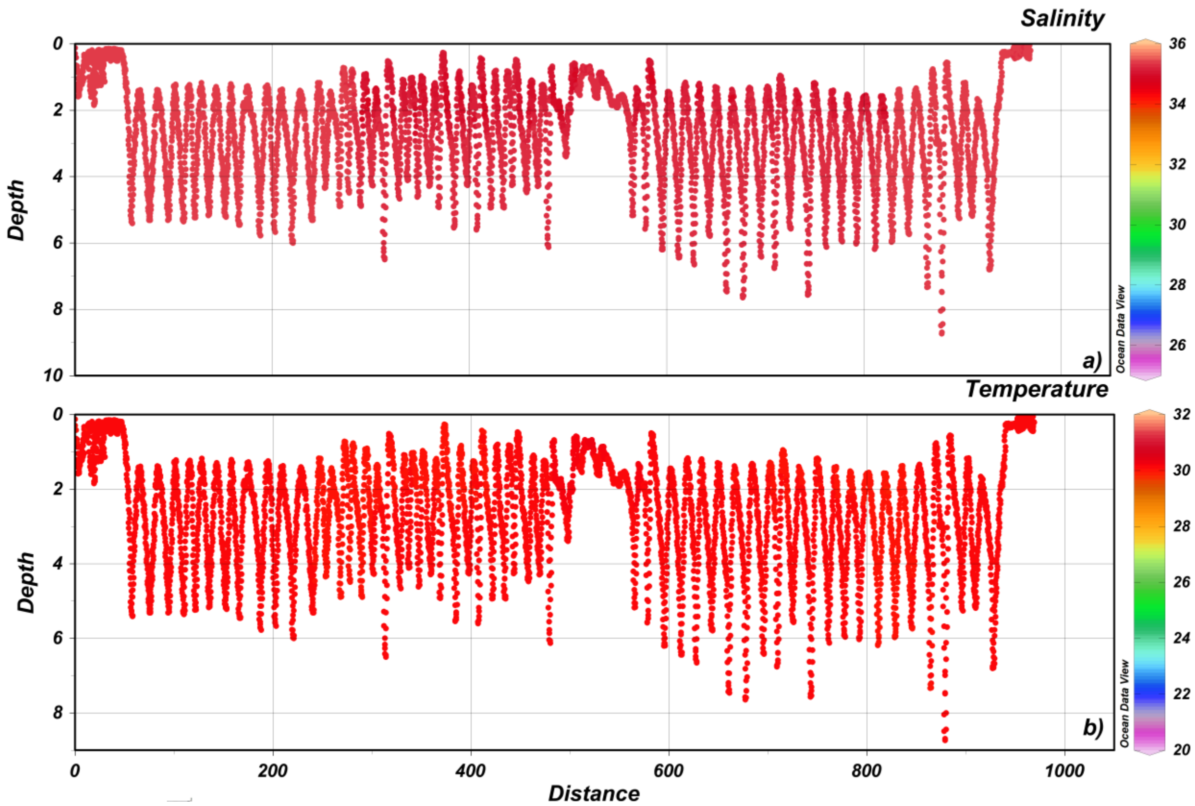


Figure G-5: MiniBAT depth profiles of a) salinity and b) temperature along a transect near to the Tully River. Note that the distance reported is arbitrary.

Assessment of the utility of using the MiniBAT for routine sampling under the MMP:

- For safe handling, a large research vessel is required for deployment and retrieval of the MiniBAT. The vehicle cannot be deployed from a small boat, such as the RV Aquarius, which is used for all water sampling carried out for the MMP, except for the Cairns transect that is sampled three times a year from the RV Cape Ferguson.
- The water column in the GBR lagoon is generally vertically well-mixed by wind and bottom stress and shows minimal stratification (Furnas et al. 2011). Under non-flood conditions, the datasets generated by the MiniBAT are unlikely to add significant information to the existing data sources, e.g. for large scale patterns, the underway system of the RV Cape Ferguson delivers continuous measurements of temperature, salinity, chlorophyll fluorescence and turbidity at 2 m depth (operated as part of IMOS; https://portal.aodn.org.au/). During routine MMP sampling trips, CTD casts are also taken to generate depth profiles of these parameters for the fixed MMP sampling sites and times.
- The data delivered by MiniBAT are likely to be useful during specific research studies around flood plume or upwelling events.

Recommendations:

- The deployment of the MiniBAT as part of the regular MMP water quality sampling program is not possible on a regular basis due to the small boat sampling platform used for the MMP.
- We recommend that the MiniBAT not currently be added to the routine MMP sampling program because of the substantial deployment and maintenance costs (currently not included in the MMP budget) to operate

the vehicle. These costs are not justified by the value of the data to the MMP reporting products under the existing program.

- The utility of the MiniBAT should be considered in the planning for the RIMReP environmental monitoring programs, for example for routine validation of the eReefs model.

References

Furnas MJ, Alongi DM, McKinnon D, Trott L, Skuza M, (2011). Regional-scale nitrogen and phosphorus budgets for the northern (14°S) and central (17°S) Great Barrier Reef shelf ecosystem. Continental Shelf Research 31:1967–1990

Hains JJ, Kennedy RH, (2002). Rapid collection of spatially-explicit in-situ water quality data using a programmable towed vehicle. Journal of Freshwater Ecology 17:99–107.

Appendix H. Scientific publications and presentations associated with the program, 2015–16

Publications

Petus C, Waterhouse, J., Devlin M., Da Silva E, Lewis, S., Waterhouse, J., Wenger, A, Bainbridge Z., Tracey, D. A framework for defining coastal water quality target concentrations for ecosystem conservation in the Great Barrier Reef (Australia) using empirical light attenuation models. In review, Journal of Environmental Management.

Petus C, Devlin M, Thompson A, McKenzie L, Da Silva E, Collier C, Tracey D, Martin K (2016). Estimating the exposure of coral reefs and seagrass meadows to land-sourced pollutants in river flood plumes of the Great Barrier Reef: validating a simple satellite risk framework with environmental data. Remote Sensing, 8(3), 210.

Presentations

Schaffelke B, Logan M, Lønborg C, Thompson A (2016). Acute and chronic changes in water quality ae adversely affecting inshore coral reefs of the Great Barrier Reef. Oral presentation at the Society of Conservation Biology conservation science meeting, Brisbane, Australia, (5-8 July 2016).

Schaffelke B, Logan M, Lønborg C, Thompson A (2016). Acute and chronic changes in water quality are adversely affecting inshore coral reefs of the Great Barrier Reef. Oral presentation at the 13th International Coral Reef Symposium, Honolulu, Hawai'i, USA (19–24 June 2016).