Australian Government
Great Barrier Reef Marine Park Authority

Reef Authority

GREAT BARRIER REEF MARINE MONITORING PROGRAM

Inshore water quality monitoring Annual Report 2022–23

Australian Government
Australian Institute of Marine Science

James Cook University Australia

TropWATER

Cape York Water Partnership

Published by the Great Barrier Reef Marine Park Authority

ISSN: 2208-4096

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

This publication should be cited as:

Gruber, R., Waterhouse, J., Petus, C., Howley, C., Lewis, S., Moran, D., James, C., Logan, M., Bove, U., Brady, B., Choukroun, S., Connellan, K., Davidson, J., Mellors, J., O'Callaghan, M., O'Dea, C., Shellberg, J., Tracey, D., Zagorskis, I., 2024. *Great Barrier Reef Marine Monitoring Program Inshore Water Quality Monitoring: Annual Report 2022–23.* Great Barrier Reef Marine Park Authority, Townsville. 298 pp.

Front cover image: Mooring Operations in the Burdekin region, conducted by staff member from the Australian Institute of Marine Science. ©Australian Institute of Marine Science. Photo taken by Irena Zagorskis.

The Great Barrier Reef Marine Park Authority acknowledges the continuing Sea Country management and custodianship of the Great Barrier Reef by Aboriginal and Torres Strait Island Traditional Owners whose rich cultures, heritage values, enduring connections and shared efforts protect the Reef for future generations.

Comments and questions regarding this document are welcome and should be addressed to:

Australian Institute of Marine Science
PMB No 3
Townsville MC, Qld 4810

TropWATER- Centre for Tropical Water and Aquatic Ecosystem Research
James Cook University
Townsville, Qld 4811
Tropwater@jcu.edu.au

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

Contents

List of figures

List of tables

Appendices: List of figures

Appendices: List of tables

Commonly used abbreviations, acronyms, definitions and units

Abbreviations, acronyms, and definitions

2010–11	water year (e.g., 1 October 2010 to 30 September 2011)
AIMS	Australian Institute of Marine Science
BoM	Bureau of Meteorology
CDOM	colour dissolved organic matter
Chl-*a*	chlorophyll *a*
CTD	Conductivity Temperature Depth profiler
CYWP	Cape York Water Partnership
DIN	dissolved inorganic nitrogen
DOC	dissolved organic carbon
DON	dissolved organic nitrogen
DOP	dissolved organic phosphorus
ENSO	El Nino – Southern Oscillation cycle
GAMM	generalised additive mixed effect model
GV	guideline value
JCU	James Cook University
K_D	light attenuation coefficient
LOD	limit of detection
MMP	Marine Monitoring Program
Marine Park	Great Barrier Reef Marine Park
MODIS	Moderate Resolution Imaging Spectroradiometer
NH_3	ammonia
NO_x	nitrogen oxides
NRM	natural resource management
PN	particulate nitrogen
PO_4	phosphate (dissolved inorganic phosphorus)
POC	particulate organic carbon
PP	particulate phosphorus
PSII herbicide	photosystem II inhibiting herbicide
QA/QC	quality assurance/quality control
QLUMP	Queensland Land Use Mapping Program
Reef	Great Barrier Reef
Reef Authority	Great Barrier Reef Marine Park Authority
Reef 2050 WQIP	*Reef 2050 Water Quality Improvement Plan*
Reef Plan	Reef Water Quality Protection Plan
Reef 2050 Plan	*Reef 2050 Long-Term Sustainability Plan*
SDD	Secchi disk depth
TSS	total suspended solids
WS colour scale	wet season colour scale
WQ Index	Water Quality Index

Units

GL	gigalitre
m	metre
mm d^{-1}	millimetres per day
mg L^{-1}	milligram per litre
ML	megalitre
km	kilometre
km h^{-1}	kilometres per hour
kt	kilotonne
t	tonne
µg L^{-1}	microgram per litre

Acknowledgements

We acknowledge the Australian Government funding through the Great Barrier Reef Marine Park Authority (the Reef Authority) for financial and technical support of this program. Thank you to Kaye Walker and Martina Prazeres from the Reef Authority for their overall project management and program guidance.

We are grateful to all the people involved in the field work. We acknowledge Andrew Mead from Barra Charters for the Burdekin region sampling in partnership with TropWATER James Cook University. Thanks to the Australian Institute of Marine Science (AIMS) Oceanographic Technician team, Marine Operations team, Data Systems Engineering team, and the crew of the R.V. Cape Ferguson, who have been a critical part of this program for many years, as well as Madi McLatchie. From the Cape York Water Partnership, we thank Eric Dick, Jeff Shellberg, Sarah Herkess, Sienna Thomason and the Lama Lama Rangers (Yintinga Aboriginal Corporation). We thank the Pascoe sampling crew: Lana Polglase, Steve Rehn (Albatross Hire) and Tilly Rehn, and acknowledge the Pascoe family group for their support for our work on their Traditional Sea Country. We are grateful to the dedicated staff of the TropWATER laboratory for their assistance with sample preparation and processing and the AIMS Analytical Technology Laboratory who have analysed a large volume of samples for this program.

Executive summary

The water quality component of the Great Barrier Reef Marine Monitoring Program reports on the annual and long-term condition in inshore water quality of the Great Barrier Reef (the Reef) with reference to 18 years of monitoring data. This report presents the results for the 2022–23 water year (1 October 2022 to 30 September 2023).

The program design includes the collection of samples along transects in the Cape York, Wet Tropics, Burdekin, and Mackay-Whitsunday regions year-round, with higher frequency sampling during the wet season to better characterise this period of episodic river discharge. Monitoring also occurs in the Fitzroy region through the Fitzroy Basin Marine Monitoring Program for Inshore Water Quality, and results are presented within this report (Appendix D). Satellite imagery and modelling are linked with *in situ* monitoring data to estimate the exposure of inshore areas to end-of-catchment loads from rivers for all Reef catchment regions.

Trends in key inshore water quality indicators

Key water quality indicators were used to derive a Water Quality Index which communicates the long-term trend (insensitive to year-to-year variability) and annual condition (sensitive to year-to-year variability) of water quality relative to guideline values (Figure i).

The long-term Index showed that inshore water quality:

- **improved** overall in the Wet Tropics region over the last five years after a trend of deterioration from 2008 to 2018,
- **improved** in the Burdekin region over the last two years after a trend of deterioration from 2010 to 2018,
- **improved** in the Mackay-Whitsunday region over the last four years after a trend of deterioration from 2007 to 2018, and
- **improved** in the Fitzroy region over the last two years (although this result is preliminary and more data are needed to confirm this) after a trend of improvement from 2008 to 2015.

Cape York long-term trends are not assessed yet as there are not enough data for a robust long-term assessment.

The annual condition Index showed that inshore water quality in 2022–23 was:

- **'good'** in the Cape York region, and similar to the previous year's 'good' score;
- **'moderate'** in the Wet Tropics and Burdekin regions, similar to the previous two years;
- **'moderate'** in the Mackay-Whitsunday region and continuing to improve since 2018; and
- **'good'** in the Fitzroy region, similar to the previous two years.

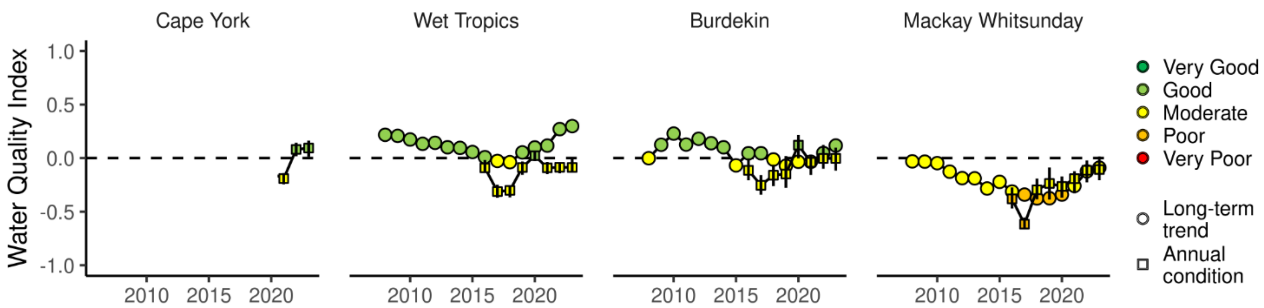


Figure i: Water Quality Index scores from 2008 to 2023 for the Cape York, Wet Tropics, Burdekin, and Mackay-Whitsunday regions. The Index is calculated to show the long-term trend in water quality since the start of monitoring (circles), where seasonal and short-term variability signals are removed. An updated Index version communicating annual condition is calculated from 2015 onwards (squares) that includes increased temporal and spatial sampling and relates water quality values to wet and dry season Reef water quality guidelines. The Index includes five indicators: water clarity, nitrate/nitrite, particulate nitrogen, particulate phosphorus, and chlorophyll *a*. Long-term data are not available for Cape York.

Individual water quality indicators were monitored for trends and compared against water quality guideline values (GVs). This water year, GVs were:

- **met in all focus regions** for chlorophyll *a*;
- **met in most focus regions** for phosphate, particulate nitrogen, particulate phosphorus, and total suspended solids; and
- **not met in any focus region** for Secchi depth and nitrate/nitrite (except for the Annan-Endeavour focus region in Cape York).

Trend analysis shows that since 2015, all water quality indicators have shown **improvement** or **stability** in all focus regions with one exception (particulate nitrogen in the Tully focus region, which has shown a trend of deterioration). Nitrate/nitrite has shown a trend of improvement in most focus regions, although concentrations are currently well above (exceeding) GVs in all focus regions except the Annan-Endeavour. This is a promising finding for nitrate/nitrite and if current trends continue, concentrations in some focus regions could approach GVs in the next few years. Improvement in water quality indicators has been occurring in the last two to five years, following a period of deterioration from ~2007–2018 that occurred in many regions.

Changes in nutrient concentrations are related to changes in nutrient sources (i.e., inputs) and sinks (i.e., outputs) in the Reef lagoon and potentially changes in the rates of key ecological processes (such as primary production or remineralisation). The spatial and temporal variability in the *in situ* water quality discussed in this report highlights the combination of complex factors that drive water quality conditions in the coastal ocean including river discharge, biogeochemical processes, and physical forcing.

Drivers and pressures

Environmental conditions over the 2022–23 wet season included rainfall and river discharge just above the long-term median for the total Reef discharge. Three Natural Resource Management regions had discharge well above the long-term median including the Cape York (2.1 times higher than long-term median), Burdekin (2.1 times higher), and Mackay-Whitsunday (2.0 times higher). River discharge in the Wet Tropics and Fitzroy regions was close to the long-term median (1.2 and 1.1 times higher, respectively), while the Burnett-Mary region was slightly below the long-term median (0.8 times the long-term median). There was no cyclone activity for the Reef in 2022–23. However, several weak tropical lows resulted in high rainfall and river discharge events in some locations.

End-of-catchment sediment and nutrient load estimates showed distinct variations between the focus regions which were consistent with the typical patterns recorded in the Reef lagoon. In 2022–23, the highest estimated dissolved inorganic nitrogen exports were from the Tully-Murray-Herbert basin (2,599 t), followed by the Burdekin-Haughton (2,221 t), Russell-Mulgrave-Johnstone (1,735 t), Mackay-Whitsunday (1,351 t), Daintree-Mossman-Barron (771 t), and Fitzroy (570 t) basins. This finding was largely due to the near-median discharges in the Wet Tropics and higher discharges from the Burdekin and Mackay-Whitsunday catchments. Estimated loads of total suspended solids were dominated by the Burdekin-Haughton basin (4,446 kt) followed by the Mackay-Whitsunday (961 kt), Fitzroy (790 kt), Tully-Murray-Herbert (715 kt), Barron-Daintree-Mossman (692 kt), and Russell-Mulgrave-Johnstone (549 kt) basins. Estimated loads of particulate nitrogen were also dominated by the Burdekin-Haughton basin (5,390 t) followed by the Mackay-Whitsunday (2,488 t), Tully-Murray-Herbert (2,104 t), Barron-Daintree-Mossman (1,885 t), Russell-Mulgrave-Johnstone (1,840 t), and Fitzroy (1,500 t) basins.

Sentinel-3 satellite images were used to map Reef optical water types (WT) for the third year. Satellite reference maps (long-term, wet, and dry frequency maps) were all updated for this report, as well as all mean long-term concentrations of water quality parameters to improve the accuracy of the water type characterisation, building on the *in situ* that are collected every wet season. Water types are classified depending on water colour and linked to water quality characteristics; Reef WT1 are brownish waters (enriched in sediment and dissolved organic matter), Reef WT2 are greenish waters (enriched in algae and dissolved organic matter), and Reef WT3 waters have low risk of detrimental ecological effects. There was a high frequency of exposure to Reef WT1 in inshore areas, with mid-shelf to offshore areas usually exposed to Reef WT3 only. In the mid-shelf and offshore water bodies, presence of Reef WT3 waters is often the result of oceanographic processes such as upwelling rather than direct influence of catchment discharge. The area exposed to any water quality potential risk in 2022–23 was spatially limited relative to the scale of the Reef; even so, the area of the Reef in the highest risk categories (risk categories III and IV) is almost 10,000 km^2. Ninety one percent of the total Reef area was exposed to no or very low potential risk. Marine habitat areas exposed to a potential risk were similar to the long-term patterns in all regions (≤ 5% change). There was, however, an increase in the area of coral reef exposed to the lowest risk category (II) (+10%) in the Cape York region, which was consistent with the relatively high river discharge measured in this region. Inversely, in the Fitzroy and Burnett-Mary regions, about 20% of the regional seagrass areas shifted from the lowest risk category (II) to no/very low risk, which was consistent with the near- or below-median river discharges measured in both regions.

Conclusions

This report presents some positive results for inshore water quality in the Reef lagoon for the 2022–23 water year. Long-term trends of stability or improvement in overall water quality were observed in all monitored focus regions. Nevertheless, some indicators (especially nitrate/nitrite) remain significantly above (not meeting) water quality guideline values and require substantial improvement before guideline values may be met. The relationship between river runoff and water quality is complex and is confounded by large inter-annual rainfall variability in tropical coastal waters. Progress of catchment management practice adoption is incremental and slow response timeframes are expected between land-based changes and marine water quality. It is therefore important to interpret the trends of improvement in this report cautiously; further work is needed to rule out oceanographic and climatic drivers of the observed trends. Associated trends in catchment load reductions from catchment monitoring programs are an important line of evidence that need to be established before trends in inshore water quality could be related to catchment practices. Additionally, further monitoring is needed to determine if trends in inshore water quality are broad-reaching and sustained over time.

1 Introduction

1.1 The Great Barrier Reef

The Great Barrier Reef (the Reef) is the most extensive reef system in the world, comprising over 2,900 km^2 of coral reefs. It also includes large areas of seagrass meadows, estimated to be over 43,000 km^2 or ~12.5% of the total area of the Great Barrier Reef Marine Park (the Marine Park) (Great Barrier Reef Marine Park Authority, 2019). The Reef catchment is divided into six natural resource management (NRM) regions, each with differing land use, biophysical and socio-economic characteristics.

1.2 Water quality monitoring in the Reef

The management of water quality remains a priority for the Great Barrier Reef Marine Park Authority (the Reef Authority) and the Australian and Queensland governments because good water quality supports the health and resilience of coastal and inshore ecosystems of the Reef (Great Barrier Reef Marine Park Authority, 2019).

In response to concerns about the impact of land-based runoff on Reef water quality, the Reef Water Quality Protection Plan was established by the Australian and Queensland governments in 2003 (Australian and Queensland governments, 2003). The Plan is updated periodically and was last updated by the Australian and Queensland governments in 2017 and was released as the *Reef 2050 Water Quality Improvement Plan* (Reef 2050 WQIP; Australian and Queensland governments, 2018a). It is a major component of the Reef 2050 Long-Term Sustainability Plan (Commonwealth of Australia, 2015, 2018, 2021, http://www.environment.gov.au/marine/gbr/reef2050), which provides a framework for the integrated management of the Great Barrier Reef World Heritage Area.

A key deliverable of the Reef 2050 WQIP is the *Paddock to Reef Integrated Monitoring, Modelling and Reporting Program* (Australian and Queensland governments, 2018b) which is used to evaluate the efficiency and effectiveness of the implementation of the Reef 2050 WQIP and report progress towards goals and targets. The Great Barrier Reef Marine Monitoring Program (MMP) forms an integral part of the *Paddock to Reef Integrated Monitoring, Modelling and Reporting Program.* The MMP has three components: inshore water quality, coral, and seagrass. Ecological components of the MMP (seagrass and coral health) are published in separate annual reports detailing the condition and trend of these ecosystems in relation to multiple stressors, including water quality presented in this report (for example, McKenzie *et al.*, 2023; Thompson *et al.*, 2023). In previous years, inshore pesticide monitoring has been presented in a separate report (for example, Thai *et al.*, 2020) or as part of the MMP water quality report. Pesticide sampling recommenced in the 2022–23 wet season and is reported separately (Kaserzon *et al*., 2023). Loads of sediments and nutrients, and concentrations of pesticides within rivers are monitored and reported by the Great Barrier Reef Catchment Loads Monitoring Program (Water Quality & Investigations, 2023).

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'* (Australian and Queensland governments, 2018b). Water quality monitoring has been delivered by the Australian Institute of Marine Science (AIMS), James Cook University (JCU) and the Reef Authority since 2005; the Cape York Water Partnership (CYWP) was added as a collaborator in 2017.

1.3 Structure of the report

Section 2 presents a summary of the program's methods. Section 3 describes the factors influencing marine water quality, referred to as drivers and pressures in the Driver-Pressure-State-Impact-Response (DPSIR) framework (Figure 1-1). Water quality results from satellite imagery and hydrodynamic modelling are presented in Section 4 at Reef and regional scales. Detailed results from focus regions are presented in Section 5, including monitoring results, indices, and catchment loading. Discussion and Conclusions are given in Section 6. More information on monitoring sites and methods is given in Appendix A and Appendix B. Detailed results tables and figures are included in Appendix C. Monitoring results from the Fitzroy NRM region are presented in a stand-alone chapter as Appendix D. The program's major publications and presentations from the year are reported in Appendix E.

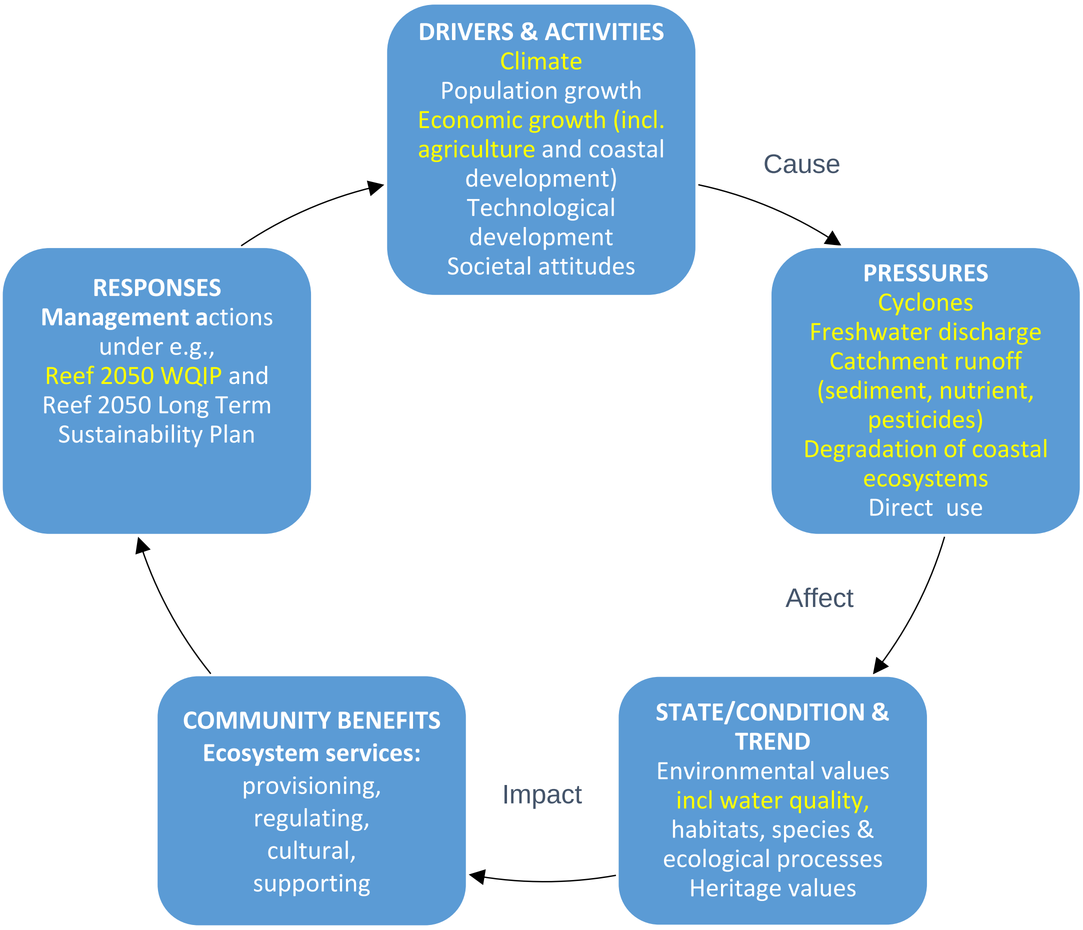


Figure 1-1: DPSIR framework used to guide the structure of the MMP derived from the Great Barrier Reef Strategic Assessment (Great Barrier Reef Marine Park Authority, 2014). The aspects highlighted in yellow are included in this report.

2 Methods

This Section provides an overview of the sampling design and indicators that are monitored as part of the MMP. More details are presented in Appendices and in a separate quality assurance and quality control (QA/QC) report (Great Barrier Reef Marine Park Authority, 2022).

2.1 Sampling design

The MMP inshore water quality monitoring program is designed to measure the annual condition and long-term trends in coastal water quality. Tropical waters are characterised by high seasonal variability in river discharge, as rainfall from low pressure systems causes river flood plumes to extend into the coastal ocean, while river discharge becomes negligible during low rainfall periods. Water quality monitoring by the MMP is thus conducted during ambient conditions as well as river discharge events.

Ambient monitoring refers to routine sampling during the wet and dry seasons outside of major flood events. It has been conducted since 2005 under the MMP, although the program design (site location, site number, monitoring frequency) has changed over time.

Event-based monitoring occurs in response to major flood events to capture conditions within flood plumes; event-based monitoring occurs at the ambient site locations, plus additional ‘event’ sites. The monitoring frequency depends on the number of flood events each year but is capped to a maximum number of samples (40 in Cape York and 40 in the Wet Tropics, Burdekin and Mackay-Whitsunday regions).

The program covers four NRM regions including Cape York, the Wet Tropics, Burdekin, and Mackay-Whitsunday, initially chosen on the basis of water quality risk assessments (Brodie *et al.*, 2013). Monitoring site locations were selected along expected water quality gradients related to exposure to land-based runoff. This was largely determined by increasing distance from a river mouth in a northerly direction to reflect the predominantly northward flow of surface water driven by the prevailing south-easterly winds (Brinkman *et al.*, 2011).

From 2005 to 2014, monitoring occurred 3 times per year at sites in the regions listed above (with the exception of Cape York) and additionally in the Fitzroy region (discontinued in 2015). An independent statistical review of the MMP in 2014 (Kuhnert *et al.*, 2015) showed that additional sites and higher sampling frequency would provide additional statistical power. The current program design was implemented in February 2015 and includes most of the sampling sites in the pre-2015 design, allowing for the continuation of the long-term time-series, and inclusion of additional sites. This program re-design was recently reviewed and the increase in power to detect change in the Great Barrier Reef’s inshore water quality was verified (Lloyd-Jones *et al.*, 2022).

The program currently includes nine ‘focus regions’, each with 5 to 6 sites measured routinely: Pascoe, Normanby, Annan-Endeavour, and Stewart (in the Cape York NRM, all added in 2017); Barron-Daintree, Russell-Mulgrave, and Tully (all in the Wet Tropics NRM); Burdekin; and Mackay-Whitsunday (Figure 2-1). The frequency of ambient monitoring was increased in 2015, and sites are now visited 3–10 times annually, depending on the focus region.

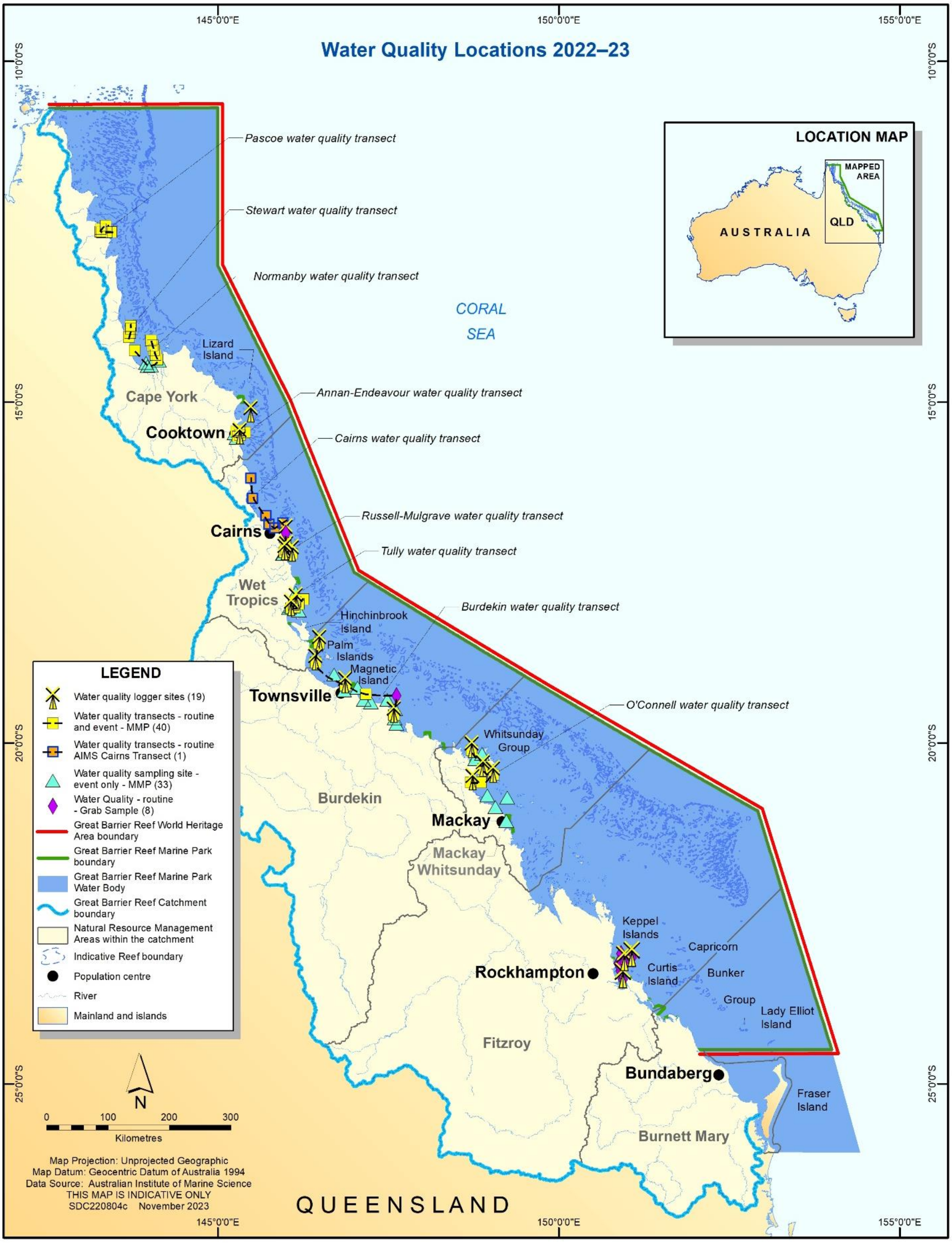


Figure 2-1: Site locations for water quality monitoring sampled from 2015 onwards. Note that the Cape York transects were added in 2017. Monitoring sites in the Fitzroy region are shown in the stand-alone report for this region (Appendix D).

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

- continuous measurement of salinity and temperature at seven sites
- continuous measurement of chlorophyll and turbidity at 16 sites
- 49 ambient sites with more frequent sampling during the wet season
- 26 event-based sites identified for sampling during flood conditions.

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

Condition	**Parameter**	**Abbreviation**	**Units of Measure**
Physico-chemical	Salinity	Salinity	
	Temperature	Temperature	Celsius degree
	Light attenuation coefficient[1]	K_D	m^{-1}
	Secchi depth	Secchi	m
	Total suspended solids	TSS	mg L^{-1}
	Coloured dissolved organic matter	CDOM	m^{-1}
	Turbidity	Turb	NTU
Nutrients	Ammonia	NH_3	µg N L^{-1}
	Nitrite[2]	NO_2	µg N L^{-1}
	Nitrate[2]	NO_3	µg N L^{-1}
	Dissolved inorganic phosphorus	PO_4	µg P L^{-1}
	Silica	Si	µg Si L^{-1}
	Particulate nitrogen	PN	µg N L^{-1}
	Particulate phosphorus	PP	µg P L^{-1}
	Total dissolved nitrogen	TDN	µg N L^{-1}
	Total dissolved phosphorus	TDP	µg P L^{-1}
	Particulate organic carbon	POC	µg C L^{-1}
	Dissolved organic carbon	DOC	µg C L^{-1}
Biological	Chlorophyll *a*	Chl-*a*	µg L^{-1}

[1]Derived from vertical profiles of photosynthetically active radiation and not sampled at all sites

[2] NO_x is the sum of NO_2 and NO_3

2.2 Water quality sampling

At each sampling location (Figure 2-1, Appendix A), vertical profiles of water salinity and temperature were measured with a Conductivity Temperature Depth (CTD) profiler (Sea-Bird Electronics SBE19plus). CTD profiles are used to characterise the water column and to identify its state of vertical mixing. Some CTD profiles included measurements of photosynthetically active radiation (PAR), which were used to derive the light attenuation coefficient (K_D). See the QA/QC report for a detailed description of CTD data processing (Great Barrier Reef Marine Park Authority, 2022).

Immediately following the CTD cast, discrete water samples were collected using Niskin bottles. Surface (~0.5 m below water surface) and bottom (~1 m above the seabed) samples were collected during ambient monitoring, whereas for some event-based monitoring only surface water samples were collected. Samples from the Niskin bottles were taken in duplicate and were analysed for a suite of water quality parameters (Table 2-1). Detailed descriptions of analytical chemistry techniques can be found in the QA/QC report (Great Barrier Reef Marine Park Authority, 2022). Values of water quality variables presented in this report are depth-weighted means calculated using surface and bottom samples.

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

- **Total Suspended Solids (TSS)** is a measure of the suspended particulate material in the water column. This includes suspended sediments (sand, silt, and clay), living plankton, and detrital (non-living organic) material. TSS concentrations are affected by oceanographic processes including primary production and wind and tide-driven resuspension, as well as inputs from other sources such as dredging and runoff from land.
- **Secchi depth** is a visual measure of water clarity and proxy for light penetration, which is measured using a high-contrast black and white patterned disc called a Secchi disc. The Secchi depth is the average of the vertical disappearance and reappearance depths of the disc, where clarity increases with increasing Secchi depth. Secchi depth is a simple method that has been used for over 150 years, so is excellent for assessing long-term change and for cross-system comparisons.
- **Turbidity** is a measure of light scattering caused by fine suspended particles, such as sediment, detritus, and plankton. Turbidity is affected by a wide range of factors including oceanographic processes such as resuspension of bottom sediments by wind and tides; river discharge; and anthropogenic factors such as dredging.
- **Chlorophyll *a* (Chl-*a*)** concentration is a measure of phytoplankton biomass in a water body. Phytoplankton grow quickly in response to nutrient availability, so elevated values of Chl-*a* can indicate increased nutrient loading.
- **Dissolved inorganic nutrients (NH_3, NO_X, PO_4 and Si)** measure the amount of readily available nutrients for plankton growth in water samples. Inorganic nitrogen (NH_3, NO_x) and phosphate (PO_4) represent around 1% of the nutrient pools in the Reef. The inorganic nutrient pools are affected by a complex range of biogeochemical processes including both natural (for example, plankton uptake, upwelling, nitrogen fixation, and remineralisation) and anthropogenic (for example, dredging and nutrient inputs from changed land use) processes.
- **Particulate nutrients (POC, PN, and PP)** are a measure of the suspended material retained on a filter with a pore size of approximately 0.7 µm. This material consists of a minor fraction of living biomass (e.g., bacteria, phytoplankton) and a major fraction of detritus (e.g., dead cells, faecal pellets). Particulate nutrient concentrations are affected by

oceanographic processes (primary production, bacterial production, resuspension, and remineralisation) as well as sources such as dredging and land-based runoff.

- **Dissolved organic carbon (DOC)** is a measure of organic carbon concentrations passing through a filter with a pore size of 0.45 µm. DOC has a complex chemical composition and is used by bacteria as a source of energy. The DOC pool is affected by a range of production and degradation pathways. The sources include primary production by phytoplankton, zooplankton grazing, resuspension events, river runoff, and abiotic breakdown of POC. DOC can be degraded by sunlight.

2.3 *In situ* loggers

Continuous *in situ* chlorophyll fluorescence and turbidity were measured using WET Labs ECO FLNTUSB Combination Fluorometer and Turbidity Sensors located at 16 sites (Appendix A), which were deployed at 3 m (Cape York region) or 5 m (all other regions) below the surface and sampled at 10 min intervals. Water samples for analyses of Chl-*a* and TSS were collected three times per year to calibrate logger fluorescence and turbidity to *in situ* conditions. Diver-operated Niskin bottles were used to sample close to the moored loggers and samples were preserved and analysed in the same manner as ship-based water samples.

Daily averages of the chlorophyll and turbidity collected by the ECO FLNTUSB instruments are presented as time-series graphs in Appendix C Figure C - 1. Annual means and medians of turbidity were also calculated for each site based on the 'water year' (1 October to 30 September the following year) and compared with the guideline value (GV) (Appendix C Table C - 2).

Salinity and temperature loggers (Sea-Bird Electronics SBE37) were deployed at seven locations, with four of these being placed on fixed moorings near the O'Connell, Russell-Mulgrave, Tully, and Burdekin River mouths (Figure 2-1; Appendix A). See the QA/QC report (Great Barrier Reef Marine Park Authority, 2022) for detailed descriptions of logger pre- and post-deployment procedures. Site-specific time-series from these loggers can be found in Appendix C Figure C - 2.

2.4 Data analyses – Summary statistics and trends

Concentrations of water quality parameters at each sampling occasion were calculated as depth-weighted means by trapezoidal integration of the data from all sampling depths. At most sites, only two vertical points are sampled (i.e., surface and bottom samples), and this method averages these values to derive the depth-weighted mean. Measurements falling below the analytical detection limit were replaced with values of half the detection limit. Summary statistics for all water quality variables are presented for all monitoring sites in Appendix C Table C - 1. Concentrations were compared to site-specific GVs (Appendix C Table C - 9), which are defined for Chl-*a*, PN, PP, TSS, Secchi depth, NO_x, and PO_4 at most sites. Concentrations of water quality parameters are presented along the sampling transects for each focus region with distance from major river mouth. Trends in water quality are represented with generalised additive models, fitted with a maximum of five knots and modelled with a gamma-distributed response and log-link function.

Temporal trends in key water quality variables (Chl-*a*, TSS, Secchi depth, turbidity, NO_x, PO_4, PN, PP, DOC, and POC) since 2005 are reported for all focus regions except Cape York. Only open coastal and mid-shelf sites are used for these analyses because GVs for enclosed coastal waters are derived differently and are not available for all variables, creating statistical imbalance.

Generalised additive mixed effects models (GAMMs) were used to decompose each irregularly spaced time-series into its trend cycles (long-term) and periodic (seasonal) components (Wood, 2006). GAMMs are an extension of additive models (which allow flexible modelling of non-linear relationships by incorporating penalised regression spline types of smoothing functions into the estimation process), where the degree of smoothing of each smooth term (and by extension, the estimated degrees of freedom of each smoother) is treated as a random effect and thus estimable via its variance as with other effects in a mixed modelling structure (Wood, 2006).

For each water quality variable within each focus region, the variable was modelled against a thin-plate smoother for date and a cyclical cubic regression spline (maximum of 5 knots) over months within 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). All GAMMs were fitted using the mgcv (Wood 2006, 2011) package in R 3.6.1 (R Core Team, 2022).

GAMMs represent long-term trends in water quality variables measured during ambient periods (i.e., not peak flood events) of the dry and wet seasons and are presented in Section 5. It is important to note that this trend analysis removes variability associated with wind, tides, and seasons. Thus, individual data points will have different values from raw data. This analysis is designed to detect **long-term** and **regional-scale** trends in water quality by removing the effect of short-term changes associated with weather and seasonal differences.

In order to provide a more quantitative assessment of trend, linear change in values of GAMMs was measured from the present sampling year to 2015. This period was chosen as it incorporates the MMP re-design, which was introduced in 2015; using earlier data would unbalance this analysis as the amount of sampling greatly increased in 2015. As GAMMs are de-trended to remove the effects of seasons, tides, and wind, this analysis aims to quantify long-term trends occurring outside of these cycles. Trend analysis results are presented for each focus region in Section 5.

2.5 Data analyses – Water Quality Index

The Water Quality Index (WQ Index) is an interpretation tool developed by AIMS to visualise trends in the suite of water quality variables measured and to compare monitored water quality to existing Water Quality Guidelines (Department of Environment and Resource Management, 2009; Great Barrier Reef Marine Park Authority, 2010). The WQ Index uses a set of five key indicators:

- Water clarity,
- Chl-*a* concentrations,
- PN concentrations,
- PP concentrations, and
- NO_x concentrations.

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

For each monitoring site, these indicators are scored based on performance relative to GVs and averaged to give an overall site-specific score. Sites are then averaged over a region or focus region to give a regional score (see Appendix B for details of Index calculation). Results are presented in Section 5.

The WQ Index is calculated using two different methods due to the objectives of the program needing to report both the long-term trend in water quality condition and the annual conditions that ecosystems experience. Changes in the MMP design that occurred in 2015 (increased number of sites, increased sampling frequency, and higher sampling frequency during the wet season [December to April]) also needed to be incorporated into WQ Index calculation. The two versions of the WQ Index have different purposes:

1. **Long-term trend**: This version is based on the pre-2015 MMP sampling design and uses only the original sites (open coastal water body) and three sampling dates per year. This sampling

design had low temporal and spatial resolution and was aimed at detecting long-term trends in inshore water quality. Key aspects of this version are:

- annual water quality GVs are used for scoring monitoring data (Table B - 1),
- only AIMS monitoring data are used,
- a four-year running mean is applied to data to reduce the effect of sampling time on the Index, and
- the Index is an average of five equally-weighted indicator scores: water clarity (the average of TSS and turbidity from loggers, where available), Chl-*a*, NO_x, PN, and PP weighted equally.

2. **Annual condition:** This version is based on the post-2015 MMP sampling design and uses all sites (except enclosed coastal sites) and sampling dates per year. Key aspects of this version are:
   - seasonal site-specific water quality GVs are used (i.e., wet season data are compared to a wet season GV and dry season data are compared to a dry season GV) (Appendix C Table C - 9),
   - both AIMS and JCU monitoring data are used,
   - a running mean is not applied, and
   - the Index is a hierarchical combination of scores for five indicators: water clarity (the average of TSS, Secchi depth, and turbidity from loggers, where available), productivity (combined score of Chl-*a* and NO_x), and particulate nutrients (combined score of PN and PP), which are weighted equally.

2.6 Data analyses – Remote sensing monitoring products

2.6.1 Mapping Reef water types

The current Program utilises optical information available from medium resolution optical satellite images combined with modelling and field water quality data to monitor the Reef water quality (e.g., Petus *et al.,* 2019; Waterhouse *et al.,* 2021). Until 2020, trends in Reef marine water composition during the wet season were monitored using a combination of Moderate-Resolution Imaging Spectroradiometer (MODIS) satellite imagery and a “wet season” colour scale specifically developed for the Reef (Alvarez-Romero *et al*., 2013). MODIS satellite pixels were reclassified into six colour classes, then into four broad groups of water type characteristics: the primary (corresponding to colour classes 1 to 4), secondary (colour class 5), and tertiary (colour class 6) wet season water types and the marine water type (Figure 2-2a and Table 2-2).

These water types represented typical colour and water quality gradients encountered in the Reef during the wet season (December to April), including river plumes. Catchment runoff in sediment-laden river discharge appears in satellite images as brownish flood plumes, while productive chlorophyll-rich waters appear with a greenish colour, and ambient (clear) marine waters are a blueish colour. Brownish-green waters also appear when sediments are re-suspended by wind or tide, and it is impossible to fully separate the direct influence of riverine plume from wind- and wave-driven sediment resuspension (some of which may have been originally derived from river discharge in previous events) in optical satellite images. Therefore, the term “wet season waters” referred collectively to flood river plumes, associated resuspension, and oceanographic processes occurring in the Reef during the wet season.

However, MODIS sensors were ageing, and the quality of the MODIS imagery was declining (MODIS-Aqua was launched in 2002). A transition to Sentinel-3 Ocean Land Colour Instrument (OLCI) satellite imagery and another colour scale (the Forel-Ule [FU] colour scale) was proposed for the continuous mapping of Reef waters in 2019 and adopted in 2020 (Petus et a, 2019) (Table 2-2). The FU colour scale is an historical colour scale standard to determine water colour and classifies waterbodies worldwide (Novoa et al., 2013). It is composed of 22 colours going from indigo blue to ‘cola’ brown, and is applicable for all natural waters (inland, estuarine, inshore and offshore) and all environmental conditions, including wet and dry season conditions (Wernand et al., 2012, 2013; Van der Woerd et al., 2016; Van der Woerd and Wernand, 2018). In a case study focusing on Wet Tropics and Burdekin regions of the Reef over the 2017–18 wet season, the MODIS-Aqua WS and Sentinel-3 FU colour class maps showed very similar patterns (Petus et al., 2019; Figure 2-2 and Table 2-2).

Equivalent FU water types were defined by grouping:

- FU colour classes 1–3 (equivalent to marine waters in the wet season scale used before 2020–21),
- FU colour classes 4–5 (equivalent to tertiary water type in the wet season scale),
- FU colour classes 6–9 (equivalent to the secondary water type), and
- FU colour classes ≥10 (equivalent to the primary water type).

Table 2-2: Description of the Sentinel-3 Reef water types (WT) and corresponding Forel-Ule (FU) colour classes (and comparison with MODIS wet season (WS) water types). Mean long-term (2004–2023) concentrations of water quality parameters (± standard deviation) across the Reef water types were updated in 2023 and are indicated in the right column (modified from Petus et al., 2019 and Waterhouse et al., 2018).

Reef water types	**FU colour classes** **(and WS colour classes)**	**Description**	**Mean long-term (2004–23) concentrations of water quality parameters***
WT1 (previously primary)	FU ≥ 10 (WS1–4)	Brownish to brownish-green turbid waters typical of inshore regions of the Reef that receive land-based discharge and/or have high concentrations of resuspended sediments during the wet season. In flood conditions, this water type typically contains high sediment and dissolved organic matter concentrations resulting in reduced light levels. It is also enriched in coloured dissolved organic matter and phytoplankton concentrations and has elevated nutrient levels.	SDD: 2.1 ± 2.1 m TSS: 17.4 ± 44.1 mg L^{-1} Chl-*a*: 1.5 ± 2.2 µg L^{-1}
WT2 (previously secondary)	FU6–9 (WS5)	Greenish to greenish-blue turbid water typical of coastal waters with colour dominated by phytoplankton (Chl-*a*), but also containing dissolved organic matter and fine sediment. This water body is often found in open coastal waters of the Reef as well as in the mid-shelf where relatively high nutrient availability and increased light levels due to sedimentation favour coastal productivity (Bainbridge et al., 2012).	SDD: 4.6 ± 2.8 m TSS: 4.6 ± 7.0 mg L^{-1} Chl-*a*: 0.6 ± 0.7 µg L^{-1}
WT3 (previously tertiary)	FU4–5 (WS6)	Greenish-blue waters corresponding to waters with slightly above-ambient suspended sediment concentrations and high light penetration typical of areas towards the open ocean. This water type includes the outer areas of river flood plumes, fine sediment resuspension around reefs and islands and oceanographic processes such as upwelling. Reef WT3 waters are associated with low land-based contaminant concentrations and the ecological relevance of these waters is likely to be minimal although not well researched. The Type III areas have a low magnitude score in the Reef exposure assessment.	SDD: 8.2 ± 4.1 m TSS: 2.3 ± 3.9 mg L^{-1} Chl-*a*: 0.4 ± 0.4 µg L^{-1}
WT4 (previously marine)	FU1–3 No number	Blueish marine waters with high light penetration.	SDD**: 11.0 ± 4.8 m TSS**: 1.8 ± 3.5 mg L^{-1} Chl-*a***: 0.5 ± 0.9 µg L^{-1}

*SDD = Secchi disk depth, TSS = total suspended solids, and Chl-*a* = chlorophyll-*a*.

**Please note that the number of data points collected in the Reef WT4/Marine water type is limited in comparison to the data available in the other water types (Appendix B). Long-term concentrations of water quality parameters in the Reef WT4 are thus just given as an indication and are not used in the monitoring products presented in this report. A pilot study funded by Reef Trust Partnership collected water quality data in mid-shelf and offshore locations via the Crown of Thorns Starfish Control Program (Waterhouse *et al*., 2023). Water quality data collected as part of this study are included in the long-term dataset to help in progressing the characterisation of the Reef WT4, but more data are still needed to improve accuracy of the characterisation.

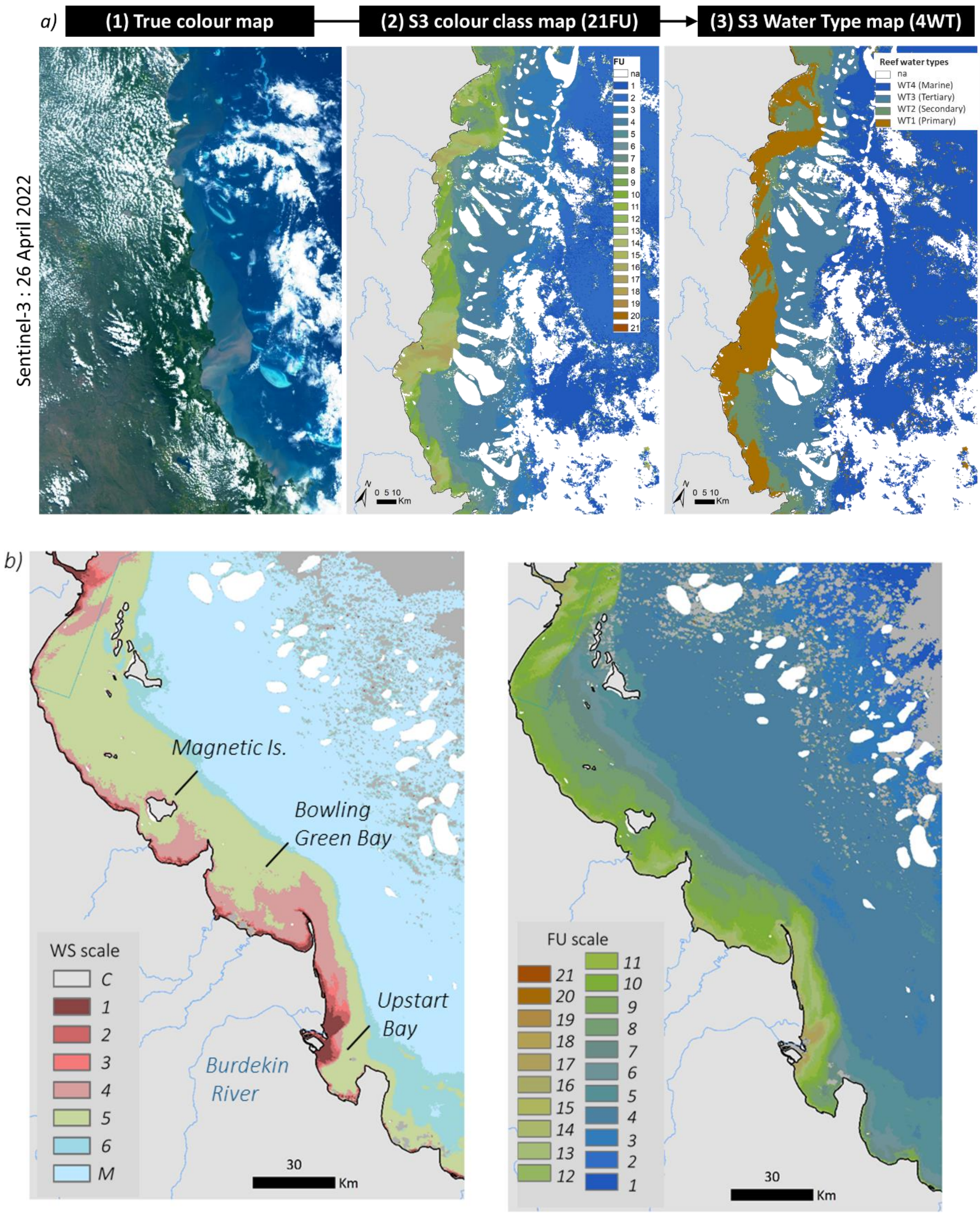


Figure 2-2: Methods for Reef water type, frequency, and exposure maps a) Summary of the process to produce the Reef water type maps (1) downloading of the Sentinel-3-OLCI true colour imagery, (2) processing of Sentinel-3 Forel-Ule colour class map using the Forel-Ule (FU) colour scale Toolbox implemented in the Sentinel Application Platform, and (3) reclassification into Reef water type map. Sentinel-3 images are from the Eumetsat data centre and were captured on 26 April 2022 (source: Sentinel Hub EO browser). b) Burdekin River plume (14 March 2018) (the Wet Season [WS] scale ranges from 1 to 6, plus marine [M]; the catchment [C] is shown in grey). This panel illustrates the very similar colour patterns between the (right) Sentinel-3 Forel-Ule colour class maps and (left) the MODIS wet season water type maps. The MODIS wet season water type maps were mapped using a supervised classification of MODIS true colour data developed by Álvarez-Romero *et al*. (2013) (modified from Devlin *et al*., 2015).

In the 2021–22 report (Moran *et al*., 2023), the water type (WT) terminology was modified to: Reef WT1, WT2, WT3, and WT4 instead of primary, secondary, tertiary, and marine wet season water types. This change was made in response to recognition that the previous terminology may be misleading and systematically implied the presence of flood plume waters, while the Reef WT1 (primary waters) may also represent sediment resuspension in shallower parts of the Reef lagoon, and the Reef WT3 (tertiary waters) may represent oceanographic processes such as upwelling or sediment resuspension around reefs and islands (Table 2-2). Importantly, while names of the water types changed, the definition of the water types in Table 2-2 essentially remains the same.

Several monitoring products are derived from the Sentinel-3 FU water type maps to report on water quality trends. These products map water quality gradients during the wet season and are used to:

- Map the extent of river flood plumes during high flow conditions;
- Characterise the composition of the Reef water types (mean long-term total suspended solids [TSS], chlorophyll *a* [Chl-*a*], coloured dissolved organic matter [CDOM], dissolved inorganic nitrogen [DIN], dissolved inorganic phosphorus [DIP], particulate phosphorus [PP], and particulate nitrogen [PN] concentrations and Secchi disk depth [SDD] values) and identify where mean long-term concentrations of TSS, Chl-*a*, PP, and PN are likely to be above wet season GVs. Wet season GVs for the whole of the Reef (hereafter Reef-wide GVs) are derived from De'ath and Fabricius (2008) (Appendix B Table B-4); and
- Assess the exposure of coral reefs and seagrass ecosystems to potential risk from land-based pollutants.

These products are used to illustrate wet season conditions for every wet season and to compare seasonal trends with baseline reference trends in water composition including long-term conditions, typical wet year and dry year conditions and conditions over a documented recovery period for coral reefs. Available satellite data are biased toward clear, non-cloudy days, and may underrepresent poor water quality in regions of higher rainfall and cloudiness like the Wet Tropics and Cape York. However, they provide a unique large-scale and long-term view of the Reef that is not available using water quality data only.

2.6.2 Characterising composition of Reef water types

The classification of four Reef water types allows mapping of a broad grouping of water type characteristics with different colours, concentrations of optically active components (TSS, CDOM, and Chl-*a*), water quality indicators (e.g., nutrients levels; Devlin *et al*., 2015; Petus *et al*., 2019), and light attenuation levels (Petus *et al*., 2018) typically found in the Reef during the wet season (Table 2-2 and Figure 2-2). These characteristics vary the potential impact on the underlying ecological systems. In summary:

- **The brownish Reef WT1 *(FU ≥ 10)*** represents turbid waters from river flood plumes, and also sediment resuspension in the shallower parts of the Reef;
- **The greenish Reef WT2 *(FU6–9)*** represents the less turbid parts of flood plumes enriched in Chl-*a* and fine sediment. It is usually found in the inshore to mid-shelf regions of the Reef;
- **The greenish-blue Reef WT3 *(FU4–5)*** represents waters with suspended sediment concentrations slightly above ambient conditions and high light penetration typically found in the outer areas of river flood plumes. It can also represent oceanographic processes such as upwelling or the fine sediment resuspension around reefs and islands; and
- **The blueish Reef WT4 *(FU1–3)*** represents ambient waters with high light penetration and negligible concentrations of optically active water quality constituents.

Match-ups of *in situ* concentrations of water quality parameters and the four Reef water types are regularly performed to validate this concept and quantify the range and average of concentrations of water quality parameters found in each Reef water type. The previous update was in 2018–19

(Gruber *et al.,* 2020). All mean concentrations of water quality parameters were reviewed for this report to ensure that the water type characterisation remains appropriate, and to improve its accuracy building on the field data that are collected every wet season. The colour class category and water type corresponding to the location and week of acquisition of each water quality sample were extracted from the archive of MODIS-Aqua (wet seasons 2003–2020) and Sentinel-3 (wet seasons 2020–2023) weekly colour class maps (see method in Appendix B). Weekly composites were used rather than daily colour class/water type data to minimise data loss due to the periodic dense cloud cover in the Reef. This approach maximises the incorporation of water quality parameters measured during each wet season since 2003–04 that can be associated with a Reef water type (and colour class) category.

Ideally, match-ups between satellite and *in situ* water quality information should be performed using field data collected ±2 hours from the satellite overpass. This is very complicated to achieve in the MMP, which is in part focused on responsive monitoring of flood events and in areas of the Reef where the cloud cover has a major influence during the wet season. The methodology above was thus selected to maximise the number of data points used to assess the water quality characteristics of each Reef water type. The limitations are considered acceptable as the mean concentrations of water quality parameters are used as a relative measure to assign a potential risk grading for each Reef water type (see below). However, the long-term average concentration values should not be used as an exact value *per se.*

The long-term concentrations of water quality parameters were calculated using all surface data (<0.2 m) collected between December and April by JCU since the 2003–04 water year, and up to April 2022. It included data collected by AIMS and the CYWP since the 2016–17 water year and covered all regions and waterbodies of the Reef, and all Reef water types. TSS and Chl-*a* data collected in mid-shelf and offshore areas as part of a Reef Trust Partnership project with the locations via the Crown of Thorns Starfish Control Program between December 2021 and April 2023 (Waterhouse et al., 2023) were also included. In previous assessments, long-term mean DIN, PP, and PN concentrations were calculated as: DIN = nitrite + nitrate + ammonia, PP = Total Phosphorus – Total Dissolved Phosphorus, and PN = Total Nitrogen – DIN, respectively. In the current assessment, mean long-term direct measurements of PP and PN were used (rather than indirectly estimated values as above), and NO_x was used instead of DIN and calculated as NO_x = nitrite + nitrate due to its greater robustness than ammonia as an indicator of N availability in marine waters.

Boxplots of water quality concentration and Secchi disk depth were plotted against their water type and colour class categories. The mean long-term TSS, Chl-*a*, PP, and PN concentrations were then assessed against wet season GVs as a relative measure to assign potential risk grading for each Reef water type. Reef-wide wet season GVs were derived from De'ath and Fabricius (2008) (Appendix B Table B-4).

Reef water type, frequency, and exposure maps

Several summary maps are produced every wet season including weekly panel maps of environmental and marine wet season conditions, frequency maps of occurrence of wet season water types and exposure maps. The area (km^2) and percentage (%) of coral reefs and seagrass meadows affected by different relative categories of exposure (or potential risk) was summarised. Details are in Appendix B.

Reef water type maps of the 2022–23 wet season were produced using daily Sentinel-3 OLCI Level 2 (hereafter, Sentinel-3 or S3) imagery (Figure 2-2a, Step 1) reclassified to 21 distinct colour classes defined by their colour properties and using the FU colour classification scale (Figure 2-2a, Step 2). Sentinel-3 imagery of the study area was downloaded on the EUMETSAT Data centre (https://www.eumetsat.int/eumetsat-data-centre). Sentinel-3 images are atmospherically corrected and were processed with the FU Satellite Toolbox implemented in the Sentinel Application Platform (https://step.esa.int/main/toolboxes/snap/) and using automated tools (python scripts and ArcGIS toolboxes) developed through MMP funding.

Weekly water type composites were created to minimise the image area contaminated by dense cloud cover and intense sun glint (Álvarez-Romero *et al*., 2013). The maximum FU value of each pixel/week was used to keep the colour class with the highest turbidity and/or colour for each wet season week. The weekly composite maps were cleaned to remove single or small clusters of cells sometimes misclassified by the FU satellite algorithm in the offshore regions of the Reef (e.g., around coral reefs due to bottom interference and residual glint contamination). The method involved sequentially infilling contiguous areas one FU class at a time from FU1 through to FU21 then replacing nearshore pixels in FU classes ≥10 with the original pixels using Python 2.7.3 (Python Software Foundation, 2012) and ArcGIS 10.2 (ESRI, 2013). In order to produce weekly Reef water type maps, the FU maps were subsequently clustered by grouping the Reef WT1 (previously primary waters) as FU colour classes ≥10 (FU≥10), the Reef WT2 (previously secondary waters) as FU6–9, the Reef WT3 (previously tertiary waters) as FU4–5 and the Reef WT4 (previously marine waters) as FU1–3 (Figure 2-2a, Step 3).

Frequency maps were produced to predict the areas affected by the Reef WT1, WT2 and WT3 individually (i.e., of the brownish, greenish and greenish-blue waters, respectively) and by the Reef WT1–2 combined (previously a combination of WT1–3; this has been modified to recognise that the ecological relevance of the water quality variables at concentrations in WT3 waters is not well understood, but expected to be relatively minor).

Average frequency maps were produced for several periods intending to represent the most relevant reference periods for comparison of the results for the current year:

(i) this reporting wet season (2022–23),
(ii) over the long-term (2002–03 to 2021–22: 20 wet seasons), and
(iii) over a documented recovery period for coral reefs (2012–2017; Thompson *et al*., 2019) intended to represent a favourable exposure scenario.

Composite frequency maps were also produced to represent typical wet year and dry year conditions, considering the wettest and driest years for each NRM region over the previous 20 years. This is explained further in Appendix B. Except for the ‘coral recovery period’, reference maps (long-term, Wet, and Dry frequency maps) were all updated for this report (20 years: 2002–03 to 2021–22) to ensure they remain appropriate and to improve their accuracy as more satellite data are available. The previous update was in the 2018–19 reporting (Gruber *et al*., 2020).

The presence and spatial extent of each Reef water type is the result of the complex physico-chemical transformations occurring within river plumes, but also of resuspension, transport, and other oceanographic processes. As a result, the extent of the Reef WT2 and WT3 is rarely attributed to an individual river and is usually merged into one heterogeneous area.

Exposure maps were produced for the whole of the Reef, for all focus regions, and over the same timeframes as those reported for the frequency maps (above). The maps were produced using an exposure assessment framework developed through a collaborative effort between the MMP monitoring providers (JCU water quality and seagrass monitoring teams and the AIMS coral monitoring team) and modified from Petus *et al*. (2016). Long-term exposure composites were also reviewed for this report to produce 20-year composite maps.

In this *magnitude* × *likelihood* framework, the ‘potential risk’ corresponds to an exposure to above Reef-wide wet season GV concentrations of land-based pollutants during the wet season and focuses on TSS, Chl-*a*, PP, and PN concentrations. The *‘magnitude of the exposure’* corresponds to the mean long-term wet season concentration of pollutants (the proportional exceedance of the Reef-wide wet season GV) mapped through the Reef WT1, WT2 and WT3. The *‘likelihood of the exposure’* is estimated by calculating the frequency of occurrence of each Reef water type mapped through the frequency maps (see above). The exposure for each of the water quality parameters defined is the proportional exceedance of the GV multiplied by the likelihood of exposure in each of the Reef water types.

1. *Calculation of the exposure (magnitude) scores:* The long-term mean concentrations of water quality parameters (Reef-wide) measured across the Reef water types (Section 2.6.2) are assessed against Reef-wide wet season GVs to calculate magnitude scores for TSS, Chl-*a*, PP, and PN. The GVs were calculated based on annual GVs (Great Barrier Reef Marine Park Authority, 2010) that were seasonally adjusted as described in De'ath and Fabricius (2008) (see Appendix B Table B-4). Mean long-term concentrations of water quality parameters include samples collected from the enclosed coastal zone, where high TSS, Chl-*a*, PN, and PP concentrations are likely to contribute to exceedances of the Reef-wide GVs (see Appendix B Table B-5). The only GV currently available for Secchi depth is an annual mean, and thus comparison with wet season Secchi depth data was not possible.
2. *Production of the exposure maps:* The magnitude scores were used in combination with the seasonal, long-term, coral recovery, wet-year and dry-year frequency maps (described above) to derive seasonal, long-term, coral recovery, wet-year, and dry-year exposure maps, respectively. Exposure from each map produced was then grouped into potential risk categories (I to IV) based on a "Natural Break (or Jenks)" classification[1] (Appendix B-3). The exposure classes were defined by applying the Jenks classification to the mean long-term (2003–2022) exposure map, because this map presented the highest number of observations (20 wet seasons). Category I and areas not exposed were re-grouped into a unique category corresponding to no or very low exposure to a potential risk. Magnitude scores have no designated ecological significance but are used in the risk framework as a relative measure to assign relative potential risk grading for each Reef water type.
3. *Exposure assessment*: Exposure maps were overlaid with information on the spatial distribution of coral reefs and surveyed seagrass meadows to identify areas and percentages of these ecosystems that may experience exposure to pollutants during the wet season. The area (km^2) and percentage (%) of coral reefs and seagrass meadows affected by the different categories of exposure (I to IV) was calculated in the Reef and marine NRM regions. Exposure maps are presented in the context of the long-term reference period (average of 20 wet seasons), the representative coral recovery period (2012–2017), and typical wet-year and dry-year composites. Areas and percentages of exposure are presented in the context of the long-term reference period.

The methods are described in further detail in Appendix B. The 'potential risk' is influenced by the available satellite data on cloud-free days, with the likelihood of exposure likely to be underestimated in higher rainfall and areas with high cloud cover like the Wet Tropics and Cape York regions.

2.7 River discharge and catchment loads

River flow is reported annually and can be derived from several sources. In many cases, river flow gauges that measure discharge (and are used to calculate constituent loads) are located well upstream of the river mouth and only capture a certain proportion of the catchment or basin area. Such disparities mean that river gauge data should not be directly compared across basins and NRM regions. For example, the Daintree and Barron Basins within the Wet Tropics region contain a similar area (2,100–2,200 km^2); however, the Daintree River at Bairds and the Bloomfield River at China Camp gauges collectively only measure 56% of the Daintree Basin whereas the Barron River at Myola captures 89% of the Barron Basin. If gauge data are used to compare discharge between these basins, the gauge on the Barron Basin is covering a much larger proportion of the area compared to the gauges on the Daintree Basin. A scaling factor is used on these data so that discharge (and constituent loads) can be directly compared across basins and NRM regions.

[1] Jenks is a statistical procedure, embedded in ArcGIS that analyses the distribution of values in the data and finds the most evident breaks in it (i.e., the steep or marked breaks; Jenks and Caspall 1971).

To account for these differences, the relevant discharge data for each basin were compiled, where available (Table 2-3; Department of Regional Development, Manufacturing and Water [DRMW], 2023). The total annual discharge for each gauge was then up-scaled using the recommended scaling factors outlined in Puignou Lopez *et al.* (in review). Briefly, this work examined different upscale factors based on basin area to total gauged area, mean annual flow for the gauged basin, and the mean annual basin flow from either the Bureau of Meteorology's G2G model (BoM, 2017; Wells *et al*., 2018) or the Source Catchments model (McCloskey *et al.*, 2021) or the linear relationships between annual river gauge data and the two models. The most appropriate upscale factor was then recommended for each basin (Puignou Lopez *et al*., in review). Where a flow gauge did not exist in a basin (e.g., Jacky Jacky Creek, Lockhart River, Jeannie River, Proserpine River, Styx River, Shoalwater Creek, and Boyne River, all marked with an asterisk in Table 2-3), the gauge from the nearest neighbouring basin was used. The calculation of the long-term medians for each basin has been anchored to cover the 30-year period from 1990–91 to 2019–20 water years.

There were three flow gauges with problematic data over the 2022–23 water year that needed to be addressed.

1. The Pascoe River at Garraway Creek gauge had no flow data from 19 April 2023 onwards. As this gauge captured the majority of the wet season, it was assumed that the record captured most of the water year flow for this basin. To include an estimate of the flows for the remainder of the water year, the daily baseflow values (250 ML) were added from 1 May 2023 onwards and interpolated the flows between 19–30 April.
2. The Daintree River at Bairds gauge had no flow data for the period 23 December 2022 to 21 March 2023 (inclusive) and between 12 June and 26 September 2023 (inclusive). As this gauge missed the majority of the wet season flows, it was excluded. To estimate the water year flow for the Daintree Basin, the Bloomfield River at China Camp gauge was used with an area upscale factor of 8.0.
3. The Ross River at Aplins Weir data were unavailable for the 2002–23 water year and so the flow was estimated using an upscale from the Alligator Creek at Allendale gauge.

Table 2-3. The 35 basins of the Reef catchment, the gauges for each Basin, and the correction factors used to upscale flows to provide annual discharge estimates. (*Australian Water Resources Council).

NRM Region	Basin	AWRC No.*	Basin area (km^2)	Relevant gauges	% of Basin covered by key gauges	Correction factor
Cape York	Jacky Jacky Creek	101	2,963	Jardine River at Monument*	0	1.1x + 560,000
	Olive Pascoe River	102	4,180	Pascoe River at Garraway Creek	31	3.1
	Lockhart River	103	2,883	Pascoe River at Garraway Creek*	0	1.5
	Stewart River	104	2,743	Stewart River at Telegraph Road	17	5.6
	Normanby River	105	24,399	Normanby River at Kalpowar Crossing + Hann River at Sandy Creek (from 2005/06). Previous upscale period uses Normanby at	53	1.8

NRM Region	Basin	AWRC No.*	Basin area (km²)	Relevant gauges	% of Basin covered by key gauges	Correction factor
				Battle Camp + Hann River gauges with factor of 4.7		
	Jeannie River	106	3,638	Endeavour River at Flaggy + Annan at Beesbike	0	3.2
	Endeavour River	107	2,182	Endeavour River at Flaggy + Annan at Beesbike	27	3.5x + 21,000
Wet Tropics	Daintree River	108	2,107	Daintree River at Bairds + Bloomfield River at China Camp	56	1.6
	Mossman River	109	473	Mossman River at Mossman	22	2.3
	Barron River	110	2,188	Barron River at Myola	89	1.3
	Mulgrave-Russell River	111	1,983	Mulgrave River at Peets Bridge + Russell River at Bucklands	42	2.0x + 450,000
	Johnstone River	112	2,325	South Johnstone River at Upstream Central Mill + North Johnstone at Tung Oil	57	1.6x + 540,000
	Tully River	113	1,683	Tully River at Euramo	86	1.1
	Murray River	114	1,107	Murray River at Upper Murray	14	5.0x + 600,000
	Herbert River	116	9,844	Herbert River at Ingham	87	1.2
Burdekin	Black River	117	1,057	Black River at Bruce Highway + Bluewater Creek at Bluewater	32	3.1
	Ross River	118	1,707	Ross River at Aplins Weir + Alligator Creek at Allendale (from 2001/02). Previous upscale period uses Ross River Dam HW + Bohle at Hervey Range Rd + Alligator Creek with factor of 1.6x + 75,000	52	1.9
	Haughton River	119	4,051	Haughton River at Powerline + Barratta at Northcote	62	1.6
	Burdekin River	120	130,120	Burdekin River at Clare	100	1.0

NRM Region	Basin	AWRC No.*	Basin area (km^2)	Relevant gauges	% of Basin covered by key gauges	Correction factor
	Don River	121	3,736	Don River at Reeves + Elliot River at Guthalungra + Euri Creek at Koonandah (from 1999/00). Previous upscale period uses Don + Elliot gauges with factor of 2.9x + 170,000	46	1.5x + 210,000
Mackay-Whitsunday	Proserpine River	122	2,494	O'Connell River at Staffords Crossing + Andromache River at Jochheims + St Helens Creek at Calen	0	3.6
	O'Connell River	124	2,387	O'Connell River at Staffords Crossing + Andromache River at Jochheims + St Helens Creek at Calen	29	3.5
	Pioneer River	125	1,572	Pioneer River at Dumbleton Weir TW	95	1.1
	Plane Creek	126	2,539	Sandy Creek at Homebush + Carmila Creek at Carmila	16	5.6x + 210,000
Fitzroy	Styx River	127	3,013	Waterpark Creek at Byfield*	0	5.7x + 260,000
	Shoalwater Creek	128	3,601	Waterpark Creek at Byfield*	0	6.6x + 300,000
	Water Park Creek	129	1,836	Waterpark Creek at Byfield	12	5.4x + 43,000
	Fitzroy River	130	142,552	Fitzroy River at The Gap	95	1.1
	Calliope River	132	2,241	Calliope River at Castlehope	57	1.9x + 95,000
	Boyne River	133	2,496	Calliope River at Castlehope*	0	2.1
Burnett-Mary	Baffle Creek	134	4,085	Baffle Creek at Mimdale	34	2.4x + 95,000
	Kolan River	135	2,901	Kolan River at Springfield + Gin Gin Creek at Brushy Creek	37	2.4x + 19,000
	Burnett River	136	33,207	Burnett River at Figtree Ck (from 1996/97). Previous upscale period uses Burnett River at Mount Lawless with factor of 1.2x + 84,000	92	1.1

NRM Region	Basin	AWRC No.*	Basin area (km^2)	Relevant gauges	% of Basin covered by key gauges	Correction factor
	Burrum River	137	3,362	Gregory River at Leesons + Elliott River at Dr Mays Crossing + Isis River at Bruce Highway	40	3.0x + 27,000
	Mary River	138	9,466	Mary River at Home Park	72	1.4
* Gauges used which are not in the basin area						

Current annual and pre-development TSS, DIN and PN load estimates were calculated for all basins using a consistent, systematic approach. The DIN loads for all of the basins of the Wet Tropics and the Haughton Basin were calculated using the model originally developed in Lewis *et al*. (2014) which uses a combination of the annual nitrogen fertiliser applied in each basin coupled with basin discharge (calculated as per previous description). DIN loads for the Burdekin, Pioneer, and Fitzroy basins were taken from those measured in the Great Barrier Reef Catchment Loads Monitoring Program (Water Quality & Investigations, 2023). Where the measured data for the most recent years in these basins were unavailable, a mean of the long-term annual mean concentration from the previous monitoring data was coupled with the annual discharge to estimate a load. DIN loads for the remaining basins were calculated using an annual mean concentration which was multiplied by the corresponding annual basin discharge calculations. The annual mean concentration for each basin was informed using a combination of available monitoring data and Source Catchments model outputs. The pre-development DIN loads were calculated using a combination of the estimates from the Source Catchments model as well as available monitoring data from 'pristine' locations.

The TSS and PN loads were similarly determined through a step-wise process. For the basins where the Great Barrier Reef Catchment Loads Monitoring Program captured >95% of the basin area (e.g., Burdekin, Pioneer, and Fitzroy) the reported TSS and PN loads were used. If the measured data for the most recent years were unavailable, a mean of the long-term annual mean concentration from the previous monitoring data was coupled with the annual discharge to calculate a load. For other basins with monitoring data, the range of annual mean concentrations were compiled and compared with the latest Source Catchment modelling values. From these data a 'best estimate' of an annual mean concentration was produced and applied with the annual discharge data to calculate loads. Finally, for the basins that have little to no monitoring data, the annual mean concentration from the Source Catchments data was examined along with nearest neighbour monitoring data to determine a 'best estimate' concentration to produce the load. The pre-development TSS and PN loads were calculated using a combination of the annual mean concentrations from the Source Catchments model and available monitoring data from 'pristine' locations. The corresponding discharge was used as calculated previously to produce a simulation of the pre-development load for the water year.

2.8 Load mapping

Maps representing the dispersion of river-derived DIN, TSS, and PN loads into the Reef lagoon have been developed as part of the MMP since 2003. The maps were initially produced using the method described in Gruber *et al*., (2018). In 2018–19 a revised approach was developed using the eReefs marine models (Margvelashvili et al., 2018; Skerratt et al., 2019; Steven et al., 2019) to estimate river dispersion (Gruber et al., 2020).

River plumes were modelled using a conservative tracer in the 1 km resolution eReefs marine model (GBR1). The daily files, containing individual river plumes, were downloaded from https://dapds00.nci.org.au/thredds/catalog/fx3/gbr1_2.0_rivers/catalog.html and used to estimate the cumulative sum of each river tracer concentration over a water year (1 October to 30 September the following year). The cumulative exposure index 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 example, if a grid cell was exposed to concentrations of 5% river water for 2 days, this gives an exposure index of 0.1 (0.05 x 2). If a grid cell was exposed to concentrations of 50% river water for 10 days, this gives an exposure index of 5 (0.5 x 10). Whenever river water concentration is greater than 1%, the exposure index is calculated and added to all other exposures in that wet season (i.e., it is cumulative). This index provides a consistent approach to assessing relative differences in exposure of Reef shelf waters to inputs from various rivers.

The mathematical formulation that expresses this concept is given below:

$$\text{Conc.Days} = \sum_{t=0}^{T} \text{Conc}_{exceedance} * \text{t}$$

where,

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

and $\text{Conc}_{threshold}$ is defined here as 1% of the river 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 October) and $T_{\text{end of wet season}}$ = 1 May. Cumulative exposure is calculated for each grid point in the model domain.

In this step, the end-of-catchment load for fine sediment, DIN, or PN was dispersed for each river assuming a direct relationship between pollutant and tracer concentration (conservative mixing). Thus, the surface load of fine sediment, DIN, or PN per km^2 was calculated as:

$$Surf.load = \frac{\text{tracer}}{pixel} \times \frac{[\text{total load}]}{[\text{sum of tracer}]} \times \frac{pixel}{km^2}$$

The total Reef surface load was calculated by summing the surface load outputs for the 17 rivers for which tracer data were available: Normanby, Daintree, Barron, Russell-Mulgrave, Johnstone, Tully, Herbert, Haughton, Burdekin, Don, O'Connell, Pioneer, Fitzroy, Calliope, Boyne, Burnett, and Mary.

The difference between the estimated wet season fine sediment, DIN, and PN loadings (tonnes km^{-2}) in the Reef lagoon for the current water year was calculated and compared to the pre-development loads derived from the Source Catchments model (which have a degree of uncertainty; refer to McCloskey *et al*., 2021). This can be interpreted as 'anthropogenic' fine sediment, DIN, or PN loadings, highlighting the areas of greatest change with current land use characteristics.

3 Drivers and pressures influencing water quality in 2022–23

3.1 Coastal development including agriculture

The Wet Tropics, Burdekin, and Mackay-Whitsunday regions are characterised by a variety of land uses including agricultural (sugarcane, grazing, cropping, and other horticulture), mining, and urban development. Parts of the Cape York region are less developed than other Reef catchments. Land-based activities in this region are assumed to have a reduced impact on marine ecosystems (Waterhouse *et al.*, 2017) despite a history of widespread grazing and mining impacts. Specifically:

- Cape York
  - The Pascoe River catchment has an area of 2,088 km^2 with a high proportion (84%) of nature/conservation land use with ~15% closed grazing (QLUMP, 2015). However, there is no longer any active grazing within the Pascoe catchment (Polglase pers. comm., February 2023). Feral cattle and pigs, fire, and road erosion are the main pressures affecting water quality. These impacts are considered to be minimal in this focus region relative to other Cape York and Reef catchments (Cape York NRM and South Cape York Catchments, 2016).
  - The Stewart River catchment has an area of 2,770 km^2 and is mostly nature/conservation land use (94%) with ~2% current grazing land use (QLUMP, 2015). However, feral cattle continue to graze much of the catchment area. Current and legacy cattle grazing impacts and road erosion are current pressures affecting sediment loads within the catchment.
  - The Normanby Basin is 24,550 km^2 and has a high proportion of nature/conservation land use (46%) and grazing (52%) (QLUMP, 2015). Additional lands have shifted from grazing to conservation since 2015, resulting in ~53% conservation land use and ~47% grazing. Horticulture accounts for only 1% of land use but has been expanding in the Laura and West Normanby sub-catchments. Current and historic cattle grazing, post-European initiation and acceleration of gully erosion, agricultural land clearing, alluvial mining, wildfires, and road erosion are the primary pressures affecting water quality across the Normanby catchment (Brooks *et al.*, 2013; Shellberg and Brooks, 2013; Cape York NRM and South Cape York Catchments, 2016; Spencer *et al.*, 2016). Horticulture in the Laura sub-catchment has also increased nutrient concentrations in the Laura River (Howley, 2020).
  - The Annan-Endeavour River Basin is 2,186 km^2 and has a high proportion of nature/conservation land use (52% as of 2015) and closed grazing (40%) (QLUMP, 2015). Additional grazing land has been converted to conservation land use since 2015 and approximately 80% of the Annan catchment is now under conservation or Aboriginal freehold. Sources of pollution in the Endeavour catchment include urban runoff from the township of Cooktown, cattle grazing, horticulture, and road erosion. Historic mining disturbances, cattle grazing impacts (current and historic), wildfires, and road erosion are the primary sources of pollution to the Annan River (Shellberg *et al.*, 2016).
- Wet Tropics
  - The Barron-Daintree focus 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 focus region (Brodie *et al.*, 2013; Waterhouse *et al.*, 2017). The Daintree catchment is 2,107 km^2 and has a high proportion of protected areas (56% natural/minimal use lands and 32% forestry). The remaining area consists of 7% grazing and, to a lesser extent, sugarcane and urban areas. The Mossman catchment is 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.

- 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 is 2,326 km^2 and has a relatively high proportion of natural/minimal use lands (55%). The remaining area has 16% grazing, 12% sugarcane, and smaller areas of dairy (in the upper catchment), bananas and other crops, and urban land uses (Terrain NRM, 2015).
- The Tully River Basin is 1,685 km^2 and has a high proportion of natural/minimal use lands (75%). The remaining area is comprised of 12% sugarcane, 4% bananas, 5% grazing, and smaller areas of forestry, other crops and urban land uses. The Murray River Basin has an area of 1,115 km^2 and has a high proportion of natural/minimal use lands (64%). The remaining area is comprised of 14% sugarcane, 10% forestry, 6% grazing and smaller areas of bananas, other crops and urban land uses. The Herbert River Basin is 9,842 km^2 and consists of 27% natural/minimal use lands, 56% grazing, 8% sugarcane, and smaller areas of forestry.

- The Burdekin region is one of the two large dry tropical catchment regions adjacent to the Reef. The region is primarily influenced by discharge from the Burdekin, Haughton, Ross and Black Rivers, with cattle grazing as the primary land use on over 95% of the catchment area (NQ Dry Tropics, 2016). There is also intensive irrigated sugarcane on the floodplains of the Burdekin and Haughton Rivers. Fluctuations in climate and cattle numbers greatly affect the state and nature of vegetation cover and, therefore, the susceptibility of soils to erosion and off-site transport of suspended sediments and associated nutrients.
- The Mackay-Whitsunday region has a wet or mixed wet and dry tropical climate. The region is influenced by the Pioneer, Gregory, Proserpine, O'Connell, and Don Rivers. Catchment land use is dominated by agriculture broadly divided into grazing in the upper catchments (43%), sugarcane cultivation on the coastal plains (19%), and dispersed areas of nature conservation (19%) (Folkers *et al.*, 2014). In addition, there are expanding urban areas along the coast.

3.2 Climate and cyclone activity

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

The 2022–23 wet season had no active cyclone influence in the region of interest (Figure 3-1), although some weak tropical lows produced considerable rainfall in some catchments, particularly in the Cape York region.

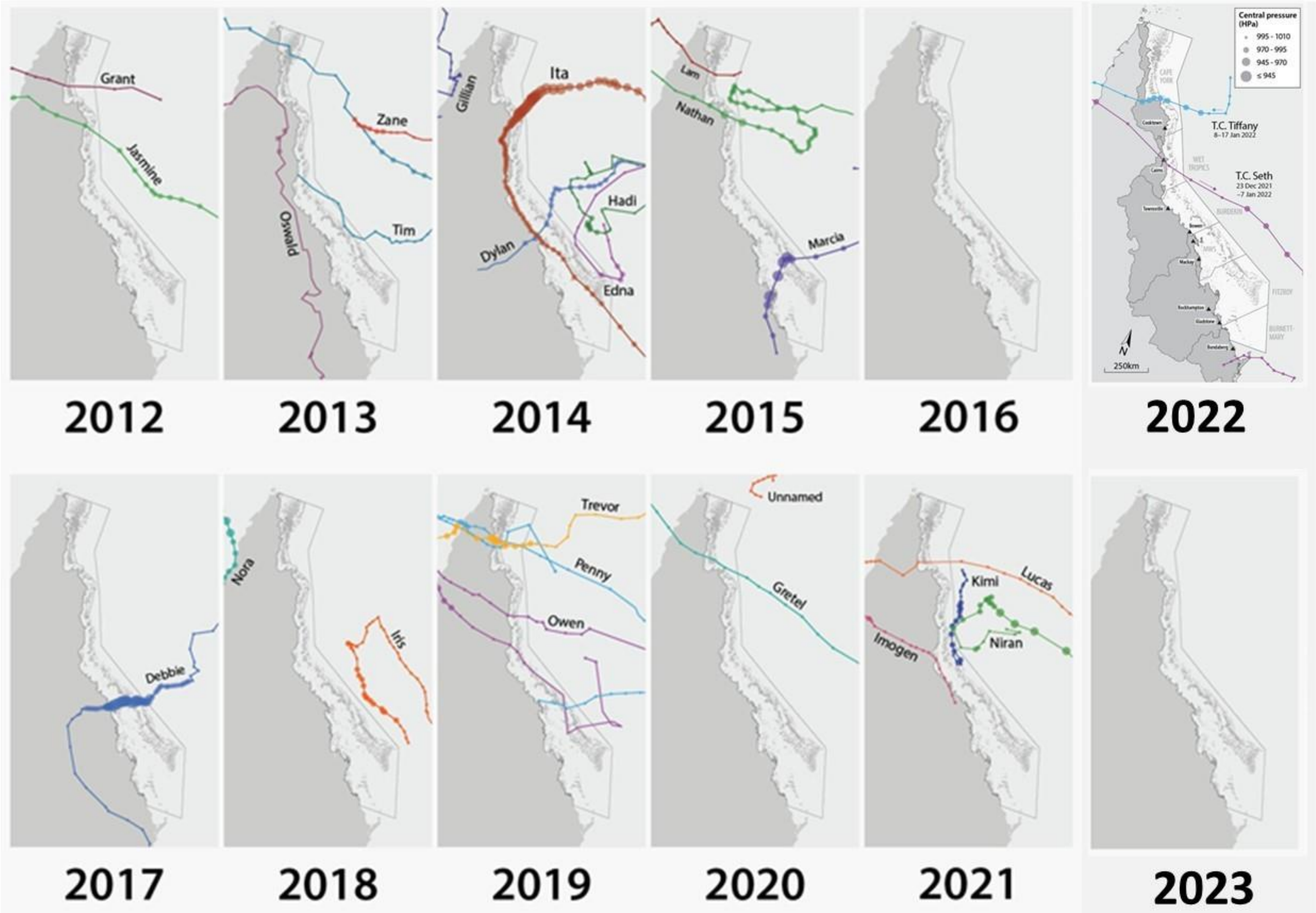


Figure 3-1: Trajectories of tropical cyclones affecting the Reef in 2022–23 and in previous years (2013 to 2022).

3.2.1 Rainfall for the Reef, NRM regions, and basins

Queensland rainfall is highly variable on seasonal, inter-annual, and decadal timescales. Wet season (December to April) rainfall in 2022–23 was generally similar to the long-term average of wet seasons from 1961–1990 (Figure 3-2 and Figure 3-3). Above-average rainfall was predominantly concentrated in the Cape York region, northern Wet Tropics basins, Burdekin, and northern Mackay-Whitsunday basins in the 2022–23 wet season (Figure 3-2 and Figure 3-3). The data presented for the Lockhart Basin require further investigation as they are inconsistent with the wetter trends observed for other Cape York basins. There is no flow gauge in the Lockhart Basin to enable cross-checking with the corresponding flow data (the neighbouring gauge on the Pascoe is used to estimate flow). As a result, if this relatively lower rainfall in the Lockhart Basin is confirmed to be correct then the flow data estimates for this basin would also be much lower than reported.

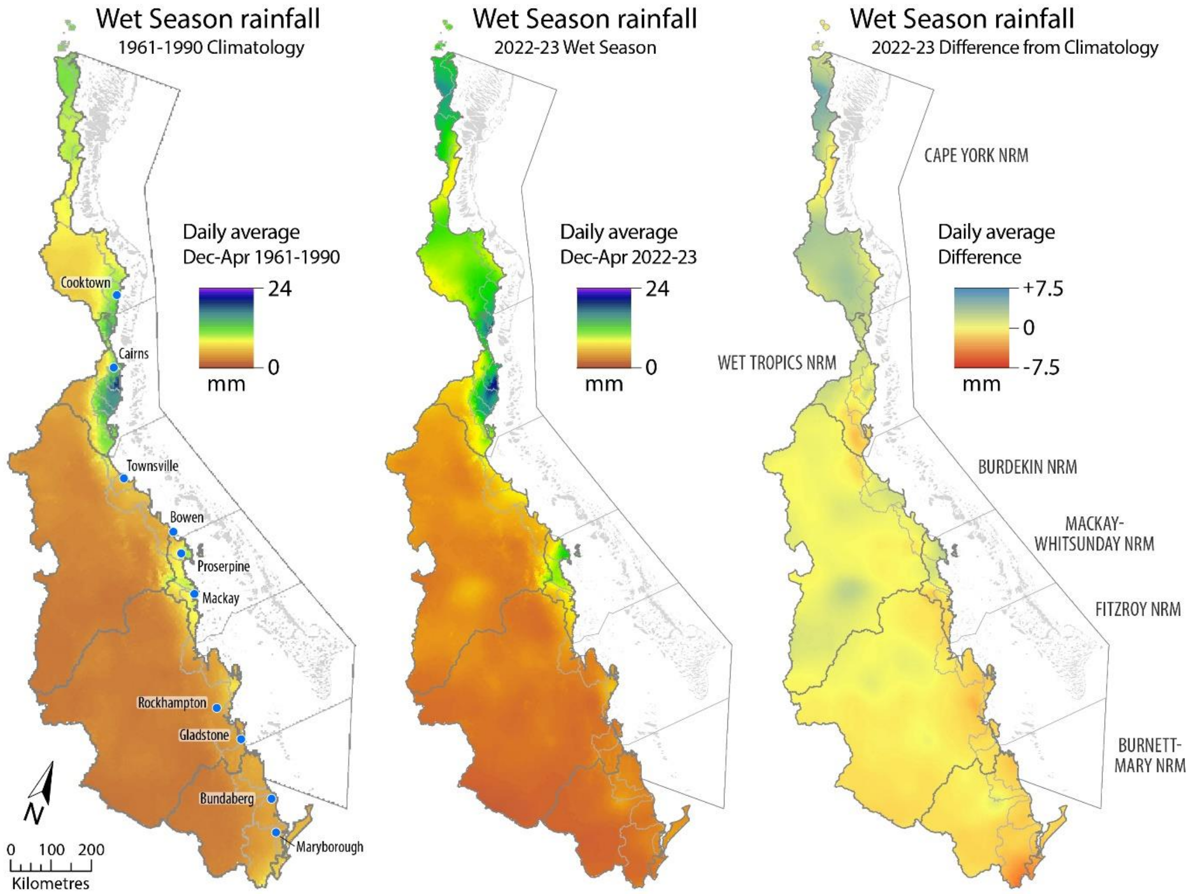


Figure 3-2: Average daily wet season rainfall (mm d^{-1}) in the Reef catchment (left) long-term daily average (1961–1990 time period produced by BoM), (centre) 2022–23 and (right) the difference between the long-term average and 2022–23 rainfall. Source data: Bureau of Meteorology (2023).

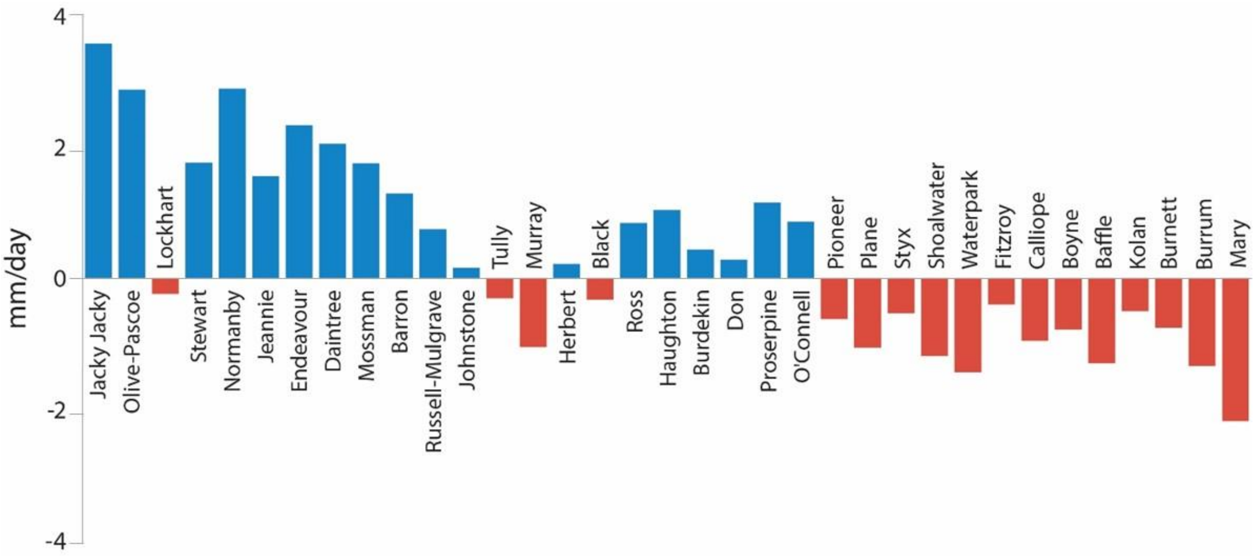


Figure 3-3: Difference between daily average wet season rainfall (December 2022–April 2023) and the long-term wet season rainfall average (from 1961–1990). Red and blue bars denote basins with rainfall below and above the long-term average, respectively. Note that the basins are ordered from north to south (left to right). Source data: Bureau of Meteorology (2023).

3.2.2 Freshwater discharge for the Reef, NRM regions, and basins

Freshwater discharge volumes into the Reef lagoon are typically closely related to rainfall during the wet season and have a significant influence on coastal and inshore water quality. The total annual water year freshwater discharge for all Reef basins relative to long-term medians (calculated as described in Section 2.7) is shown in Figure 3-4. Discharge for each NRM region is shown in Figure 3-5.

In 2022–23, the overall Reef catchment area had discharge just above the long-term median (1.4 times the long-term median). On a regional basis, discharge was either at or above the long-term median with the exception of the Burnett-Mary NRM region. Several NRM regions had discharge well above the long-term median including the Cape York (2.1 times higher than long term median), Burdekin (2.1 times higher), and Mackay-Whitsunday (2.0 times higher) regions. The discharge in the Wet Tropics (1.2 times above) and Fitzroy (1.1 times above) regions were just above the long-term median while the Burnett-Mary was below the long-term median discharge (0.8 times the long-term median).

Annual discharge for each of the 35 Reef basins in 2022–23 is shown in Table 3-1 and compared to long-term median annual flows. All the basins in the Cape York region had discharge greater than 1.5 times the long-term median, with the Normanby Basin discharge exceeding 3 times its long-term median. The discharge in the Waterpark Creek Basin (Fitzroy region) exceeded 1.5 times the long-term median. The Daintree, Barron (Wet Tropics region), Haughton, Burdekin, Don (Burdekin region), Proserpine, O'Connell (Mackay-Whitsunday region) and Burrum (Burnett-Mary region) Basins all had discharge between 2 and 3 times above the long-term median.

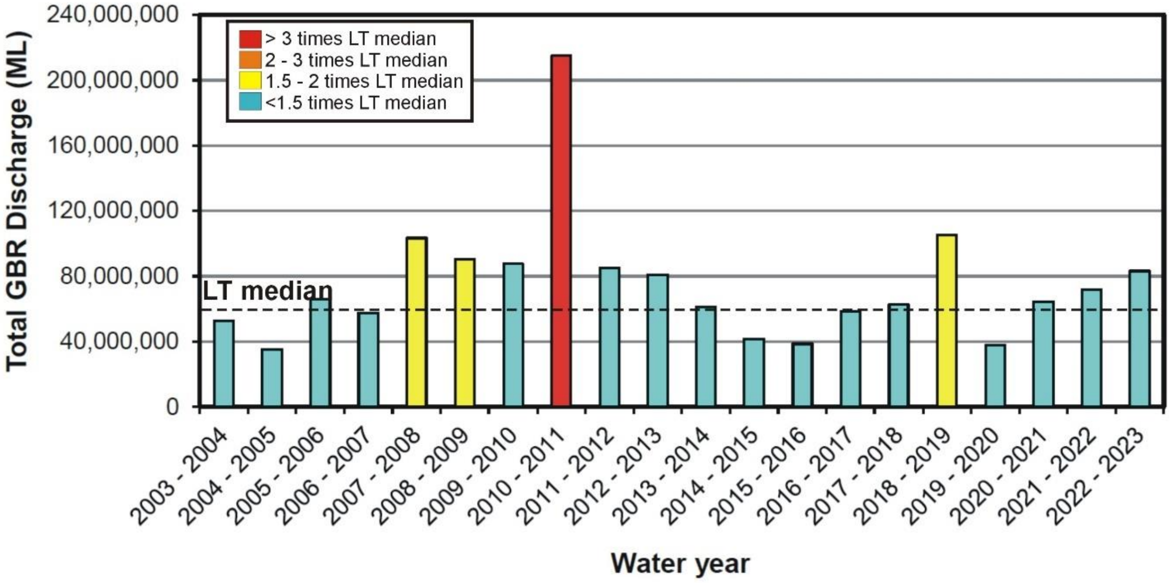


Figure 3-4: Total discharge in megaliters (ML) for the 35 main Reef basins in a water year (1 October to 30 September the following year). Data derived from DRMW (2023).

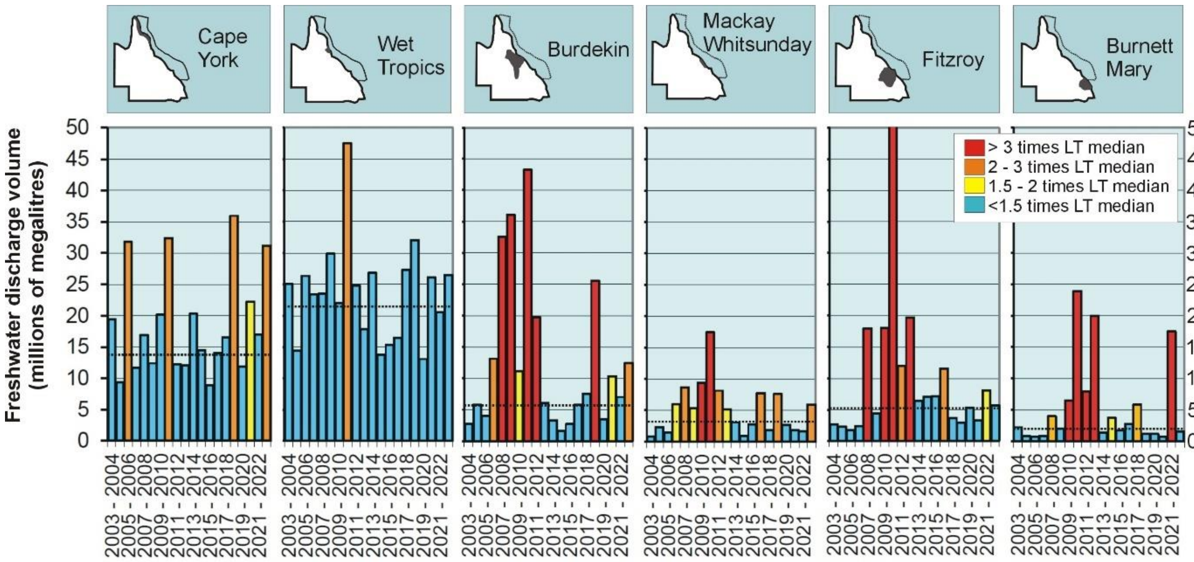


Figure 3-5: Corrected annual water year (1 October to 30 September the following year) discharge from each NRM region (using the correction factors in Table 2-3) for 2003–04 to 2022–23 in megaliters (ML) per year. Data derived from DRMW (2023).

Table 3-1: Annual water year (1 October to 30 September the following year) discharge in megalitres of the 35 main Reef basins and subtotals for the six NRM regions, and 30-year long-term (LT) median discharge (1990–91 to 2019–20). Colours indicate levels above the long-term median: yellow for 1.5 to 2 times, orange for 2 to 3 times and red greater than 3 times.

Basin	LT median	2019 - 2020	2020 - 2021	2021 - 2022	2022 - 2023
Jacky Jacky Creek	2,471,267	2,320,007	3,607,722	2,365,731	4,611,721
Olive Pascoe River	3,180,267	3,295,502	5,540,683	4,879,388	6,053,581
Lockhart River	1,538,839	1,594,598	2,680,976	2,360,994	2,929,152
Stewart River	758,172	564,816	1,419,942	569,738	1,366,633
Normanby River	3,864,344	2,752,573	6,149,878	3,562,637	11,791,399
Jeannie River	1,428,920	668,813	1,342,490	1,566,621	2,093,623
Endeavour River	1,583,881	752,514	1,489,348	1,734,492	2,310,900
Cape York subtotal	**14,825,689**	**11,948,821**	**22,231,037**	**17,039,601**	**31,157,008**
Daintree River	1,918,174	1,109,229	1,834,774	2,519,318	4,685,640
Mossman River	604,711	399,108	654,566	800,754	815,267
Barron River	622,447	346,727	667,265	692,908	1,217,590
Mulgrave-Russell River	4,222,711	2,870,672	4,771,460	4,091,750	4,291,804
Johnstone River	4,797,163	3,466,725	5,324,040	4,712,174	5,385,426
Tully River	3,393,025	2,200,744	4,123,338	3,175,489	3,660,701
Murray River	1,484,246	1,053,705	1,947,050	1,269,280	1,526,232
Herbert River	3,879,683	1,606,187	6,842,168	3,283,590	4,919,143
Wet Tropics subtotal	**20,922,161**	**13,053,095**	**26,164,662**	**20,545,264**	**26,501,804**
Black River	293,525	144,144	429,282	273,677	353,756
Ross River	279,376	293,165	232,975	202,811	209,681
Haughton River	558,735	335,094	595,709	735,754	1,219,825
Burdekin River	4,406,780	2,203,056	8,560,072	5,442,976	9,702,259
Don River	496,485	481,577	510,906	383,927	999,723
Burdekin subtotal	**6,034,901**	**3,457,036**	**10,328,944**	**7,039,144**	**12,485,244**
Proserpine River	859,348	592,063	537,613	446,839	1,869,821
O'Connell River	835,478	575,617	522,680	434,427	1,817,882
Pioneer River	616,216	383,506	235,359	277,610	761,905
Plane Creek	1,058,985	1,141,784	600,958	489,222	1,440,350
Mackay Whitsunday subtotal	**3,370,027**	**2,692,970**	**1,896,610**	**1,648,098**	**5,889,958**
Styx River	629,037	796,233	927,219	1,080,829	849,506
Shoalwater Creek	727,306	920,902	1,072,570	1,250,433	982,586
Water Park Creek	392,614	551,010	675,102	820,627	601,479
Fitzroy River	2,875,792	2,786,994	436,730	4,505,289	3,078,896
Calliope River	257,050	184,697	123,050	250,551	135,396
Boyne River	179,108	99,139	31,002	171,925	44,649
Fitzroy subtotal	**5,060,908**	**5,338,975**	**3,265,673**	**8,079,653**	**5,692,512**
Baffle Creek	347,271	161,554	112,323	1,000,587	170,693
Kolan River	115,841	28,792	19,211	818,716	83,734
Burnett River	264,307	332,366	118,241	3,894,616	358,852
Burrum River	130,835	112,113	44,691	1,612,683	270,059

Basin	LT median	2019 - 2020	2020 - 2021	2021 - 2022	2022 - 2023
Mary River	908,873	551,344	420,909	10,139,380	673,298
Burnett Mary subtotal	**1,767,127**	**1,186,169**	**715,375**	**17,465,982**	**1,556,636**
Sum of basins	**59,819,075**	**37,677,067**	**64,602,302**	**71,817,742**	**83,283,163**

4 Modelling and mapping marine water quality

This section presents results from satellite remote sensing of wet season water quality as well as outputs from eReefs model simulations of cumulative exposure to river discharge and estimated dispersal of nutrient and sediment loads.

4.1 Satellite remote sensing of Reef water types

To illustrate wet season influence on coastal water quality and identify potential risk to ecosystems, satellite-derived map products were produced for the Reef. This includes frequency maps predicting the areas affected by the Reef WT1–2 combined (Figure 4-1) or the three Reef water types individually (Figure 4-2) from December 2022 to April 2023 (the 2022–23 wet season).

4.1.1 Areas affected

The extent and frequency of the occurrence of combined Reef WT1 and WT2 was variable across regions, cross-shelf, and between years, reflecting the concentrations and intensity of the river discharge and resuspension events (Figure 4-1). The maps illustrate a well-documented inshore to offshore gradient (for example, Devlin *et al.*, 2013, 2015), with coastal areas experiencing the highest frequency of the Reef WT1 and mid-shelf and offshore areas less frequently exposed to the Reef WT1 (Figure 4-2).

Frequency of occurrence: The frequencies of occurrence of the combined Reef WT1 and WT2 were lower than the mean long-term frequencies in the southern Mackay-Whitsunday, Fitzroy, and Burnett-Mary regions (Figure 4-1a,e,f), indicating drier conditions. Frequencies were greater in Cape York and closer to the long-term average in the Burdekin and Wet Tropics regions, but with some local variability. These results agreed with the rainfall distribution in 2023 (Figure 3-2). The frequencies of occurrence measured across the Tully focus region were slightly above the long-term average (Figure 4-1g).

Reef area exposed: In 2022–23 only 4% of the Reef was exposed to the Reef WT1, 21% of the Reef was exposed to the Reef WT2 and 62% of the Reef was exposed to the Reef WT3 (Figure 4-3b and Table C - 10). The area exposed to the Reef WT1 was similar to both the long-term and coral recovery period percentages and only the inshore (enclosed coastal and open coastal) Reef waters were exposed (Figure 4-3c: 76% and 21% of the total enclosed coastal and open coastal waterbody areas, respectively). The area exposed to the Reef WT2 was similar (+5–6%) to both the long-term and coral recovery period percentages (21% of the Reef) and 97% of the total open coastal, 59% of the total enclosed coastal and 24% of the total mid-shelf waterbody areas were exposed.

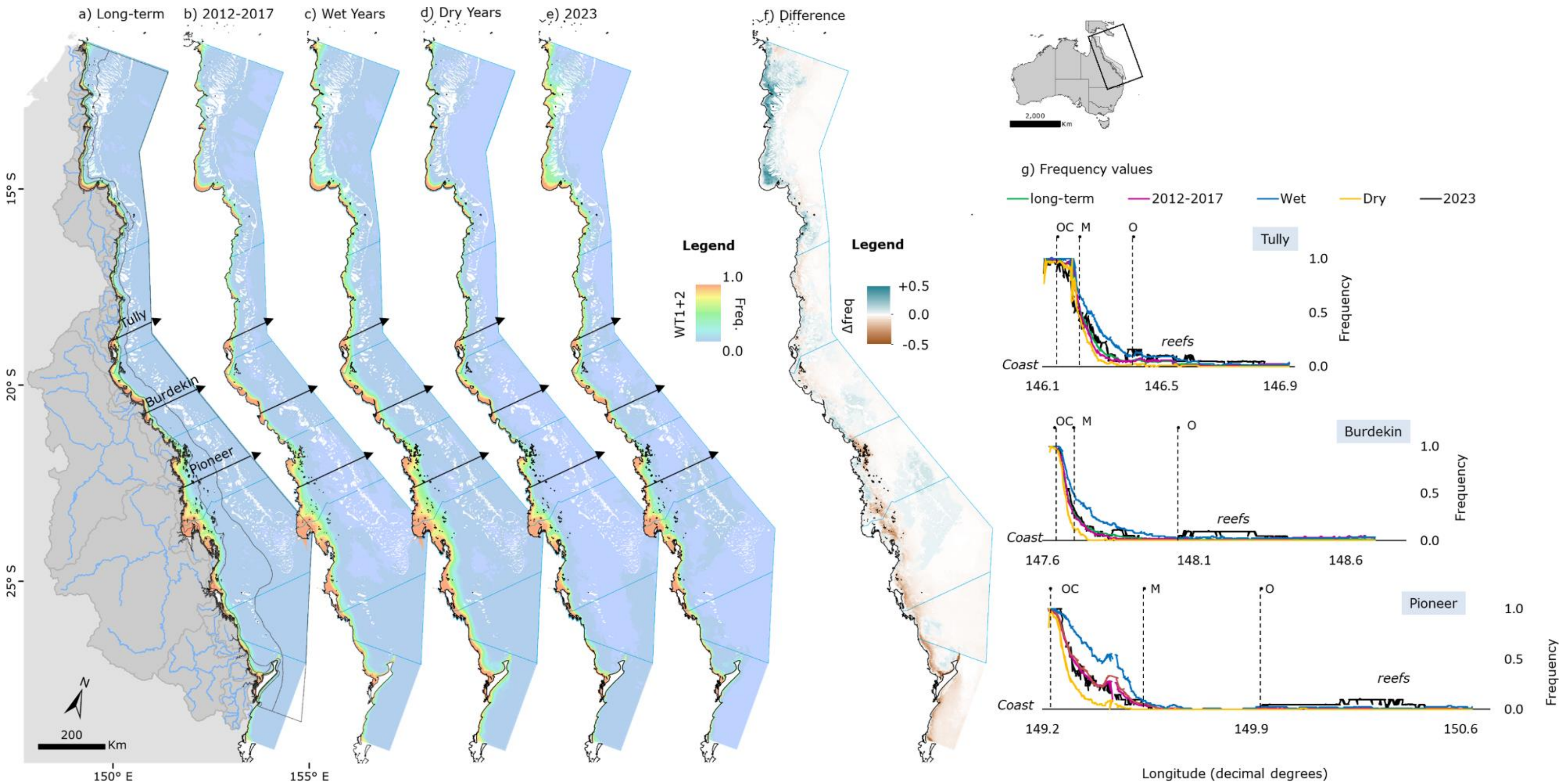


Figure 4-1: Map showing the frequency of the Reef WT1–2 combined in the a) long-term (20 wet seasons since 2002–03) b) representative coral recovery period (2011–12 to 2016–17, 6 wet seasons or 132 weeks), c) typical wet-year composite, d) typical dry-year wet season composites and e) 2022–23 wet season (22 weeks). The 2022–23 frequency maps were produced using Sentinel-3 images and the FU colour scale. Previous wet seasons (prior to 2021) and reference period composites have been produced using both MODIS satellite imagery and the wet season colour scale (Waterhouse *et al.*, 2021) and Sentinel-3 satellite imagery and the Forel-Ule colour scale (from 2021). The highest frequency is shown in orange and the lowest frequency is shown in blue. f) Difference map showing areas with an increase (in blue) and decrease (in brown) in exposure to Reef WT1–2 in 2022–23 against long-term trends (calculated as (e) 2023 minus (a) long-term). g) Plots on the right show the frequency values recorded along three transects extending from the Tully, Burdekin, and Pioneer Rivers to the external boundaries of the Marine Park and illustrate the differences in the spatial distribution and frequency of occurrence between the different representative periods. OC: open coastal, M: mid-shelf and O: offshore marine water body boundaries.

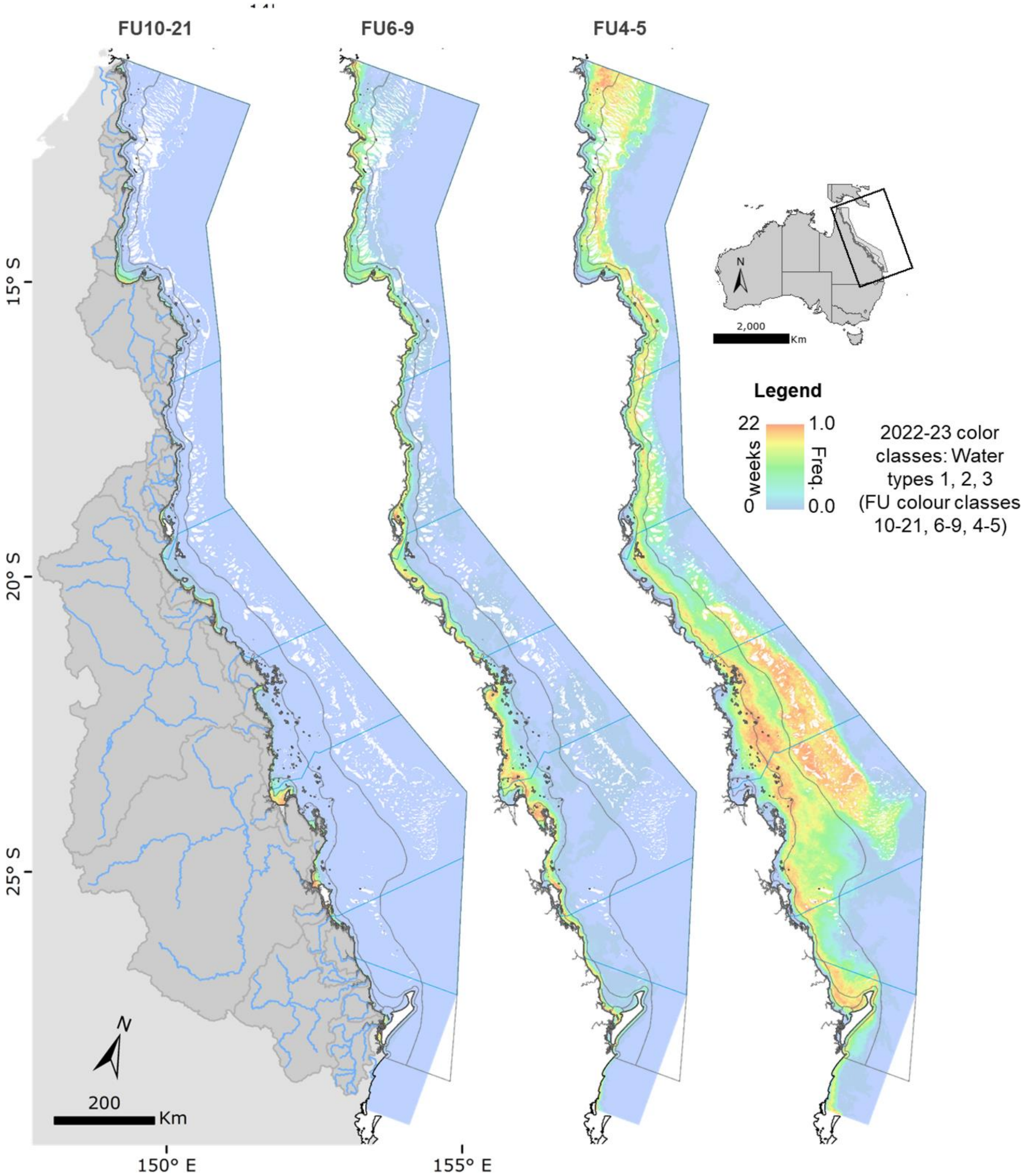


Figure 4-2: Map showing the frequency of the Reef WT1, WT2, and WT3 in the 2022–23 wet season (22 weeks). The highest frequency is shown in orange and the lowest frequency is shown in blue. These maps are used in the exposure assessment to represent the spatial likelihood of exposure of each of the wet season water types in 2022–23.

Figure 4-3: Areas (km²) and percentages (%) of the Reef lagoon (total 348,839 km²) and division by waterbodies (enclosed coastal, open coastal, mid-shelf, and offshore) affected by the Reef WT1–2 combined, and the three Reef water types individually during the current wet season and for a range of reference periods (23: 2022–23 wet season, LT: long-term, CR: Coral Recovery, W: Wet years, and D: Dry years). The data are presented in detail in Table C - 10.

As described in Section 2.6, the multi-year reference maps (long-term, wet, and dry years) were reviewed this year to include 20 years of satellite imagery (Figure 4-1). As in the three previous years, the Reef area exposed to Reef WT3 was greater than the long-term average (62% of the Reef) and the 'wet' year's area (58% of the Reef). This result is related to anomalously large areas exposed to Reef WT3 measured in the mid-shelf and offshore Reef (99% and 49% of the total mid-shelf and offshore waterbody areas, respectively). This result is not fully understood but is likely an indication of shelf upwelling in the central and southern Reef areas. Image classification by optical type does not directly elucidate the cause of variations in water colour, and Reef WT3 in particular (but also, to some extent, Reef WT1 and WT2 in some coastal areas) is sometimes due to oceanographic processes not related to catchment runoff. This should be further investigated in a future case study by comparing Reef WT3 areas with sea-surface temperature climatology (for example, Wijffels *et al.*, 2018). Furthermore, major reprocessing of the MODIS and Sentinel 3-OLCI radiance has been undertaken in 2018 and 2021, respectively. This could have influenced the result of the classification of the colour classes, particularly for the clearest waters. Reef WT3 is associated with low land-based contaminant concentrations and has a low magnitude score in the Reef exposure assessment (Figure 4-4 and Figure 4-5). While Reef WT3 areas were larger than in the reference periods, this did not result in increasing the potential risk offshore as 100% of the offshore areas were classified as no/very low potential risk in the 2022–23 exposure assessment (Figure 4-6 and Figure 4-7).

4.1.2 Composition of Reef water types

All mean concentrations of water quality parameters were reviewed for this report using surface field data collected from 2004 to April 2023 and the archive of weekly MODIS-Aqua and Sentinel-3 water type maps. Detailed summaries of water quality parameters for the long-term period (20 wet seasons) and reporting year are provided in Appendix B. Boxplots of long-term water quality parameters are shown in Figure 4-4 and are fully described below.

Mean long-term concentrations of water quality parameters showed similar patterns between focus regions, with maximum concentrations measured in Reef WT1 and minimum concentrations in Reef WT3 (Figure B - 2). However, there were distinct differences in the concentrations of individual parameters across regions. Across years, the frequency of sampling in flood events as well as the location, timing, and number of samples historically collected in each region is a major influence on these results. Thus, the *magnitude scores* for the exposure maps are calculated using the mean long-term concentrations of water quality parameters across the whole of the Reef (Section 4.1.3 and Figure 4-5).

The long-term mean TSS, Chl-*a*, PP, and PN concentrations (± standard deviation) were above the Reef-wide wet season GVs in the Reef WT1 and WT2, with Chl-*a* only slightly above in Reef WT2 (Chl-*a* = 0.65 ± 0.75 µg L^{-1}) and only the long-term mean PN concentration was above the wet season GV in the Reef WT3 (PN = 28.30 ± 21.31 µg L^{-1}) (Figure 4-5). Using these data, magnitude scores in the exposure mapping were finally calculated as the proportional exceedance of the GVs, and negative magnitude scores capped to zero (Figure 4-5). Magnitude scores have no defined ecological significance but are used in the risk framework as a relative measure to assign potential risk grading for each Reef water type (refer Section 4.1.3).

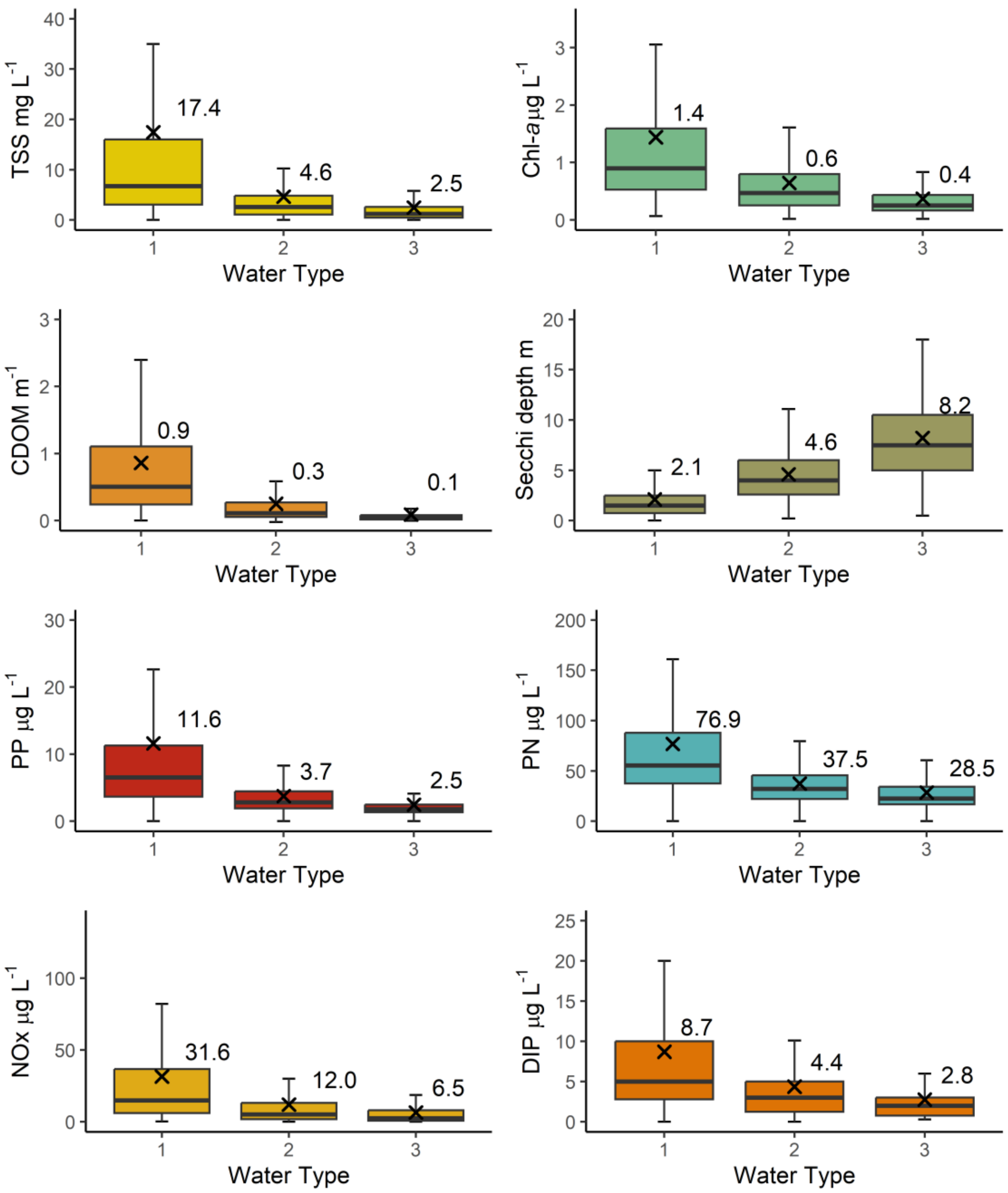


Figure 4-4: Long-term (2004–2023) concentrations of water quality parameters and Secchi disk depth boxplots for each Reef water type (WT1, WT2, and WT3). Water types were extracted from the MODIS-Aqua (2004–2020) and Senitnel-3 (2021–2023) weekly satellite databases. The mean is plotted as a cross (x) and its numerical value is indicated in text. The interquartile range is delimited by the box and the median by the line inside the box. Whiskers indicate variability outside the upper and lower quartiles. Data beyond the whiskers range are considered outliers and are not plotted. Long-term WQ values have been reviewed for this report (last update was in 2019).

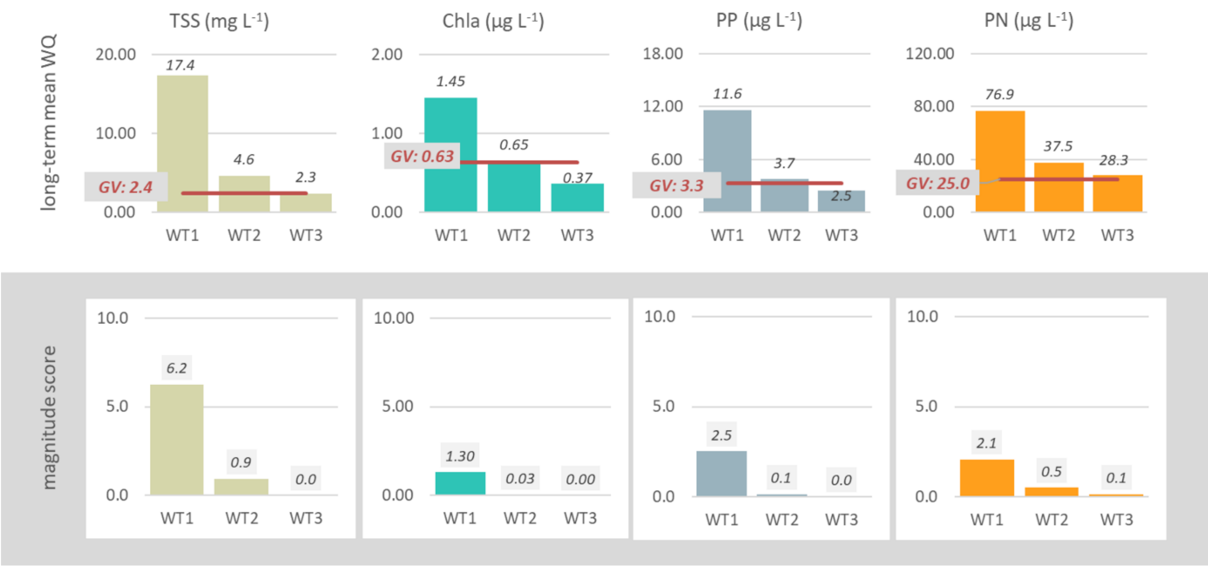


Figure 4-5: Mean long-term concentrations of water quality parameters (top) and magnitude scores across the three Reef water types (bottom). Red lines show the Reef-wide wet season GVs (Appendix B Table B-4). Magnitude scores are calculated as the proportional exceedance of the guideline: $magnitude_{water\ type} = ([Poll.]_{water\ type} - GV)/GV$ and Poll. = TSS, Chl-*a*, PP, or PN. Negative magnitude scores are scored as zero. Mean long-term concentrations of water quality parameters and magnitude scores have been reviewed for this report (last update was in 2019).

4.1.3 Potential exposure risk to Reef ecosystems

This section presents the area (km^2) and percentage (%) of coral reefs and seagrass meadows affected by different categories of exposure (or potential risk) based on satellite-derived Reef water types.

The exposure categories are not validated against ecological health data and represent relative potential risk categories for seagrass and coral reef ecosystems. The areas and percentages of ecological communities affected by the different categories of exposure were calculated as a relative measure between regions and the long-term average.

Reef-wide: The area exposed to a potential risk in 2022–23 was spatially limited relative to the scale of the Reef with 91% exposed to no or very low potential risk (Table 4-1 and Figure 4-6e). This result is similar to the long-term patterns (91% of the Reef). Approximately 9% of the Reef was exposed to combined potential risk categories II–IV, which is still a relatively large area at approximately 31,102 km^2. However, only 1% of the Reef was in the highest exposure category (IV) and only 2% of the Reef was in category III (Table 4-1); the total area of these categories combined was 10,096 km^2. These patterns were very similar to the long-term patterns (Table 4-1). Patterns were also similar across marine regions, with more than 89% of each region classified as no / very low risk and less than 2% classified as category III or category IV, respectively (Figure 4-7b). It is important to note that while these percentages are relatively small, the total areas are still significant, especially when considering specific habitat areas.

Reef waterbodies: Only the inshore Reef waters, including the enclosed (macro-tidal enclosed coastal and enclosed coastal waterbodies combined) and open coastal (macro-tidal open coastal and open coastal waterbodies combined) were exposed to the highest categories of potential risk (III and IV, Figure 4-7a). However, open coastal waters were largely exposed to the lowest category of potential risk only (no/very low risk = 44% and II: 46%) and only 9% and 1% of the open coastal waters where exposed to the potential risk category III and IV. The enclosed coastal waters had the largest proportion of waters classified as higher relative risk, with 48% of the combined inshore waters exposed to risk category IV. Approximately

77% (<3,600 km^2) of Reef seagrasses occur in the inshore waters, but only 4% (<900 km^2) of coral reefs (Appendix C-6). The mid-shelf and offshore waterbodies were largely classified as no/very low potential risk (97% of the mid-shelf and 100% of the offshore waters) (Figure 4-7a).

Table 4-1: Areas (km^2) and percentages (%) of the Reef lagoon, coral reefs, and surveyed seagrass affected by different risk categories of exposure during the 2022–23 wet season and the long-term (2003–2022). The last three rows show the differences between % affected in 2022–23 and the long-term average (: increase, : decrease, and : no change, difference <5%). Areas south of the Marine Park (Hervey Bay) are not included.

Reef lagoon		Total		Potential Risk category				Total area exposed II–IV
				No / very low	Lowest		Highest	
				I	II	III	IV	
Surface area	area	348,839	2023	317,738	21,006	5,987	4,108	31,102
			LT	317,183	23,596	4,247	3,813	31,657
	%	*100%*	2023	91%	6%	2%	1%	9%
			LT	91%	7%	1%	1%	9%
Coral reefs	area	24,914	2023	23,048	1,489	236	141	1,866
			LT	24,072	564	179	99	842
	%	*100%*	2023	93%	6%	1%	1%	7%
			LT	97%	2%	1%	0%	3%
Surveyed seagrass	area	4,660	2023	1,462	1,645	884	668	3,197
			LT	1,373	1,943	609	734	3,287
	%	*100%*	2023	31%	35%	19%	14%	69%
			LT	29%	42%	13%	16%	71%
Difference (2022–23 to long-term average)	*Surface area*			<1%	<-1%	<1%	<1%	<-1%
	Coral reefs			-4%	4%	<1%	<1%	4%
	Surveyed seagrass			2%	-7%	6%	-2%	-2%

Similar cross-shore patterns were observed across Reef marine regions and all mid-shelf and offshore waterbodies were largely classified as no/very low potential risk (Figure 4-7c). Mid-shelf waterbodies in the Cape York region had the greatest exposure to potential risk category II (18% of the Cape York mid-shelf waterbody), followed by the Wet Tropics and Burdekin regions (4% and 2% of the Wet Tropics and Burdekin mid-shelf waterbodies, respectively). The Cape York and Burdekin region open coastal waterbodies had the greatest exposure to risk categories III (17% and 15% of the Cape York and Burdekin open coastal waterbodies, respectively). In the other Reef regions, <10% of the open coastal waterbodies were exposed to risk categories III. Differences across regions are further described in the Regional Results section below (Section 4.3).

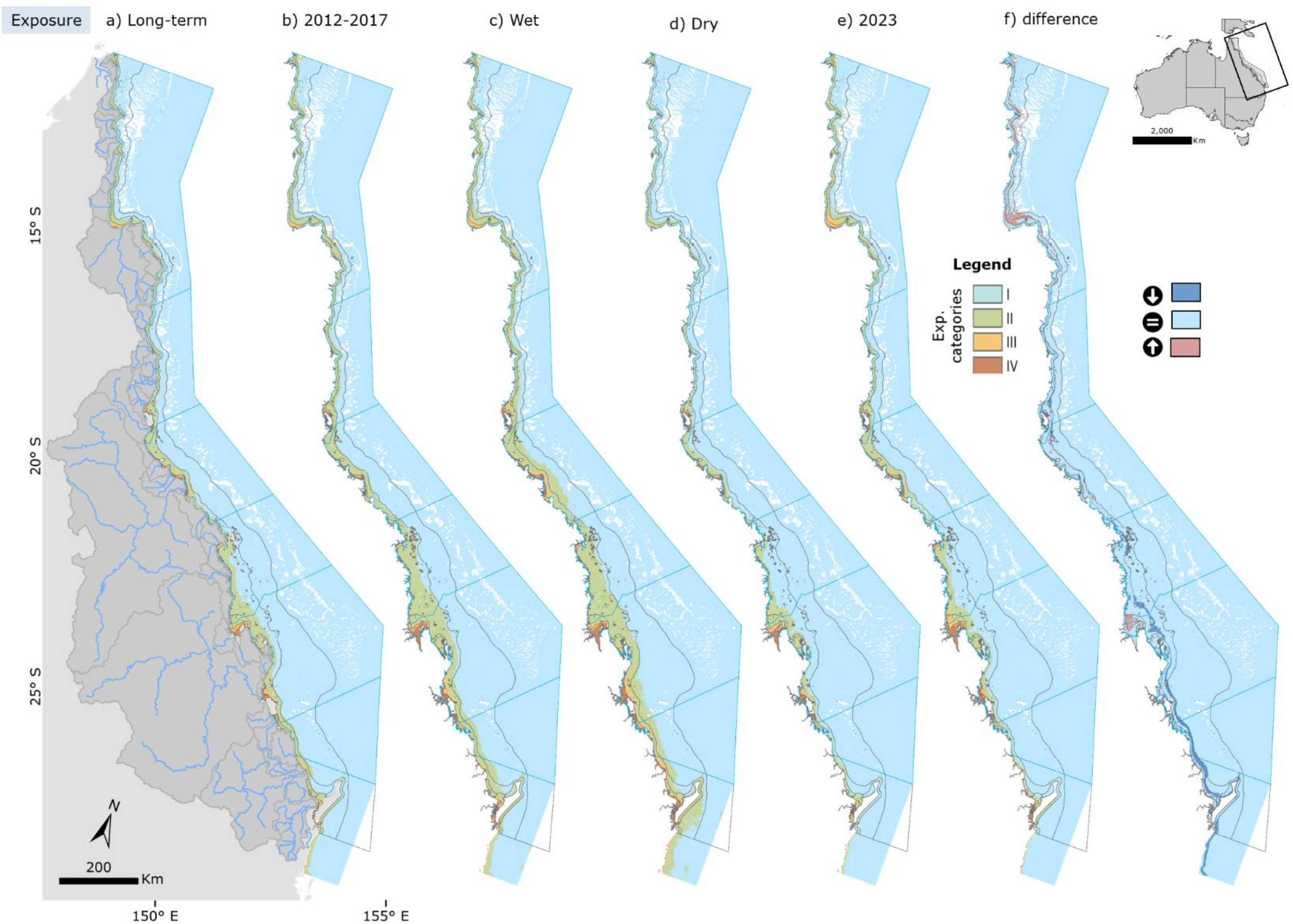


Figure 4-6: Map showing the reclassified surface exposure in the a) long-term (20 wet seasons since 2002–03), b) representative coral recovery period (2012–2017, 132 weeks), c) typical wet-year and d) typical dry-year wet season composites and e) 2022–23 wet seasons (22 weeks). Relative potential risk categories range from I: no/low risk to IV: highest relative risk. f) Difference map showing areas with an increase (in red, ⬆) and decrease (in purple, ⬇) in risk category in 2022–23 against long-term trends (calculated as (e) 2023 minus (a) long-term).

a) Reef waterbodies

	EC	OC	Mid	Off
IV	48%	1%	0%	0%
III	28%	9%	0%	0%
II	11%	46%	4%	0%
No/ V. Low	13%	44%	97%	100%

b) Reef regions

	CY	WT	Bu	MW	Fi	BM
IV	1%	1%	1%	1%	2%	0%
III	2%	2%	2%	2%	1%	1%
II	8%	8%	7%	8%	4%	1%
No / V. Low	89%	89%	90%	89%	93%	98%

c) Regional waterbodies

	Cape York				Wet Tropics				Burdekin				Mackay-Whit.				Fitzroy				Burnett -Mary			
	EC	OC	Mid	Off	EC	OC	Mid	Off	EC	OC	Mid	Off	EC	OC	Mid	Off	EC	OC	Mid	Off	EC	OC	Mid	Off
IV	30%	1%	0%	0%	47%	1%	0%	0%	69%	2%	0%	0%	58%	0%	0%	0%	77%	2%	0%	0%	40%	2%	0%	0%
III	53%	17%	0%	0%	40%	9%	0%	0%	29%	15%	0%	0%	35%	6%	0%	0%	20%	8%	0%	0%	45%	8%	0%	0%
II	16%	68%	18%	1%	11%	70%	4%	0%	1%	63%	2%	0%	5%	32%	0%	0%	2%	39%	0%	0%	11%	44%	0%	0%
No / V. Low	1%	14%	82%	99%	2%	20%	96%	100	1%	20%	98%	100	2%	61%	100	100	2%	51%	100	100	4%	47%	100	100

d) Seagrass habitats

	EC	OC	Mid	Off
IV	45%	1%	0%	0%
III	39%	15%	0%	0%
II	16%	64%	2%	7%
No / V. Low	1%	20%	98%	93%

e) Coral habitats

	EC	OC	Mid	Off
IV	55%	4%	0%	0%
III	36%	24%	0%	0%
II	6%	47%	25%	2%
No / V. Low	3%	26%	75%	98%

Figure 4-7: Percentage of the a) Reef waterbodies, b) Reef regions, c) regional Reef waterbodies, d) seagrass and e) coral habitats affected by different risk categories of exposure during the 2022–23 wet season. Water body classifications are shown along the x-axes: enclosed coastal (EC), open coastal (OC), mid-shelf (Mid), and offshore (Off).

Reef habitats (coral reefs and seagrasses): In 2022–23, it was estimated that:

- Approximately 7% of coral reefs (or almost 1,900 km^2) were exposed to combined potential risk categories II–IV (Table 4-1). However, <2% were in the highest exposure categories IV and III combined and only the enclosed coastal and open coastal coral reef habitats were exposed, equating to 377 km^2. The total enclosed coastal coral reef area affected by the highest exposure categories was 91% (55% to cat. IV and 36% to cat. III, Figure 4-7e). Only 4% of the open coastal reefs were exposed to cat. IV and 24% to category III. Mid-shelf and offshore coral reefs were only exposed to the lowest risk category II or to no potential risk. The coral areas exposed to potential risk categories III and IV in 2022–23 were similar to the long-term patterns (<2% of the coral reefs, Table 4-1).
- Approximately 69% of seagrasses (or almost 3,200 km^2) were exposed to combined potential risk categories II–IV. Approximately 14% (668 km^2) were in the highest exposure category (IV) and 19% were in category III (884 km^2) and only the enclosed coastal and open coastal seagrass habitats were exposed (Figure 4-7d). The total enclosed coastal seagrass area affected by the highest exposure categories was 84% (45% to cat. IV and 39% to cat. III, Figure 4-7d). Only 15% of the open coastal seagrasses were exposed to cat. III and 1% only were exposed to the highest category IV. Mid-shelf and offshore seagrasses were only exposed to the lowest risk category II or to no potential risk. The seagrass areas exposed to combined potential risk categories II to IV in 2022–23 were similar to the long-term (-2%). There was, however, an increase in area exposed to the lowest potential risk category (II: +6%).

4.2 Mapping the dispersal of river-derived DIN, fine sediment, and PN

As described in Section 2.8, an improved understanding of dispersal of river-derived DIN, fine sediment, and PN has been developed using the eReefs marine models. The process involves using modelled dispersal of river plumes to assess potential cumulative annual exposure of each location to terrestrially-derived fine sediment or nitrogen, including nitrogen derived from DIN or PN that might be transformed to other forms within the marine receiving environment. For all variables, the ‘anthropogenic’ influence was predicted by calculating the difference between a pre-development load scenario and the 2022–23 loading. A time-series from 2003 to 2023 is also presented. Prior to 2011 and in 2017, eReefs simulations were not available, so a multi-annual average tracer was used to disperse loads in these years. While the estimates have lower reliability relative to the years where tracer maps were available, they are still considered more robust than methods used in previous reports.

4.2.1 River-derived DIN dispersal

2022–23 water year

The estimated wet season river-derived DIN loading in the Reef lagoon for the 2022–23 water year is shown in Figure 4-8 (left panel), with a relatively constrained area of influence. The most significant differences between the 2022–23, pre-development, and anthropogenic loading scenarios were in the Wet Tropics and Burdekin regions.

There is lower confidence in the pre-development DIN load in the Normanby basin (Cape York region) and for this model, there is considered to be limited anthropogenic DIN. This is reflected in the difference map where there is very limited DIN influence in this area.

Trends in annual river-derived DIN loading to the Reef 2003–2023

The model-predicted river-derived DIN loading provides an estimate of the dispersion of end-of-catchment DIN loads in Reef waters and the resulting maps highlight spatial and temporal variation in DIN loading. The time series from 2003 to 2023 (Figure 4-9) showed distinct inter-annual variability, driven by river flow and pollutant loads. The areas of influence in 2022-23 were comparable to other years with river discharge around the long-term median (for example, 2020–21) but considerably smaller than in the more extreme high-flow years, 2018–19 and 2010–11.

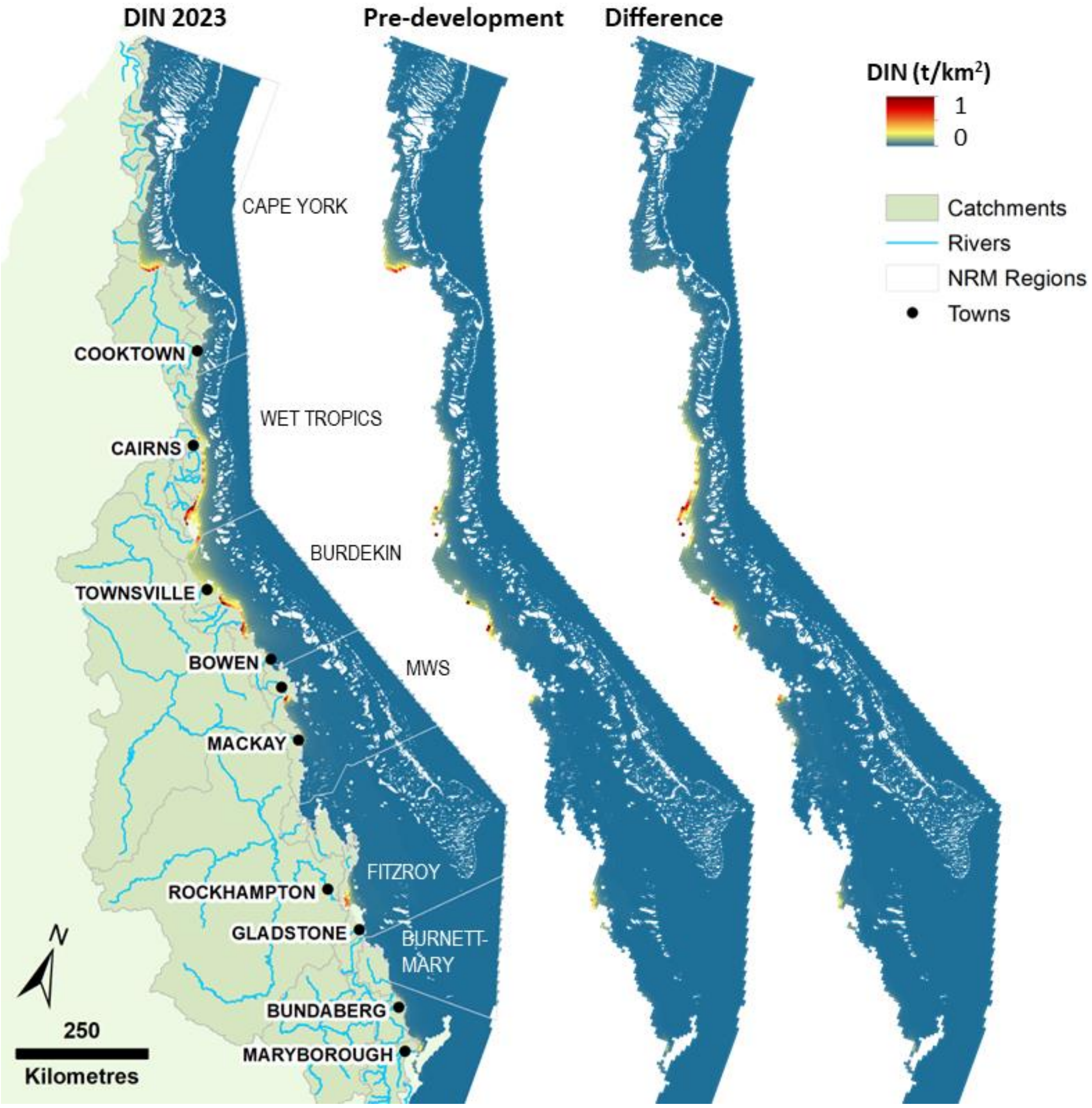


Figure 4-8. River-derived DIN loading (tonnes km^{-2}, relative scale) in the Reef lagoon, modelled for the (left panel) 2022–23 water year (1 October to 30 September), (centre panel) pre-development loads, and (right panel) difference between the DIN loading for pre-development and 2022–23 estimates.

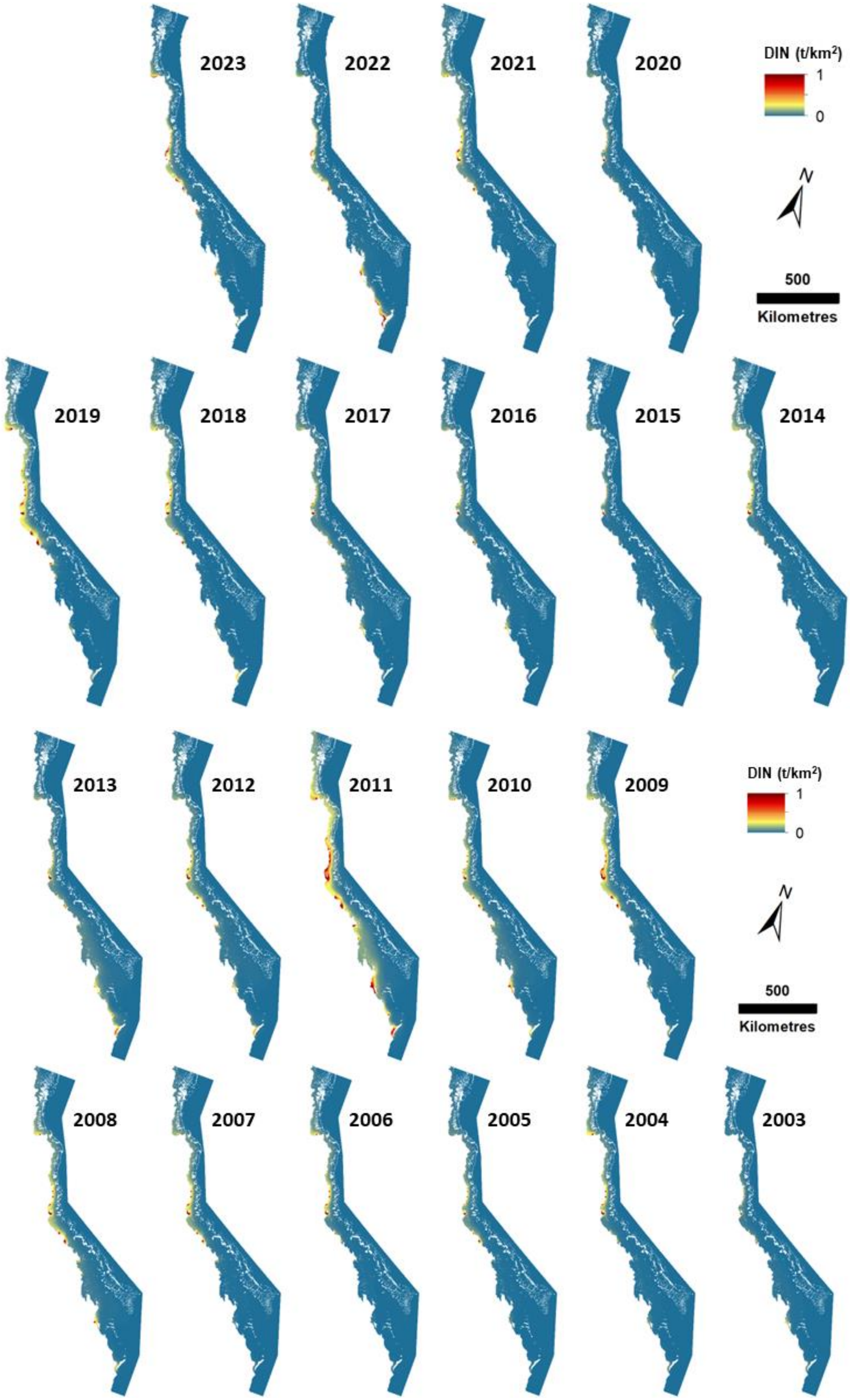


Figure 4-9. River-derived DIN loading (tonnes km^{-2}, relative scale) over the Reef lagoon for the 2002–03 to 2022–23 water years (1 October to 30 September). Outputs prior to 2011 and in 2017 were modelled using a multiannual average tracer.

The greatest extent of model-predicted DIN loading was observed in 2011 (associated with Tropical Cyclone Yasi), with large areas of dispersed DIN estimated in all regions except for Cape York.

The regions presenting higher DIN loading have remained relatively constant over the years, with higher loading typically observed in the Wet Tropics, Burdekin, and Mackay-Whitsunday regions. The greatest incidence of high DIN loading occurred in the Wet Tropics region in all years. Within the Wet Tropics, the areas of greatest values were correlated with large river discharge events in 2009, 2011, 2018, and 2019. High loading was also observed in each region during different years. For example, high values in the Burdekin region in 2005, 2008–2012, 2018, and 2019 (Figure 4-9).

4.2.2 River-derived TSS dispersal

The 2022–23 water year

The estimated wet season river derived TSS loading for the 2022–23 water year is shown in Figure 4-10 (left panel), with the largest area of influence in the Burdekin region. Notable differences were shown between the 2022–23 and pre-development loading scenarios, with the area of greatest anthropogenic influence also in the Burdekin region.

While there has clearly been increased erosion in the Normanby basin since the pre-development scenario, there is still debate on the export of TSS to the Reef lagoon as sediment is deposited on the floodplain. Hence the model has treated the pre-development and current loads from the Normanby basin the same, as reflected in the difference map. This needs to be updated in future models as improved estimates are now available.

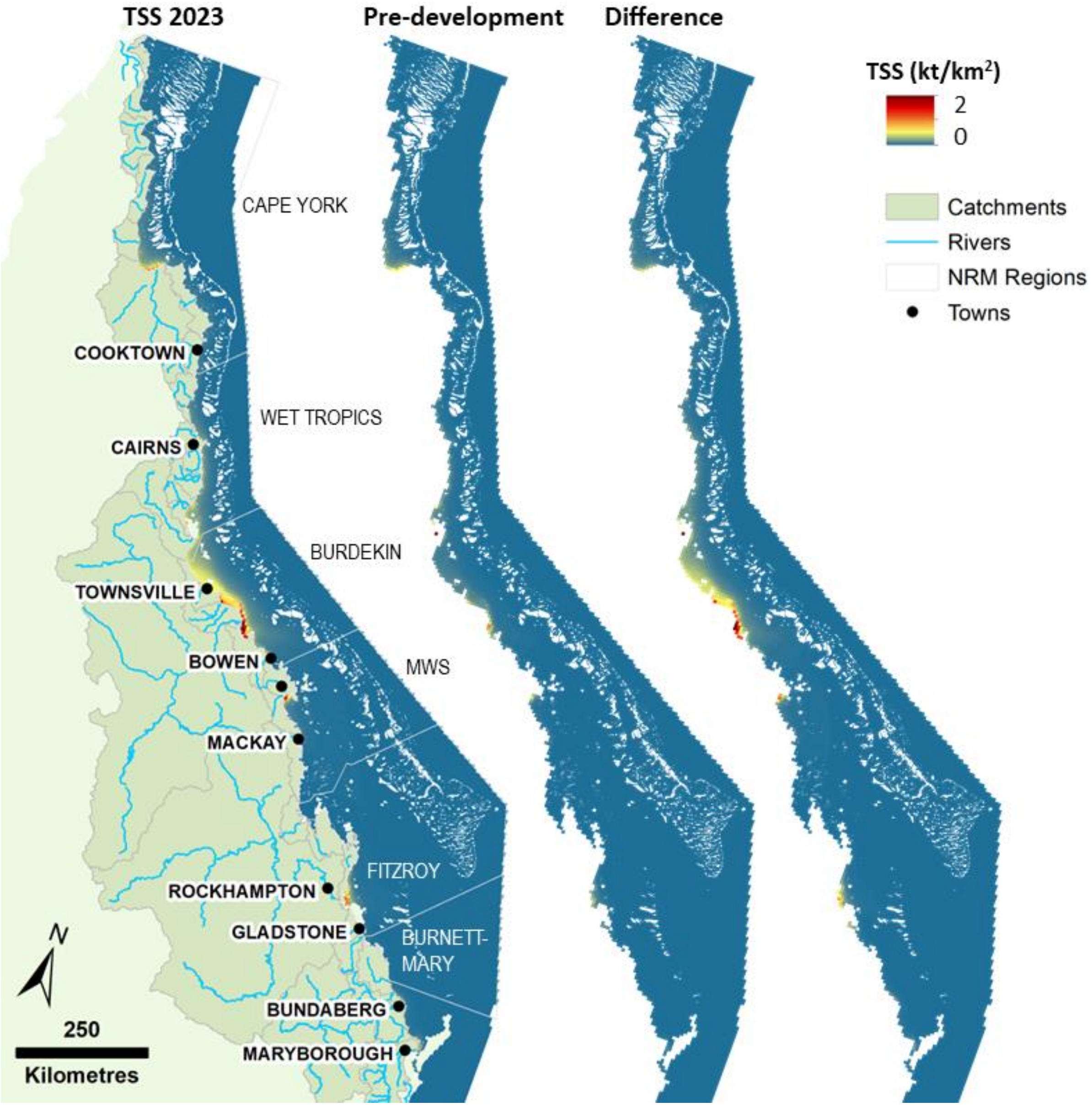


Figure 4-10. TSS (kilotonnes km^{-2}, relative scale) in the Reef lagoon, modelled for the (left panel) 2022–23 water year (1 October to 30 September), (centre panel) pre-development loads, and (right panel) difference between the TSS loading for pre-development and 2022–23 estimates.

Trends in annual river-derived TSS loading to the Reef 2003–23

The time-series from 2003 to 2023 (Figure 4-11) showed distinct inter-annual differences, driven by river flow and pollutant loads. The areas of influence in 2022–23 were comparable to other years close to or slightly above the long-term median river discharge. The greatest extent was observed in 2011 linked to heavy rain associated with Tropical Cyclone Tasha and the subsequent influence of Severe Tropical Cyclone Yasi. The regions with the highest TSS loading were typically the Burdekin, and to a lesser extent, the Fitzroy. The greatest frequency of the high river-derived TSS loading occurred in the Burdekin region and was correlated with large river discharge events (for example, in 2005, 2007–2009, 2011–2012, 2017, and 2019). High loading was also observed in each region in different years (Figure 4-11).

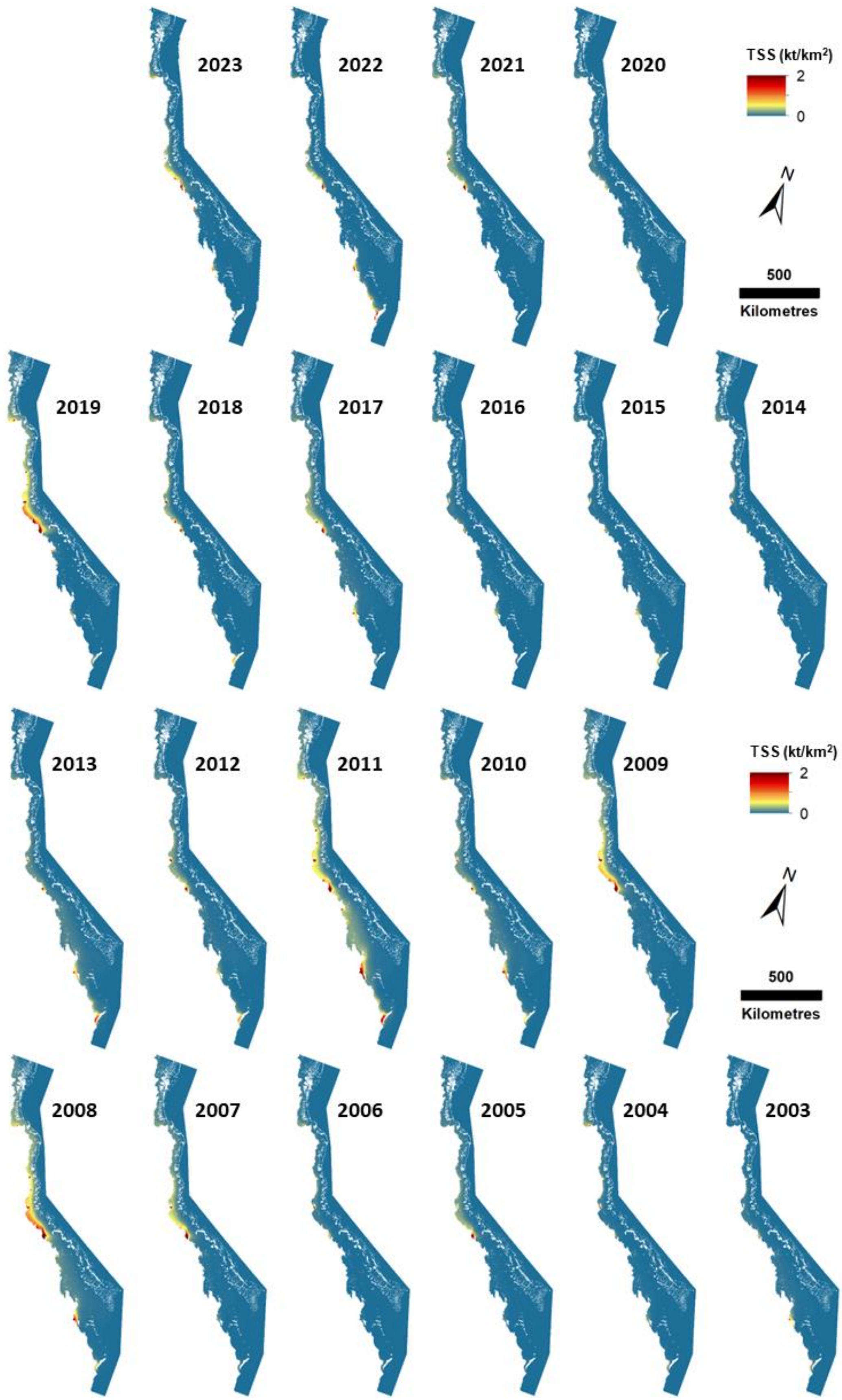


Figure 4-11. TSS loading (kilotonnes per km^2, relative scale) over the Reef lagoon for the 2003 to 2023 water years (1 October to 30 September). Outputs prior to 2011 and in 2017 weremodelled using a multiannual average tracer.

4.2.3 River-derived PN dispersal

The 2022–23 water year

The estimated wet season river derived PN loading for the 2022–23 water year is shown in Figure 4-12 (left panel) and showed similar patterns to both the DIN and TSS loading maps, with limited influence of PN loading along most of the Reef coast with the exception of the Burdekin region and Normanby Basin.

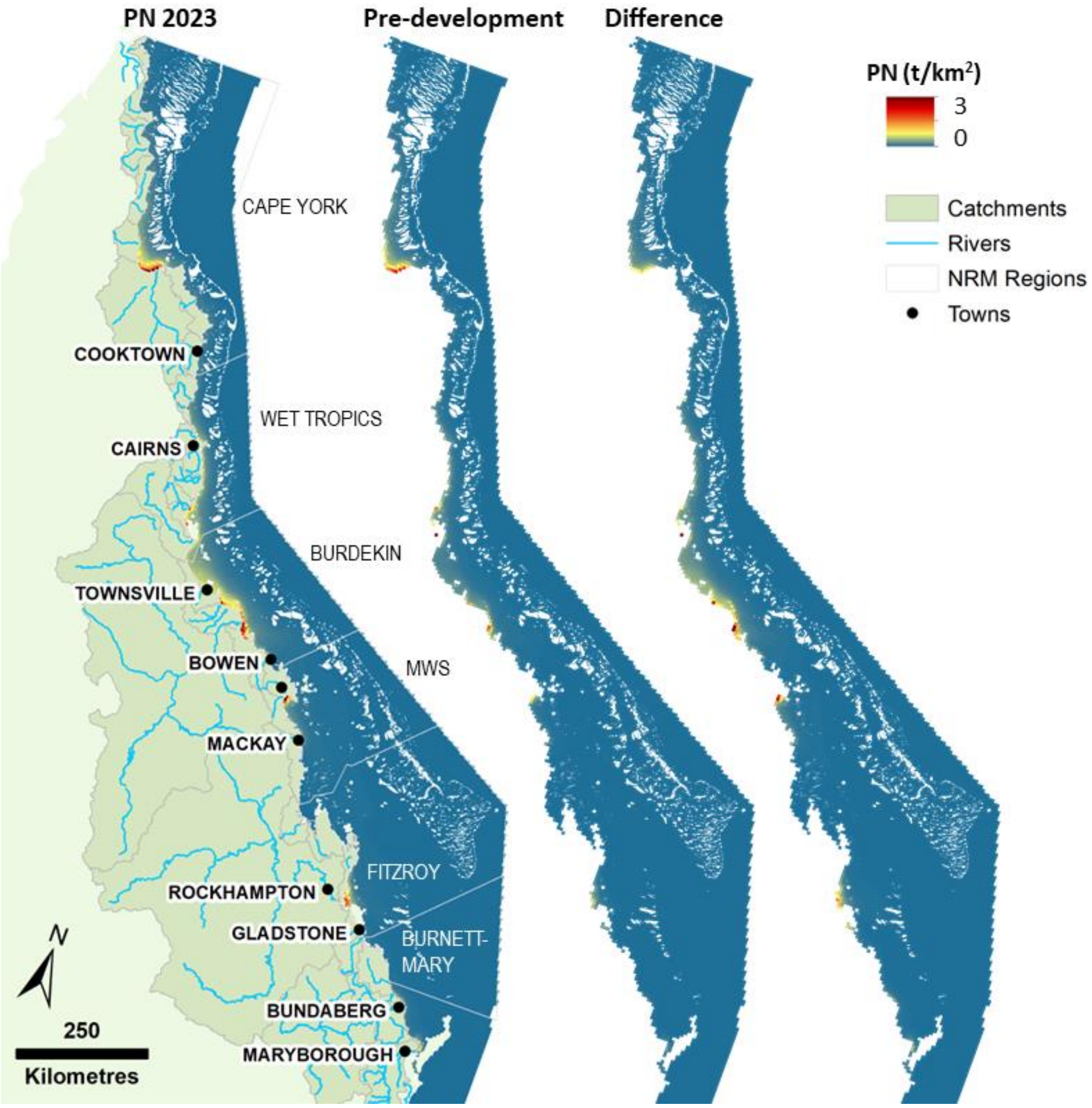


Figure 4-12. River-derived PN loading (tonnes km^{-2}, relative scale) in the Reef lagoon, modelled for the (left panel) 2022–23 water year (1 October to 30 September), (centre panel) pre-development loads, and (right panel) difference between the PN loading for pre-development and 2022–23 estimates.

The 'anthropogenic' influence map (Figure 4-12 right panel) was similar to the 2022–23 output, suggesting anthropogenic influence was confined to coastal waters. The same issues exist for PN in the Normanby basin as described for DIN and TSS above, giving this result low confidence.

Trends in annual river-derived PN loading to the Reef 2003–2023

The times series from 2003 to 2023 for PN loading (Figure 4-13) also showed distinct inter-annual differences, driven by river flow and pollutant loads. The greatest extent of the higher model predicted PN loading was observed in 2008, 2009, 2011 (covering almost the entire Reef), 2013, 2017, and 2019. The areas with the highest PN loading in these years were typically in the Burdekin region.

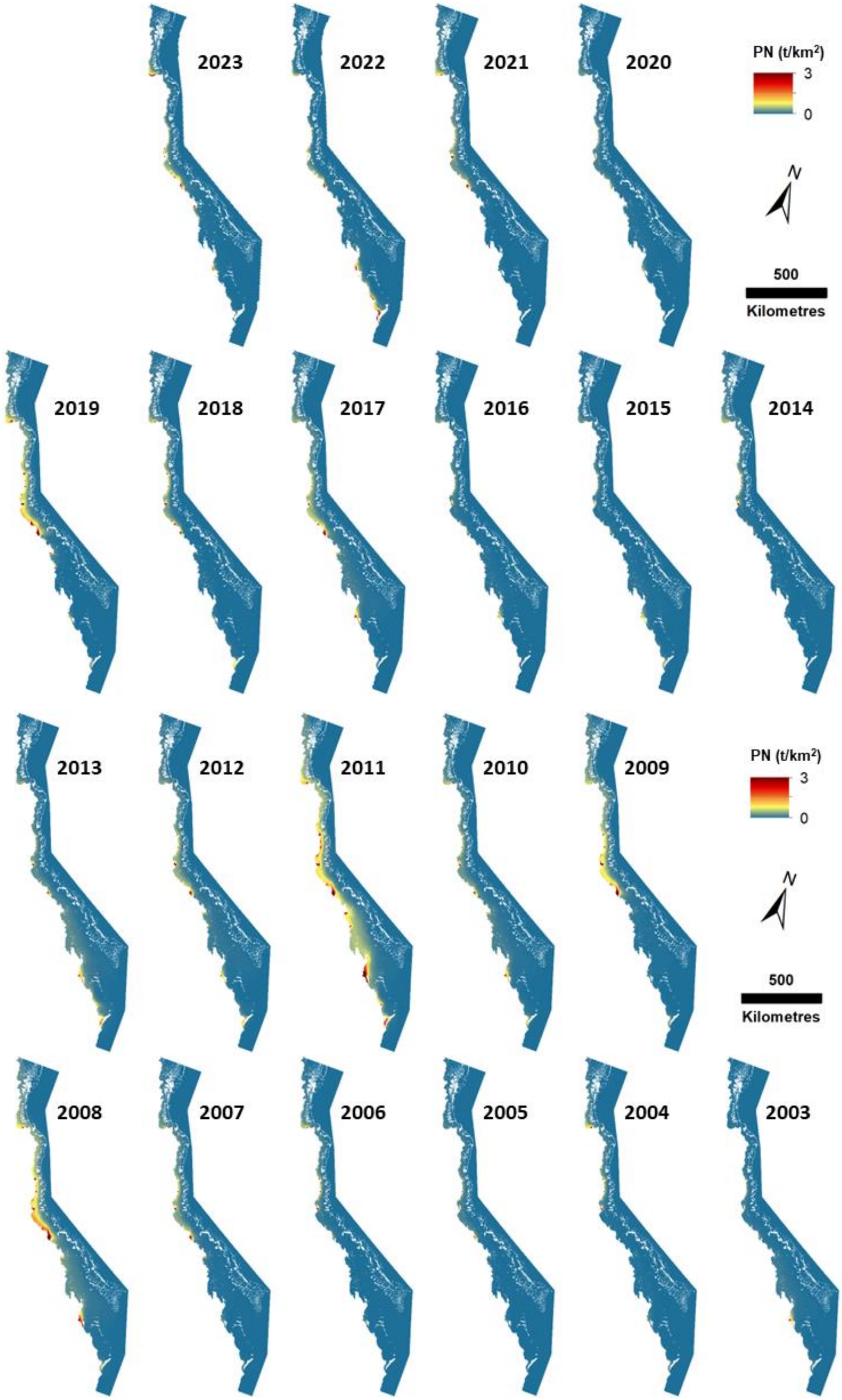


Figure 4-13. River-derived PN loading (tonnes km^{-2}, relative scale) over the Reef lagoon for the 2003 to 2023 water years (1 October to 30 September). Outputs prior to 2011 and in 2017 were modelled using a multi-annual average tracer.

4.3 Regional exposure of coastal waters and ecosystems to wet season discharge

The results of the remote sensing analysis for each region are presented below. This provides smaller-scale interpretation of the results which can be highly variable between locations, thereby enhancing the relevance of the remote sensing products for regional managers.

4.3.1 Cape York region

As described for the Reef, a number of remote sensing products were generated to represent wet season water quality conditions in the Cape York region. These maps are presented in a panel of weekly characteristics throughout the 22 week wet season period (Figure 4-14 and Figure 4-15) and in Figure 4-16, which presents the frequency of the combined Reef WT1–2, the frequency of Reef WT1, WT2, and WT3 individually; the exposure maps - each in the long-term and 2022–23 wet season; and a difference map showing areas exposed to an increased risk in 2022–23. Details in the panels include river discharge, wind speed and direction, weekly maps of wet season colour classes, and the location and timing of *in situ* data collection.

The Sentinel monitoring products (when not obstructed by cloud cover) clearly illustrated wet season surface water movements in the Cape York region, as well as the influence of river discharge including changes in water colour from nutrient and sediment inputs and resuspension (Figure 4-14 and Figure 4-15). Discharge in the Cape York region was 2.1 times the long-term median. There were two major flood events in January (weeks 6–9) and in early March (weeks 12–14). The larger flood plumes were captured following this larger event off the Normanby, Stewart, Lockhart, and Pascoe Rivers. The quality of the weekly composites around these dates was however degraded due to the frequent cloud cover.

Reef WT1 waters generally had minimal exposure on mid-shelf reefs in Princess Charlotte Bay and the Northern Cape York (Figure 4-16) but reached the mid-shelf waters of Princess Charlotte Bay in weeks 14–15. Reef WT2 waters extended further offshore around the January and March floods and reached the mid-shelf reefs (weeks 7–9 and weeks 12–18). In the southern region of Cape York, WT1 waters were captured in the same weeks but stayed largely within inshore waters.

Sampling of the Cape York waters occurred during and between the main flood events. A full description of water quality patterns and flood plumes is available in Section 5 of this report.

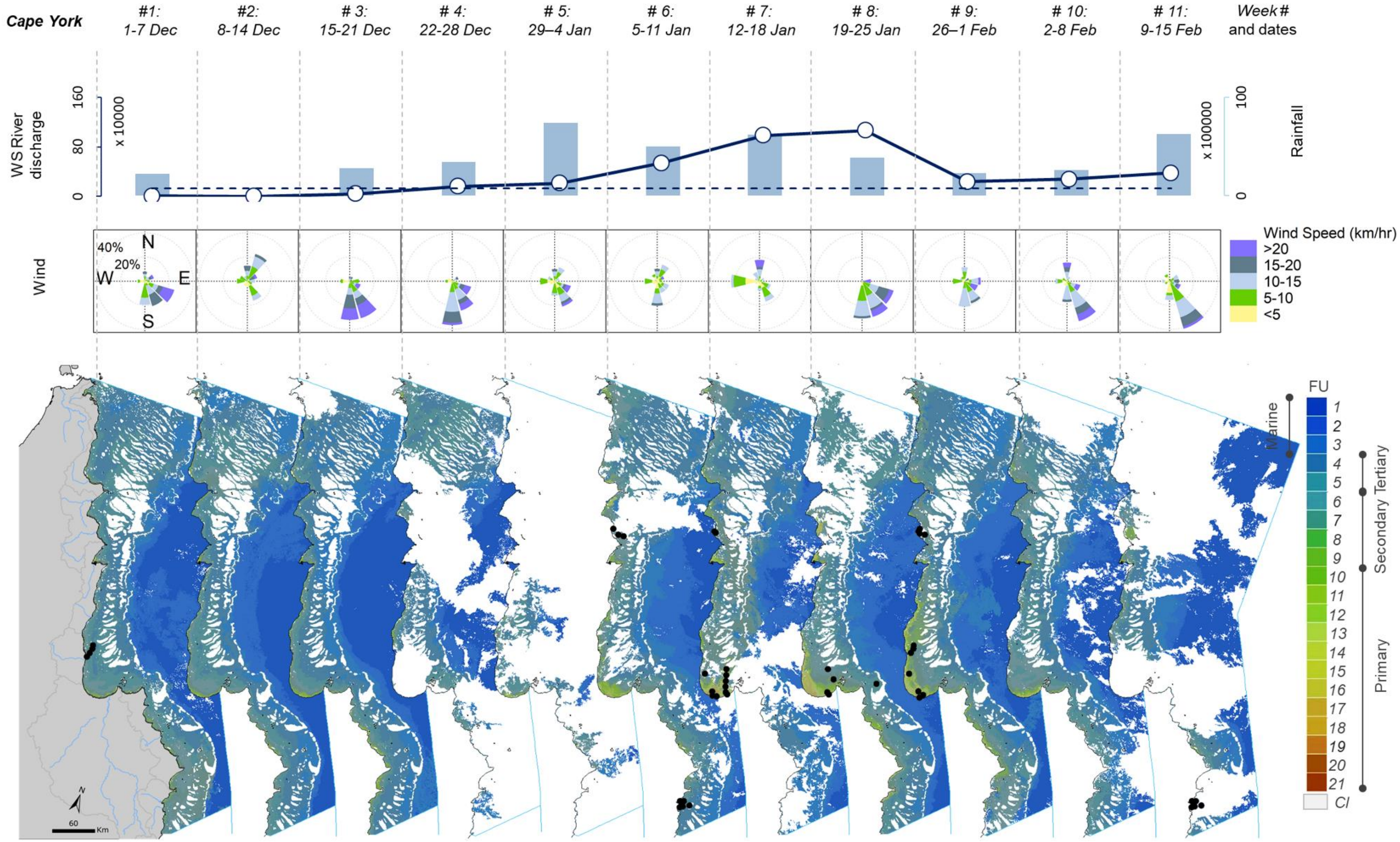


Figure 4-14. Panel of water quality and environmental characteristics in the Cape York region throughout the 2022–23 wet season period: weeks 1 to 11. Includes: 2022–23 weekly river discharge (ML) and rainfall (ML); wind roses showing the wind direction and speed (km h^{-1}) for each week; and FU colour class maps showing the location of the *in situ* data collected (black dots). The mean long-term weekly river discharge is indicated by a dotted blue line. Weekly river discharges are the sum of discharge (ML) from the Pascoe, Stewart, Normanby, and Endeavour Rivers.

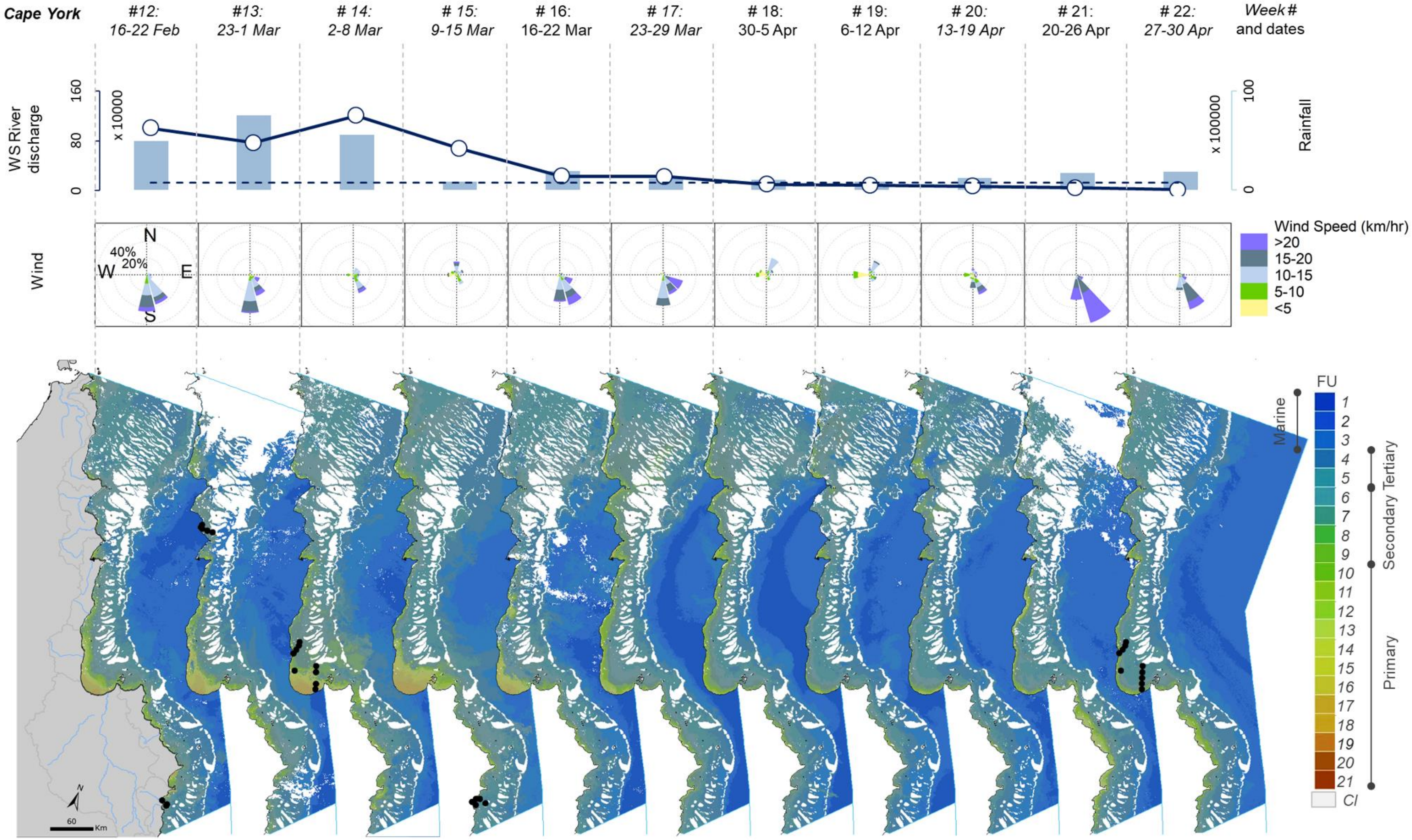


Figure 4-15. Panel of water quality and environmental characteristics in the Cape York region throughout the 2022–23 wet season period: weeks 12 to 22. Includes: 2022–23 weekly river discharge (ML) and rainfall (ML); wind roses showing the wind direction and speed (km h^{-1}) for each week; and FU colour class maps showing the location of the *in situ* data collected (black dots). The mean long-term weekly river discharge is indicated by a dotted blue line. Weekly river discharges are the sum of discharge (ML) from the Pascoe, Stewart, Normanby, and Endeavour Rivers.

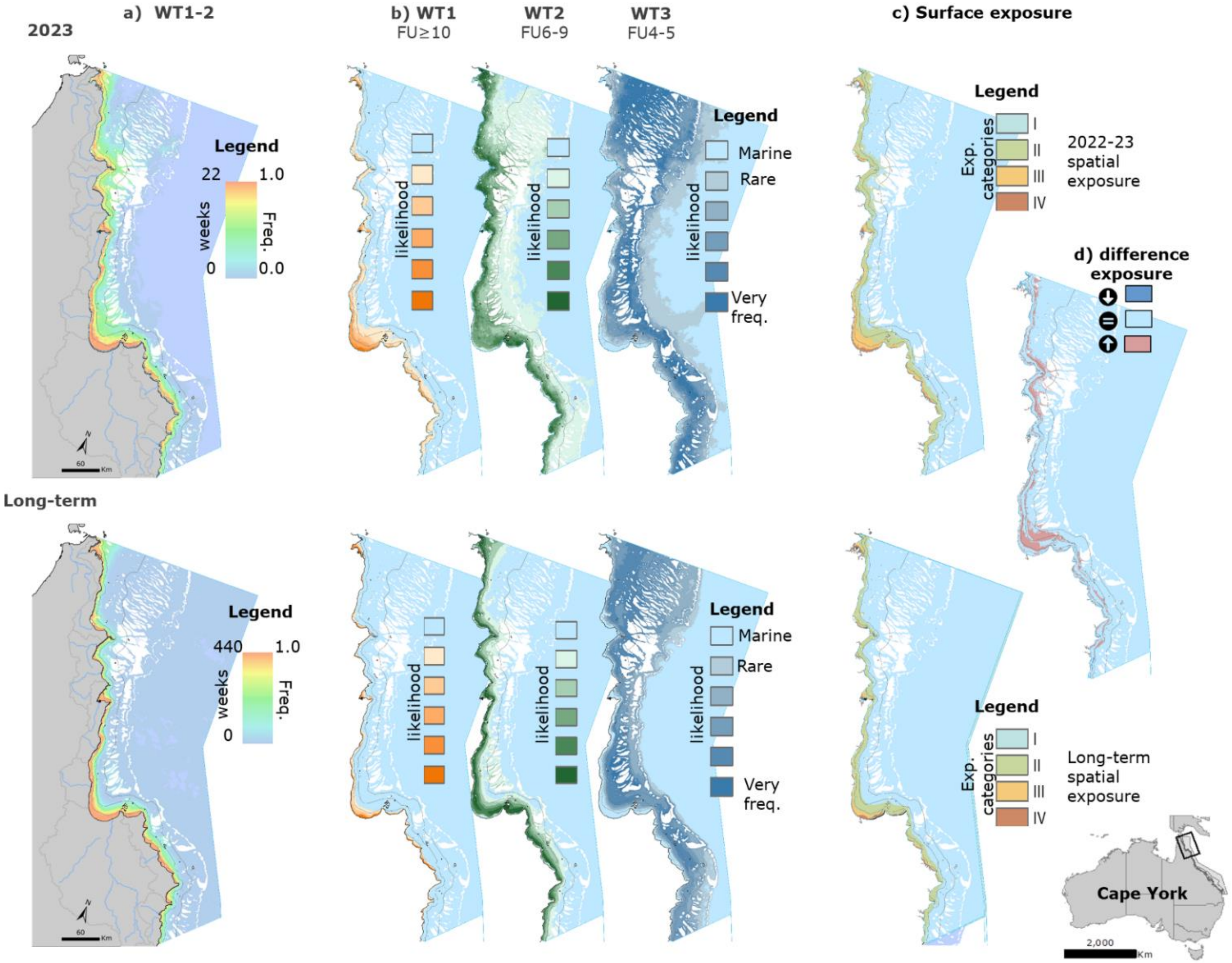


Figure 4-16: Long-term and current year remote sensing results for the Cape York region showing the a) frequency of combined Reef WT1–2; b) the frequency of Reef WT1, WT2 and WT3 individually regrouped into five likelihood categories [<0.2 (Rare), 0.2–0.4, 0.4–0.6, 0.6–0.8 and 0.8–1 (very frequent)]; c) exposure to potential risk - each in the long-term (bottom) and 2022–23 wet season (top). d) Difference map showing any areas with an increase (in red, ➊) or decrease (in purple, ➋) in risk category in 2022–23 against long-term trends [calculated as (c, top) exposure in 2023 minus (c, bottom) long-term]. Note that optical water types – especially the Reef WT3– do not always correspond to direct catchment discharge influence and can also be due to oceanographic processes (see definitions in Table 2-2).

Table 4-2 presents the areas (km^2) and percentages (%) of Cape York region, coral reef, and seagrass areas affected by different categories of exposure (or potential risk) based on satellite-derived Reef water types. The exposure categories are not validated against ecological health data and represent relative potential risk categories for seagrass and coral reef ecosystems. Category I (no/very low risk) represents waters with ambient or detectable, but low concentrations of the water quality parameters investigated and therefore low risk of any detrimental ecological effect. The areas and percentages of ecological communities affected by the different categories of exposure were calculated as a relative measure between regions and the long-term average.

In 2022–23, it was estimated that:

- Cape York region: Approximately 89% of Cape York was not exposed to a potential risk, similar to long-term patterns (93%, Table 4-2). Approximately 11% (or about 10,500 km^2) of the Cape York region was exposed to combined potential risk categories II–IV. However, only 1% (692 km^2) of the Cape York region was in the highest exposure category (IV) and 2% (2,153 km^2) was in category III.
- Cape York waterbodies: The mid-shelf and offshore waterbodies were largely exposed to no/very low risk (82% and 99% of the Cape York mid-shelf and offshore waterbodies, Figure 4-7c). Only the enclosed coastal and open coastal Cape York waters were exposed to the highest categories of potential risk (III and IV). The area exposed corresponded to 53% (cat. III) and 30% (cat. IV) of the total Cape York enclosed coastal area (Figure 4-7c) and 17% (cat. III) and 1% (cat. IV) of the open coastal areas.
- Cape York habitats:
  - **Coral reefs**: Approximately 86% of coral reefs in the Cape York region were not exposed to a potential risk. About 1% of corals were in the highest exposure category (IV) and 1% in category III (combined 182 km^2) and they were all inshore and enclosed coastal reefs (Figure 4-17a). Approximately 1% and 2% (<300 km^2) of the Cape York corals reefs occur in the enclosed and open coastal waters, respectively (Appendix C-6).

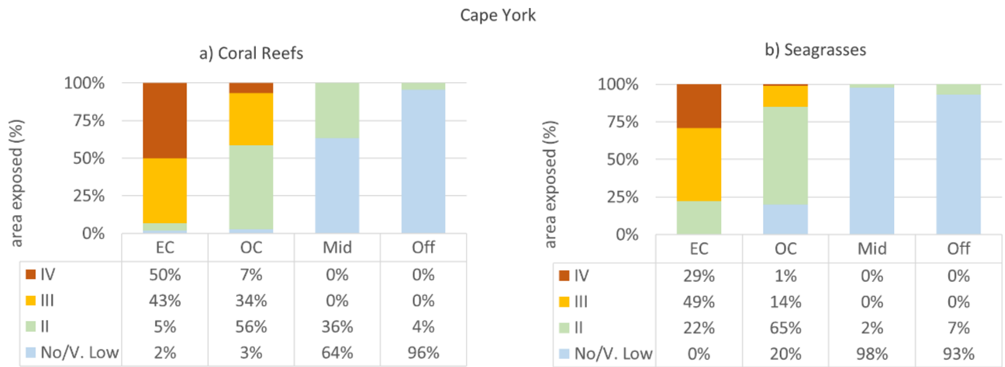
    The coral area exposed to higher potential risk corresponded to 43% (cat. III) and 50% (cat. IV) of the total enclosed coastal coral reef area in Cape York, and to 34% (cat. III) and only 7% (cat. IV) of the total open coastal coral reef area (Figure 4-17a). Mid-shelf reefs were exposed to the lower risk category II or to no / very low risk (36% and 64% of the total mid-shelf coral reef area in Cape York). 96% of the Cape York offshore reefs were classified as no / very low risk.
  - **Seagrasses**: Approximately 60% (or 1,602 km^2) of seagrasses in the Cape York region were exposed to combined potential risk categories II–IV (Table 4-2). 8% (221 km^2) of seagrasses were in the highest exposure category (IV) and 19% were in category III (502 km^2), and they were all inshore and enclosed coastal seagrasses (Figure 4-17b). A total of 27% and 40% (~1,800 km^2) of the Cape York seagrass occur in the enclosed and inshore waters respectively (Appendix C-6).

    The seagrass area exposed to higher potential risk corresponded to 49% (cat. III) and 29% (cat. IV) of the total enclosed coastal seagrass area in Cape York and to only 14 % (cat. III) and 1 % (cat IV) of the total open coastal seagrass area (Figure 4-17b). Mid-shelf and offshore seagrasses were largely classified as no/very low risk (98% and 93% of the Cape York mid-shelf and offshore seagrasses).
  - **Comparison to long-term trends:** The coral areas exposed to highest potential risk categories III and IV were similar to the long-term patterns (<3% of the coral reefs). There was however an increase in the coral area exposed to the lowest

potential risk category (II: +10%). There was an increase in the seagrass area exposed to the middle potential risk category (III: +9%).

Table 4-2: Areas (km^2) and percentages (%) of the Cape York region, coral reefs, and surveyed seagrass affected by different categories of exposure during the 2022–23 wet season and the long-term (2003–2022). The last three rows show the differences between % affected in 2022–23 and the long-term average (: increase, : decrease, : no change, difference <5%).

Cape York		Total		Potential Risk category: No / Very low I	Lowest II	III	Highest IV	Total area exposed II–IV
Surface area	area	96,316	2022-23	85,892	7,579	2,153	692	10,424
			LT	89,387	5,351	1,026	553	6,929
	%	*100%*	2022-23	89%	8%	2%	1%	11%
			LT	93%	6%	1%	1%	7%
Coral reefs	area	10,375	2022-23	8,932	1,261	112	70	1,443
			LT	10,030	209	92	44	345
	%	*100%*	2022-23	86%	12%	1%	1%	14%
			LT	97%	2%	1%	0%	3%
Surveyed seagrass	area	2,655	2022-23	1,053	879	502	221	1,602
			LT	1,175	1,012	265	203	1,480
	%	*100%*	2022-23	40%	33%	19%	8%	60%
			LT	44%	38%	10%	8%	56%
Difference (2022–23 to long-term average)	*Surface area*			-4%	2%	1%	<1%	4%
	Coral reefs			-11%	10%	<1%	<1%	11%
	Surveyed seagrass			-4%	-5%	9%	<1%	4%



a) Coral Reefs

	EC	OC	Mid	Off
IV	50%	7%	0%	0%
III	43%	34%	0%	0%
II	5%	56%	36%	4%
No/V. Low	2%	3%	64%	96%

b) Seagrasses

	EC	OC	Mid	Off
IV	29%	1%	0%	0%
III	49%	14%	0%	0%
II	22%	65%	2%	7%
No/V. Low	0%	20%	98%	93%

Figure 4-17: Percentage of the Cape York region a) coral reef and b) surveyed seagrass habitats affected by different risk categories of exposure during the 2022–23 wet season. Water body classifications are shown along the x-axes: enclosed coastal (EC), open coastal (OC), mid-shelf (Mid), and offshore (Off).

4.3.2 Wet Tropics region

As described for the Reef, a number of remote sensing products were generated to represent wet season water quality conditions in the Wet Tropics region. These maps are presented in a panel of weekly characteristics throughout the 22 week wet season period (Figure 4-18 and Figure 4-19) and in Figure 4-20, which presents the frequency of the combined Reef WT1–2, the frequency of Reef WT1, WT2, and WT3 individually; the exposure maps – each in the long-term and 2022–23 wet season; and a difference map showing areas exposed to an increased risk in 2022–23. Details in the panels include river discharge, wind speed and direction, weekly maps of wet season colour classes, and the location and timing of *in situ* data collection.

The Sentinel monitoring products (when not obstructed by cloud cover as around weeks 4, 5, 12 and 13) clearly illustrated wet season surface water movements in the Wet Tropics region, as well as the influence of river discharge including changes in water colour from nutrient and sediment inputs and resuspension (Figure 4-18 and Figure 4-19). Discharge in the Wet Tropics region was 1.2 times the long-term median. There were three flood events influencing the Wet Tropics during the 2022–23 wet season: around mid-January (weeks 5–7), early February to early March (weeks 10–14), and towards the end of April (weeks 21–22).

Weekly composites of the Wet Tropics region and the Reef WT1 likelihood map (Figure 4-20b) showed that WT1 waters were confined to the Wet Tropics river mouths and in the enclosed coastal waters most of the wet season. Tully WT1 waters (FU ≥10) reached the open coastal waterbody (including the vicinity of the Dunk Island group) in week 8 (19–25 January), 11 (9–15 February) and 15 (9–15 March, most probably linked to greater rainfall in weeks 7, 9, and 15. Reef WT1 waters from the Johnstone, Russell-Mulgrave, and Barron Rivers all reached the open coastal waterbody in weeks 14 and 15 (2–15 March), and also around week 21. Generally, WT1 flood waters had minimal impact on the open coastal and mid-shelf regions and ecosystems of the Wet Tropics in 2022–23. Reef WT2 waters extended further offshore in early March and reached the mid-shelf region. This was also the period of greatest discharge in the region.

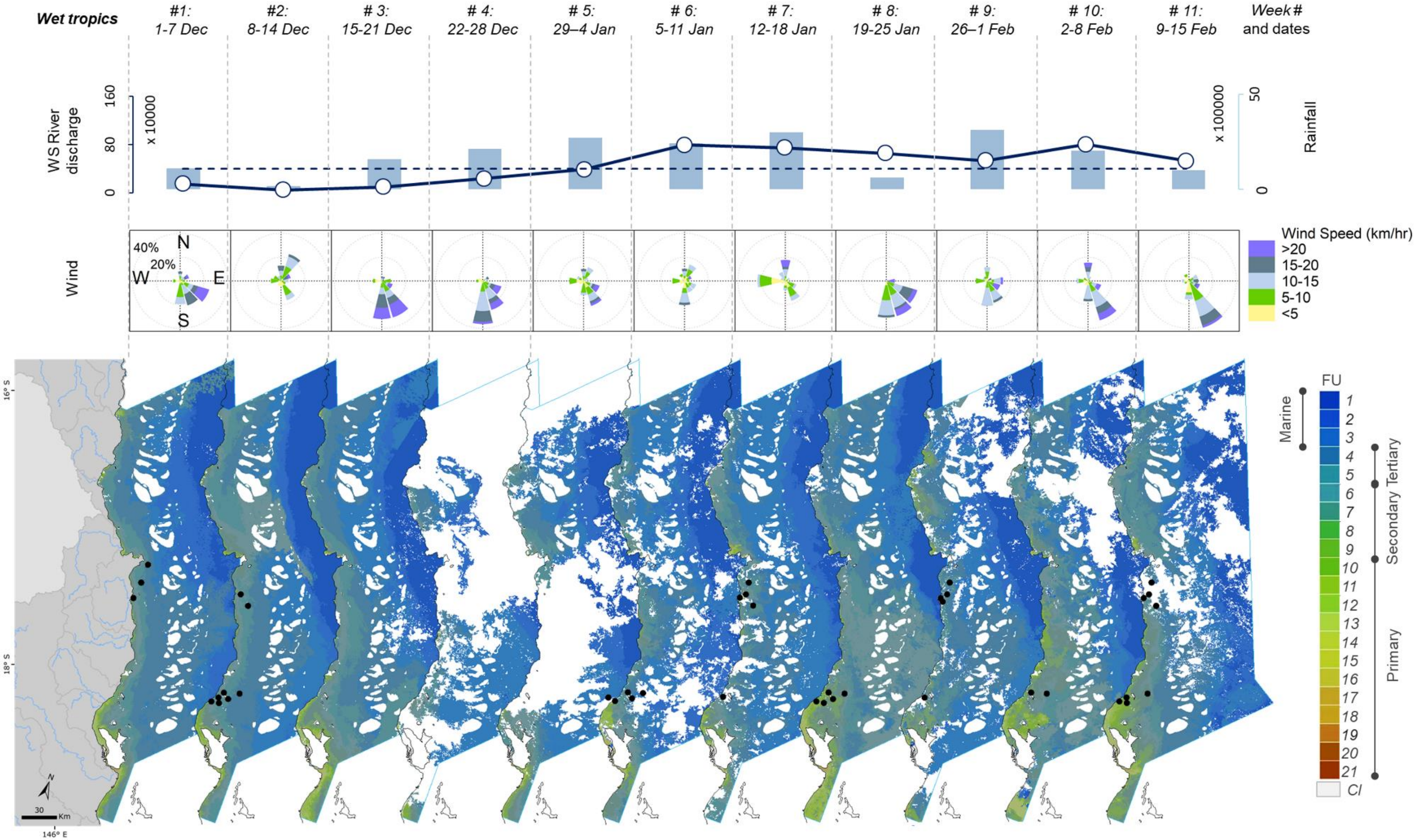


Figure 4-18. Panel of water quality and environmental characteristics in the Wet Tropics region throughout the 2022–23 wet season period: weeks 1 to 11. Includes: 2022–23 weekly river discharge (ML) and rainfall (ML); wind roses showing the wind direction and speed (km h^{-1}) for each week; and FU colour class maps showing the location of the *in situ* data collected (black

dots). The mean long-term weekly river discharge is indicated by a dotted blue line. Weekly river discharges are the sum of discharge (ML) from the Daintree, Mossman, Barron, Mulgrave, Russell, North Johnstone, South Johnstone, Tully, Murray, and Herbert Rivers.

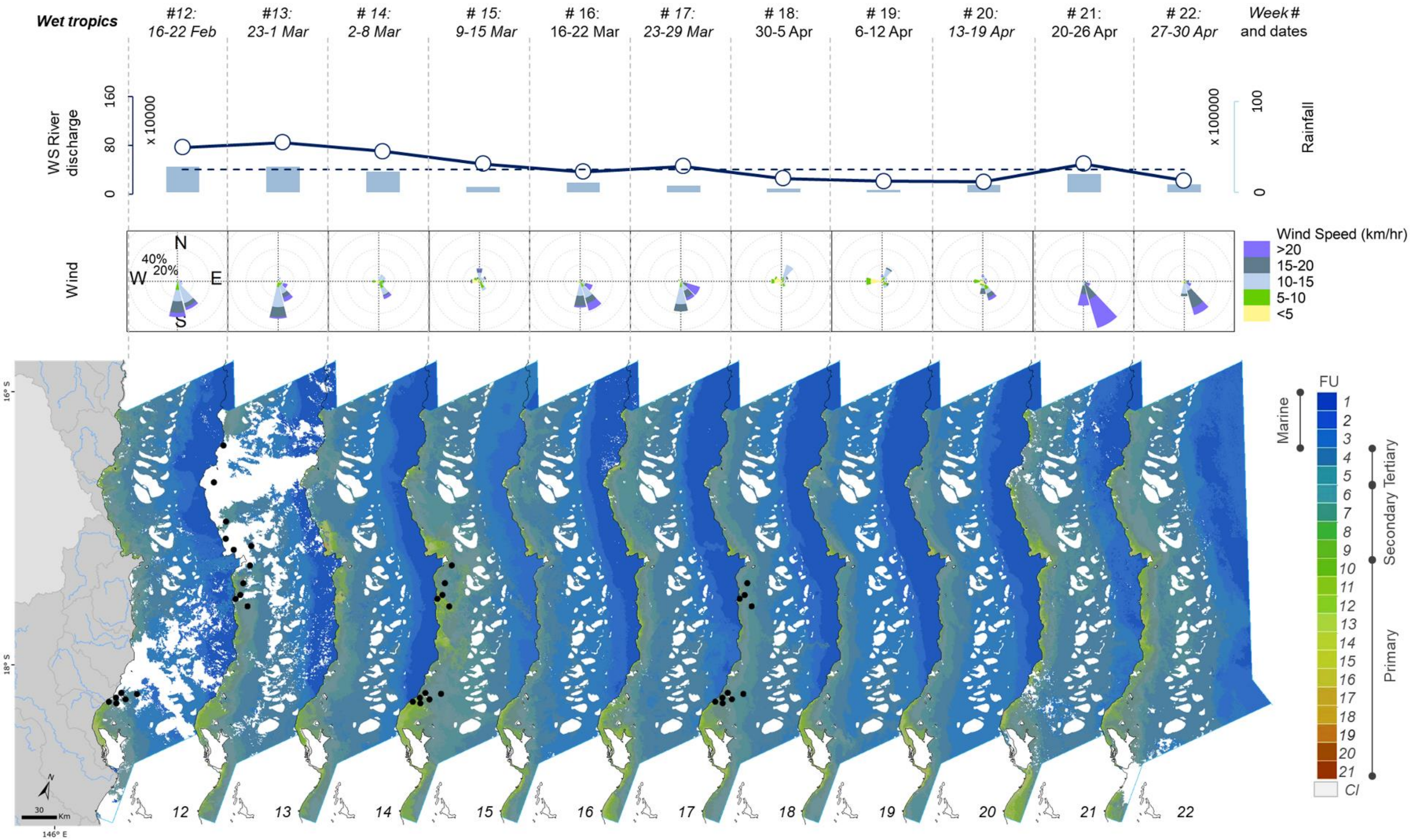


Figure 4-19. Panel of water quality and environmental characteristics in the Wet Tropics region throughout the 2022–23 wet season period: weeks 12 to 22. Includes: 2022–23 weekly river discharge (ML) and rainfall (ML); wind roses showing the wind direction and speed (km h^{-1}) for each week; and FU colour class maps showing the location of the *in situ* data collected (black dots). The mean long-term weekly river discharge is indicated by a dotted blue line. Weekly river discharges are the sum of discharge (ML) from the Daintree, Mossman, Barron, Mulgrave, Russell, North Johnstone, South Johnstone, Tully, Murray, and Herbert Rivers.

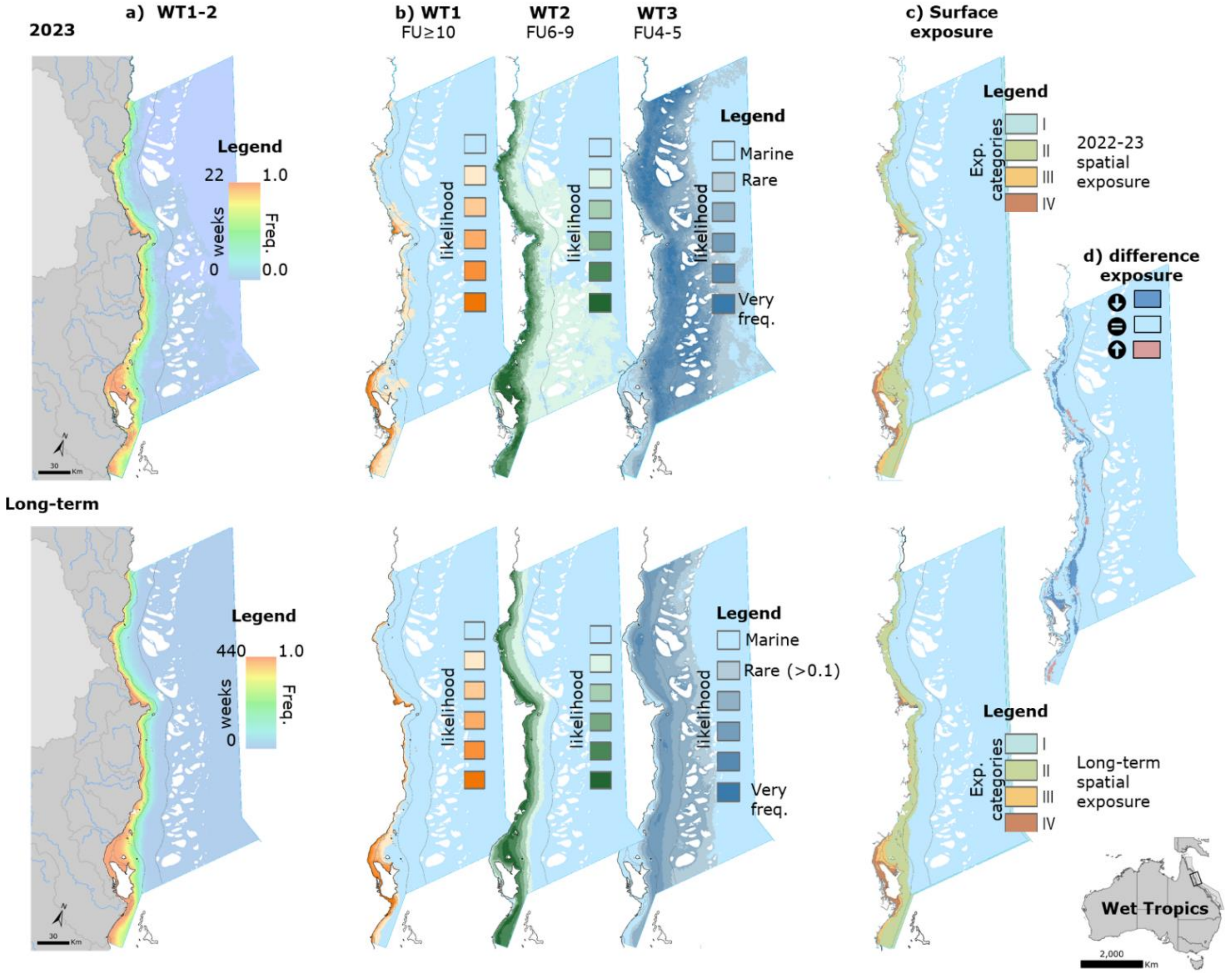


Figure 4-20: Long-term and 2022–23 remote sensing results for the Wet Tropics region showing the a) frequency of combined Reef WT1–2 II; b) the frequency of Reef WT1, WT2, and WT3 individually regrouped into five likelihood categories [<0.2 (Rare), 0.2–0.4, 0.4–0.6, 0.6–0.8 and 0.8–1 (very frequent)]; c) exposure to potential risk - each in the long-term (bottom) and 2022–23 wet season (top). d) Difference map showing any areas with an increase (in red, ➊) or decrease (in purple, ➋) in risk category in 2022–23 against long-term trends [calculated as (c, top)

exposure in 2023 minus (c, bottom) long-term]. Note that optical water types – especially Reef WT3– do not always correspond to direct catchment discharge and can also be due to oceanographic processes (see definitions in Table 2-2).

Table 4-3 presents the areas (km^2) and percentage (%) of Wet Tropics region, coral reef, and seagrass areas affected by different categories of exposure (or potential risk) based on satellite-derived wet season water maps.

The exposure categories are not validated against ecological health data and represent relative potential risk categories for both seagrass and coral reef ecosystems. Category I (no/very low risk) represents waters with ambient or detectable but low concentrations of the water quality parameters investigated and therefore low risk of any detrimental ecological effect. The areas and percentages of ecological communities affected by the different categories of exposure were calculated as a relative measure between regions and the long-term average.

In 2022–23, it was estimated that:

- Wet-Tropics wide: 89% of the Wet Tropics region was not exposed to a potential risk, similar to long-term patterns (88%, Table 4-3). 11% (or about 3,500 km^2) of the Wet Tropics region was exposed to combined potential risk categories II–IV. However, only 1% (352 km^2) of the region was in the highest exposure category (IV) and only 2% was in category III (578 km^2).
- Wet Tropics waterbodies: only the enclosed coastal and open coastal Wet Tropics waters were exposed to the highest categories of potential risk (III and IV). The open coastal area exposed was however spatially limited and corresponded to 9% (cat. III) and 1% (cat. IV) of the total Wet Tropics inshore area (Figure 4-7c). A total of 40% and 47% of the enclosed coastal areas were exposed to categories III and IV, respectively. The mid-shelf and offshore Wet Tropics waterbodies were largely exposed to no/very low risk (96% and 100% of the mid-shelf and offshore waterbodies).
- Wet Tropics habitats:
  - **Coral reefs:** 3% of coral reefs in the Wet Tropics region were exposed to a potential risk (combined potential risk categories II–IV, Table 4-3). Less than 1% of coral were in the highest exposure category (IV), 1% were in the category III (combined 37 km^2) and they were all enclosed coastal or open coastal reefs (Figure 4-21a). Only 3% (~80 km^2) of the Wet Tropics corals occur in the inshore waters (Appendix C-6).

    The open coastal coral area exposed to higher potential risk was limited and corresponded to 29% (cat. III) and 9% (cat. IV) of the total open coastal reef area in the Wet Tropics (Figure 4-21a). A total of 41% and 53% of the enclosed coastal areas were exposed to categories III and IV respectively. Mid-shelf and offshore reefs were largely exposed to no potential risk (>98% of the total mid-shelf and offshore reef areas in the Wet Tropics).
  - **Seagrasses:** A total of 98% (or 227 km^2) of seagrasses in the Wet Tropics region were exposed to a potential risk (combined potential risk categories II–IV, Table 4-3). A total of 27% (62 km^2) of seagrasses were in the highest exposure category (IV) and 20% (47 km^2) were in category III, and they were all inshore seagrasses (Figure 4-21b). 98% (~230 km^2) of the Wet Tropics seagrass occur in the inshore waters (Appendix C-6).

    The open coastal seagrass area exposed to higher potential risk was limited. It corresponded to 13% (cat. III) and 1% (cat. IV) of the total inshore coastal seagrass in the Wet Tropics (Figure 4-21b). A total of 26% and 46% of the total enclosed coastal seagrass were exposed to categories III and IV, respectively. Mid-shelf seagrasses were all classified as no / very low risk (100% of the Wet Tropics mid-shelf seagrasses).

- **Comparison with long-term trends:** The coral areas in the Wet Tropics region exposed to combined potential risk categories II–IV in 2022–23 were similar to the average long-term areas (changes <1%). The total seagrass areas exposed to the risk categories II–IV was similar to the long-term patterns (changes ≤5%). There was however a decrease in the seagrass area exposed to the highest potential risk categories (IV: -14% and III: -15%) toward the lowest potential risk category (II: +29%)

Table 4-3: Areas (km²) and percentages (%) of the Wet Tropics region, coral reefs, and surveyed seagrass affected by different risk categories of exposure during the 2022–23 wet season and the long-term (2003–2022). The last three rows show the differences between % affected in 2022–23 and the long-term average (red: increase, blue: decrease, green: no change, difference <5%).

Wet Tropics		Total		Potential Risk category: No / Very low (I)	Lowest (II)	III	Highest (IV)	Total area exposed II–IV
Surface area	area	31,976	2022-23	28,515	2,530	578	352	3,460
			LT	28,022	2,912	605	436	3,953
	%	*100%*	2022-23	89%	8%	2%	1%	11%
			LT	88%	9%	2%	1%	12%
Coral reefs	area	2,425	2022-23	2,348	41	24	13	78
			LT	2,349	41	29	7	77
	%	*100%*	2022-23	97%	2%	1%	1%	3%
			LT	97%	2%	1%	0%	3%
Surveyed seagrass	area	232	2022-23	5	118	47	62	227
			LT	5	51	82	95	227
	%	*100%*	2022-23	2%	51%	20%	27%	98%
			LT	2%	22%	35%	41%	98%
Difference (2022–23 to long-term average)	*Surface area*			1%	-1%	<-1%	<-1%	-2%
	Coral reefs			<-1%	<1%	<-1%	<1%	<1%
	Surveyed seagrass			<-1%	29%	-15%	-14%	<1%

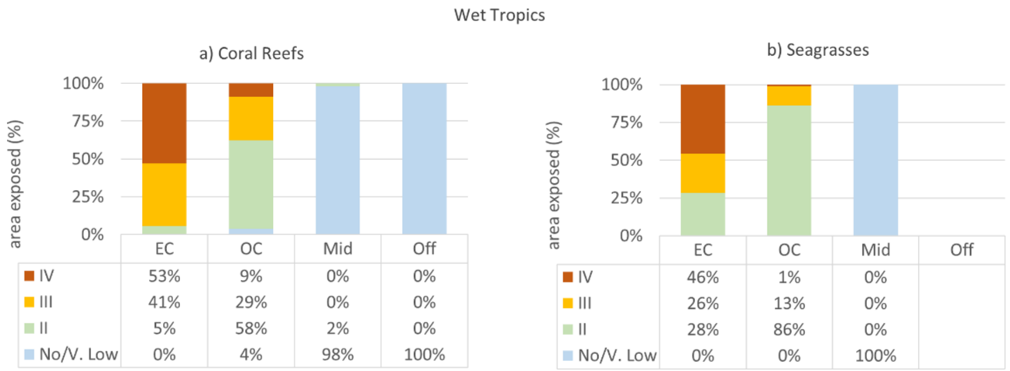


Figure 4-21: Percentage of the Wet Tropics region a) coral reef and b) surveyed seagrass habitats affected by different risk categories of exposure during the 2022–23 wet season. Water body classifications are shown along the x-axes: enclosed coastal (EC), open coastal (OC), mid-shelf (Mid), and offshore (Off).

4.3.3 Burdekin region

As described for the Reef, a number of remote sensing products were generated to represent wet season water quality conditions in the Burdekin region. These maps are presented in a panel of weekly characteristics throughout the 22 week wet season period (Figure 4-22 and Figure 4-23) and in Figure 4-24, which presents the frequency of the combined Reef WT1–2; the frequency of Reef WT1, WT2, and WT3 individually; the exposure maps – each in the long-term and 2022–23 wet season; and a difference map showing areas exposed to an increased risk in 2023. Details in the panels include river discharge, wind speed and direction, weekly maps of wet season colour classes, and the location and timing of *in situ* data collection.

The Sentinel monitoring products (when not obstructed by cloud cover as in weeks 8 and 12) clearly illustrated wet season surface water movements in the Burdekin region, as well as the influence of river discharge including changes in water colour from nutrient and sediment inputs and resuspension (Figure 4-22 and Figure 4-23). Discharge in the Burdekin region was 2.1 times greater than the long-term median during the 2022–23 wet season. Two flood events influenced the Burdekin region around mid-January (weeks 7–8) and one smaller around early February (weeks 10–12).

Weekly composites and the Reef WT1 likelihood map (Figure 4-24) of the Burdekin region showed that WT1 waters were confined next to the Burdekin River mouth and in the enclosed coastal waters most of the wet season. Burdekin WT1 waters (FU ≥10) reached the open coastal waters and the boundary between the open coastal and mid-shelf region in weeks 8–11, during the major discharge event of mid-January. Reef WT1 waters also reached the open coastal waters, including around Magnetic Island in weeks 8–11. Generally, WT1 waters had minimal impact on the open coastal and mid-shelf regions and ecosystems of the Burdekin region in 2022–23. Reef WT2 waters were largely confined to the open coastal water body most of the wet season.

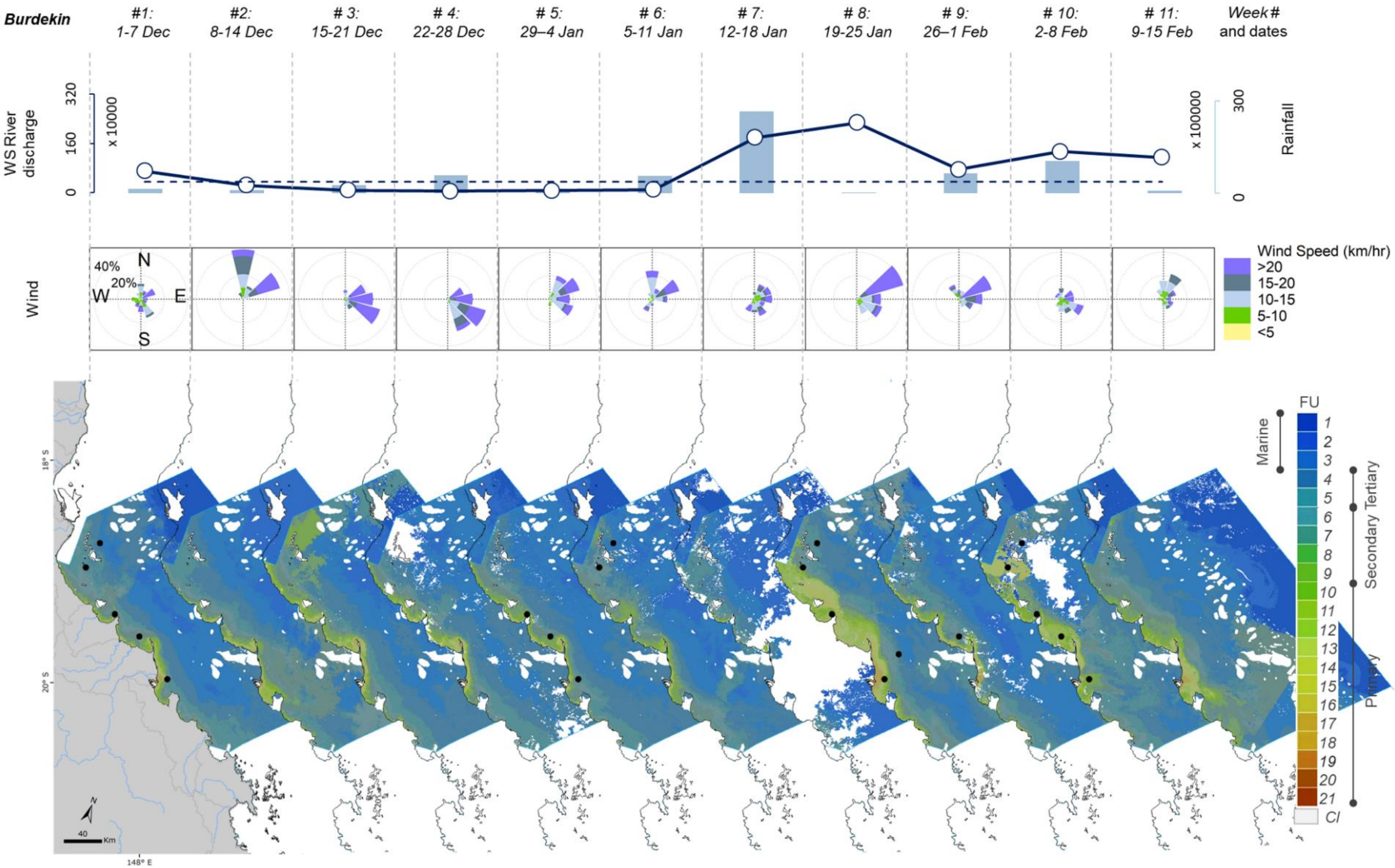


Figure 4-22. Panel of water quality and environmental characteristics in the Burdekin region throughout the 2022–23 wet season period: weeks 1 to 11. Includes: 2022–23 weekly river discharge (ML) and rainfall (ML); wind roses showing the wind direction and speed (km h[-1]) for each week; and FU colour class maps showing the location of the *in situ* data collected (black

dots). The mean long-term weekly river discharge is indicated by a dotted blue line. Weekly river discharges are the sum of discharge (ML) from the Black, Ross, Haughton, Burdekin, and Don Rivers.

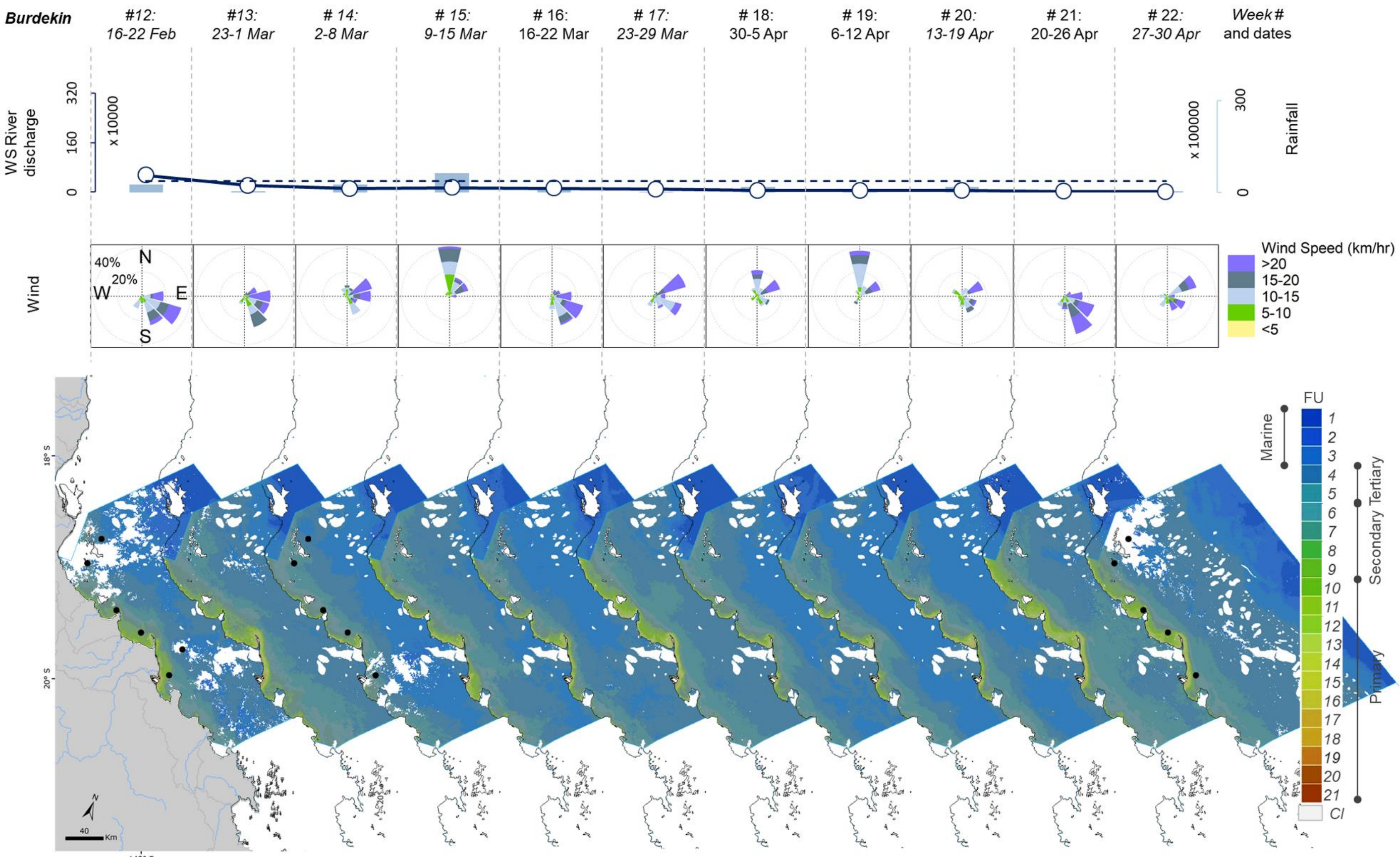


Figure 4-23. Panel of water quality and environmental characteristics in the Burdekin region throughout the 2022–23 wet season period: weeks 12 to 22. Includes: 2022–23 weekly river discharge (ML) and rainfall (ML); wind roses showing the wind direction and speed (km h^{-1}) for each week; and FU colour class maps showing the location of the *in situ* data collected (black

dots). The mean long-term weekly river discharge is indicated by a dotted blue line. Weekly river discharges are the sum of discharge (ML) from the Black, Ross, Haughton, Burdekin, and Don Rivers.

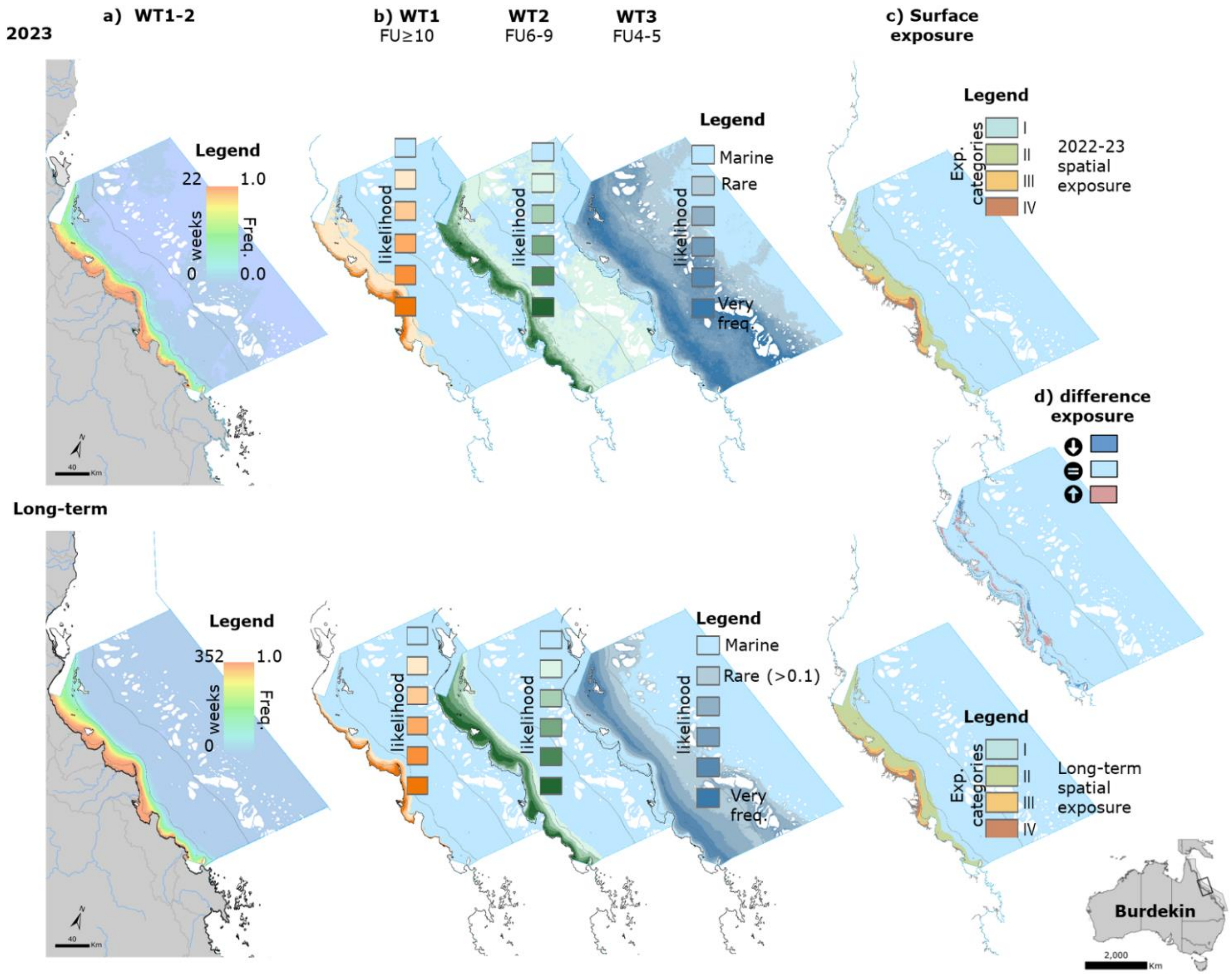


Figure 4-24: Long-term and current year remote sensing results for the Burdekin region showing the a) frequency of combined Reef WT1–2; b) the frequency of Reef WT1, WT2, and WT3 individually regrouped into five likelihood categories [<0.2 (Rare), 0.2–0.4, 0.4–0.6, 0.6–0.8 and 0.8–1 (very frequent)]; c) exposure to potential risk - each in the long-term (bottom) and 2022–23 wet season (top). d) Difference map showing any areas with an increase (in red, ➊) or decrease (in purple, ➋) in risk category in 2022–23 against long-term trends [calculated as (c, top) exposure in 2023 minus (c, bottom) long-term]. Note that optical water types – especially the Reef WT3 – do not always correspond to direct catchment discharge and can also be due to oceanographic processes (see definitions in Table 2-2).

Table 4-4 presents the areas (km^2) and percentage (%) of Burdekin region, coral reef, and seagrass areas affected by different categories of exposure (or potential risk) based on satellite-derived Reef water types.

The exposure categories are not validated against ecological health data and represent relative potential risk categories for seagrass and coral reef ecosystems. Category I (no/very low risk) represents waters with ambient or detectable but low concentrations of the water quality parameters investigated and therefore low risk of any detrimental ecological effect. The areas and percentages of ecological communities affected by the different categories of exposure were calculated as a relative measure between regions and the long-term average.

In 2022–23, it was estimated that:

- Burdekin-wide: 90% of the region was not exposed to a potential risk, similar to long-term patterns (90%, Table 4-4). 10% (or about 4,700 km^2) of the Burdekin region was exposed to combined potential risk categories II–IV. However, only 1% (694 km^2) of the region was in the highest exposure category (IV) and 2% (946 km^2) was in category III.
- Burdekin waterbodies: only the enclosed coastal and open coastal Burdekin waters were exposed to the highest categories of potential risk (III and IV). The open coastal area exposed was however spatially limited and corresponded to 15% (cat. III) and 2% (cat. IV) of the total Burdekin open coastal area (Figure 4-7c). 29% and 69% of the enclosed coastal areas were exposed to categories III and IV, respectively. The mid-shelf and offshore Burdekin waterbodies were largely exposed to no / very low risk (>98% of both waterbodies).
- Burdekin habitats:
  - **Coral reefs:** Approximately 1% of coral reefs in the Burdekin region were exposed to combined potential risk categories II–IV, with less than 1% in the highest exposure categories IV and III (combined 20 km^2, Table 4-4). Only 1% (<40 km^2) of the Burdekin corals occur in the inshore waters (Appendix C-6).

    The open coastal coral area exposed to higher potential risk was limited and corresponded to 48% (cat. III) and 1% (cat. IV) of the total open coastal reefs area in the Burdekin region (Figure 4-25a). A total of 25% and 75% of the enclosed coastal areas were exposed to categories III and IV respectively. Mid-shelf and offshore coral reefs were exposed to no risk (>99% in both waterbodies).
  - **Seagrasses:** 90% (or 634 km^2) of seagrasses in the Burdekin region were exposed to combined potential risk categories II–IV. 22% (156 km^2, Table 4-4) of seagrasses were in the highest exposure category (IV) and 26% (185 km^2) were in category III, and they were all inshore seagrasses (Figure 4-25b). A total of 99% (~700 km^2) of the Burdekin seagrasses occur in the inshore waters (Appendix C-6).

    The open coastal seagrass area exposed to higher potential risk was limited and corresponded to 27% (cat. III) and 1% (cat. IV) of the total inshore seagrass area in the Burdekin region (Figure 4-25b). A total of 25% and 75% of the enclosed coastal seagrass areas were exposed to categories III and IV respectively. Mid-shelf seagrasses were largely exposed to no / very low risk (94% of the Burdekin mid-shelf seagrasses).
  - **Comparison to long-term trends:** The coral and seagrass areas in the Burdekin region exposed to combined potential risk categories II–IV in 2022–23 were similar to the average long-term areas (± <2% change).

Table 4-4: Areas (km^2) and percentages (%) of the Burdekin region, coral reefs, and surveyed seagrass affected by different risk categories of exposure during the 2022–23 wet season and the long-term (2003–2022). The last three rows show the differences between % affected in 2022–23 and the long-term average (red: increase, blue: decrease, green: no change, difference <5%).

Burdekin		**Total**		**Potential Risk category**				**Total area exposed II–IV**
				No / very low	**Lowest Highest**			
				I	**II**	**III**	**IV**	
Surface area	area	47,009	2022–23	42,268	3,101	946	694	4,741
			LT	42,281	3,363	747	617	4,728
	%	*100%*	2022–23	90%	7%	2%	1%	10%
			LT	90%	7%	2%	1%	10%
Coral reefs	area	2,966	2022–23	2,932	15	15	5	34
			LT	2,924	28	12	3	42
	%	*100%*	2022–23	99%	0%	1%	0%	1%
			LT	99%	1%	0%	0%	1%
Surveyed seagrass	area	708	2022–23	74	292	185	156	634
			LT	88	311	154	156	621
	%	*100%*	2022–23	10%	41%	26%	22%	90%
			LT	12%	44%	22%	22%	88%
Difference (2022–23 to long-term average)	*Surface area*			<-1%	<-1%	<1%	<1%	0%
	Coral reefs			<1%	<-1%	<1%	<1%	0%
	Surveyed seagrass			-2%	-3%	4%	<1%	2%

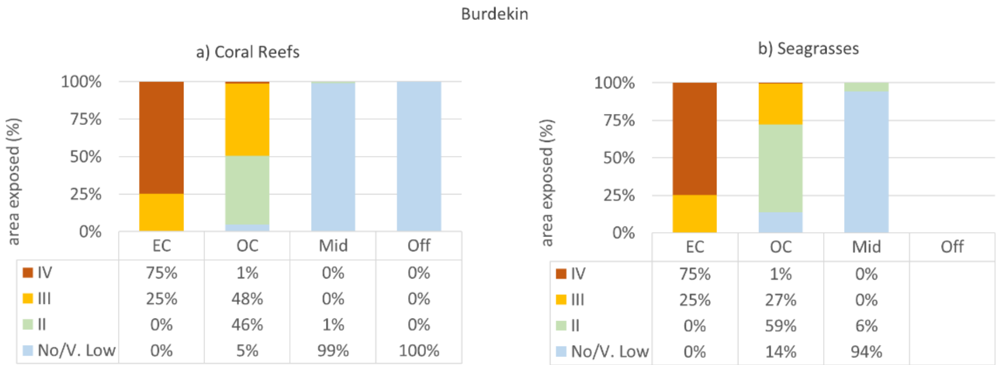


Figure 4-25: Percentage of the Burdekin region a) coral reef and b) surveyed seagrass habitats affected by different risk categories of exposure during the 2022–23 wet season. Water body classifications are shown along the x-axes: enclosed coastal (EC), open coastal (OC), mid-shelf (Mid), and offshore (Off).

4.3.4 Mackay-Whitsunday region

As described for the Reef, a number of remote sensing products were generated to represent wet season water quality conditions in the Mackay-Whitsunday region. These maps are presented in a panel of weekly characteristics throughout the 22 week wet season period (Figure 4-26 and Figure 4-27) and in Figure 4-28, which presents the frequency of the combined Reef WT1–2; the frequency of Reef WT1, WT2, and WT3 individually; the exposure maps in the long-term and 2022–23 wet season; and a difference map showing areas exposed to an increased risk in 2022–23. Details in the panels include river discharge, wind speed and direction, weekly maps of wet season colour classes, and the location and timing of *in situ* data collection.

The Sentinel-3 monitoring products (when not obstructed by cloud cover as in week 7) clearly illustrated wet season surface water movements in the Mackay-Whitsunday region, as well as the influence of river discharge including changes in water colour from nutrient and sediment inputs and resuspension (Figure 4-26 and Figure 4-27). Discharge in the Mackay-Whitsunday region was 2.0 times above the long-term median. One major flood event influenced the region during the 2022–23 wet season in mid-January (week 7), and a smaller one in early February (weeks 10–11, 2–15 February). The January 2023 event is described in more detail in Section 5.4.

Weekly composites and the Reef WT1 likelihood map (Figure 4-28) of the Mackay-Whitsunday region showed that WT1 waters were confined to the river mouths and in the enclosed coastal waters most of the wet season. WT1 waters reached the open coastal waters in week 8, following the major flood event, but WT1 flood waters had minimal impact on the open coastal and mid-shelf regions and ecosystems of the Mackay-Whitsunday region in 2022–23. Reef WT2 waters extended largely into the open coastal region from mid-January to the end of February. Similarly, WT3 waters also frequently affected the mid-shelf and offshore reefs of the Mackay-Whitsunday region in 2022–23, which did not seem to be linked to the riverine discharge in the region. Possible explanations include shelf upwelling or temperature-related influences.

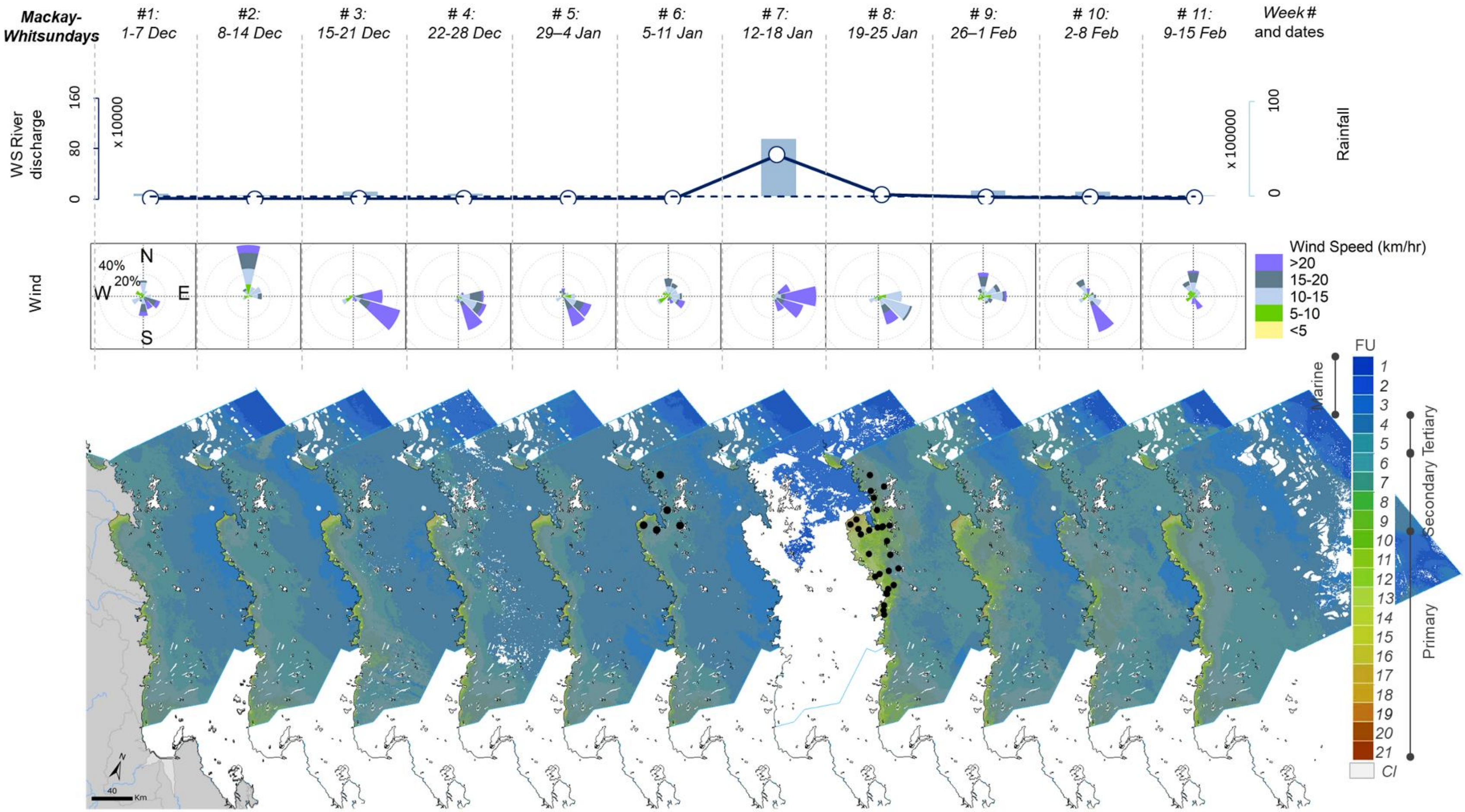


Figure 4-26. Panel of water quality and environmental characteristics in the Mackay-Whitsunday region throughout the 2022–23 wet season period: weeks 1 to 11. Includes: 2022–23 weekly river discharge (ML) and rainfall (ML); wind roses showing the wind direction and speed (km h^{-1}) for each week; and FU colour class maps showing the location of the *in situ* data. The mean

long-term weekly river discharge is indicated by a dotted blue line. Weekly river discharges are the sum of discharge (ML) from the O'Connell and Pioneer Rivers and Sandy Creek.

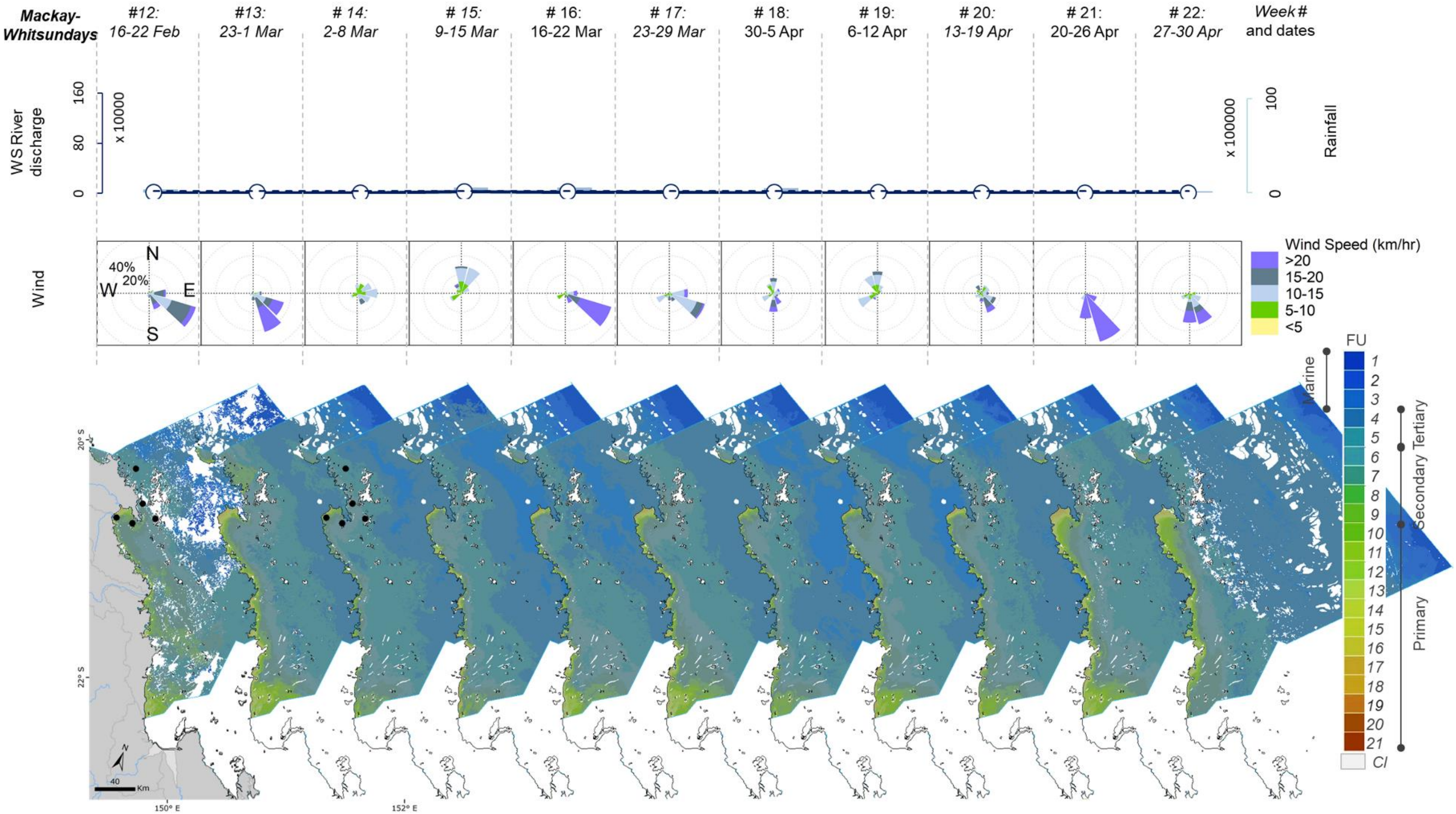


Figure 4-27. Panel of water quality and environmental characteristics in the Mackay-Whitsunday region throughout the 2022–23 wet season period: weeks 12 to 22. Includes: weekly river discharge (ML) and rainfall (ML); wind roses showing the wind direction and speed (km h^{-1}) for each week; and FU colour class maps showing the location of the *in situ* data. The mean long-

term weekly river discharge is indicated by a dotted blue line. Weekly river discharges are the sum of discharge (ML) from the O'Connell and Pioneer Rivers and Sandy Creek.

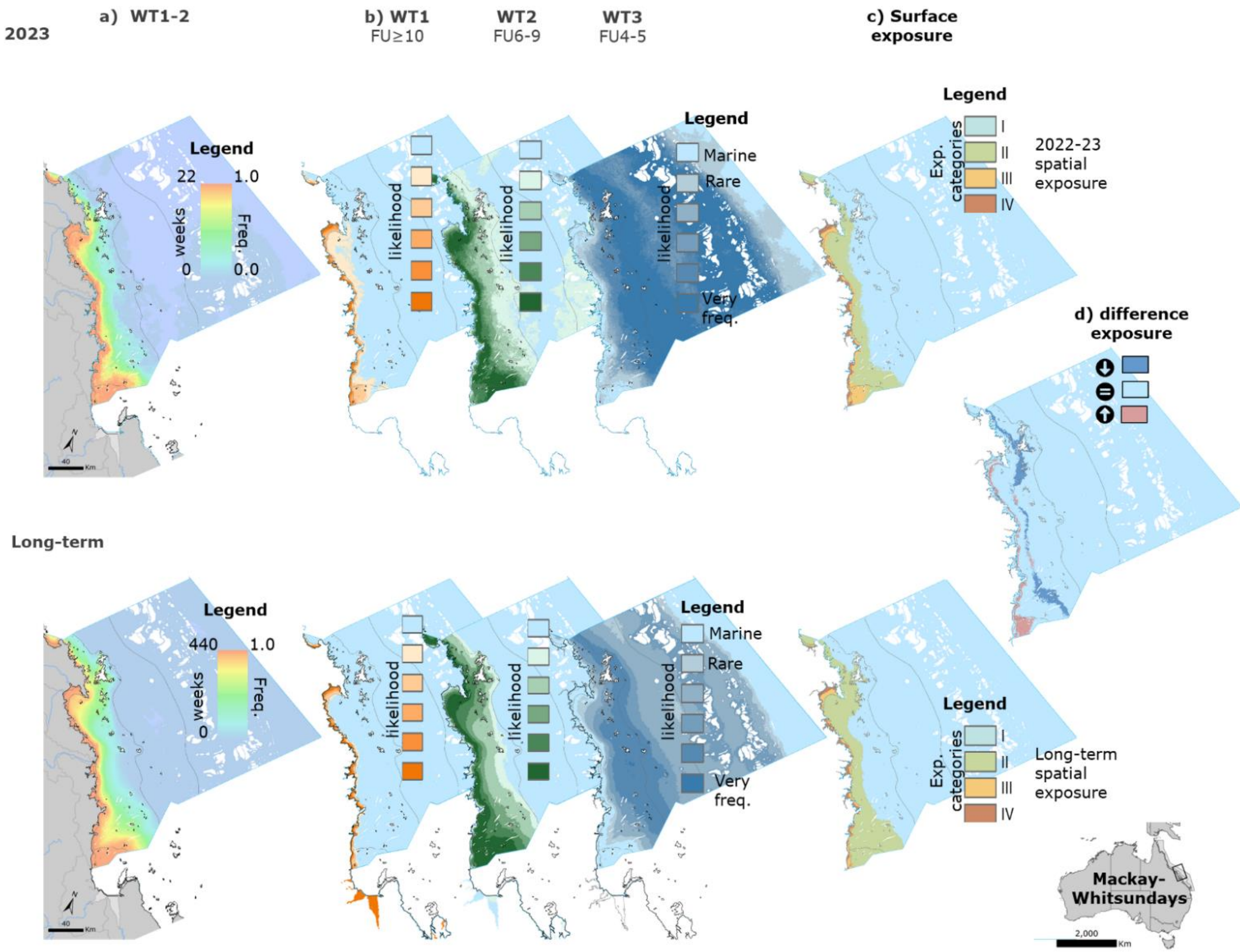


Figure 4-28: Long-term and current year remote sensing results for the Mackay-Whitsunday region showing the a) frequency of Reef WT1–2; b) the frequency of Reef WT1, WT2, and WT3 individually regrouped into five likelihood categories [<0.2 (Rare), 0.2–0.4, 0.4–0.6, 0.6–0.8 and 0.8–1 (very frequent)]; c) exposure to potential risk - each in the long-term (bottom) and 2022–23

wet season (top). d) Difference map showing areas with an increase (in red, ➊) or decrease (in purple, ➋) in risk category in 2022–23 against long-term trends [calculated as (c, top) exposure in 2023 minus (c, bottom) long-term]. Note that optical water types – especially the Reef WT3 – do not always correspond to direct catchment discharge and can also be due to oceanographic processes (see definitions in Table 2-2).

Table 4-5 presents the areas (km^2) and percentage (%) of Mackay-Whitsunday region, coral reef, and seagrass areas affected by different categories of exposure (or potential risk) based on satellite-derived Reef water types.

The exposure categories are not validated against ecological health data and represent relative potential risk categories for seagrass and coral reef ecosystems. Category I (no/very low risk) represents waters with ambient or detectable but low concentrations of the water quality parameters investigated and therefore low risk of any detrimental ecological effect. The areas and percentages of ecological communities affected by the different categories of exposure were calculated as a relative measure between regions and the long-term average.

Table 4-5: Areas (km^2) and percentages (%) of the Mackay-Whitsunday region, coral reefs, and surveyed seagrass affected by different risk categories of exposure during the 2022–23 wet season and the long-term (2003–2022). The last three rows show the differences between % affected in 2022–23 and the long-term average (red: increase, blue: decrease, green: no change, difference ≤5%).

Mackay-Whitsunday		Total		Potential Risk category				Total area exposed II–IV
				No / very low	Lowest		Highest	
				I	II	III	IV	
Surface area	area	48,957	2022–23	43,662	3,785	995	514	5,295
			LT	42,449	5,602	471	434	6,507
	%	*100%*	2022–23	89%	8%	2%	1%	11%
			LT	87%	11%	1%	1%	13%
Coral reefs	area	3,216	2022–23	3,084	78	38	16	133
			LT	3,019	166	25	7	197
	%	*100%*	2022–23	96%	2%	1%	0%	4%
			LT	94%	5%	1%	0%	6%
Surveyed seagrass	area	307	2022–23	49	135	53	71	258
			LT	10	186	36	76	297
	%	*100%*	2022–23	16%	44%	17%	23%	84%
			LT	3%	60%	12%	25%	97%
Difference (2022–23 to long-term average)	*Surface area*			2%	-4%	1%	<1%	-2%
	Coral reefs			2%	-3%	<1%	<1%	-2%
	Surveyed seagrass			13%	-16%	5%	-2%	-13%

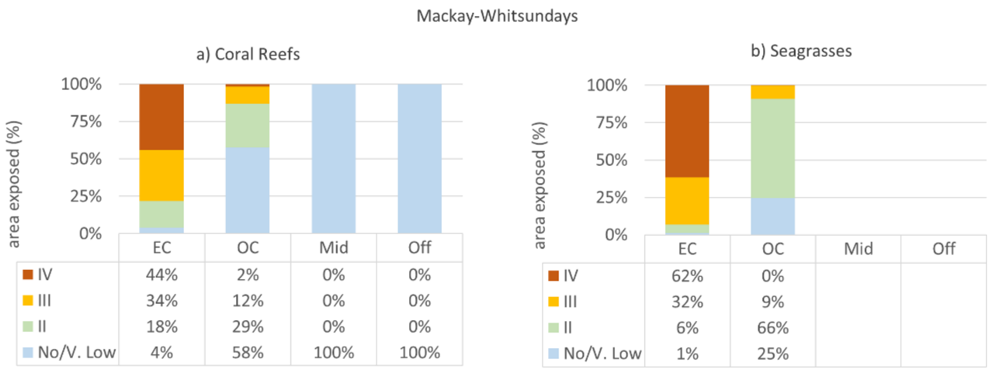


Figure 4-29: Percentage of the Mackay-Whitsunday region a) coral reef and b) surveyed seagrass habitats affected by different risk categories of exposure during the 2022–23 wet season. Water body classifications are shown along the x-axes: enclosed coastal (EC), open coastal (OC), mid-shelf (Mid), and offshore (Off).

In 2022–23, it was estimated that:

- Mackay-Whitsunday wide: 89% of the region was not exposed to a potential risk, similar to long-term patterns (87%, Table 4-5). A total of 11% of the Mackay-Whitsunday region was exposed to combined potential risk categories II–IV (or about 5,300 km^2). However, only 1% (514 km^2) of the region was in the highest exposure category (IV) and 2% (995 km^2) in category III.
- Mackay-Whitsunday waterbodies: only the enclosed coastal and open coastal waters were exposed to the highest categories of potential risk (III and IV, (Figure 4-7c). The open coastal area exposed was however spatially limited and corresponded to 6% (cat. III) of the total Mackay-Whitsunday inshore area. A total of 35% and 58% of the enclosed coastal areas were exposed to categories III and IV, respectively. The mid-shelf and offshore Mackay-Whitsunday waterbodies were not exposed to potential risk.
- Mackay-Whitsunday habitats:
  - **Coral reefs:** Approximately 4% (or 133 km^2) of coral reefs in the Mackay-Whitsunday region were exposed to combined potential risk categories II–IV (Table 4-5). However, less than 1% of coral were in the highest exposure category (IV) and 1% in category III (combined 54 km^2), and they were all enclosed coastal or open coastal reefs (Figure 4-29a). A total of 9% (< 300 km^2) of the Mackay-Whitsunday corals occur in the inshore waters (Appendix C-6).

    The open coastal coral area exposed to higher potential risk was spatially limited and corresponded to 12% (cat. III) and 2% (cat. IV) of the total open coastal reef area in the Mackay-Whitsunday region. A total of 34% and 44% of the enclosed coastal areas were exposed to categories III and IV respectively. Mid-shelf and offshore reefs were not exposed to a potential risk.
  - **Seagrasses:** All of the surveyed seagrass beds in the Mackay-Whitsunday region are located in the inshore area (Appendix C-6). Approximately 84% of seagrasses in the Mackay-Whitsunday region were exposed to combined potential risk categories II–IV (258 km^2, Table 4-5). A total of 23% (71 km^2) of seagrasses were in the highest exposure category (IV) and 17% (53 km^2) were in category III.

    The open coastal seagrass area exposed to higher potential risk was spatially limited and corresponded to 9% (cat. III) of the total open coastal seagrass area in the Mackay-Whitsunday region Figure 4-29b. Approximately 32% and 62% of the enclosed coastal areas were exposed to categories III and IV respectively.

- **Comparison with long-term trends:** The coral areas in the Mackay-Whitsunday region exposed to combined potential risk categories II–IV in 2022–23 were very similar to the long-term areas -2% change). There was a decrease in the seagrass area exposed to the lowest potential risk categories (II: –16%) toward the no/very Low risk category (I: +13%).

4.3.5 Fitzroy and Burnett-Mary regions

In 2022–23, water quality monitoring in the Fitzroy region continued in accordance with the MMP monitoring design via a separately funded project, and the results of this are included as Appendix D. There is still no formal water quality monitoring program in the Burnett-Mary region that is reported as part of the Paddock to Reef program. It should be noted that exposure maps have a higher degree of uncertainty in the Fitzroy and Burnett-Mary regions than in those described above due to limited validation from *in situ* monitoring. Discharge in the Fitzroy region was close to the long-term median (1.1 times higher) and in the Burnett Mary region was below the long-term median (0.8 times long-term median) (Figure 3-5).

As with all regions, the exposure categories are not validated against ecological health data and represent relative potential risk categories for seagrass and coral reef ecosystems. Category I (no/very low risk) represents waters with ambient or detectable but low concentrations of the water quality parameters investigated and therefore low risk of any detrimental ecological effect. The areas and percentages of ecological communities affected by the different categories of exposure were calculated as a relative measure between regions and the long-term average.

Fitzroy

Table 4-6 presents the areas (km^2) and percentage (%) of Fitzroy region, coral reef, and seagrass areas affected by different categories of exposure (or potential risk) based on satellite-derived wet season water maps. In 2022–23, it was estimated that:

- Fitzroy-wide: 93% of the Fitzroy region was not exposed to a potential risk, similar to long-term patterns (91%, Table 4-6). 7% (or about 6,500 km^2) of the Fitzroy region was exposed to combined potential risk categories II–IV. However, only 2% (1,723 km^2) of the region was in the highest exposure category (IV) and 1% (1,117 km^2) in category III.
- Fitzroy waterbodies: only the enclosed coastal and open coastal Fitzroy waters were exposed to the highest categories of potential risk (III and IV). The open coastal area exposed was however spatially limited and corresponded to 8% (cat. III) and 2% (cat. IV) of the total Fitzroy inshore area (Figure 4-7c). 45% and 40% of the enclosed coastal areas were exposed to categories III and IV, respectively. The offshore and mid-shelf Fitzroy waterbodies were not exposed to a potential risk.
- Fitzroy habitats:
  - **Coral reefs:** Approximately 3% of coral reefs in the Fitzroy region were exposed to combined potential risk categories II–IV (Table 4-6). 2% of coral were in the highest exposure category (IV) and 1% in category III (combined 66 km^2), and they were all enclosed coastal or mid-shelf reefs (Figure 4-30a). Only 4% (<200 km^2) of the Fitzroy corals occur in the inshore waters (Appendix C-6).

    The open coastal coral area exposed to higher potential risk was limited and corresponded to 23% (cat. III) and 1% (cat. IV) of the total open coastal coral reef area in the Fitzroy. Approximately 11% and 86% of the enclosed coastal areas were exposed to categories III and IV respectively. All of the mid-shelf and offshore reefs were classified as no / very low risk.

- **Seagrasses:** Approximately 65% (or about 310 km^2) of seagrasses in the Fitzroy region were exposed to combined potential risk categories II–IV (Table 4-6), which was over the long-term trends (10% or 49 km^2). 23% (109 km^2) of seagrasses were in the highest exposure category (IV) and 13% (61 km^2) were in category III, and they were all inshore seagrasses (Figure 4-30b). Approximately 81% (<400 km^2) of the Fitzroy seagrasses occur in the inshore waters (Appendix C-6).

  The open coastal seagrass area exposed to higher potential risk was limited and corresponded to 5% (cat. III) of the total open coastal seagrass area in the Fitzroy region (no open coastal seagrasses were exposed to the higher risk category IV). 35% and 73% of the enclosed coastal areas were exposed to categories III and IV respectively and 100% of the mid-shelf areas were exposed to the lowest risk category II.

- **Comparison with long-term trends:** The coral and seagrass areas exposed to highest potential risk categories II to IV were similar to the long-term patterns. There was a decrease in the seagrass area exposed to the risk cat. III and I (-8% and -22% toward the no/very low risk category (+25%).

Table 4-6: Areas (km^2) and percentages (%) of the Fitzroy region, coral reefs, and surveyed seagrass affected by different risk categories of exposure during the 2022–23 wet season and the long-term (2003–2022). The last three rows show the differences between % affected in 2022–23 and the long-term average (red: increase, blue: decrease, green: no change, difference ≤5%). Areas south of the Marine Park (Hervey Bay) are not included.

Fitzroy		Total		Potential Risk category: No / Very low – I	Lowest – II	III	Highest – IV	Total area exposed II–IV
Surface area	area	86,869	2022–23	80,439	3,591	1,117	1,723	6,430
			LT	78,805	5,265	1,189	1,610	8,064
	%	*100%*	2022–23	93%	4%	1%	2%	7%
			LT	91%	6%	1%	2%	9%
Coral reefs	area	4,881	2022–23	4,726	89	36	30	155
			LT	4,719	113	14	35	161
	%	*100%*	2022–23	97%	2%	1%	1%	3%
			LT	97%	2%	0%	1%	3%
Surveyed seagrass	area	478	2022–23	168	140	61	109	310
			LT	49	243	41	145	429
	%	*100%*	2022–23	35%	29%	13%	23%	65%
			LT	10%	51%	9%	30%	90%
Difference (2022–23 to long-term average)	*Surface area*			2%	-2%	<-1%	<1%	-2%
	Coral reefs			<1%	<-1%	<1%	<-1%	<-1%
	Surveyed seagrass			25%	-22%	4%	-7%	-25%

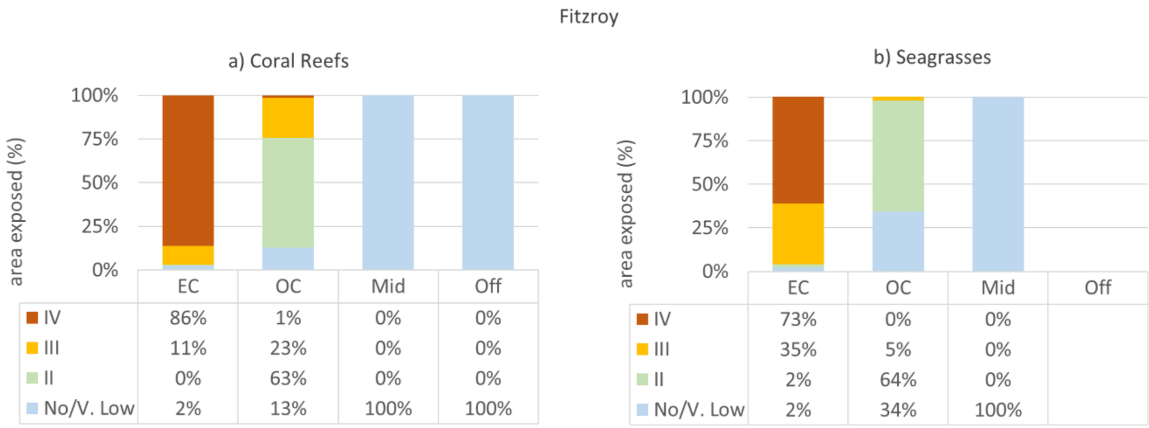


Figure 4-30: Percentage of the Fitzroy region a) coral reef and b) surveyed seagrass habitats affected by different risk categories of exposure during the 2022–23 wet season. Water body classifications are shown along the x-axes: enclosed coastal (EC), open coastal (OC), mid-shelf (Mid), and offshore (Off).

Burnett-Mary

Table 4-7 presents the areas (km^2) and percentage (%) of Burnett-Mary region, coral reef, and seagrass areas affected by different categories of exposure (or potential risk) based on satellite-derived wet season water maps.

In 2022–23, it was estimated that:

- Burnett-Mary wide: Approximately 98% of the Burnett-Mary region was not exposed to a potential risk, which was similar long-term patterns (96%, Table 4-7). 2% of the Burnett-Mary region (or about 751 km^2) was exposed to combined potential risk categories II–IV, with <1% in the highest exposure category (IV) and 1% in category III (combined 332 km^2).
- Burnett-Mary waterbodies: only the enclosed costal and open coastal Burnett-Mary waters were exposed to the highest categories of potential risk (III and IV). The open coastal area exposed corresponded to 8% (cat. III) and 2% (cat. IV) of the total Burnett-Mary inshore area (Figure 4-7c). A total of 45% and 40% of the enclosed coastal areas were exposed to categories III and IV respectively. 100% of the mid-shelf and offshore Burnett-Mary waterbodies were exposed to no / very low risk.
- Burnett-Mary habitats:
    - **Coral reefs:** Approximately 2% of coral reefs in the Burnett-Mary region were exposed to combined potential risk categories II–IV (Table 4-7). <1% of coral reefs were exposed to the highest risk categories III and IV (about 4 km^2) and these were all enclosed coastal or open coastal reefs (Figure 4-31a). Only 2% (<10 km^2) of the Burnett-Mary corals occur in the inshore waters (Appendix C-6).

      The open coastal coral area exposed to potential risk category III and IV corresponded to 64% and 9% of the total enclosed coastal and open coastal coral reef area in the Burnett-Mary region. The enclosed coastal area exposed to potential risk category III and IV corresponded to 36% and 41% of the total enclosed coastal area in the Burnett-Mary region. All of the mid-shelf coral reefs were exposed to no / very low risk. There are no offshore reefs in the Burnett-Mary region.
    - **Seagrasses:** Approximately 58% (or 150 km^2) of seagrasses in the Burnett-Mary region were exposed to combined potential risk categories II–IV (Table 4-7). 14% (37 km^2) of seagrasses were in the highest exposure category (IV) and 13% (33 km^2) were in category III and they were all enclosed coastal or open coastal

seagrasses (Figure 4-31b). A total of 71% (<200 km^2) of the Burnett-Mary corals occur in the inshore waters (Appendix C-6).

The open coastal seagrass area exposed to higher potential risk corresponded to only 1% (cat. III) of the total inshore seagrass area in the Burnett-Mary region. A total of 36% and 41% of the enclosed coastal seagrass areas were exposed to categories III and IV respectively 100% of the mid-shelf seagrasses in the Burnett-Mary region were exposed to the lowest risk category II.

- **Comparison to long-term trends:** The coral areas in the Burnett-Mary region exposed to combined potential risk categories II–IV in 2022–23 were similar to long-term areas. There was a decrease in the seagrass area exposed to the risk cat. II (-8% and -23% toward the no/very low risk category (+26%).

Table 4-7: Areas (km^2) and percentages (%) of the Burnett-Mary region, coral reefs, and surveyed seagrass affected by different risk categories of exposure during the 2022–23 wet season and the long-term (2003–2022). The last three rows show the differences between % affected in 2022–23 and the long-term average (: increase, : decrease, : no change, difference ≤5%). Areas south of the Marine Park (Hervey Bay) are not included.

Burnett-Mary		Total		Potential Risk category				Total area exposed II–IV
				No / Very low	Lowest		Highest	
				I	II	III	IV	
Surface area	area	37,713	2022–23	36,961	419	198	134	751
			LT	36,238	1,103	209	163	1,475
	%	*100%*	2022–23	98%	1%	1%	0%	2%
			LT	96%	3%	1%	0%	4%
Coral reefs	area	285	2022–23	279	1	4	0	6
			LT	279	3	3	0	6
	%	*100%*	2022–23	98%	1%	1%	0%	2%
			LT	98%	1%	1%	0%	2%
Surveyed seagrass	area	259	2022–23	109	80	33	37	150
			LT	43	140	30	46	217
	%	*100%*	2022–23	42%	31%	13%	14%	58%
			LT	17%	54%	12%	18%	83%
Difference (2022–23 to long-term average)	*Surface area*			2%	<-1%	<-1%	<-1%	-2%
	Coral reefs			<-1%	<-1%	<1%	<1%	<1%
	Surveyed seagrass			25%	-23%	1%	-4%	-25%

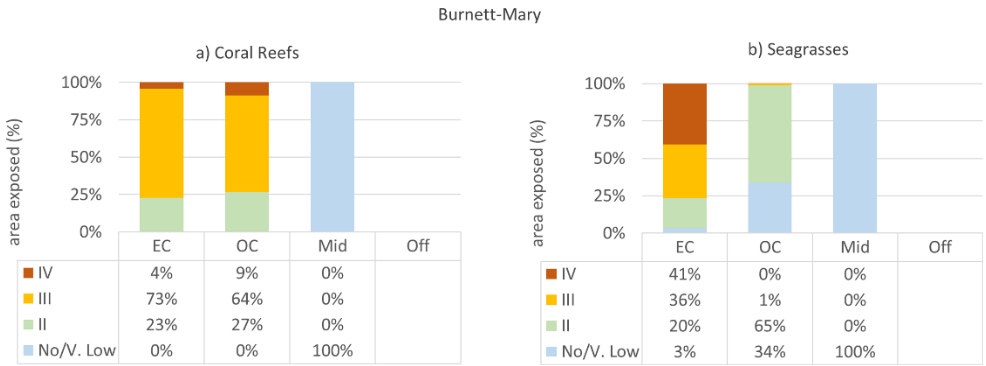


Figure 4-31: Percentage of the Burnett-Mary region a) coral reef and b) surveyed seagrass habitats affected by different risk categories of exposure during the 2022–23 wet season. Water body classifications are shown along the x-axes: enclosed coastal (EC), open coastal (OC), mid-shelf (Mid), and offshore (Off).

4.4 Modelling and mapping summary and discussion

Water type frequency maps (Sentinel-3 data)

Sentinel-3 satellite images of the reef and the Forel-Ule colour scale were used to produce map Reef water types instead of the MODIS imagery and the wet season colour scale for the third year. FU equivalent water types were defined by grouping the FU colour classes 1–3 as “Reef WT4” (equivalent to marine waters in the WS scale), FU colour classes 4–5 as “Reef WT3” (equivalent to WS Tertiary water type), FU colour classes 6–9 as “Reef WT2” (equivalent to wet season secondary water type) and FU≥10 as “Reef WT1” (equivalent to wet season primary water type), as defined in Petus *et al.* (2019) and Table 2-2.

Except for the ‘coral recovery period’, reference maps (long-term, wet, and dry frequency maps) were all updated for this report using a combination of MODIS-Aqua (wet seasons 2003 to 2020) and Sentinel-3 (wet seasons 2021 to 2023) satellite water type maps. The latest update was in the 2018–19 reporting (Gruber et al., 2020). The long-term reference maps now include 20 years of satellite imagery (2003 to 2022).

All mean long-term concentrations of water quality parameters were also reviewed for this report to improve the accuracy of the water type characterisation building on the additional field data that is collected every wet season. TSS (80 samples) and Chl-*a* (110 samples) data collected as part of a pilot program in partnership with the Reef Trust Partnership Crown of Thorns Starfish Control Program (Waterhouse et al., 2023) were also included in the analyses. The dataset, largely collected in the mid-shelf to offshore waterbodies, helped progress the characterisation of the Reef WT4 even though much more data are still needed (Table 2-2). The colour class category and water type corresponding to the location and week of acquisition of each water quality sample were extracted from the archive of MODIS-Aqua (wet seasons from 2004) and Sentinel-3 (wet seasons from 2021) weekly colour class maps.

This year’s results are in agreement with previous results and confirmed that Sentinel-3 satellite data and the FU scale are useful for mapping Reef optical water types. Sentinel maps showed an inshore-to-offshore spatial pattern similar to the well-documented MODIS patterns (for example, Waterhouse *et al.*, 2021), with the highest frequency of the Reef WT1 (typically enriched in sediment and dissolved organic matter, brownish turbid waters) in the inshore waterbody, and more particularly in the enclosed coastal waters. Mid-shelf waterbodies were most frequently exposed to the Reef WT2 and WT3, and offshore waterbodies were most frequently exposed to the Reef WT3 (typically with low land-based contaminant concentrations and including the influence of oceanographic processes).

Only 4% of the Reef (inshore waters only) was exposed to Reef WT1 waters during the 2022–23 wet season, and 21% was exposed to Reef WT2, which is similar to the pattern for the long-term and representative coral recovery periods. As observed in previous years, the Reef area exposed to Reef WT3 was larger than all reference periods (62% of the Reef), including the 'wet' years (58% of the Reef). This result is related to anomalously large Reef WT3 areas measured in the mid-shelf and offshore, which are almost certainly due to oceanographic processes such as upwelling rather than direct catchment discharge influence. This should be further investigated in a future case study by comparing the Reef WT3 maps with sea surface temperature climatology (for example, Wijffels et al., 2018) or by using the eReefs model to investigate whether the Reef WT3 waters are due to processes not influenced by catchment discharges. Oceanographic processes that influence water colour might in turn be influenced by climate change, which would require further investigation.

Exposure maps (Sentinel-3 and field water quality data)

Reef WT3 waters are associated with low land-based contaminant concentrations with only the long-term mean PN concentration above the wet season GV in the Reef WT3, and a low magnitude score in the Reef exposure assessment (Figure 4-5). While Reef WT3 areas in 2022–23 were larger than expected, this did not result in increasing the Reef-wide potential risk. The total Reef area exposed to a potential risk in 2022–23 was spatially limited and similar to the long-term patterns. Ninety one percent of the Reef was exposed to no/very low potential risk and only 3% (but about 10,000 km^2) of the Reef was in the highest exposure categories III and IV.

The offshore and mid-shelf and waterbodies were largely classified as no/very low potential risk (97% and 100%, respectively), and this pattern was observed in all Reef regions. Open coastal waters were largely exposed to the lowest category of risk (II, 46% of the open coastal waterbody) or to no/very low risk (44% of the open coastal waterbody), and only 9% and 2% of the open coastal waters were exposed to the highest potential risk categories III and IV. The Reef enclosed coastal waters had the highest relative potential risk, with 28% and 48% of the enclosed coastal waters exposed to categories III and IV, respectively. This, however, represent a very small proportion of the total size of the Reef (less than 2% of the Reef). The Cape York and Burdekin region open coastal waterbodies had the greatest exposure to risk categories III (17% and 15% of the Cape York and Burdekin open coastal waterbodies), with all other regions between 6% and 9% (Figure 4-7).

As a result, mid-shelf and offshore Reefs habitats (surveyed seagrass and coral reefs) were either exposed to the lowest risk category II or to no potential risk. Open coastal seagrasses and coral reefs were largely exposed to the lowest category of risk (II, 64% and 47% of the total Reef seagrass and coral areas, respectively). Enclosed coastal habitats were the most at risk, with 91% (less than 1% of the total coral reef area of the Reef) and 84% (~24% of the total seagrass area in the Reef) of the total enclosed coastal seagrasses and corals in the Reef classified as combined category II–IV. Enclosed coastal areas are shallow regions of the Reef and it is likely that wind-driven resuspension (some of which was originally derived from river discharge in previous events) may influence the TSS concentrations and resulting exposure results in this very inshore region.

Habitat areas exposed to a potential risk (combined risk categories II–IV) were largely similar to the long-term patterns in all regions (≤5% change) (Figure 4-32). There was, however, an increase in coral areas exposed to the lowest risk category (II) (+10%), and an increase in seagrass areas exposed to the risk category III in the in the Cape York region which was consistent with the high discharge measured in 2022–23 (2.1 times the long-term median).

There was a decrease in the seagrass area exposed to the lowest potential risk (cat. II) toward the no/very low risk category in the Mackay-Whitsunday, Fitzroy, and Burnett-Mary regions.

It should be noted there are several caveats to the exposure maps:

- Reef-wide water quality GVs are applied rather than site or waterbody-specific GVs.
- This assessment does not take into account the current condition of Reef ecosystems and long-term impacts on these communities. For example, it is recognised that inshore communities may have adapted to the most turbid Reef water types and exposure history; therefore, the highest risk of an ecological response could be during large events when Reef WT1 and WT2 extend into otherwise low exposure (more offshore) areas.
- Reporting the areas of coral reefs and seagrass in the highest potential exposure categories cannot be assessed in terms of ecological relevance at this stage and is included as a comparative measure between regions and between years.
- One-week exposures are reported. The ecological consequence of exposure of this duration is not presently known.
- The degree of validation against *in situ* data varies between regions, with limited water quality data in the Fitzroy and Burnett-Mary regions.
- It is impossible to fully separate the direct influence of riverine plume from wind- and wave-driven sediment resuspension in optical satellite images, and this may particularly influence exposure results in the shallow enclosed coastal Reef waters. Similarly, it is impossible at this stage to separate catchment versus oceanographic processes in offshore Reef WT3 waters.

Satellite methods and tools developed though the MMP to map Reef water types have now proved to be efficient for the mapping of water quality trends. However, there is a need to keep integrating spatial and temporal information obtained from the water type maps and *in situ* water quality measurements with environmental data to better understand physical influences that can lead to light reduction and water colour changes in both wet and dry seasons, and from the inshore to offshore Reef. Multivariate statistical analyses would be useful to gain further understanding of these processes. Furthermore, it would be interesting to collect extra samples in the transition zone between Reef WT1 and WT2 in the future to better understand drivers of water colour variability there and further characterise concentrations and productivity in this region of flood plumes. Furthermore, there might also be a need to discard water quality samples collected in the enclosed coastal waters in the characterisation of the water type composition (Section 2.6.2) and the calculations of the exposure scores (Figure 4-5), as GVs for enclosed coastal waters are different from other areas of the Reef. This however would discard important water quality information collected in the higher turbidity part of flood plumes. Separating the enclosed coastal waters information in the exposure assessment process and applying higher water quality guideline values to these samples should however be investigated in a future case study to improve the accuracy of the risk classification.

Finally, there is a major gap in the availability of *in situ* water quality data in the Burnett-Mary region and in mid-shelf and offshore waterbodies across the Reef. These data are essential for improving confidence in the remote sensing products across all regions and waterbodies. The pilot study to investigate options for water quality sampling as part of the Reef Trust Partnership Crown of Thorns Starfish Control Program (Waterhouse et al., 2023.) is a good example of the opportunities that exist to expand these water quality datasets. The pilot study also highlighted the potential of using a Smartphone app, the Eye on Water (https://www.eyeonwater.org/) to collect vessel-based Forel-Ule colour information. Using the Eye on Water app concomitantly to the water quality data allowed retrieval of water colour information at the exact site location, even when satellite images are obscured by clouds. It thus increases the number of data available to match up concentrations of water quality parameters and the four Reef water types and can help improve the characterisation of water quality concentrations across Reef water types. Using the Smartphone water colour data in combination to the satellite FU data could, in the future, improve the mapping of water quality patterns in the Reef and should be investigated for greater integration in the MMP.

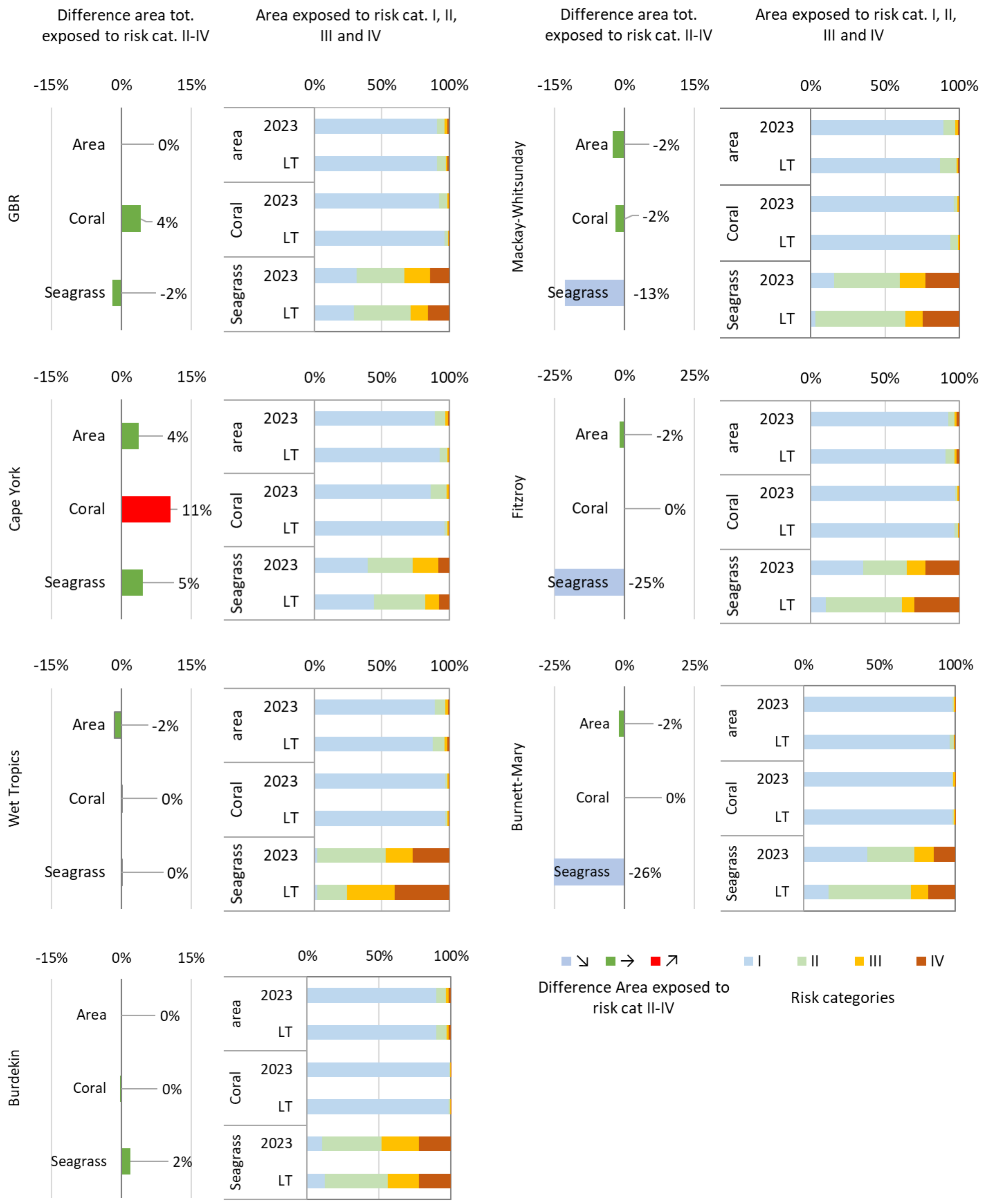


Figure 4-32: Areas (km²) and percentages (%) of the Reef and Reef regions, coral reefs, and surveyed seagrass affected by different risk categories of exposure during the 2022–23 wet season and the long-term (2003–2022). The left figures show

the differences between % affected in 2022–23 and the long-term average (red: increase, blue: decrease, green: no change, difference ≤5%). Note the different x-axis scale for the Fitzroy and Burnett-Mary difference plots.

River-derived DIN, TSS, and PN loading maps

The estimated wet season river-derived DIN, TSS, and PN loading in the Reef lagoon for the 2022–23 water year showed an area of influence that is similar to other years with close to long-term median discharge. Only relatively small differences were shown between the 2022–23, pre-development, and anthropogenic loading scenarios at the scale of the whole Reef, with an area of greater anthropogenic DIN loading in the Wet Tropics and Burdekin regions and anthropogenic TSS loading in the Burdekin region.

Over the extended dataset, the NRM regions typically presenting higher loading are:

- DIN: Wet Tropics, Burdekin, and Mackay-Whitsunday;
- TSS: Burdekin, and to a lesser extent, Fitzroy; and
- PN: Burdekin, and to a lesser extent, Princess Charlotte Bay in Cape York (low confidence), Wet Tropics, and Fitzroy.

Note that the limitations of the previous model which was driven by average wind conditions that are typically represented in a south-easterly direction was addressed in Gruber *et al*. (2020) by using the eReefs hydrodynamic model and adopting the tracer outputs to represent dispersal. The model is only available from 2010 (and in 2017 due to model error), so results prior to that are assumed using the multiannual average tracer output but using the annually-specific end-of-catchment loads. Further investigation of the results in the context of *in situ* concentrations of water quality parameters over time is the next step. However, it is unlikely at this stage that there is sufficient *in situ* data across the Reef to fully validate these results, particularly in the offshore and southern areas of the Reef.

The next steps for refinement remain the same as those identified in the 2018–19 report (Gruber et al., 2020), which highlighted that a decay function for modelled material should be incorporated to account for removal from the system. For DIN, a measure of the influence of river DIN rather than actual DIN concentrations is required; if phytoplankton take up DIN but it is still in the system, it should still be counted, so rather than an uptake rate, a removal rate is necessary (incorporating losses due to burial, denitrification and perhaps uptake by benthic biota).

5 Focus region water quality and Water Quality Index

The following sections provide detailed analysis of key water quality variables in focus regions in the context of local environmental drivers, specifically focused on the annual water quality condition and long-term trends. Monitoring results from the duration of the MMP (since 2005) are used to provide context for interpreting recent monitoring. For each of the four focus regions, the following information is included and discussed (except Cape York where data are presented differently, as some aspects of monitoring in this region differ from other regions):

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

Site-specific data and additional information are presented in Appendix C and include:

- Appendix C-1 Figure C - 1: Time-series of chlorophyll and turbidity measured by moored FLNTUSB instruments;
- Appendix C-2 Figure C - 2: Time-series of temperature and salinity measured by moored Sea-Bird Electronics instruments;
- Appendix C-3 Table C - 1: Cape York, Wet Tropics, Burdekin and Mackay-Whitsunday: Summary statistics for each water quality variable from each monitoring location, October 2022 to September 2023;
- Appendix C-3 Table C - 2: Annual summaries of moored FLNTUSB turbidity measurements for each monitoring location, including percentage exceedances of GVs; and
- Table C - 3 to Table C - 8: Summary of water quality data (collected as part of the JCU event-based sampling) across the Reef colour classes and water types.

5.1 Cape York region

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

Water quality monitoring commenced in the Cape York region as part of the MMP in January 2017. Twenty-one sites in four focus regions (Figure 5-1) are sampled four to five times per year during ambient conditions. Additional event samples are collected depending on the location and accessibility of flood plumes at these and additional sites (Appendix A). Ambient sampling primarily occurs between November to April (wet season) due to strong trade winds (>25 km h^{-1}) preventing access during the winter months.

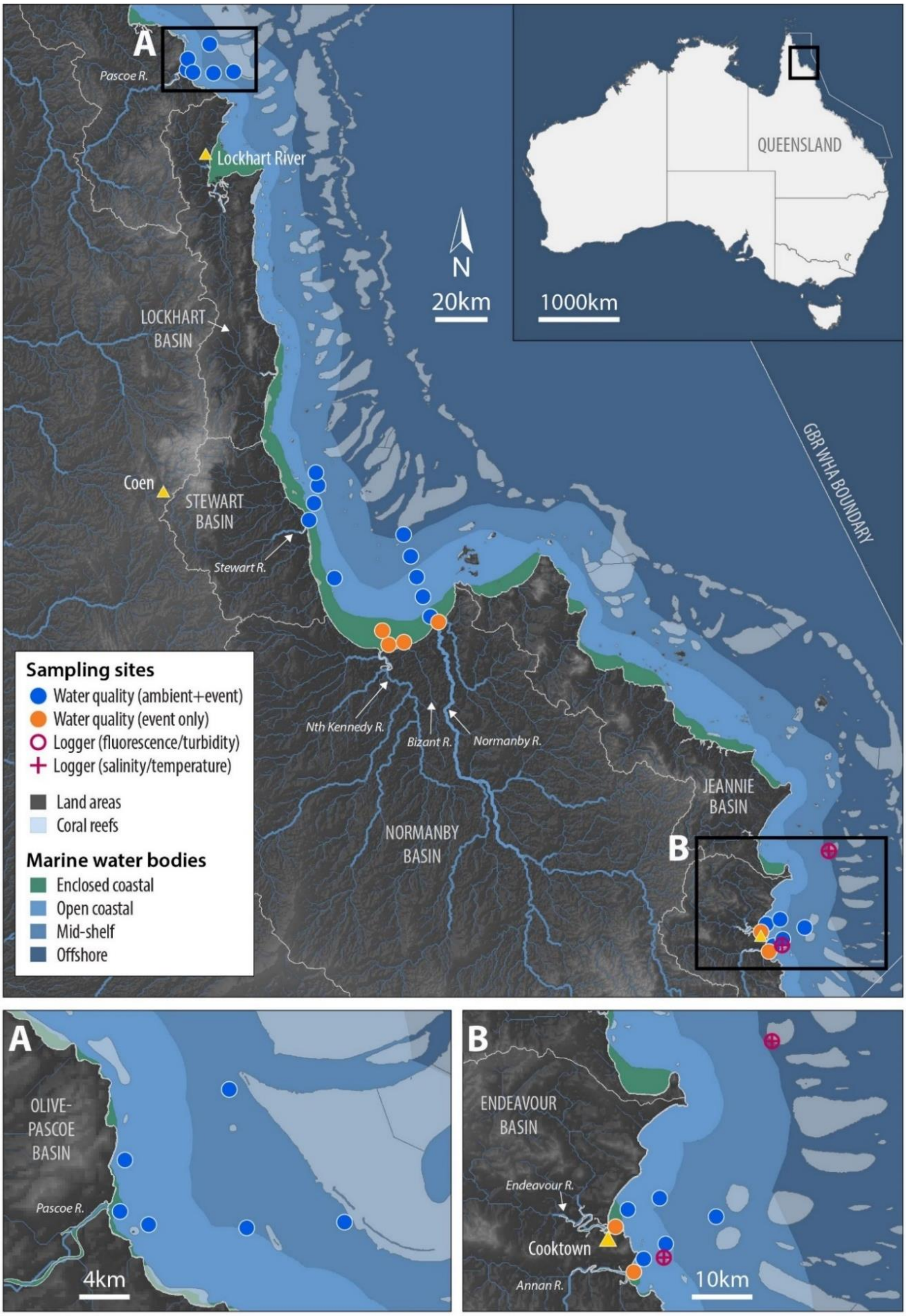


Figure 5-1: Water quality sampling sites in the Cape York region shown with water body boundaries. River datasets for map courtesy Grill *et al.* (2019).

The 2022–23 water year is the seventh year of sampling for the Cape York region. In consultation between CYWP, AIMS, and the Reef Authority, the laboratory analysis methods and the number of sites sampled in Cape York changed in 2020 (Moran *et al*., 2023). Because of this change, long-term trends cannot yet be assessed. Water quality results within each focus region have been assessed relative to distance from river mouths and compared against the Eastern Cape York Water Quality Guidelines for the enclosed coastal, open coastal, mid-shelf and offshore water bodies (State of Queensland, 2020). For comparison with the GVs, water quality results have been categorised as ambient wet season, ambient dry season, or event based on an evaluation of the river hydrograph at the time of sampling, antecedent rainfall, salinity measurements, and field observations. The annual condition Water Quality Index has also been calculated for each focus region. This Index is based on the current year only and not a comparison against previous data. Due to the limited number of years that the annual condition WQ Index has been generated for Cape York, a "coaster" format has been used to present the scores, rather than the time-series format used in other regions.

The Cape York region received a 'good' annual Water Quality Index score for the 2022–23 monitoring year (Figure 5-2). While this overall score was the same as score for the 2021–22 monitoring year, there were some changes and variations within the focus regions. Both the Annan-Endeavour and Pascoe focus regions received a 'good' annual score (0.49 and 0.04, respectively) while the Normanby and Stewart focus regions received 'moderate' scores for the 2022–23 year (-0.05 and -0.10, respectively). These scores are generated as described in Appendix B and are averaged to generate the overall regional score. Total discharge for the Cape York region over the 2022–23 water year was more than double the long-term median discharge for the region. The focus region scores are presented in the following sections along with more detailed information on the sub-indicators that are used to calculate the annual WQ Index and the drivers and pressures seen within each focus region over the 2022–23 water year.

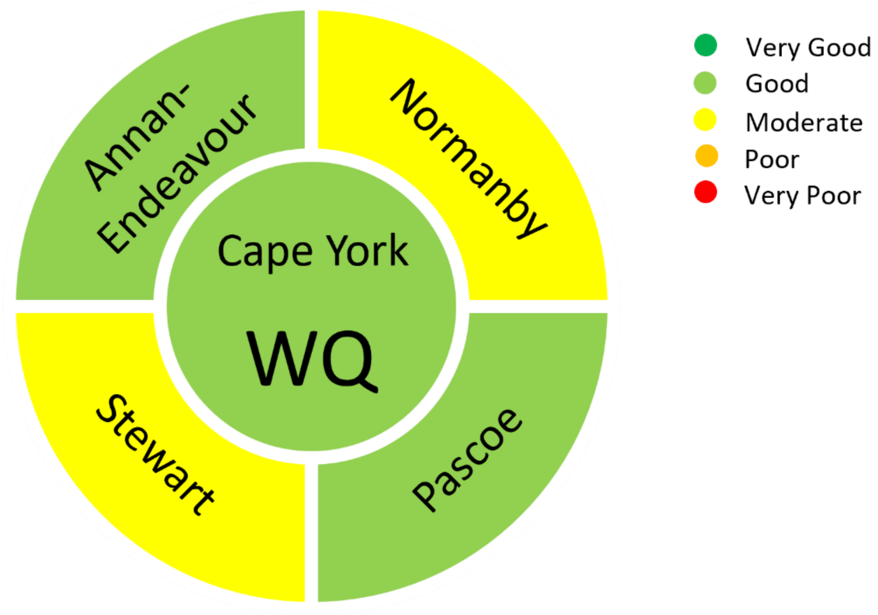


Figure 5-2: Annual condition version of the WQ Index for the Cape York Region for 2022–23. Calculations for WQ Index formulations are described in Appendix B.

5.1.1 Pascoe

The Pascoe focus region is influenced primarily by discharge from the Pascoe and Olive Rivers. Six sampling sites (Figure 5-3) are located along two transects to the northeast and southeast from the Pascoe River mouth out to Eel Reef and past Middle Reef (locally known as Blue Bells). Floodwaters have been observed flowing in both directions depending on wind and other local conditions. Enclosed coastal waters near the mouth of the Pascoe and site PRS01 are highly turbid due to tidal and wind-driven resuspension of shallow sediments.

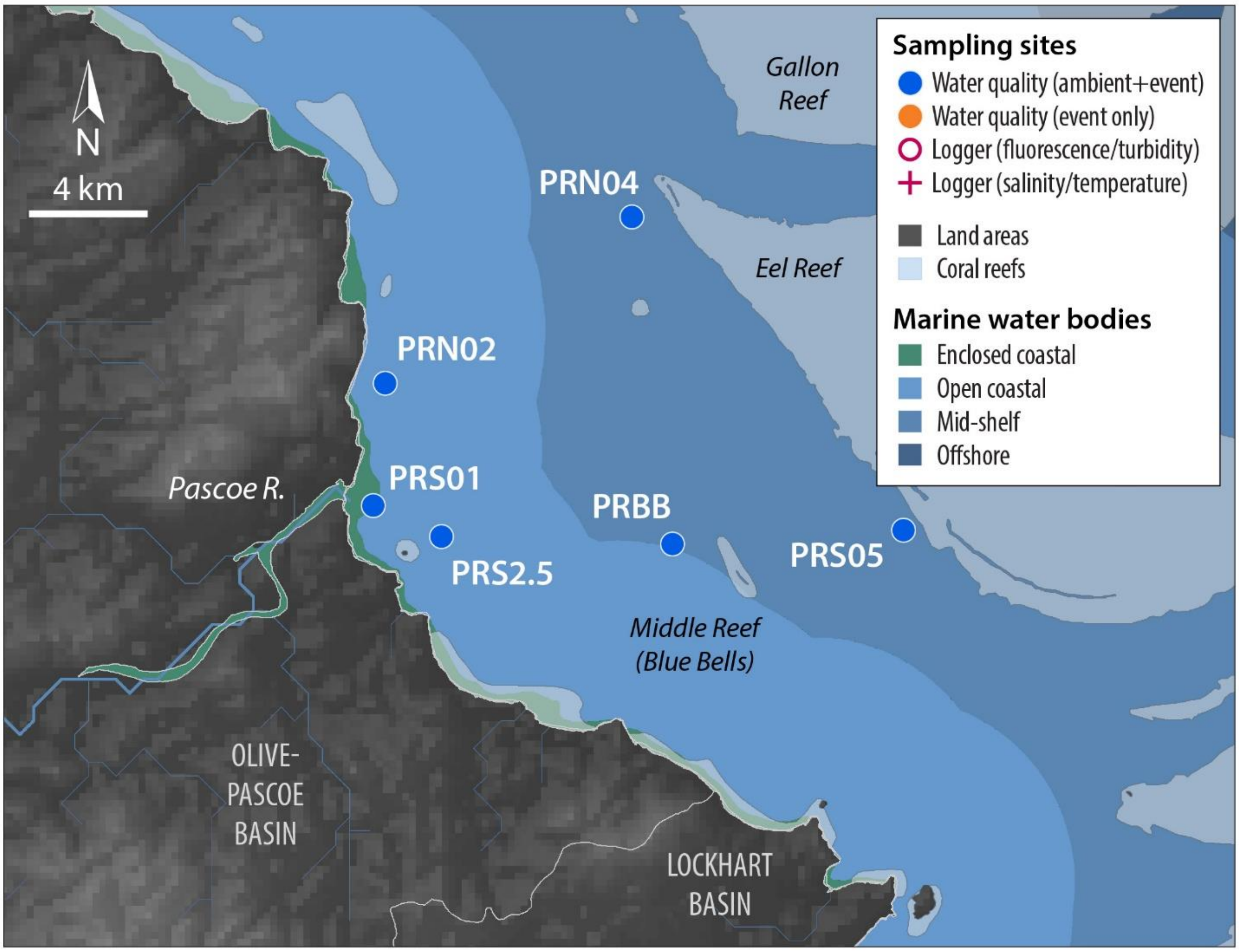


Figure 5-3: Water quality sampling sites in the Pascoe River transect with water body boundaries.

The Pascoe River transect was sampled four times under ambient wet season conditions and once under ambient dry season conditions from October 2022–May 2023 (Figure 5-4). A total of 42 samples were collected. Total discharge for the year was approximately twice the annual median discharge (Figure 5-5), with one major flood event peaking on 21 January (Figure 5-4). Significant rainfall continued into July, although the downstream river gauge did not record discharge after April and total discharge volumes are therefore uncertain.

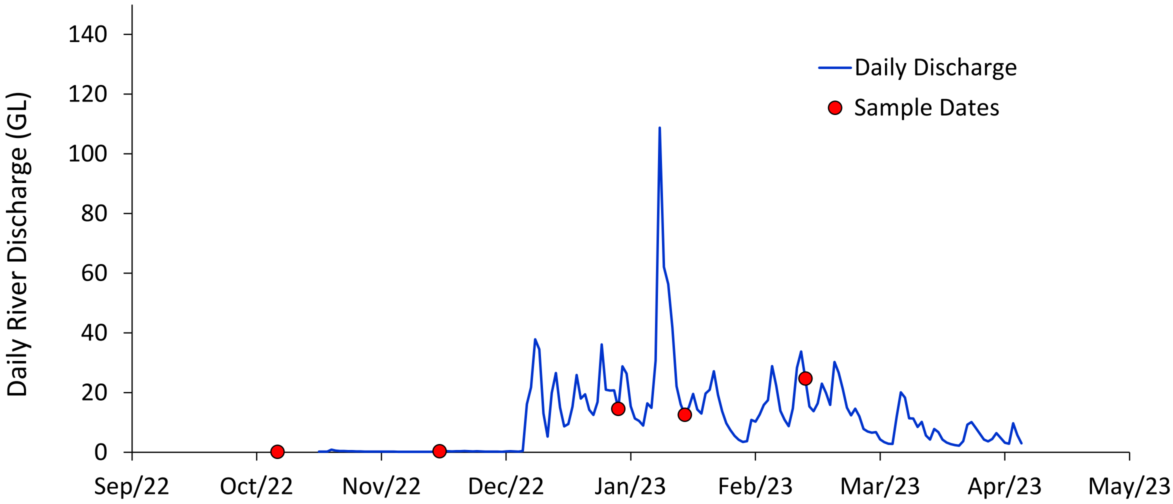


Figure 5-4: Daily discharge for the Pascoe River (gauge 102102A) for the 2022–23 water year. Red dots represent sampling dates.

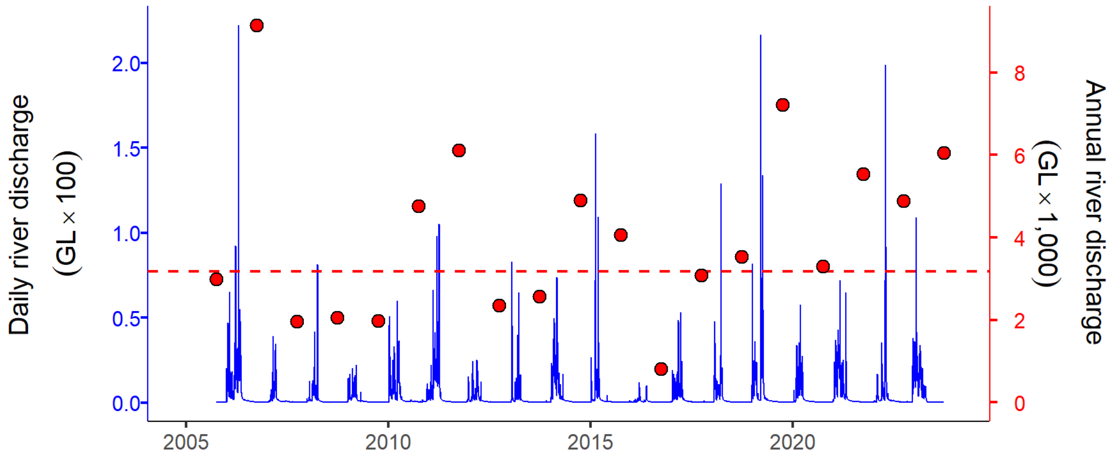


Figure 5-5: Long-term discharge for the combined Olive-Pascoe Rivers. Daily (blue) and water year (October to September, red symbols) discharge volumes shown. Red dashed line represents long-term median of the combined annual discharge.

Estimated annual discharge for the Olive-Pascoe basin was 6,054 GL for the 2022–23 water year (Figure 5-5). The total discharge and modelled loads estimated for the 2022–23 water year from the Pascoe catchment (upscaled from the Garraway gauge) are shown in Figure 5-6. The discharge and loads calculated for the 2022–23 water year from the Pascoe catchment (not including the Olive catchment) were 1.9 times above the long-term median. Over the 17-year period from 2006–07:

- discharge ranged from 425 GL (2015–16) to 3,770 GL (2018–19),
- TSS loads ranged from 19 kt (2015–16) to 194 kt (2018–19),
- DIN loads ranged from 34 t (2015–16) to 275 t (2018–19), and
- PN loads ranged from 68 t (2015–16) to 1,068 t (2018–19).

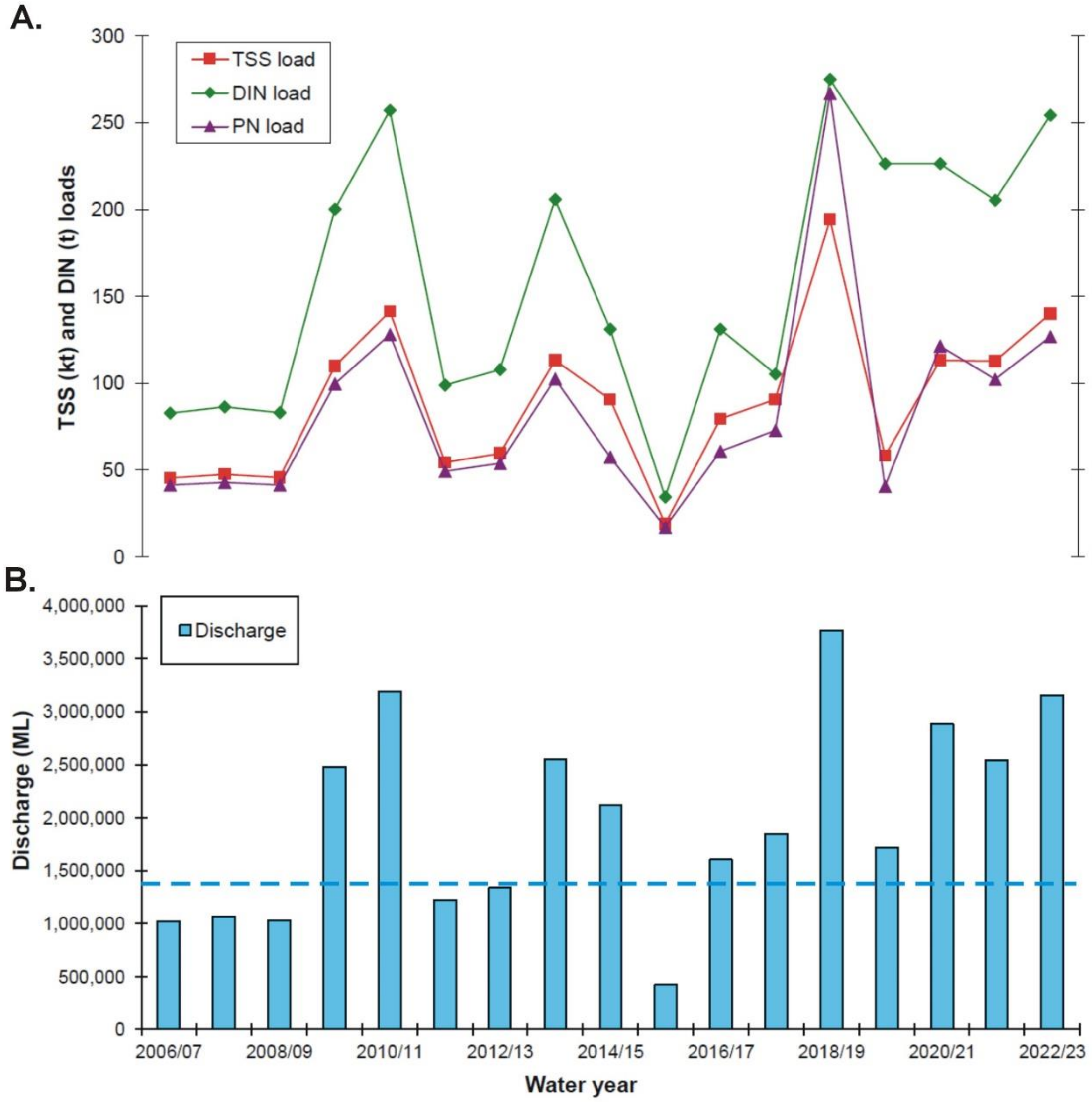


Figure 5-6: Modelled loads of (A) TSS, DIN, and PN and (B) discharge for the Pascoe catchment (note Pascoe catchment only, does not include the Olive catchment) from 2006 to 2023. The loads reported here are a combination of 'best estimates' based on 'up-scaled' discharge data from gauging stations and monitoring data for the 2014–15, 2016–17, 2017–18, 2018–19, 2019–20 and 2020–21 water years and an average of the annual mean concentrations for these six water years applied to the remaining dataset. Dotted line represents the long-term median for basin discharge. Note the different scales on the two y-axes.

Ambient water quality

According to modelled estimates, total TSS, PN, and DIN loads increased slightly over the 2022–23 water year compared to recent years associated with increased total discharge (Figure 5-6). Significant freshwater influence was measured in the enclosed coastal and open coastal waterbodies in January, extending out to Eel Reef in the mid-shelf waterbody during ambient sampling on 25 February. Despite this, the overall WQ Index score for the Pascoe region improved from 'moderate' in 2021–22 to 'good' in the 2022–23 water year, with clarity and productivity scores remaining the same and the particulates score improving from 'moderate' to 'good'.

All sample results are plotted against distance from the river mouth in Figure 5-7.

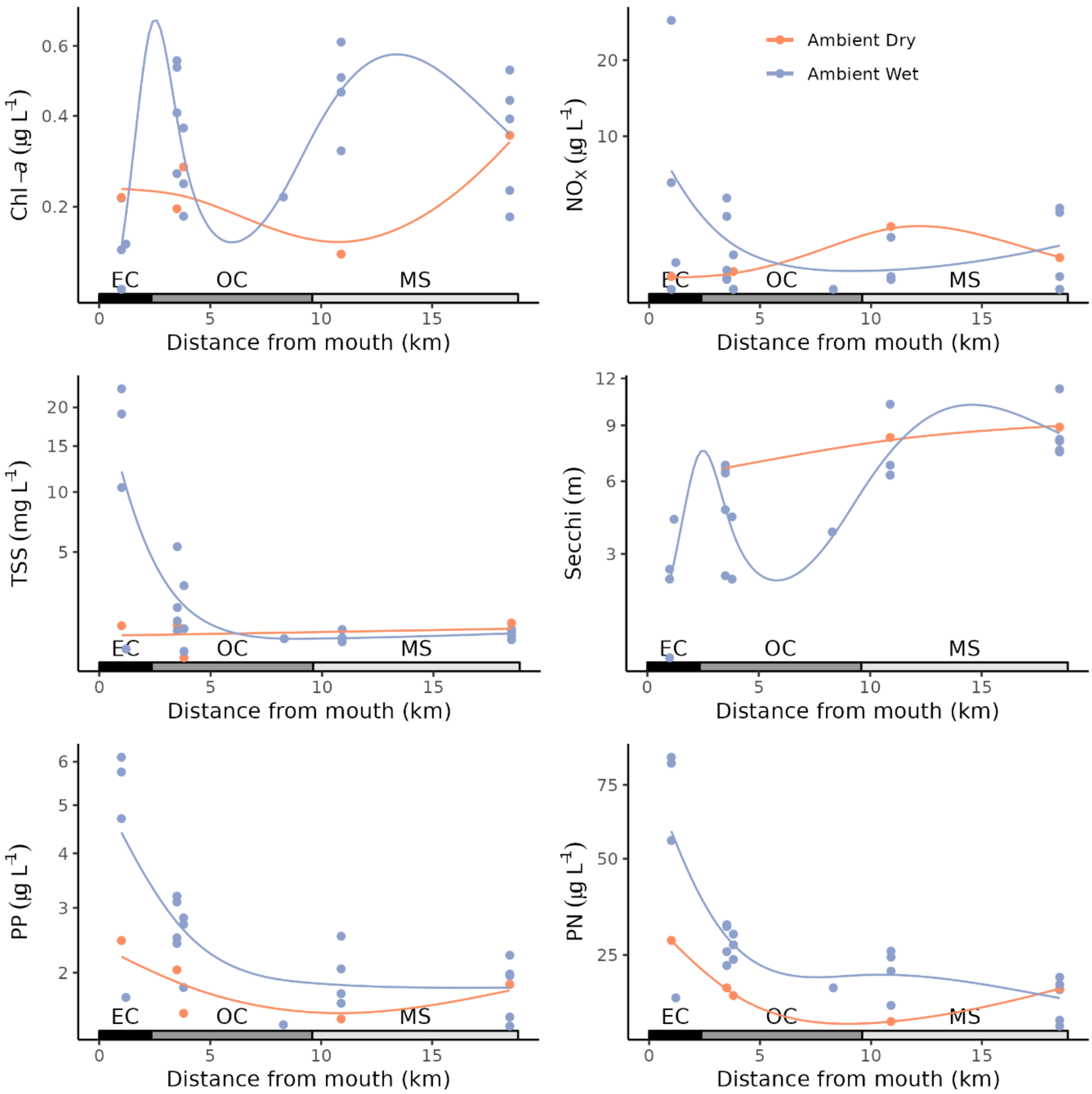


Figure 5-7: Water quality parameters (surface and subsurface samples) and Secchi depth over distance (km) from river mouth for the Pascoe River focus region (all 2022–23 samples). Water body classifications are shown along the x-axes: enclosed coastal (EC), open coastal (OC) and mid-shelf (MS). Note the y-axes are logarithmic scales. Fitted lines are generalised additive models.

Comparison of the 2022–23 ambient results with previous years and the GVs (Table C - 1) highlights that:

- There were significant increases in mean and median TSS concentrations, particularly at the enclosed coastal water body (PRS01) and open coastal water body (PRN02). However, mean and median TSS concentrations at all sites remained below annual and wet season GVs (Table C - 9). This is reflected in the 'good' annual condition WQ Index score for water clarity.
- Mean Secchi depths also decreased (water clarity worsened), likely as a result of the increased river discharge. Mean Secchi depths were less than (did not meet) the annual GV (≥10 m) at all open coastal and mid-shelf sites. Although a decline in mean

Secchi depth was observed, this was not enough to drive a change in the overall annual condition WQ Index score for water clarity.

- NO_x and Chl-*a* concentrations exceeded the GVs at all open coastal and mid-shelf sites. This is consistent with previous years.
- The productivity sub-indicator has remained ‘moderate’ due to the continued exceedance of annual and wet season NO_x and Chl-*a* GVs.

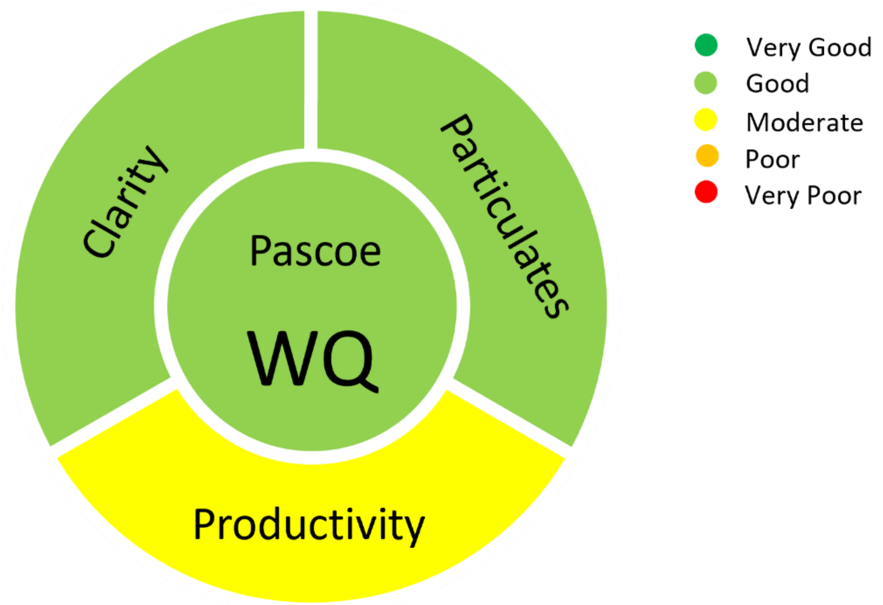


Figure 5-8: Annual condition version of the WQ Index for the Pascoe focus region for 2022–23. Calculations for Index formulations are described in Appendix B.

Event water quality

One major flood event occurred in the Pascoe River over the 2022–23 wet season, with an estimated total event discharge of 300 GL measured at the Garroway gauge (102102A) from 20–24 January 2023 (Figure 5-4), peaking at 1,422 $m^3 s^{-1}$ on 21 January. No targeted flood monitoring was conducted during this event due to access issues; however, ambient monitoring on 27 January showed that freshwater was present in the enclosed coastal water body and to the north at site PRN02. There was also significant freshwater influence in the enclosed coastal and open coastal water bodies on 10 January 2023 before the late January flood event, while the freshwater influence extended to Eel Reef (mid-shelf water body) on 25 February (Figure 5-4). Freshwater influence in the enclosed coastal waterbody during the wet season is common for the Pascoe River; however, the extension into open coastal and mid-shelf water bodies outside of major flood events is rare.

There were no satellite images available from the late January flood event. A Sentinel satellite image from 9 January 2023 shows the influence of flood waters inundating northern Eel Reef (Figure 5-9), demonstrating the impact of this continually high discharge wet season.

Figure 5-9: Sentinel-3 true colour image showing minor flooding from the Pascoe River on 09 January 2023. Source: Sentinel Hub EO Browser, extracted by Dr Caroline Petus, JCU TropWater.

5.1.2 Stewart

The Stewart focus region is influenced primarily by discharge from the Stewart River. During flood conditions it can also be influenced by floodwater from the Normanby and Kennedy Rivers and potentially by runoff from coastal creeks and mudflats.

Four sampling sites for the Stewart River are located in a transect from the river mouth to mid-shelf reefs, representing a gradient in water quality (Figure 5-10). The transect was sampled five times (four times during ambient wet conditions and once during ambient dry conditions) between November 2022 and April 2023 (Figure 5-11; Table A - 1). Although there were no major flood events in the Stewart River over the 2022–23 wet season, total river discharge was almost twice the average annual discharge. Thus, there was significant freshwater influence across the transect over the wet season. Satellite images from late January and mid-March show that floodwater from the Normanby and Kennedy rivers also influenced the Stewart transect region over the wet season (Figure 5-22). Discharge from the Normanby Basin in 2022–23 was over 3 times the long-term annual median discharge. Thus, the river influence in 2022–23 is likely to have been more significant than in other recent years.

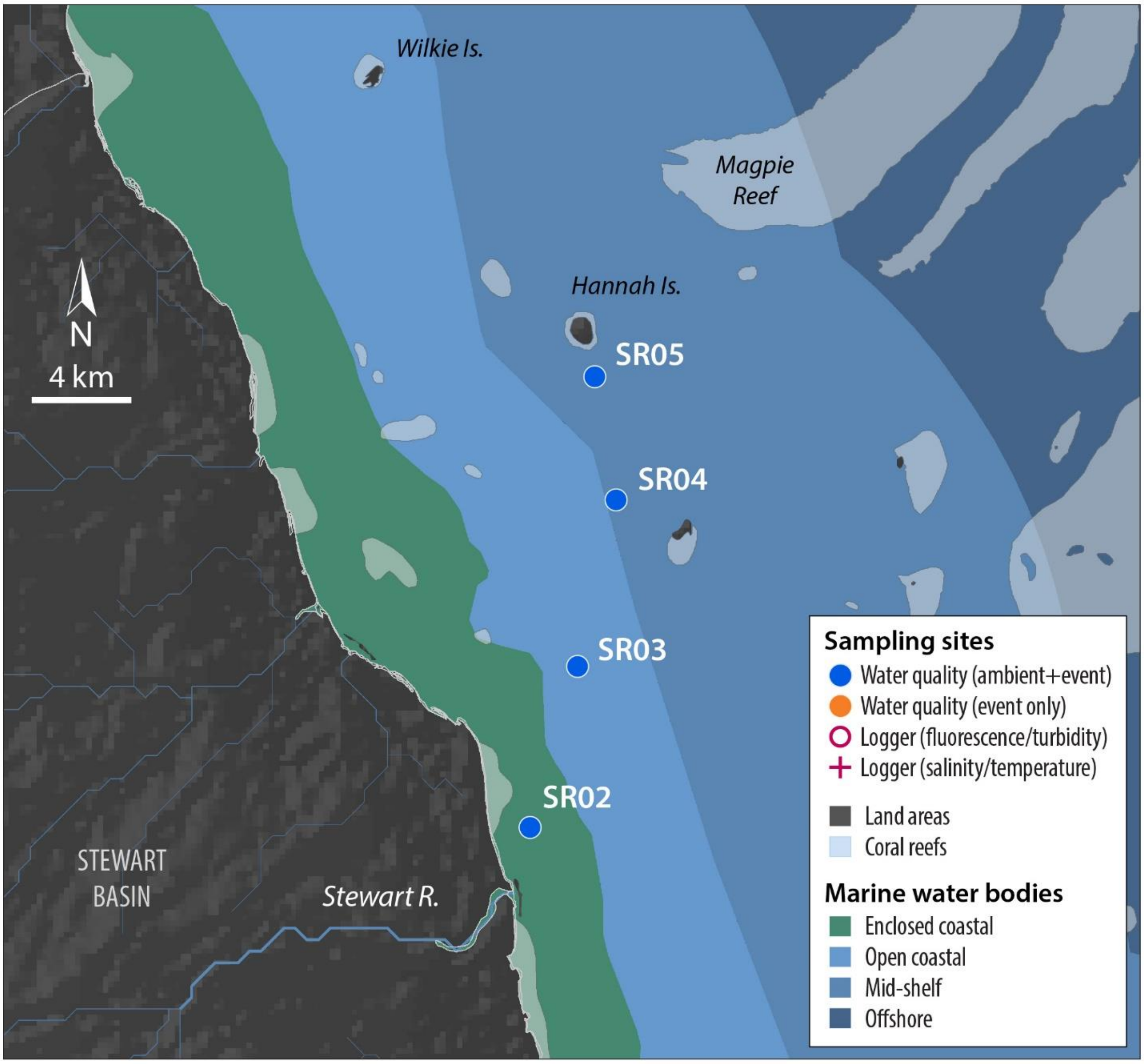


Figure 5-10: Water quality sampling sites in the Stewart River transect with water body boundaries.

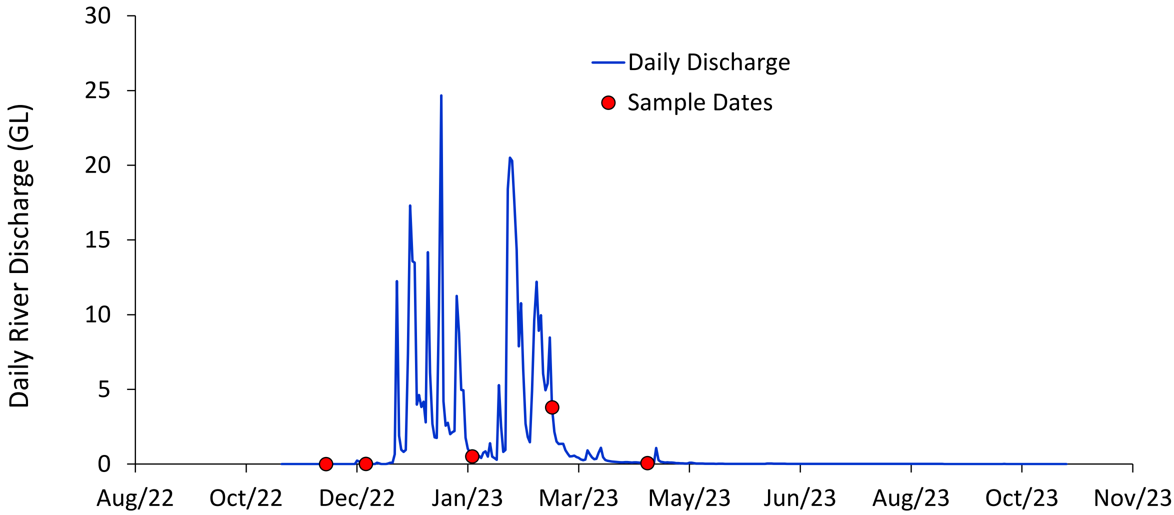


Figure 5-11: Daily discharge and sampling dates for the Stewart River (gauge 104001A) for the 2022–23 wet season.

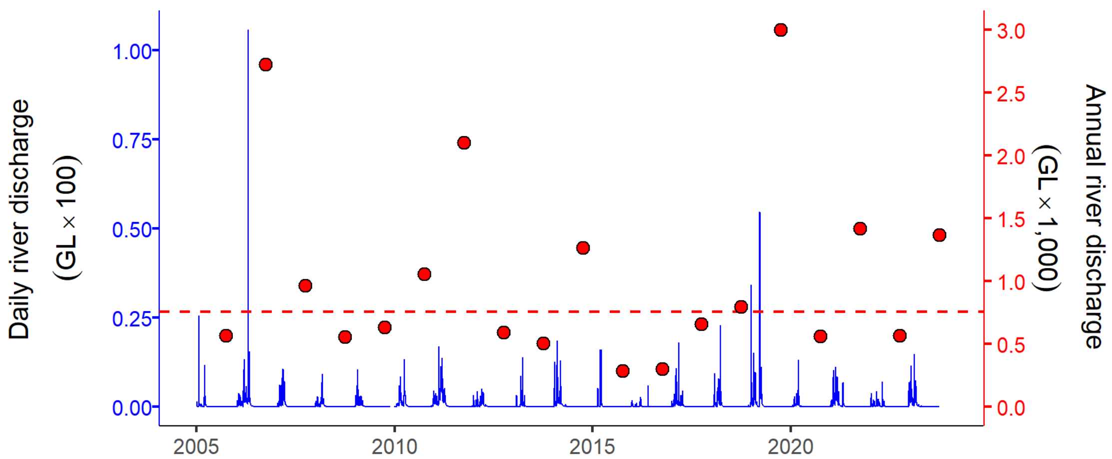


Figure 5-12: Long-term discharge for the Stewart River (gauge 104001A). Daily (blue) and water year (October to September, red circles) discharge volumes shown. Red dashed line represents long-term median annual discharge.

The total annual discharge for 2022–23 water year is estimated at 1,367 GL based on the measurements from the Upper Stewart River gauge (Figure 5-12) corrected for catchment area. The combined discharge and modelled loads estimated for the 2022–23 water year from the Stewart Basin are shown in Figure 5-13. The discharge and loads calculated for the 2022–23 water year from the Stewart Basin were above (1.8 times) the long-term median. Over the 17-year period from 2006–07:

- discharge ranged from 289 GL (2014–15) to 3,002 GL (2018–19);
- TSS loads ranged from 8.7 kt (2014–15) to 90 kt (2018–19);
- DIN loads ranged from 13 t (2014–15) to 135 t (2018–19); and
- PN loads ranged from 40 t (2014–15) to 420 t (2018–19).

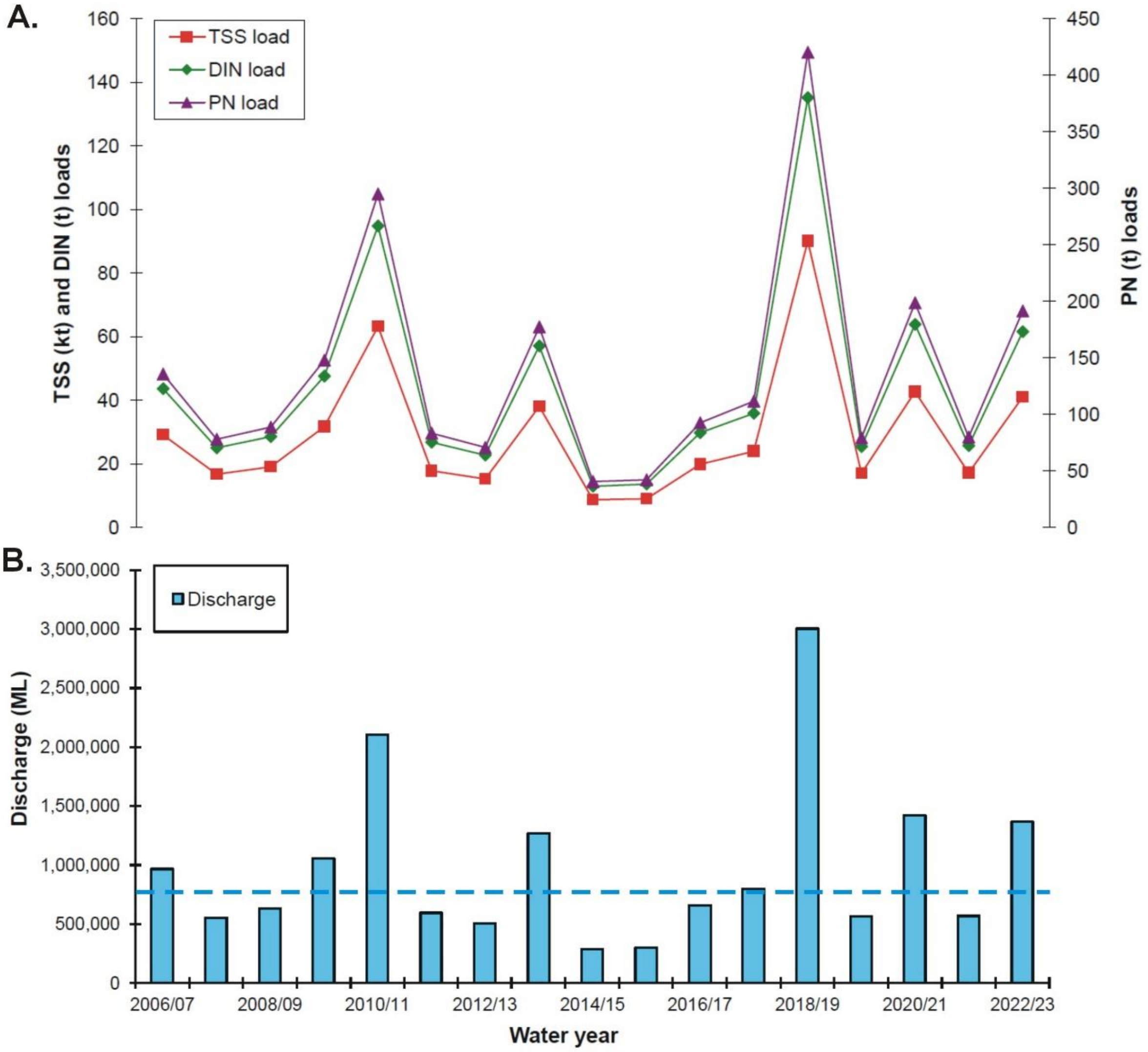


Figure 5-13. Loads of (A) TSS, DIN, and PN and (B) discharge for the Stewart Basin from 2006 to 2023. The loads reported here are based on the best estimates of annual mean concentration informed by nearest-neighbour monitoring and by the Source Catchments modelling data and applied to each water year. Dotted line represents the long-term median for basin discharge. Note the different scales on the two y-axes.

Ambient water quality

The Stewart River ambient condition sampling results are plotted against the distance from the river mouth in Figure 5-14 and are compared against the GVs for each water body (Table C - 1). Nutrient and Chl-*a* concentrations generally decreased with distance from the river mouth, while Secchi depth increased. TSS concentrations were low (<2 mg L^{-1}) across the transect and did not show a clear trend associated with distance from river mouth.

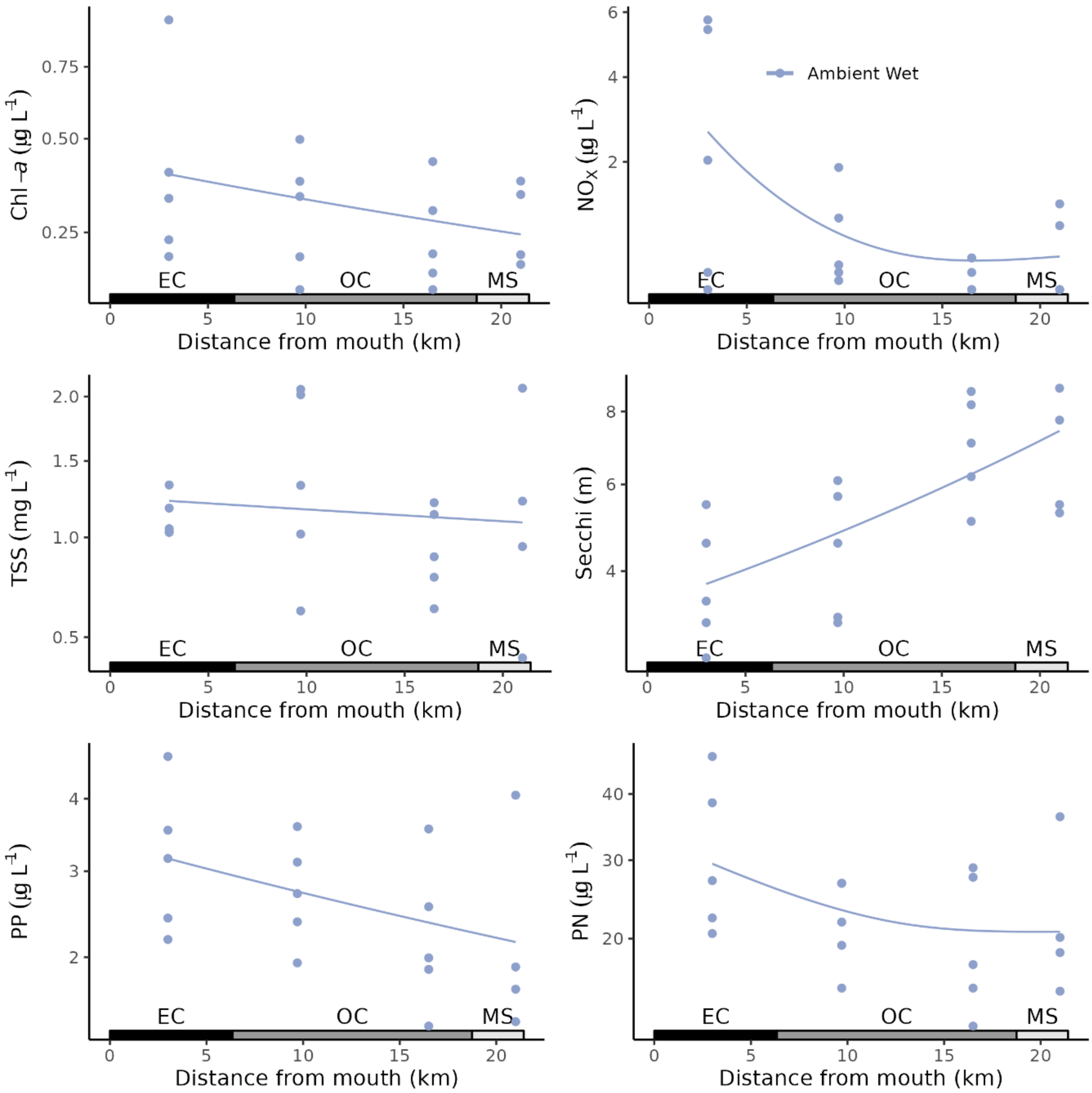


Figure 5-14 Water quality parameters (all surface and subsurface samples for the 2022–23 season) and Secchi depth over distance (km) from river mouth for the Stewart River focus region during ambient conditions in the wet season (blue circles). Water body classifications are shown along the x-axes: enclosed coastal (EC), open coastal (OC), and mid-shelf (MS). Note the y-axes are logarithmic scales. Fitted lines are generalised additive models.

Comparison of the 2022–23 ambient results with previous years and the water quality GVs (Table C - 9) highlights that:

- The annual condition WQ Index for the Stewart region scored ‘moderate’ overall, with a ‘moderate’ score for the productivity and clarity sub-indicators and a ‘good’ score for the particulate sub-indicator (Figure 5-15);
- Median TSS concentrations increased from values measured in 2021–22 at sites in the open coastal and mid-shelf waterbodies and TSS met the annual and wet season GVs at all sites;
- Mean Secchi depth was below (did not meet) the annual GV at open coastal and mid-shelf sites. Depths decreased (water clarity worsened) compared to 2021–22, which contributed to a decline in the clarity score to ‘moderate’ in 2022–23. This decline is

likely due to the influence from increased Stewart and Normanby-Kennedy river discharge;

- Mean Chl-*a* concentrations met both the annual and wet season GVs at all sites;
- Median NO_x concentrations exceeded the annual and wet season GVs, contributing to the 'moderate' score for productivity. This is similar to the previous two years;
- Median PP concentrations were below the annual or wet season GVs at all sites;
- Median PN results were mixed, exceeding annual or wet season GVs at SR03 and SR05, but meeting GVs at SR04 and SR02;
- Median PO_4 concentrations met both the annual and wet season GVs at all sites except for SR05 (Hannah Reef) in the mid-shelf. Interestingly, 3 out of 4 GV exceedances for PO_4 at Hannah Reef occurred at depth, while surface samples generally met the GV; and
- Water quality at Hannah Reef (SR05) declined compared to the previous year, with mean or median concentrations for all indicators except for TSS exceeding GVs. This could be related to the influence of Normanby Basin floodwater or other small creeks north of the Stewart River. In March, salinity at SR05 was 17 while salinity at SR02, SR03 and SR04 (closer to the mouth of the Stewart River) ranged from 22 to 23.These lab sample results were confirmed by *in situ* CTD data, which showed stratification in the top 2 m of the water surface.

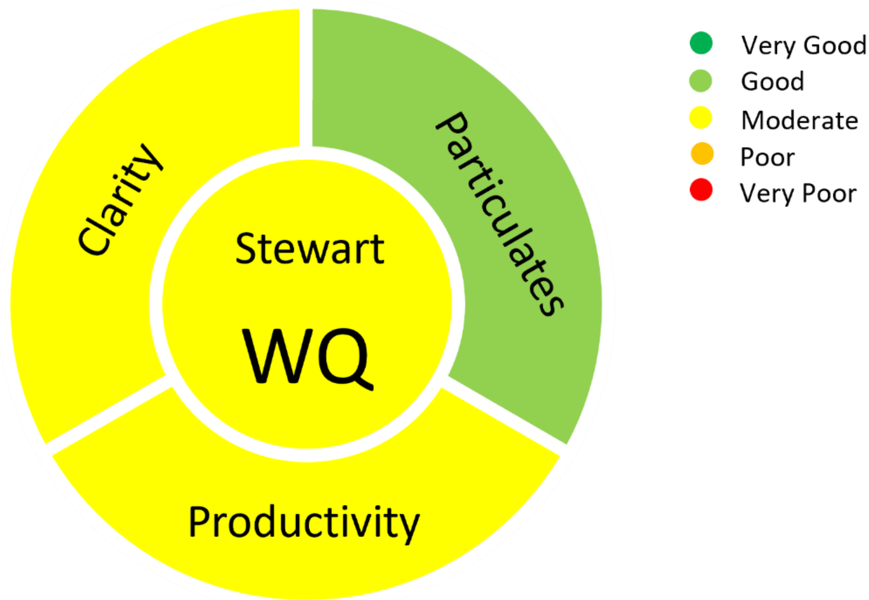


Figure 5-15: Annual condition version of the WQ Index for the Stewart focus region for 2022–23. Calculations for Index formulations are described in Appendix B.

Event water quality

There were no major flood events in the Stewart River over the 2022–23 wet season and no targeted flood monitoring.

5.1.3 Normanby

The Normanby focus region is influenced by discharge from the Normanby, Laura, Kennedy, Hann, Mossman, Morehead, and Annie Rivers via three distributaries: the North Kennedy, Normanby, and Bizant. Five sampling sites are located along a transect from the Normanby River mouth to Corbett Reef in the offshore water body (Figure 5-16). Site CI01 is located near Cliff Isles (‘Marpa’ in traditional Lama Lama language). Four additional event-only sites are NR01 at the Normanby River mouth, two sample sites located near the Kennedy River and one near the Bizant River mouth in the enclosed coastal water body.

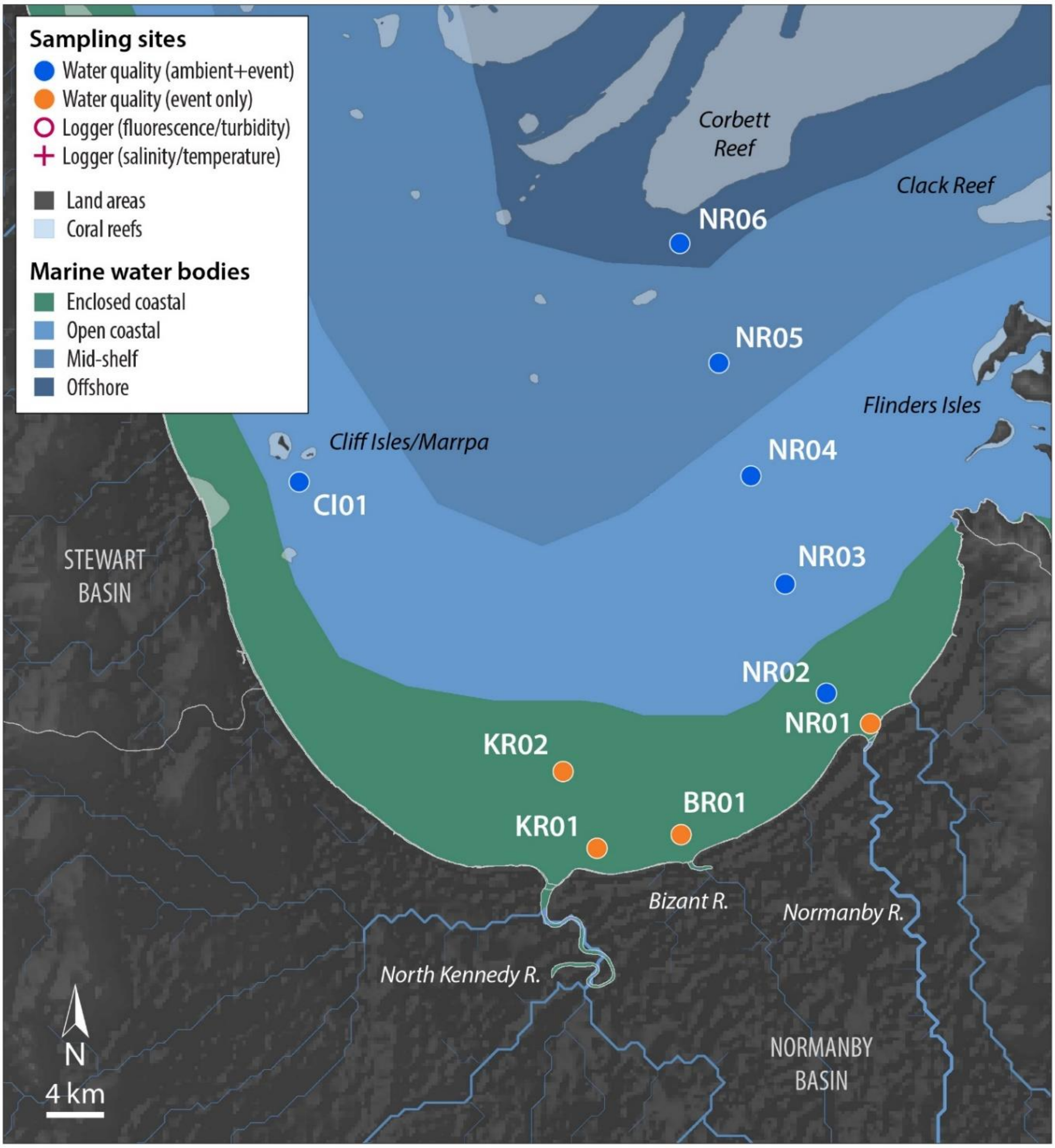


Figure 5-16: Water quality sampling sites in the Normanby Basin focus region with water body boundaries.

The Normanby transect was sampled five times (three times during high discharge wet season conditions and two times during ambient wet season conditions) from November 2022 to April 2023 (Figure 5-17). Due to the consistent above-average discharge conditions through the wet season, typical event conditions prevailed through much of the wet season and sampling trips on 14 January, 25 January, and 3 March 2023 all measured freshwater influence across Princess Charlotte Bay. Additional samples were collected from event sample locations near the Normanby, Bizant, and Kennedy River mouths (as well as along the Normanby transect) on 25 January 2023. Floodwaters from the Normanby Basin also influenced inshore samples within the Stewart transect (Figure 5-22). Long-term discharge is shown in Figure 5-18.

.

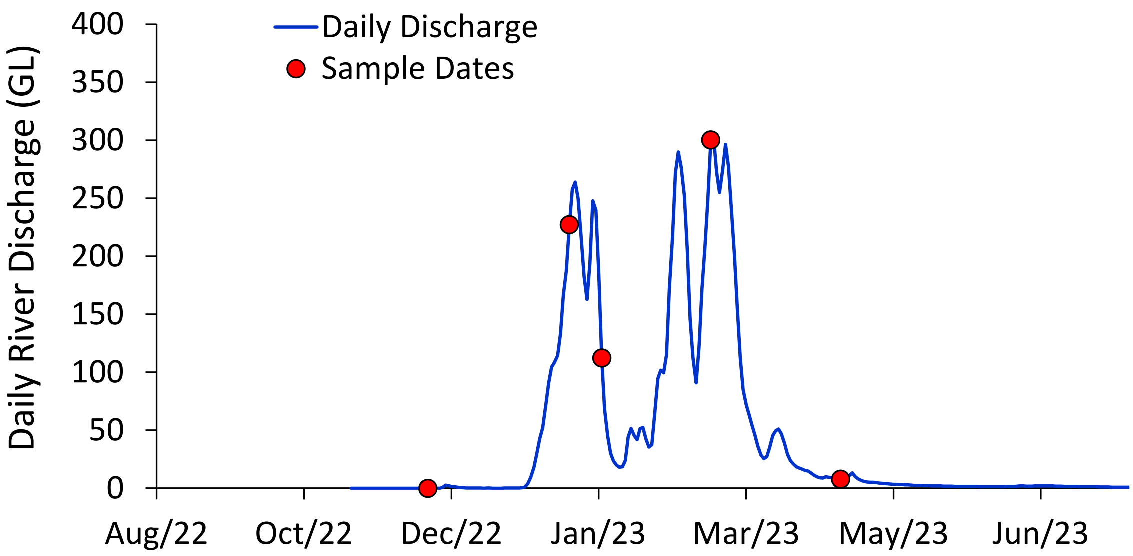


Figure 5-17: Daily discharge and sampling dates for the Normanby River (gauge 105107A) for the 2022–23 wet season. Note there is a 2 to 3-day travel time between the gauge and coastal waters, and thus samples were collected earlier in the flood stage than shown on the hydrograph.

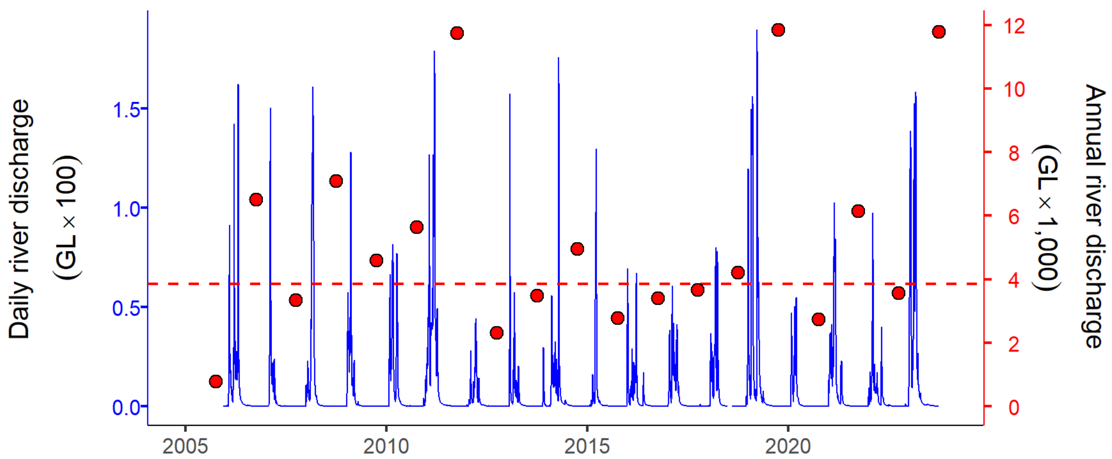


Figure 5-18: Long-term discharge for the Normanby River at gauge 105107A (Kalpowar Crossing). Daily (blue) and water year (October to September, red symbols) discharge volumes shown. Method for estimation is described in Table 2-3.

The discharge and modelled load estimates for the 2022–23 water year from the Normanby Basin were larger than most years (3.1 times above the long-term median). Our modelled loads suggest that TSS and DIN exports in the 2022–23 water year were the highest on record, although river gauge monitoring data (once available) will need to validate this finding. In any case, the discharge and loads would be amongst the highest over the 17-year program. Over the 17-year period from 2006–07:

- discharge ranged from 2,314 GL (2011–12) to 11,852 GL (2018–19);
- TSS loads ranged from 55 kt (2014–15) to 471 kt (2022–23);
- DIN loads ranged from 42 t (2011–12) to 370 t (2022-23); and
- PN loads ranged from 124 t (2009–10) to 2,470 t (2018–19).

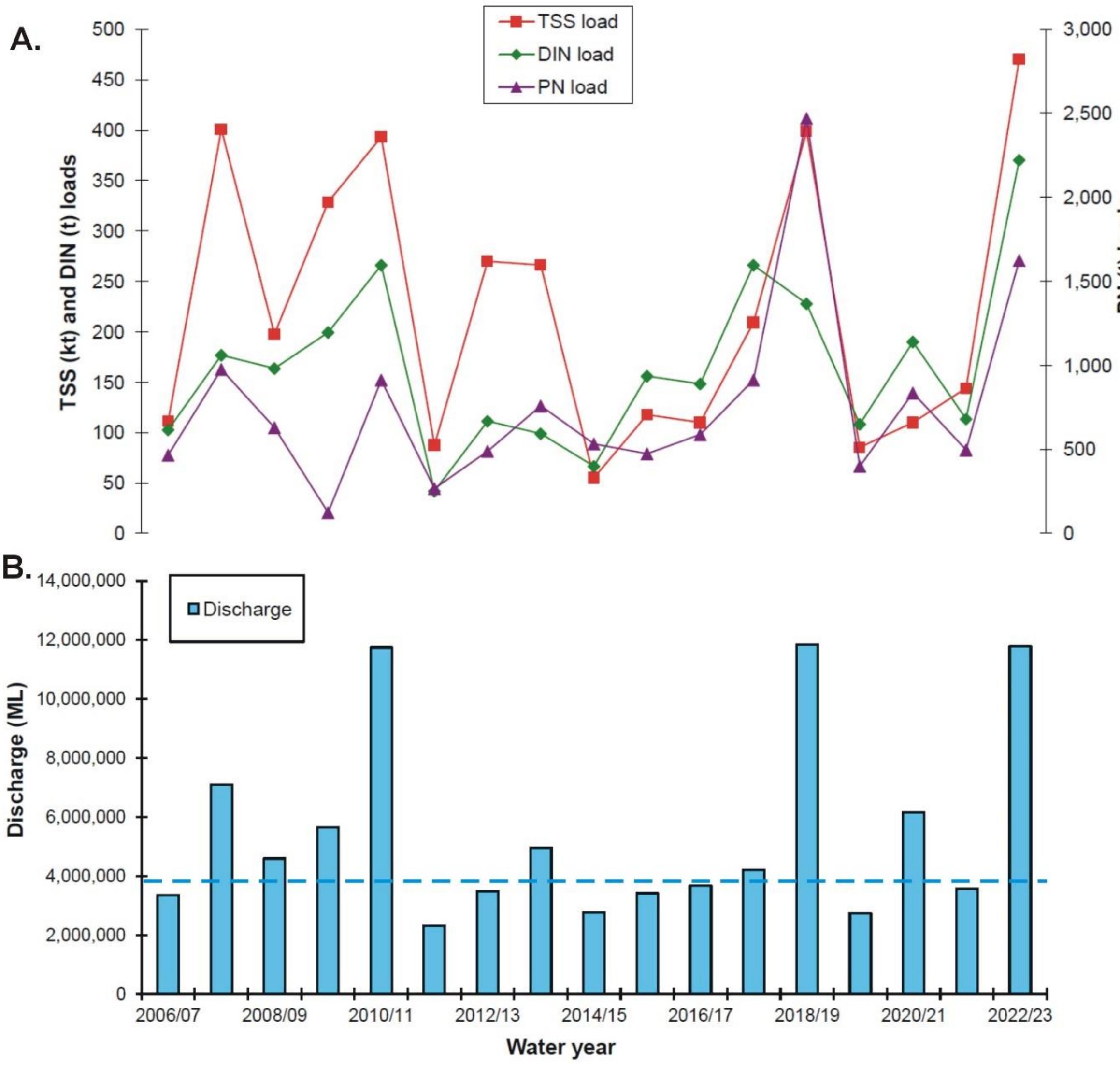


Figure 5-19: Modelled loads of (A) total suspended solids, dissolved inorganic (DIN), and particulate nitrogen (PN) and (B) discharge for the Normanby Basin. The loads reported here are a combination of 'best estimates' based on 'up-scaled' discharge and monitoring data from the Normanby River at Kalpowar gauging station (covers ~50% of the basin area). The dotted line represents the long-term median for basin discharge. Note the different scales on the two y-axes.

Ambient water quality

Due to the extensive flooding over the wet season, the Normanby ambient results presented here include only three sampling events during the wet season from November, March, and

April (Figure 5-17). The two January sampling trips are categorised as event sampling and the results are not included in the WQ Index scores or included in Table C - 1. Ambient water quality results are plotted against distance from the closest river mouth (Normanby, Bizant, or Kennedy) in Figure 5-20. Ambient results are compared against the GVs for each water body in Table C - 1.

As shown in Figure 5-20, nutrient and TSS concentrations generally declined with increasing distance from the river mouths, while Secchi depth increased (water clarity improved).

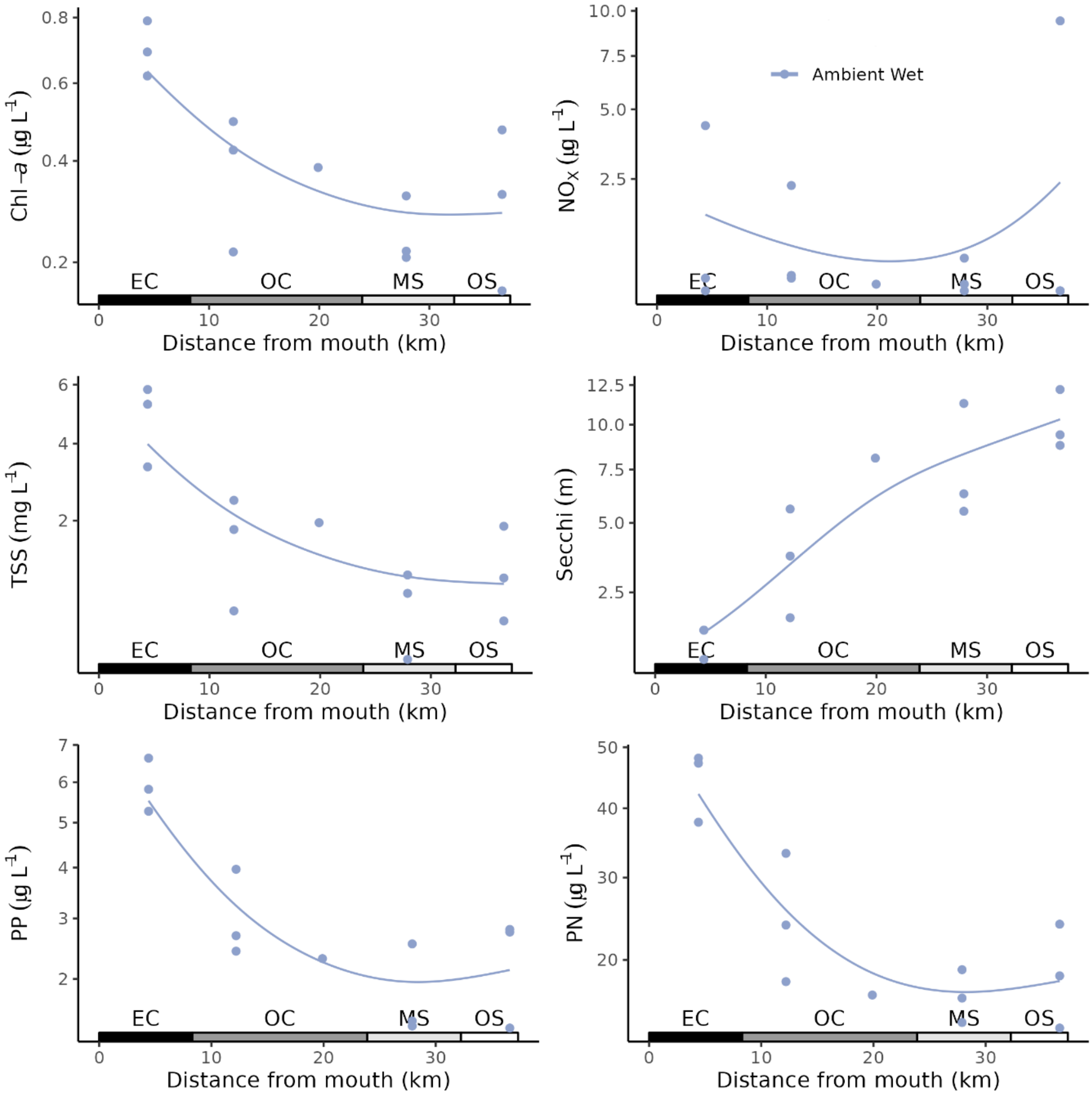


Figure 5-20: Water quality parameters (surface and subsurface) and Secchi depth over distance (km) from river mouth for the Normanby focus region, all ambient 2022–23 sampling dates. Water body classifications are shown along the x-axes: enclosed coastal (EC), open coastal (OC), and mid-shelf (MS). Note the y-axes are logarithmic scales. Fitted lines are generalised additive models.

Comparison of the 2022–23 ambient results with previous years and the GVs (Table C - 9) highlights that:

- Overall, the annual condition WQ Index score for the Normanby remained ‘moderate’, with a ‘poor’ score for the water clarity sub-indicator and a ‘good’ score for productivity and particulates (Figure 5-21);
- Secchi depth was less than (did not meet) GVs at any sites except for NR02 in the enclosed coastal zone. This contributed to the ‘poor’ score for the water clarity sub-indicator. Water clarity at Princess Charlotte Bay has consistently been ‘poor’ or ‘very poor’ over the MMP monitoring period as the Bay is relatively shallow, with frequent resuspension of muddy sediments in addition to frequent flooding;
- Despite high discharge over the 2022–23 wet season, TSS met the GVs at all sites except for Corbett Reef (NR06) and NR04 in the mid-shelf and offshore waterbodies. Exceedances at both sites were largely due to high concentrations of TSS in sub-surface samples, likely due to benthic sediment resuspension by strong currents at depth. These elevated concentrations at depth are common in Normanby transect samples;
- Median NO_x and PO_4 concentrations exceeded the annual and wet season GVs at 4 and 3 out of 6 sites, respectively;
- Median Chl-*a* concentrations met the wet season GVs at most sites with the exception of offshore site NR06 (Corbett Reef) and CI01 (Cliff Isles) in the open coastal water body. Median Chl-*a* at CI01 was particularly high (0.91 µg L^{-1}, more than twice the wet season GV), likely due to the influence of Normanby Basin floodwaters; and
- Median PP concentrations met the GVs at all sites. Median PN concentrations exceeded the wet season and annual GVs at three sites (CI01, NR03, and NR06). Median PN and PP concentrations decreased compared to 2021–22, contributing to the particulates score improvement from ‘moderate’ to ‘good’ over the past year.

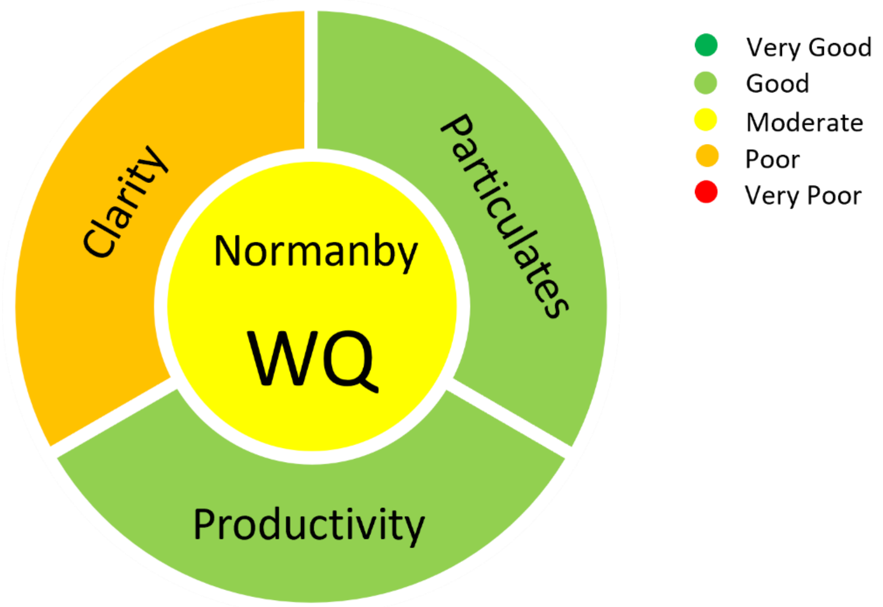


Figure 5-21: Annual condition version of the WQ Index for the Normanby focus region for 2022–23. Calculations for Index formulations are described in Appendix B.

Event water quality

Targeted flood sampling conducted on 14 and 25 January 2023 coincided with the first major flood event of the year, starting from 28 December 2022 and maintaining flood levels throughout the month of January. River discharge peaked at the Kalpowar Crossing gauge on 16 January (1,620 $m^3 s^{-1}$) and again on 21 January (1,580 $m^3 s^{-1}$), with a total discharge measured at the gauge of 2,226 GL (not including discharge from the Kennedy River). Satellite images around the time of sampling show the flood plume flowing northeast towards Corbett Reef on 14 January, with the majority of sediment discharged from the Kennedy River. On 24 January, southeasterly winds forced the flood plume to the northwest, travelling along the coast past Cliff Isles and beyond the Stewart River transect to the north (Figure 5-22).

After a short decline, discharge from the Normanby River increased again in mid-February, remaining at flood levels until mid-March. Between 16 February and 18 March, a total discharge volume of 3,363 GL was measured at the Kalpowar gauge, peaking at 1,890 m^3 s^{-1} (163 GL d^{-1}) on 3 March (Figure 5-17). Satellite images of Princess Charlotte Bay on 10 March show turbid floodwater inundating Cliff Isles and Corbett Reef to the north and extending approximately 100 km to the east beyond the outer reefs (Figure 5-22).

Not surprisingly, samples collected on 14 January showed that most parameters were significantly elevated compared to ambient conditions. Across the regular transect sites NO_X increased by a factor of 10, with particularly high concentrations detected in the enclosed coastal zone. DOC concentrations across the transect sites had doubled compared to ambient concentrations. High DIP concentrations were also measured in the enclosed coastal water body, but concentrations rapidly declined along the transect, and were below average ambient concentrations at mid-shelf and offshore sites (NR05 and NR06, respectively) and at open coastal water body sites KR02 and CI01. PN and PP concentrations across the transect were close to double the ambient concentrations. TSS was 112 and 36 mg L^{-1} at the mouth of the Kennedy and Normanby Rivers, respectively, but decreased to <1 mg L^{-1} in the mid-shelf and offshore water bodies. Chl-*a* concentrations were also elevated in the enclosed coastal and open coastal water bodies (maximum 0.98 µg L^{-1}) but remained low (<0.15 µg L^{-1}) at mid-shelf and offshore sites.

Satellite images on 24 January showed a smaller high turbidity plume near the mouth of the Kennedy River and diffuse secondary plume water over a large area along the coast to the north, inundating Cliff Isles (CI01) and the Stewart transect while most Normanby transect sites appeared relatively clear. Samples collected on 25 January showed TSS concentrations at the Normanby and Kennedy river mouths had decreased to 9 and 28 mg L^{-1}, respectively. NO_x, DOC, PN, and PP (but not DIP) remained elevated across the transect sites. Chl-*a* remained elevated at open coastal water body sites, such as CI01 (0.76 µg L^{-1}) and was particularly high in the enclosed coastal water body (>2 µg L^{-1}), where improving water clarity promoted increased phytoplankton growth.

Figure 5-22: Satellite image of Kennedy and Normanby River during flooding on 24 January (left) and 10 March 2023 (right). During the late January flood event floodwater can be seen travelling north up the coast beyond the Stewart transect (left). In March, floodwater inundated Corbett Reef and Clack Reef and flowed east beyond the outer reef (right). Source: NASA MODIS Aqua & Terra.

5.1.4 Annan-Endeavour

The Annan-Endeavour focus region is influenced primarily by discharge from the Endeavour and Annan Rivers. Five sampling sites are located along transects from the two river mouths to mid-shelf reefs, representing a gradient in water quality (Figure 5-23). Additional sites ER01 and AR01 are sampled during events. In addition to manual sampling, dataloggers monitor continuous Chl-*a* fluorescence, turbidity, and conductivity at Dawson Reef 6 km from the mouth of the Annan River and Forrester Reef 30 km north of the Endeavour River mouth (Figure 5-23).

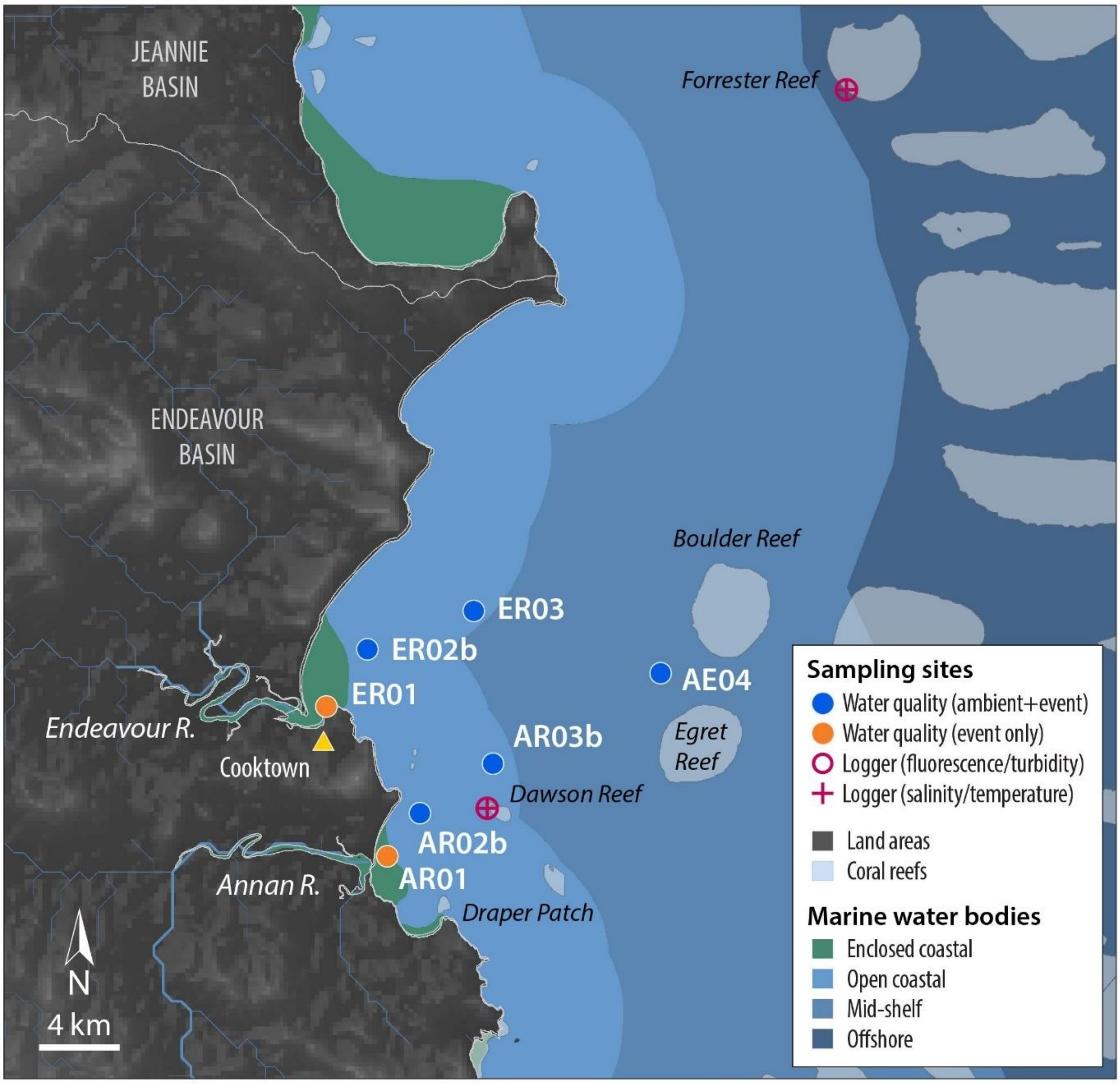


Figure 5-23: Water quality sampling sites in the Annan-Endeavour region shown with water body boundaries.

The Annan and Endeavour transect was sampled for ambient wet season conditions five times between November 2022–March 2023. Additional event samples were collected during a relatively minor flood event in January (Figure 5-24). Samples of TSS and Chl-*a* were collected contemporaneously adjacent to Dawson Reef and Forrester Reef dataloggers to estimate TSS and Chl-*a* concentrations from logger measurements of turbidity and chlorophyll fluorescence, respectively.

The estimated total discharge from the Endeavour Basin for the 2022–23 water year was 1.5 times the long-term median (Table 3-1, Figure 5-25 and Figure 5-26). The combined discharge and modelled loads estimated for the 2022–23 water year from the Endeavour Basin are shown in Figure 5-26. Over the 17-year period from 2006–07:

- discharge ranged from 753 GL (2019–20) to 3,661 GL (2018–19);
- TSS loads ranged from 38 kt (2019–20) to 183 kt (2018–19);
- DIN loads ranged from 34 t (2019–20) to 165 t (2018–19); and
- PN loads ranged from 105 t (2019–20) to 512 t (2018–19).

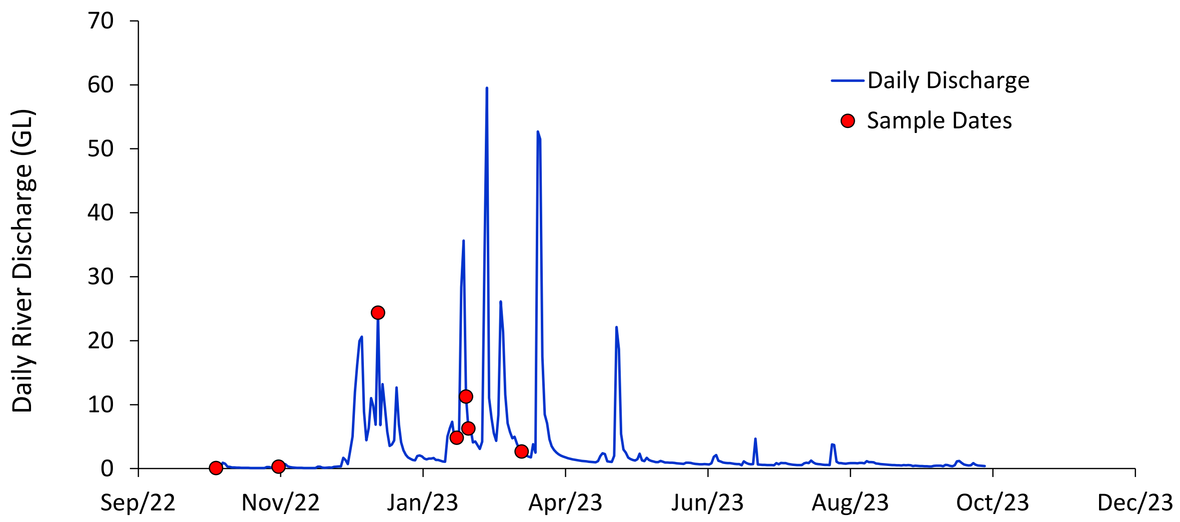


Figure 5-24: Daily discharge and sampling dates for the Endeavour Basin using combined values from the Annan River (gauge 107003A) and Endeavour River gauge (107001B) for the 2022–23 wet season.

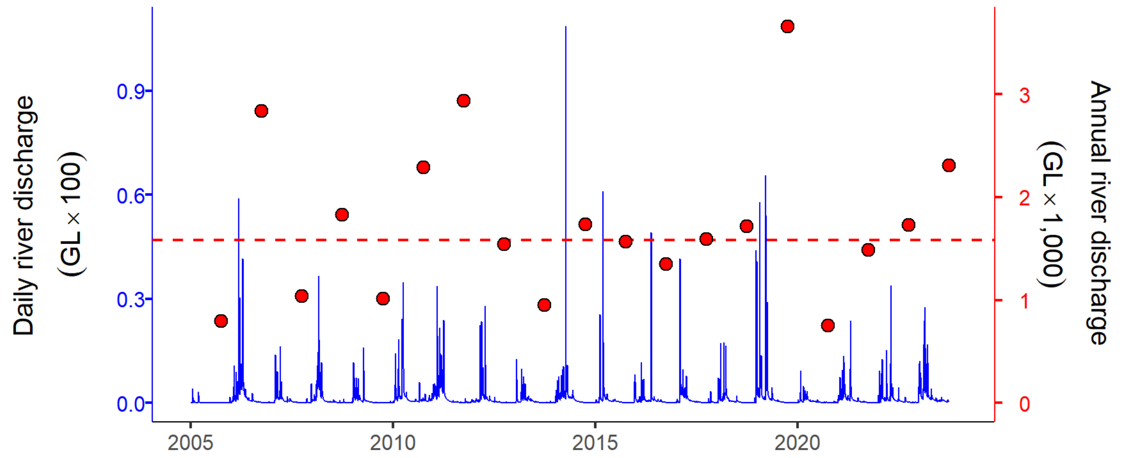


Figure 5-25: Long-term discharge for the Endeavour Basin using combined values from the Annan River (gauge 107003A) and Endeavour River (gauge 107001B). Daily (blue) and water year (October to September, red symbols) discharge volumes shown. Red dashed line represents long-term median of the combined annual discharge. Method for estimation is described in Table 2-3.

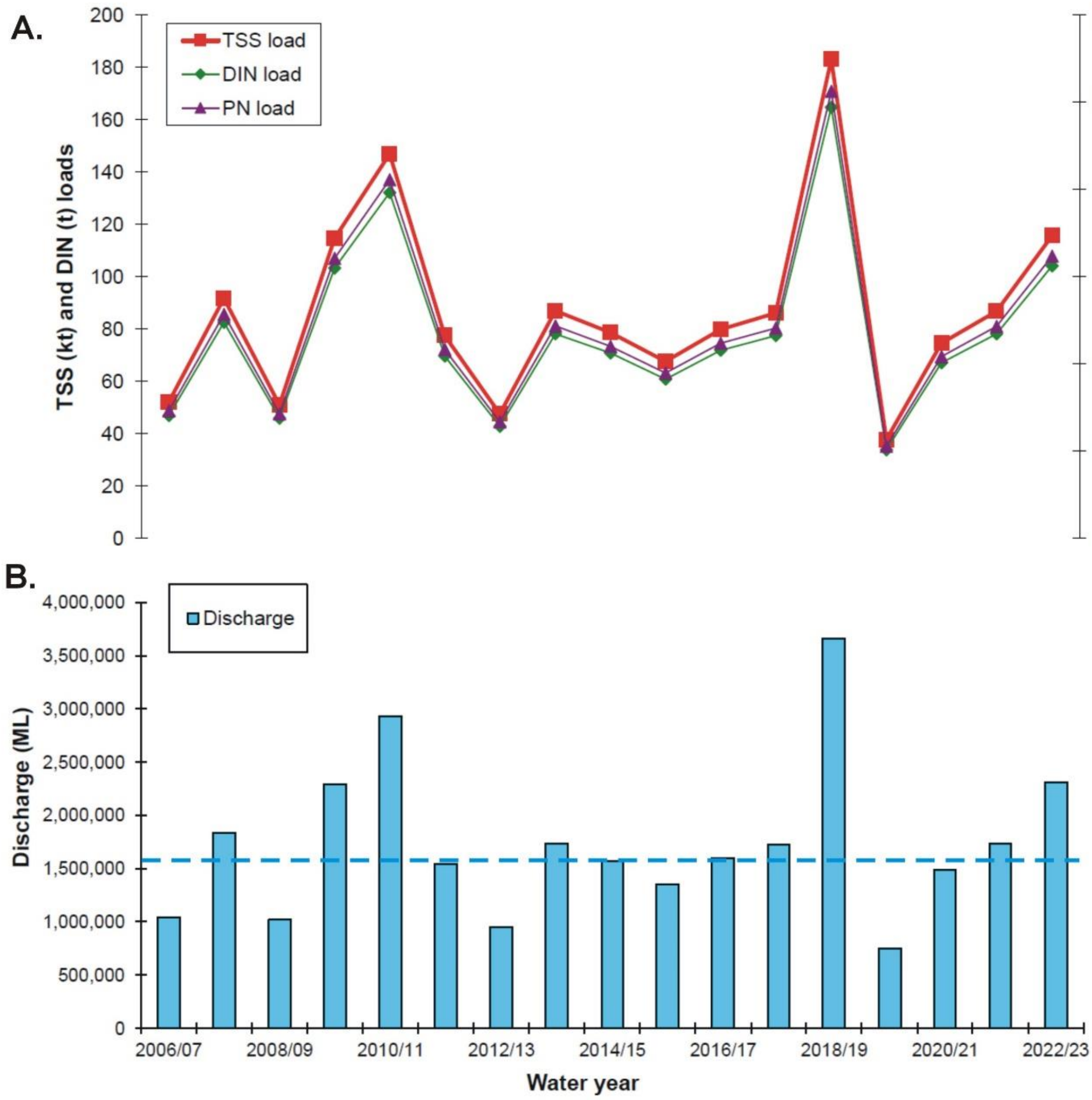


Figure 5-26. Loads of (A) total suspended solids, dissolved inorganic (DIN), and particulate nitrogen (PN) and (B) discharge for the Endeavour Basin from 2006 to 2023. The loads reported here are best estimates of annual mean concentration informed by nearest-neighbour monitoring and by the Source Catchments modelling data and applied to each water year. Dotted line represents the long-term median for basin discharge. Note the different scales on the two y-axes.

Ambient water quality

Both ambient and event water quality results were plotted against distance from the mouths of the Annan or Endeavour River (Figure 5-27). Ambient mean and median values for each parameter are compared against the Eastern Cape York regional guidelines for the open coastal (ER02, ER03, AR02, AR03, and Dawson Reef), mid-shelf (AE04), and offshore (Forrester Reef) water bodies in Table C - 1.

Trends associated with distance from the river mouth are difficult to discern due to the influence of two rivers with varying discharge on the sample sites. However, NO_x and PN concentrations generally declined with distance from the rivers, while Secchi depth increased (Figure 5-27).

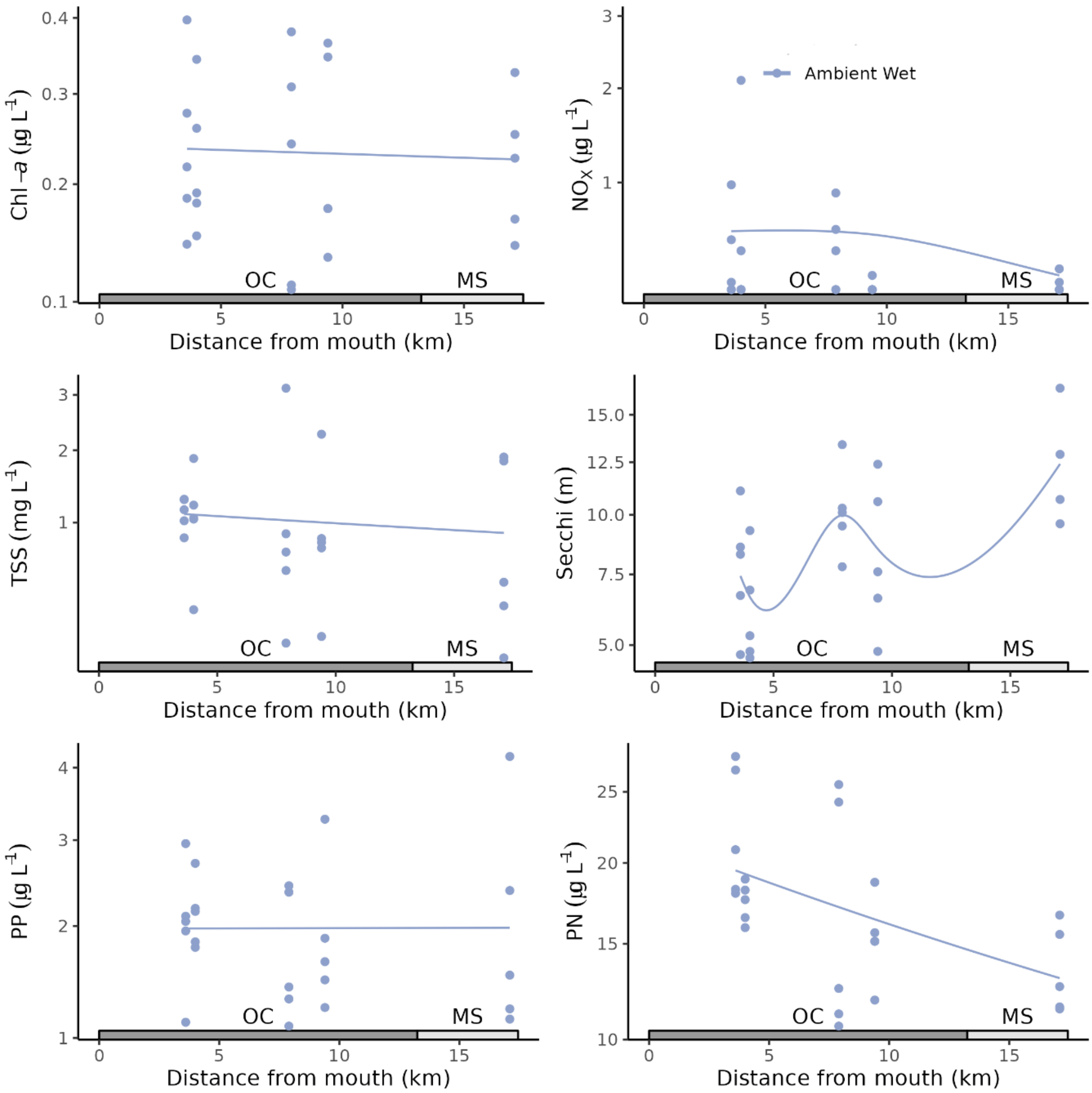


Figure 5-27: Water quality parameters (surface and subsurface samples) and Secchi depth over distance from river mouth (km) for the Endeavour Basin focus region during ambient conditions (2022–23 water year). Note that data includes samples collected at varying distances from two river mouths (Annan and Endeavour), with each site plotted at the distance from the closest river. Complex regression lines result from this combination of data and varying river influences. Water body classifications are shown along the x-axes: open coastal (OC) and mid-shelf (MS). Note the y-axes are logarithmic scales. Fitted lines are generalised additive models.

Comparison of the 2022–23 ambient results with previous years and the water quality GVs (Table C - 1) highlights that:

- Overall, the annual condition WQ Index scored ‘good’ for the Annan-Endeavour focus region (Figure 5-28), which is a slight decline from the ‘very good’ score in 2021–22;
- Chl-*a* met GVs at all sites, contributing to the ‘very good’ score for productivity;
- NO_x also met the annual and wet season GVs at all sites, with the exception of AR03. PO4 exceeded the GVs at ER02 and AR02 in the open coastal water body and at AE04 in the mid-shelf waterbody;
- TSS met the GVs at all sites, contributing to the ‘good’ score for clarity;

- Mean Secchi depth was less than (did not meet) the annual GV at ER03, ER02, and AR02, but did meet the GVs at sites AR03 and AE04. These Secchi depth and TSS results are very similar to 2021–22;
- PN and PP met the GVs at all sites, with the exception of PN at AR02, which only slightly exceeded the annual GV. These results contributed to the 'good' score for particulates;
- The median wet season turbidity values calculated from dataloggers at Dawson and Forrester Reefs were less than the respective GVs for the open coastal and offshore waterbodies (Figure 5-29). The annual median turbidity values decreased at both sites compared to the 2021–22 wet season (Table C - 2); and
- Median Chl-*a* concentrations at Dawson and Forrester Reefs were both less than half the relevant GVs. Wet season median Chl-*a* concentrations increased at Dawson Reef and decreased at Forrester compared to the 2021–22 wet season.

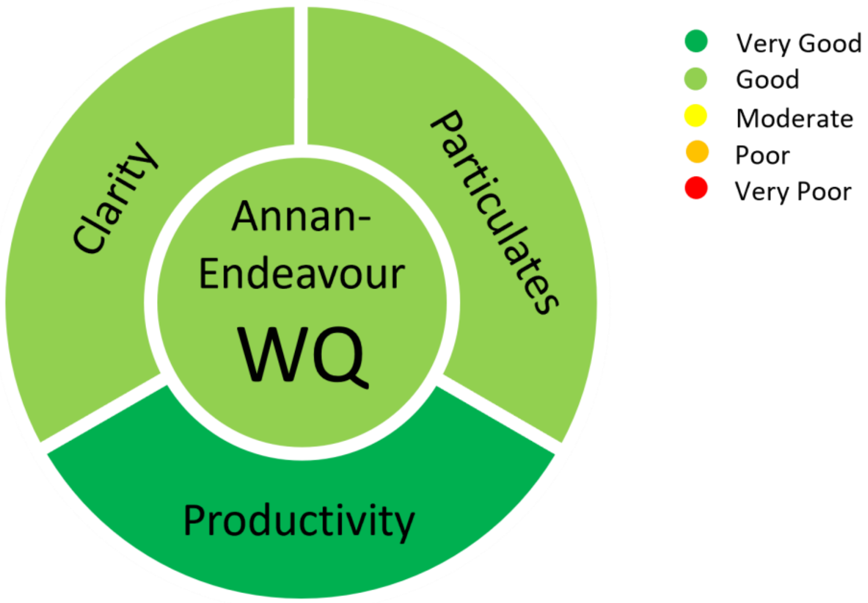


Figure 5-28: Annual condition version of the WQ Index for the Annan-Endeavour focus region for 2022–23. Calculations for Index formulations are described in Appendix B.

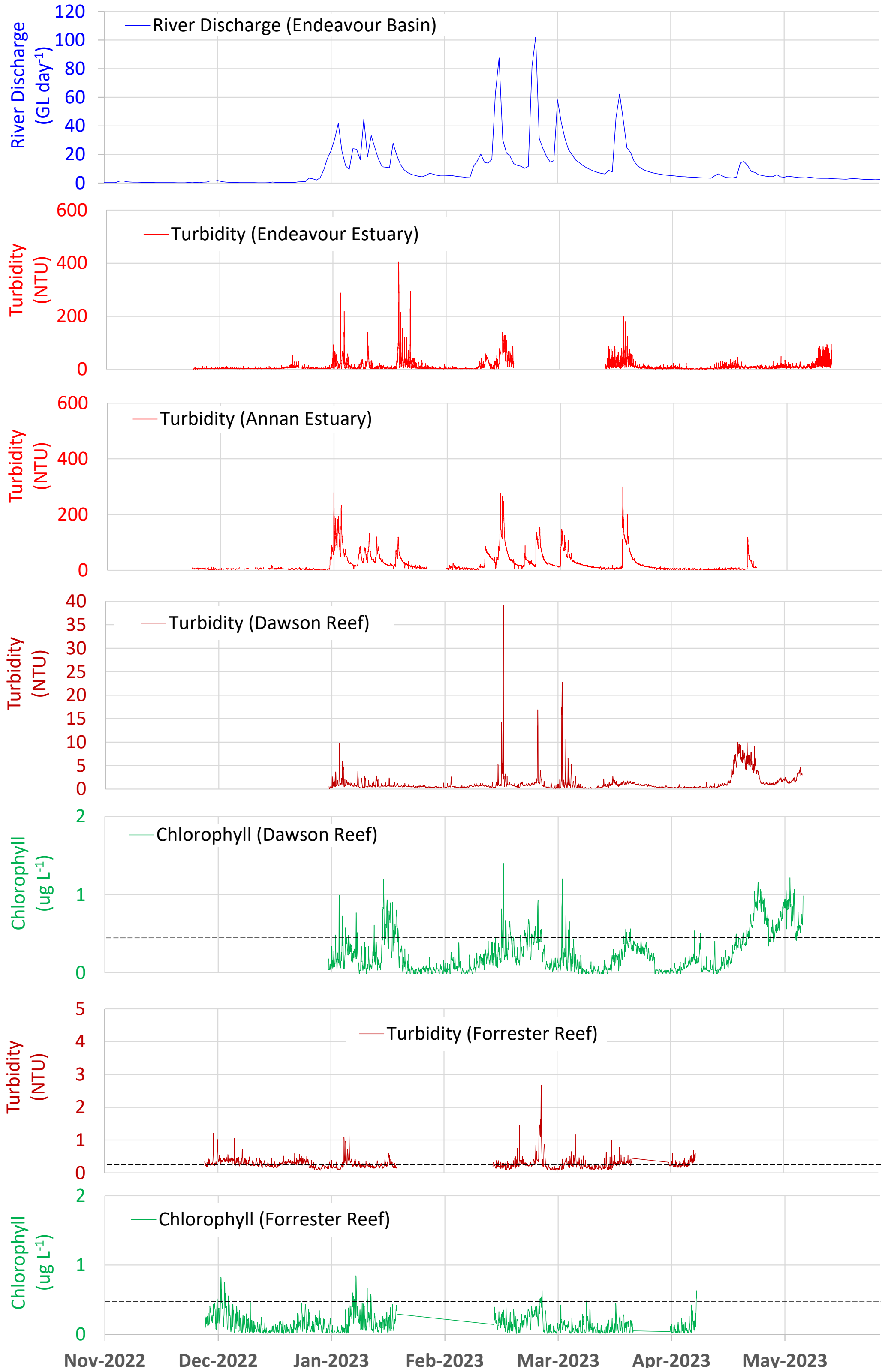


Figure 5-29: River discharge (combined Annan and Endeavour Rivers), turbidity measured on YSI EXO2s at the mouth of the Annan and Endeavour River, and turbidity and Chl-*a* fluorescence measured on the Wetlabs FLNTU at Dawson and Forrester Reefs over the 2022–23 wet season. Estuary turbidity (EXO2) data provided by CYWP and CSIRO. Dotted lines show wet season GVs.

Event water quality

The 2022–23 wet season saw above-average rainfall in the Endeavour Basin. The estuaries were consistently turbid throughout the wet season as a result of consistently high rainfall in the catchment. However, there were no above-average flood events and thus no targeted flood sampling across the transects. Southeasterly winds also consistently kept flood plumes travelling north close to the shore so mid-shelf transect sites were generally not within the influence of these plumes. Three event samples were collected near the mouth of the Endeavour (ER01) and Dawson Reef (AR03) over 18–19 January during a relatively minor flood event. These samples showed elevated (above-average ambient) concentrations of NO_x, POC, PP, PN, and TSS. Chl-*a* concentrations were also above the GV and three times the ambient average at Dawson Reef (0.68 µg L^{-1}).

Monitoring of continuous turbidity and fluorescence at Dawson Reef and Forrester Reef showed turbidity peaks (>15 NTU) at Dawson in February and March associated with flooding in the Annan and Endeavour rivers (Figure 5-29). Turbidity at Forrester remained relatively low but peaked above 2 NTU on 28 February, when visible flood plumes from both rivers reached beyond Forrester in the mid-shelf water body (Figure 5-30). Median wet season Chl-*a* concentrations increased at Dawson Reef compared to the 2021–22 wet season, likely due to the increased river flow.

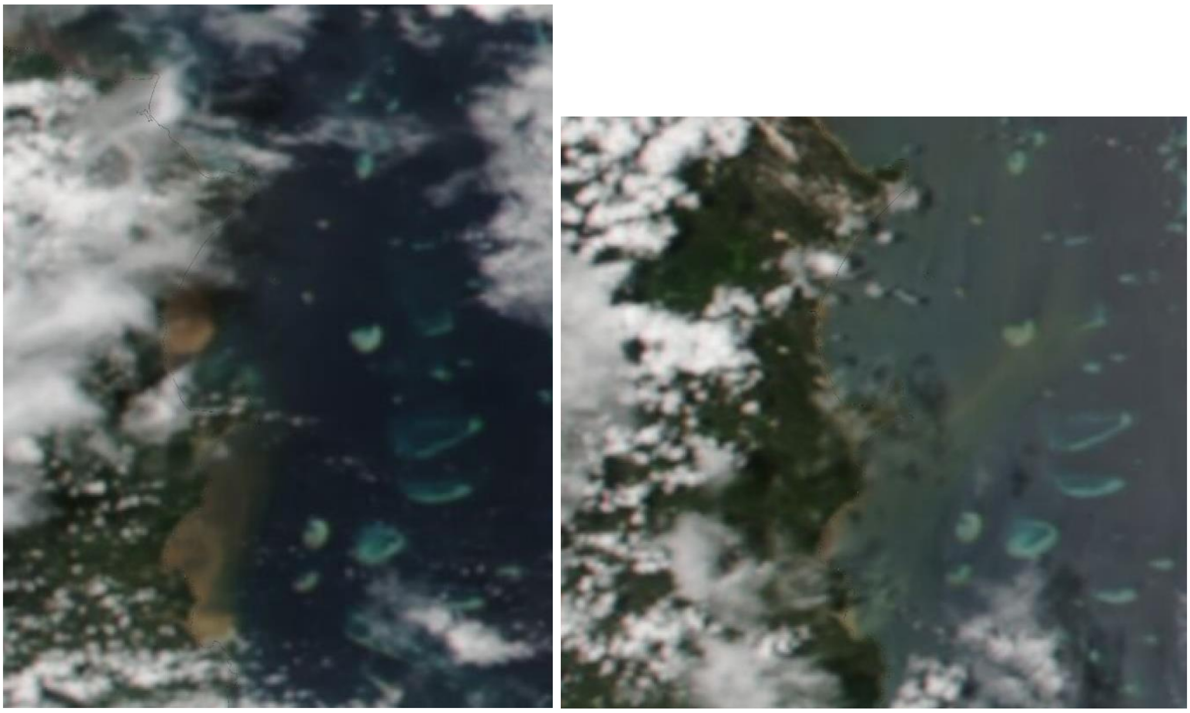


Figure 5-30: MODIS Aqua satellite images showing (left) turbid estuary and enclosed coastal water bodies during an ambient sampling event on 11 January 2023 and (right) flooding from the Annan and Endeavour Rivers inundate Dawson and Forrester Reefs on 28 February 2023.

5.2 Wet Tropics region

The Wet Tropics region is divided into three focus regions which are dominated by the Barron and Daintree Rivers (Barron-Daintree), the Russell and Mulgrave Rivers (Russell-Mulgrave) and the Tully River. The results on the pressures and monitoring findings are presented separately for each focus region.

5.2.1 Barron Daintree

This focus region contains the six sites of the 'Cairns Transect', which are sampled three times a year (Figure 5-31). This sampling design and frequency did not change in 2015 (unlike all other focus regions), as these sites are part of a long-term AIMS time-series (the Cairns Transect).

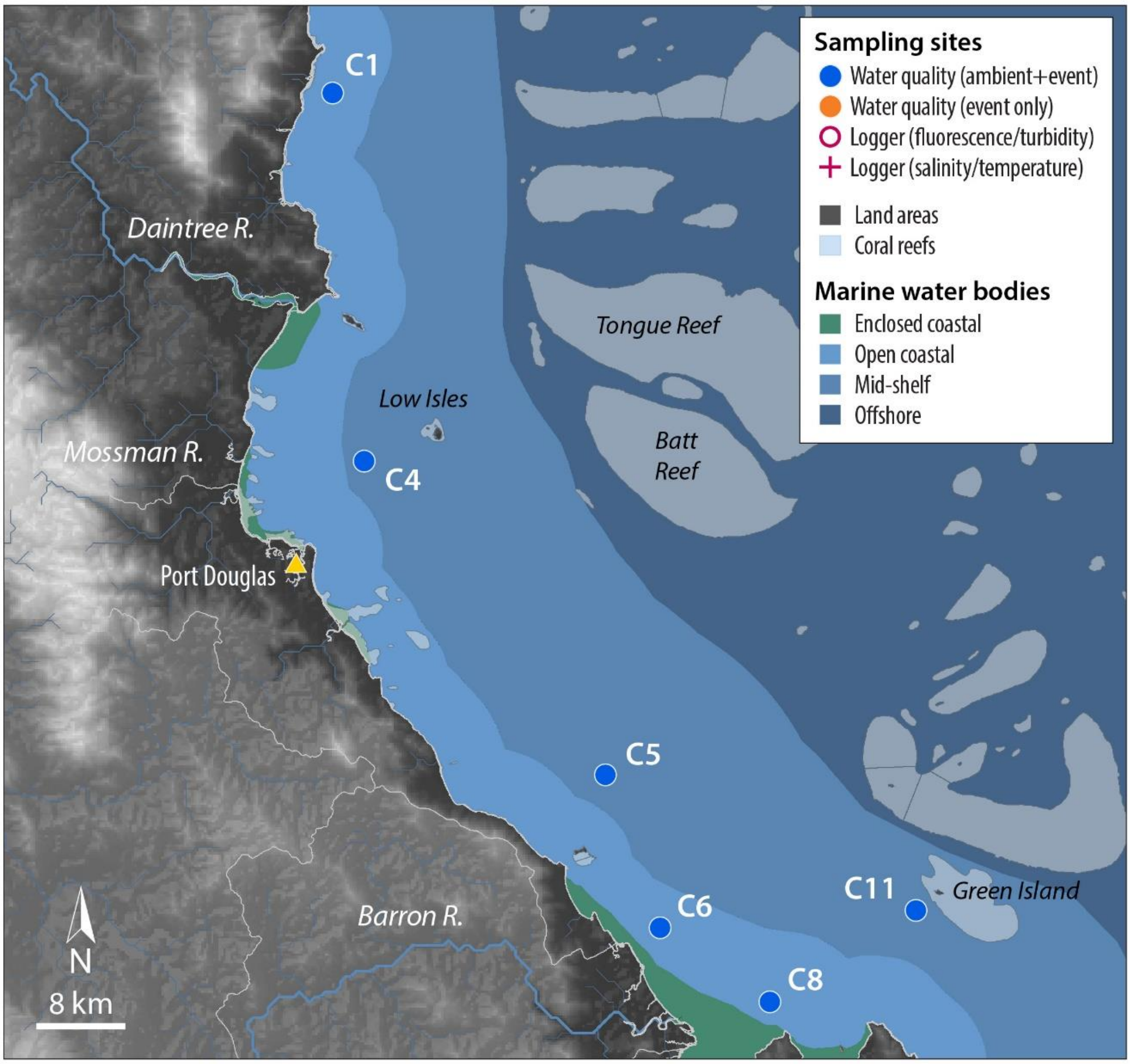


Figure 5-31: Sampling sites in the Barron Daintree focus region shown with water body boundaries.

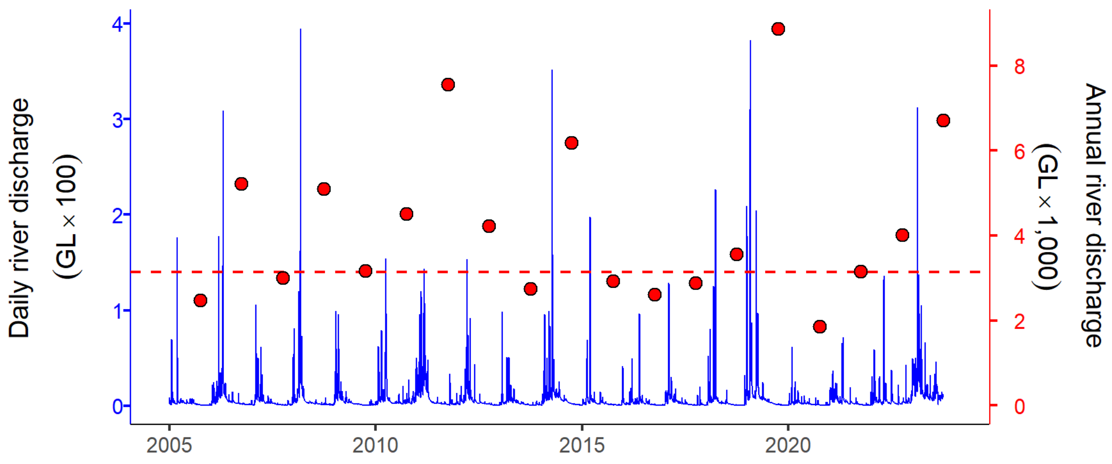


Figure 5-32: Combined discharge for the Barron (Myola gauge) and Daintree (Bairds gauge) Rivers. Daily (blue) and water year (October to September, red symbols) discharge volumes shown. Red dashed line represents long-term median of the combined annual discharge.

The combined discharge (Figure 5-32; Table 3-1) and loads (Figure 5-33) calculated for the 2022–23 water year from the Barron, Daintree, and Mossman Basins were around 2.1 times higher than the long-term median values. Over the 17-year period from 2006–07:

- discharge ranged from 1,855 GL (2019–20) to 8,868 GL (2018–19);
- TSS loads ranged from 183 kt (2019–20) to 902 kt (2018–19);
- DIN loads ranged from 211 t (2019–20) to 934 t (2018–19); and
- PN loads ranged from 493 t (2019–20) to 2,444 t (2018–19).

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

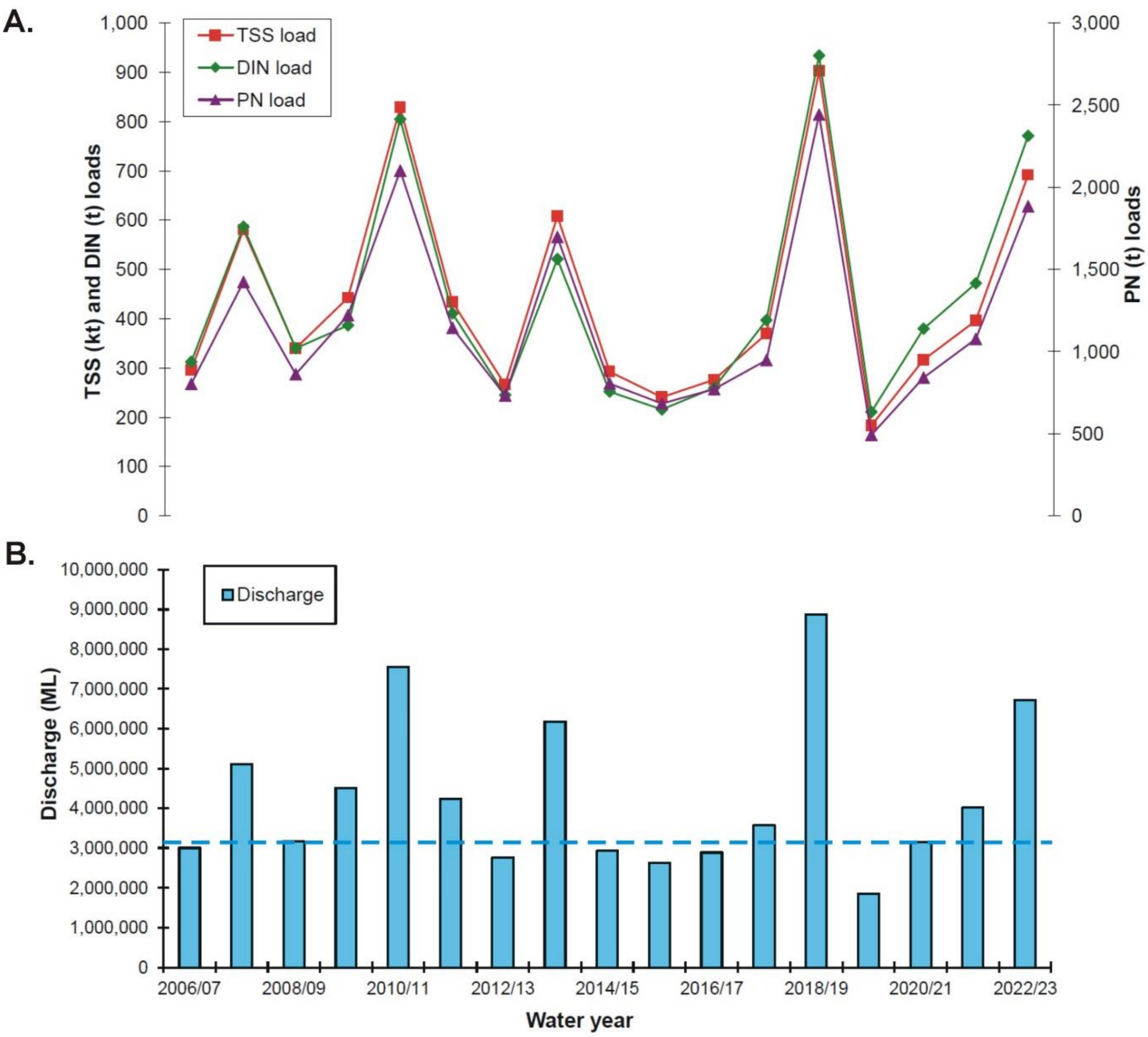


Figure 5-33: Loads of (A) TSS, DIN and PN and (B) discharge for the Barron, Daintree, and Mossman Basins from 2006–2023. The loads reported here are a combination of 'best estimates' for each basin based on up-scaled discharge data from gauging stations, monitoring data (Barron River), the DIN model developed in Lewis et al. (2014), and annual mean concentrations and discharge from monitoring data or Source Catchments modelling data. The dotted line represents the long-term median for basin discharge. Note the different scales on the two y-axes.

Ambient water quality and the in situ *Water Quality Index*

Distinct long-term trends (since 2005) were observed in some water quality variables, while others showed little change (Figure 5-34). Site-specific statistics and comparison to GVs for all variables are available in Table C - 1.

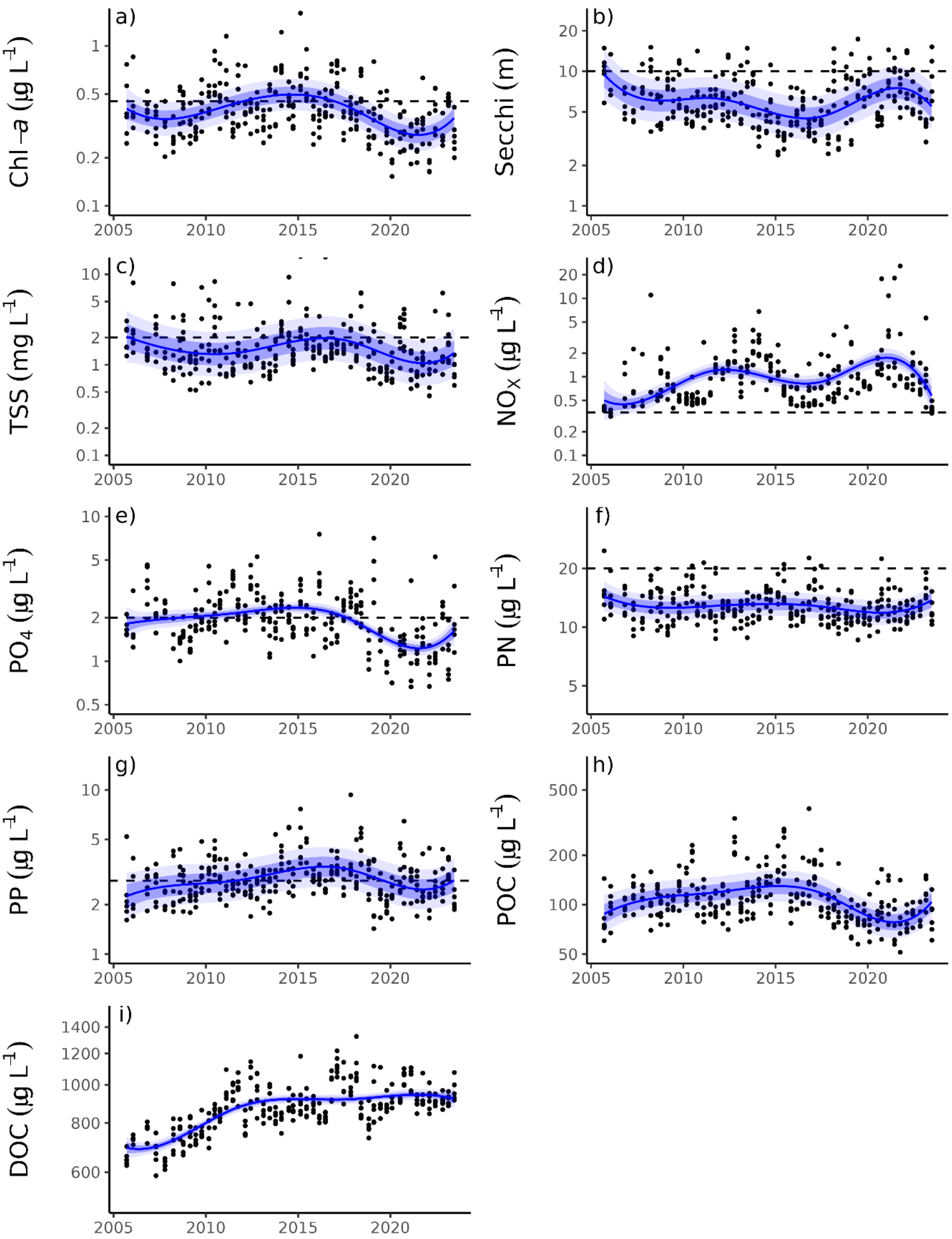


Figure 5-34: Temporal trends in water quality variables for the Barron Daintree focus region: a) chlorophyll *a* (Chl-*a*), b) Secchi depth, c) total suspended solids (TSS), d) nitrate/nitrite (NO_x), e) phosphate (PO_4), f) particulate nitrogen (PN), g) particulate phosphorus (PP), h) particulate organic carbon (POC) and i) dissolved organic carbon (DOC). Generalised additive mixed effect models (trends) are represented by blue lines with shaded areas defining 95% confidence intervals of those trends accounting for the effects of wind, waves, tides, and seasons after applying x-z detrending. Dashed horizontal reference lines indicate annual guideline values.

Concentrations of Chl-*a* remained generally stable, fluctuating slightly around local GVs from 2005 until 2015 (Figure 5-34a). Over the period 2015–2023, mean concentration of Chl-*a* has decreased overall despite a small upward trend in recent years. Chl-*a* in 2022–23 was just below (met) the local GVs.

Secchi depth gradually declined (i.e., water clarity worsened) from 2005 until 2016 (Figure 5-34b). Over the period 2015–2023, mean Secchi depth has remained stable (not improved or declined overall) despite a small oscillation over this 8-year period. Secchi depth in 2022–23 was below (not meeting) the local GVs.

Concentrations of TSS have fluctuated above and below the GVs since monitoring began in 2005 (Figure 5-34c). Over the period 2015–2023, mean concentration of TSS has decreased. TSS in 2022–23 was below (met) the local GVs.

Concentrations of NO_x generally increased and remained above the local GVs from 2005 until 2015 (Figure 5-34d). Over the period 2015–2023, mean concentration of NO_x has remained stable (not improved or declined overall) despite an oscillation over this 8-year period. NO_x in 2022–23 was above (not meeting) the local GVs.

Concentrations of PO_4 were generally stable and close to the local GVs from 2005 until 2015 (Figure 5-34e). Over the period 2015–2023, mean concentration of PO_4 has decreased overall despite a small upward trend in recent years. PO_4 in 2022–23 was just below (met) the local GVs.

Concentrations of PN have remained stable and well below the local GVs since monitoring began in 2005 (Figure 5-34f). Over the period 2015–2023, mean concentration of PN has remained very stable (not improved or declined overall) over this 8-year period. PN in 2022–23 was below (met) the local GVs.

Concentrations of PP have remained relatively stable and close to the local GVs since monitoring began in 2005 (Figure 5-34g). Over the period 2015–2023, mean concentration of PP has remained stable (not improved or declined overall) despite showing some minor variability over this 8-year period. PP in 2022–23 was below (met) the local GVs.

Concentrations of POC have remained relatively stable since monitoring began in 2005, with only a slight increase between 2005 and 2017 (Figure 5-34h). Concentrations have been declining since 2017. Concentrations of DOC have increased substantially since 2005, although concentrations have stabilised in recent years (Figure 5-34i).

The WQ Index is calculated using two different formulations to communicate the a) long-term trend in water quality (based on the pre-2015 sampling design) and b) annual condition of water quality (based on the post-2015 sampling design, which increased the power to detect change). For the Barron Daintree focus region, no additional sites were added in 2015, with sampling still conducted three times per year. Section 2.5 and Appendix B contain details of the calculations for both Index formulations.

The long-term WQ Index has shown a small trend (i.e., changing by a single grade) of decline in water quality from 2005–2018, driven by Chl-*a* and PP indicators (Figure 5-35a). Over the last six years, this trend has reversed and water quality now shows an overall trend of improvement. This improving trend is driven by improvements in Chl-*a*, water clarity, and PP indicators.

The annual condition WQ Index scored water quality as ‘moderate’ during the 2015–18 water years and ‘good’ during the past five water years, including 2022–23 (Figure 5-35b). This version of the Index scores water quality parameters against GVs relevant to the season when samples are collected (wet versus dry GVs).

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

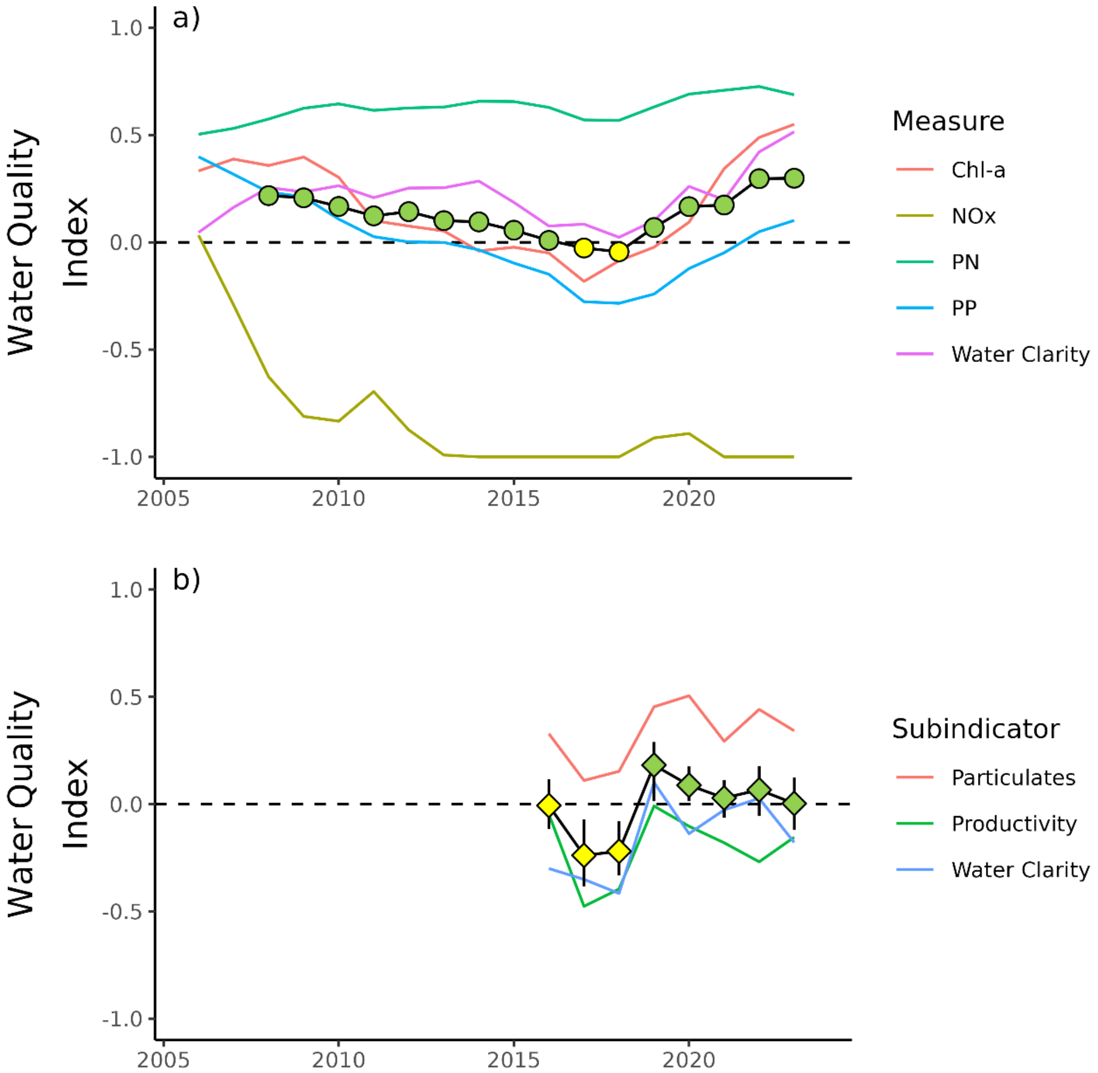


Figure 5-35: The Water Quality Index (WQ Index) for the Barron Daintree focus region. The WQ Index uses two formulations to communicate: a) long-term trend (based on pre-2015 sampling design) and b) the annual condition (based on post-2015 sampling design). WQ Index colour coding: / – 'very good'; / – 'good'; / – 'moderate; / – 'poor'; / – 'very poor'. Indicators or sub-indicators that are used to calculate the WQ Index are shown as coloured lines on each plot. Error bars (vertical black lines) on the WQ Index represent the 95% quantile intervals. Calculations for both formulations are described in Appendix B.

Event water quality

No event sampling was conducted in the Barron Daintree focus region in 2022–23.

5.2.2 Russell-Mulgrave

The Russell-Mulgrave focus region is primarily influenced by discharge from the Russell-Mulgrave and Johnstone Basins and, to a lesser extent, by other rivers south of the focus region such as the Burdekin (Brodie *et al.*, 2013; Waterhouse *et al.*, 2017). Three sites were sampled three times per year in this focus region until the end of 2014. Following the implementation of the revised MMP water quality sampling design in 2015, 12 monitoring sites are sampled in this focus region up to 10 times per year, with five sites sampled during both the dry and wet season and seven additional sites sampled during major flood events (Table A - 1). The monitoring sites form a transect from the river mouth to mid-shelf waters, representing a gradient in water quality. Five sites are in the open coastal water body, five sites are located in the mid-shelf water body, one site is in mid-estuarine waters, and one site is in enclosed coastal waters (Figure 5-36).

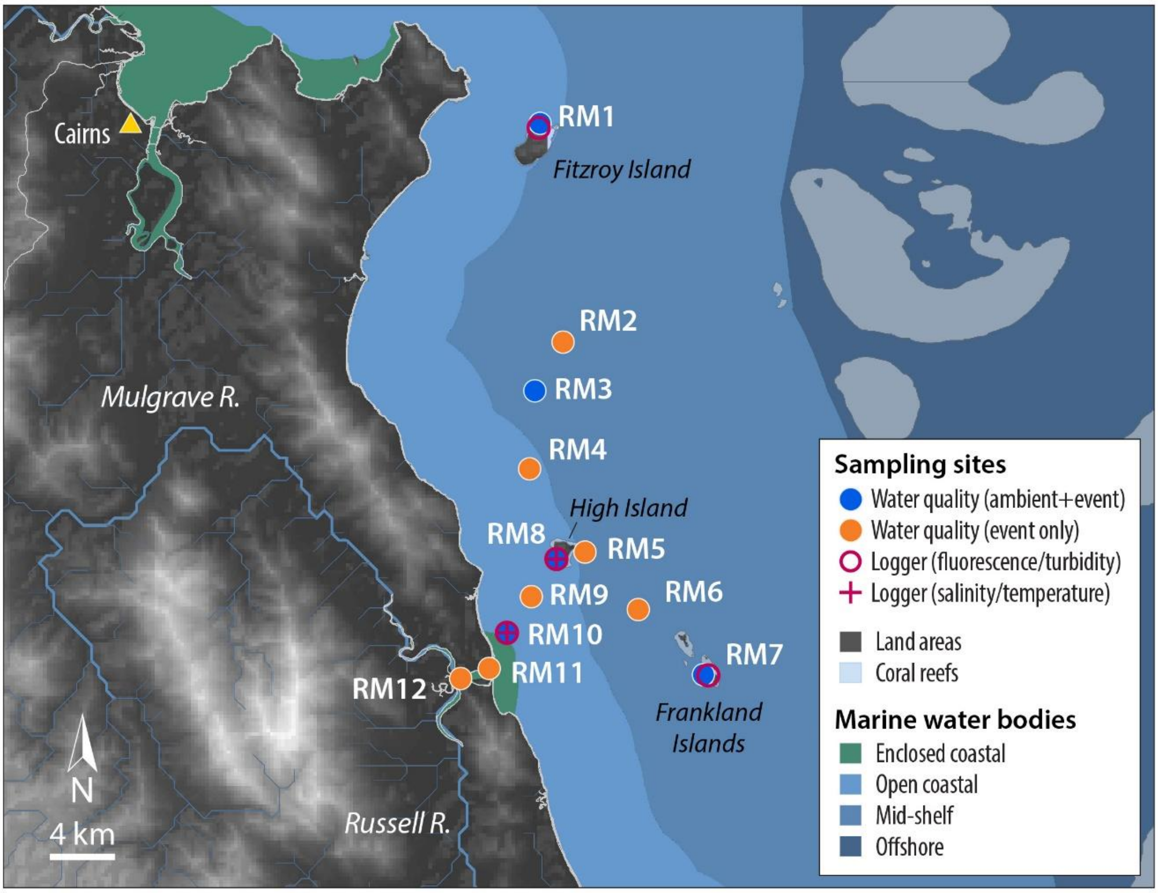


Figure 5-36: Sampling sites in the Russell-Mulgrave focus region, shown with the water body boundaries.

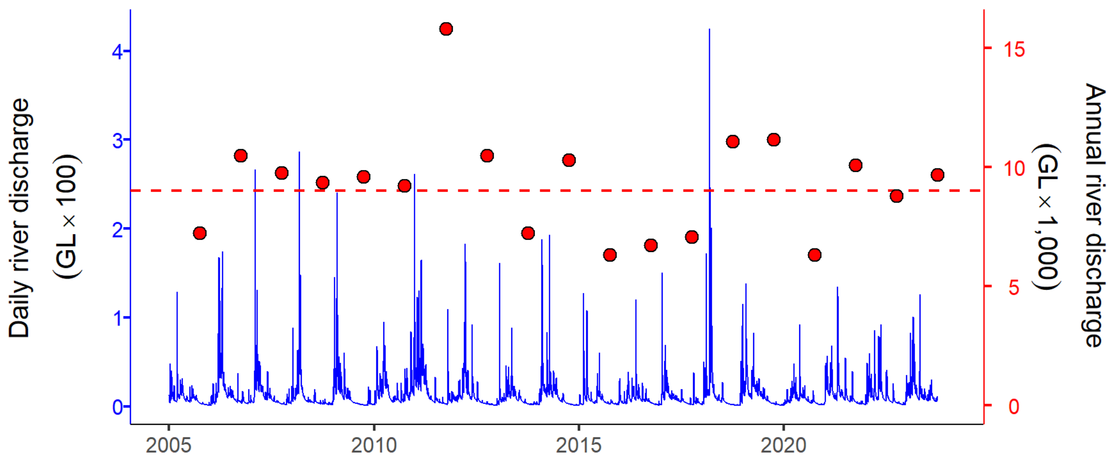


Figure 5-37: Combined discharge for the North and South Johnstone (Tung Oil and Central Mill gauges, respectively), Russell (Bucklands gauge) and Mulgrave (Peets Bridge gauge) Rivers. Daily (blue) and water year (October to September, red symbols) discharge is shown. Red dashed line represents the long-term median of the combined annual discharge.

The combined discharge volume of the Russell-Mulgrave and Johnstone Rivers for the 2022–23 water year was around the long-term median (Figure 5-37).

The combined discharge and loads calculated for the 2022–23 water year from the Russell-Mulgrave and Johnstone Basins were in the average range to that recorded over the past decade (Figure 5-38). Over the 17-year period from 2006–07:

- discharge ranged from 6,318 GL (2014–15) to 15,813 GL (2010–11);
- TSS loads ranged from 350 kt (2014–15) to 896 kt (2010–11);
- DIN loads ranged from 835 t (2014–15) to 2,722 t (2010–11); and
- PN loads ranged from 1,177 t (2014–15) to 3,005 t (2010–11).

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

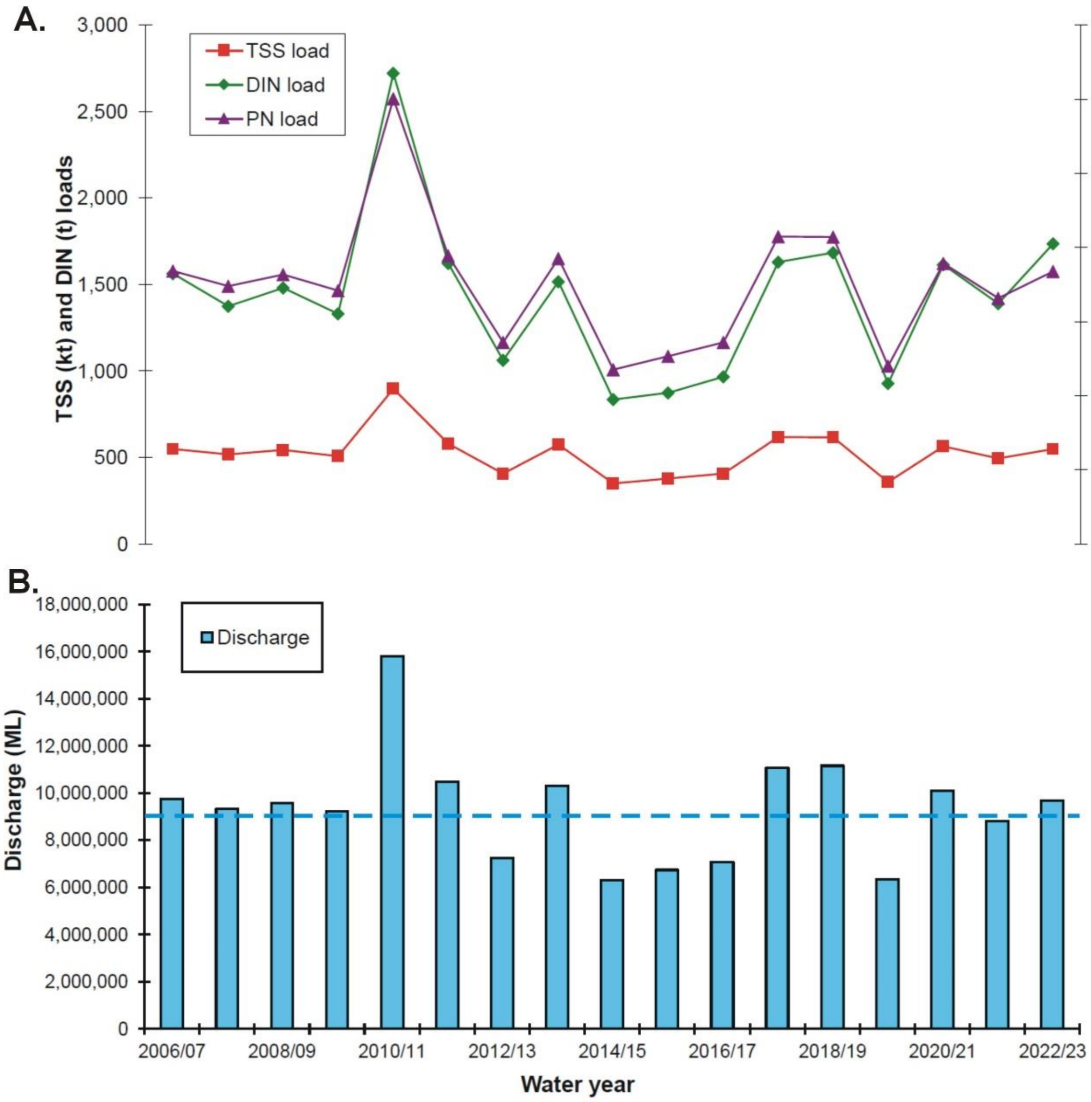


Figure 5-38: Loads of (A) TSS, DIN and PN and (B) discharge for the Russell, Mulgrave, and Johnstone Basins from 2006 to 2023. The loads reported here are a combination of 'best estimates' for each basin based on 'up-scaled discharge data from gauging stations, monitoring data, the DIN model developed in Lewis et al. (2014) and annual mean concentrations and discharge from monitoring data or Source Catchments modelling data. Dotted line represents the long-term median for basin discharge. Note the different scales on the two y-axes.

Ambient water quality and the in situ *Water Quality Index*

Water quality showed trends along the sampling transect (cross-shelf gradient in northerly direction). Sites located nearest to the river mouth (distance from river mouth = 0 km) had high concentrations of NO_x and particulate nutrients (PN and PP), which declined with distance away from the river mouth, reaching low levels in mid-shelf waters (Figure 5-39, Table C - 2). Concentrations of Chl-*a* and TSS showed a similar pattern to nutrient concentrations and tended to decline with distance from the river mouth. Secchi depths were low at sites near the river mouth (water clarity was poor) and increased (water clarity improved) with distance from the river mouth. These spatial patterns are generally consistent with those that are typically observed in the region.

This year, seasonal differences in NO_x, TSS, and PN were observed, where concentrations (especially near the river mouth) were much higher during the wet than the dry season. These seasonal differences tended to become less pronounced further offshore (e.g., concentrations of PN during wet and dry seasons were similar in mid-shelf waters). Concentrations of PP were similar between wet and dry seasons. Concentrations of Chl-*a* were higher in the dry season compared to the wet season, and Secchi depths were lower (water clarity was worse) during the dry season (Figure 5-39).

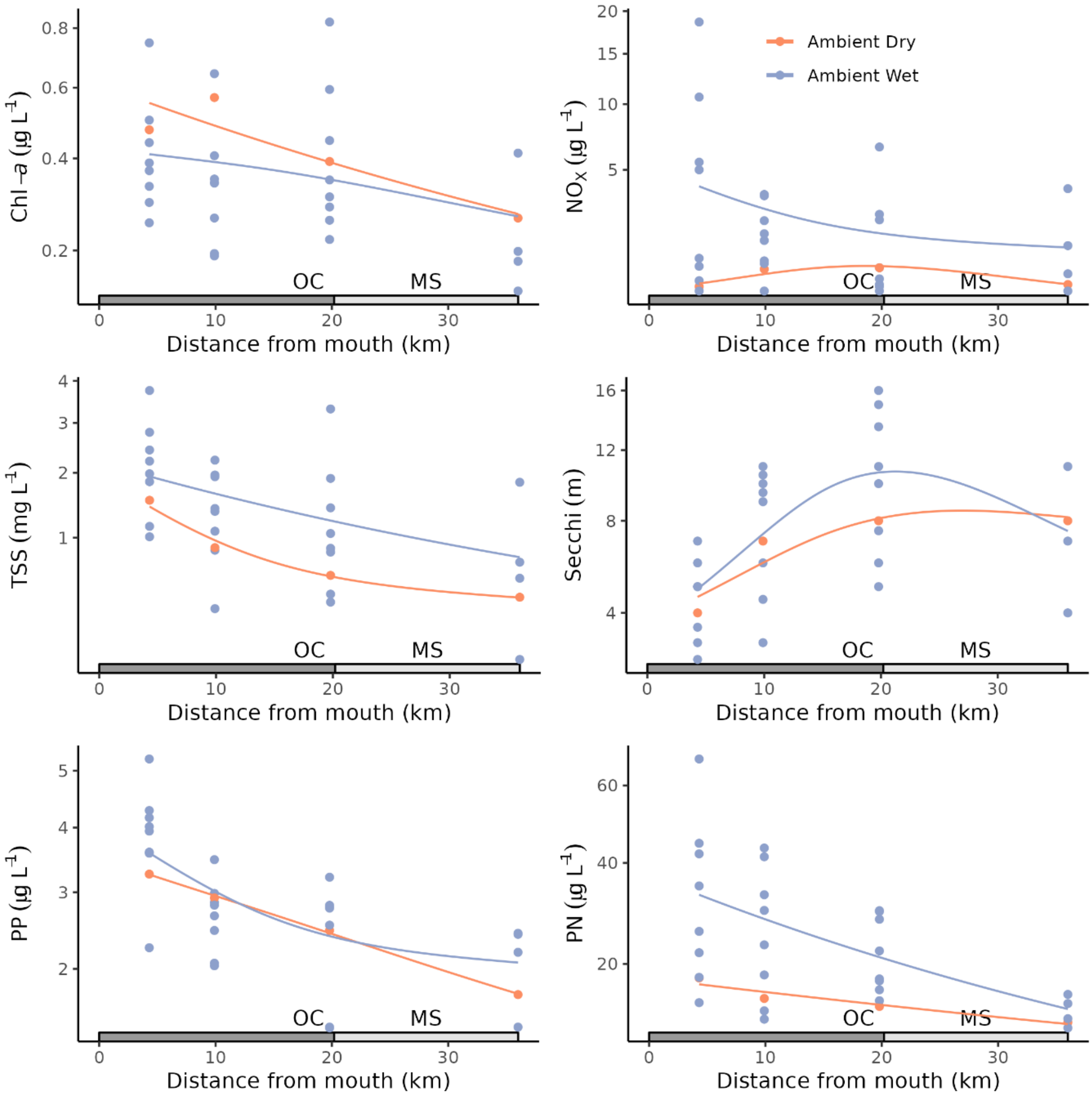


Figure 5-39: Water quality variables measured during ambient and event sampling in 2022–23 along the Russell-Mulgrave focus region transect. Chlorophyll *a* (Chl-*a*), nitrate/nitrite (NO_x), total suspended solids (TSS), Secchi depth, particulate nitrogen (PN), and particulate phosphorus (PP) are shown with distance from the Russell-Mulgrave River mouth. Water body classifications are shown along the x-axes: open coastal (OC) and mid-shelf (MS). Note the y-axes are logarithmic scales. Fitted lines are generalised additive models.

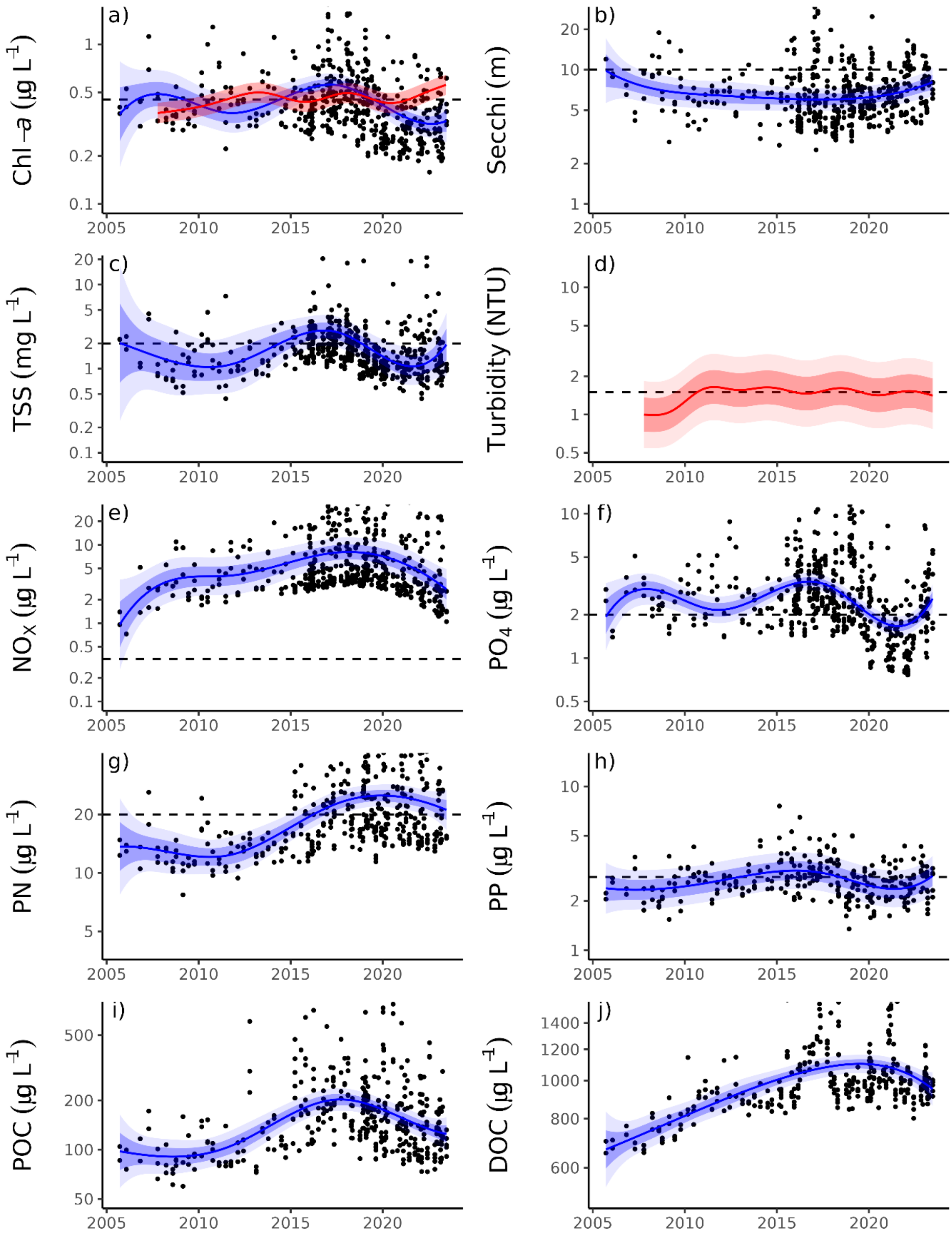


Figure 5-40: Temporal trends in water quality variables for the Russell-Mulgrave focus region: a) chlorophyll *a* (Chl-*a*), b) Secchi depth, c) total suspended solids (TSS), d) turbidity, e) nitrate/nitrite (NO_x), f) phosphate (PO_4), g) particulate nitrogen (PN), h) particulate phosphorus (PP), i) particulate organic carbon (POC) and j) dissolved organic carbon (DOC). Generalised additive mixed effect models (trends) are represented by blue lines with shaded areas defining 95% confidence intervals of those trends accounting for the effects of wind, waves, tides, and seasons after applying x-z detrending. Trends of records from ECO FLNTUSB instruments are represented in red, and individual records can be found in Figure C - 1. Dashed horizontal reference lines indicate annual guidelines.

Distinct long-term trends (since 2005) were observed in some water quality variables, while others showed little change (Figure 5-40). Site-specific statistics and comparison to GVs for all variables are available in Table C - 1.

Concentrations of Chl-*a* have fluctuated above and below the GVs since monitoring began in 2005 (Figure 5-40a). Over the period 2015–2023, mean concentration of Chl-*a* has decreased overall. Chl-*a* in 2022–23 was below (met) the local GVs. Chlorophyll fluorescence measured by FLNTU instruments (Figure 5-40a) has likewise fluctuated around GVs since monitoring began in 2007. The differences between FLNTU chlorophyll fluorescence and Chl-*a* concentration reflect differences in sampling location and measurement method.

Secchi depth gradually declined (i.e., water clarity worsened) from 2005 until 2015. Over the period 2015–2023, mean Secchi depth has increased (i.e., water clarity has improved) in a steady trend (Figure 5-40b). Secchi depth in 2022–23 was below (not meeting) the local GVs.

Concentrations of TSS have fluctuated above and below the GVs since monitoring began in 2005. Over the period 2015–2023, mean concentration of TSS has remained stable (not improved or declined overall) despite an oscillation over this 8-year period. TSS concentrations in 2022–23 were below (met) the local water quality GVs (Figure 5-40c).

Turbidity has remained relatively stable and close to the GVs since monitoring began in 2005 (Figure 5-40d). Over the period 2015–2023, turbidity has remained stable (not improved or declined overall) despite small oscillations over this 8-year period. Turbidity in 2022–23 was above (not meeting) the GVs.

Concentrations of NO_x steadily increased and remained above the local GVs from 2005 until 2015 (Figure 5-40e). Over the period 2015–2023, mean concentration of NO_x has steadily decreased. NO_x in 2022–23 was above (not meeting) the local GVs.

Concentrations of PO_4 fluctuated above the local GVs from 2005 until 2015 (Figure 5-40f). Over the period 2015–2023, mean concentration of PO_4 has remained stable (not improved or declined overall) despite a large oscillation during this 8-year period. PO_4 in 2022–23 was just below (met) the local GVs.

Concentrations of PN were below local GVs but increased over the period 2005–2015 (Figure 5-40g). Over the period 2015–2023, mean concentration of PN has remained stable (not improved or declined overall) despite an increase and subsequent decrease during this 8-year period. PN in 2022–23 was just below (met) the local GVs.

Concentrations of PP have remained relatively stable and close to the local GVs since monitoring began in 2005 (Figure 5-40h). Over the period 2015–2023, mean concentration of PP has remained stable (not improved or declined overall) despite showing some minor variability over this 8-year period. PP in 2022–23 was below (met) the local GVs.

Concentrations of POC increased dramatically over the period 2005–2017 (Figure 5-40i). Over the period 2015–2023, mean concentration of POC has decreased, similar to all other focus regions. Concentrations of DOC increased dramatically since monitoring began in 2005 but have been trending downwards since ~2020 (Figure 5-40j).

The WQ Index is calculated using two different formulations to communicate the a) long-term trend in water quality (based on the pre-2015 sampling design) and b) annual condition of water quality (based on the post-2015 sampling design, which increased the power to detect change). Section 2.5 and Appendix B contain details of the calculations for both Index formulations.

The long-term WQ Index has shown a small trend (i.e., changing within a grade) of decline in water quality from 2009–2019, which stabilised around 2020 (Figure 5-41a). This downward trend was generally driven by trends in PN, PP, and Chl-*a* indicators. Over the last two years, this trend appears to have reversed and water quality now shows early signs of overall improvement. This preliminary improving trend is driven by improvements in Chl-*a*, PN, and PP indicators.

The annual condition WQ Index has scored water quality as 'moderate' since its inception (2015–present) (Figure 5-41b). This version of the Index scores water quality parameters against GVs relevant to the season when samples are collected (wet versus dry GVs).

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

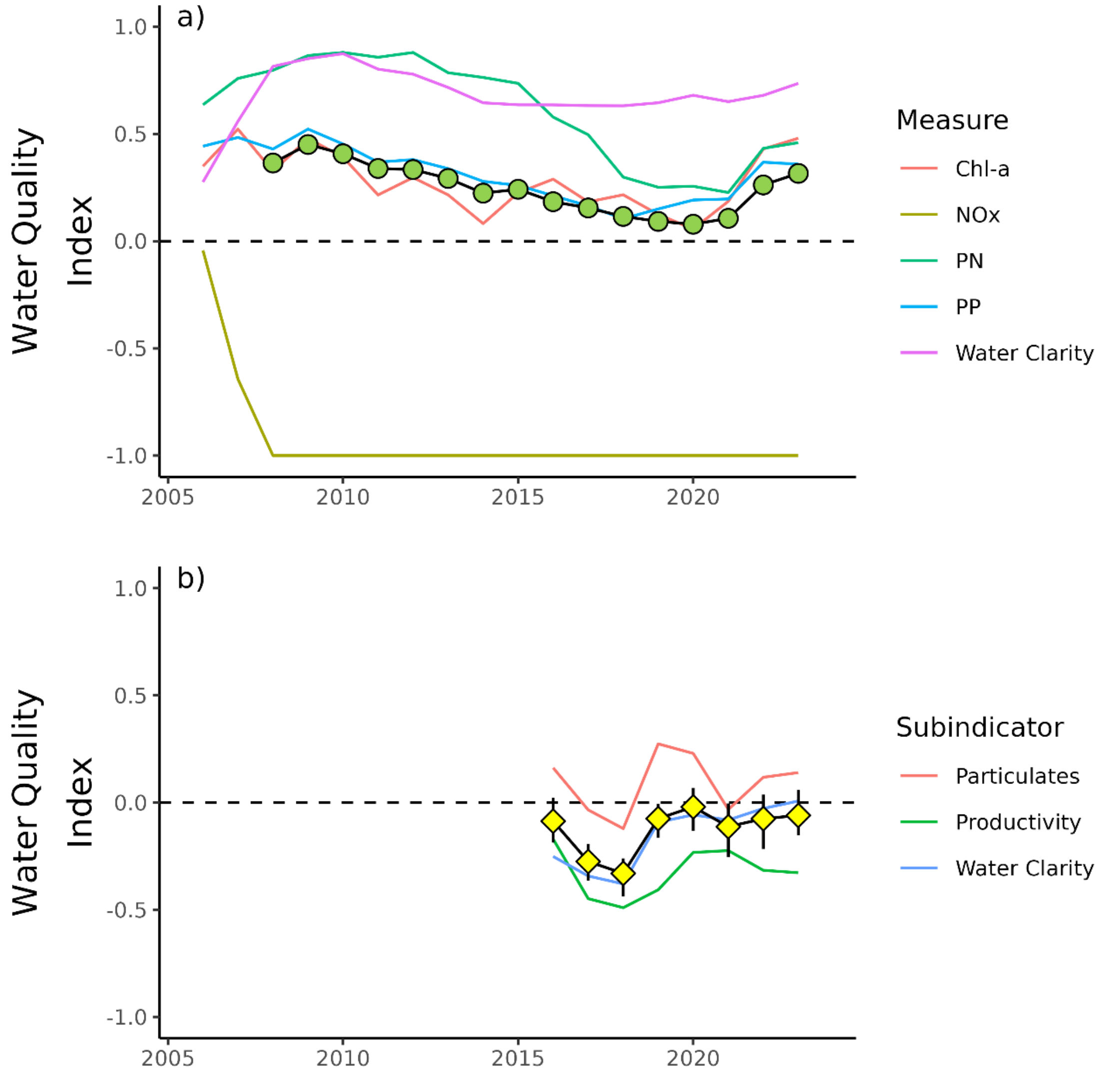


Figure 5-41: The Water Quality Index (WQ Index) for the Russell-Mulgrave focus region. The WQ Index uses two formulations to communicate the a) long-term trend (based on pre-2015 sampling design) and b) annual condition (based on post-2015 sampling design). WQ Index colour coding: ■ / ◆– 'very good'; ■ / ◆ – 'good'; ■ / ◆ – 'moderate; ■ / ◆ – 'poor'; ■ / ◆ – 'very poor'. Indicators or sub-indicators that are used to calculate the WQ Index are shown as coloured lines on each plot. Error bars (vertical black lines) on the WQ Index represent the 95% quantile intervals. Calculations for both formulations are described in Appendix B.

Event water quality

No event sampling was conducted in the 2022–23 wet season in the Russell-Mulgrave focus region.

5.2.3 Tully

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

One site was sampled in this focus region three times per year until the end of 2014. Following the implementation of the revised MMP water quality sampling design in 2015, 11 monitoring sites are sampled in this focus region up to 10 times per year, with six sites sampled during both the dry and wet seasons and five additional sites sampled during major flood events (Table A - 1). The monitoring sites form a transect from the river to mid-shelf waters, representing a gradient in water quality. Seven sites are in the open coastal water body, one is located in the mid-shelf water body, one site is in mid-estuarine waters, and two sites are in lower estuarine waters (Figure 5-42).

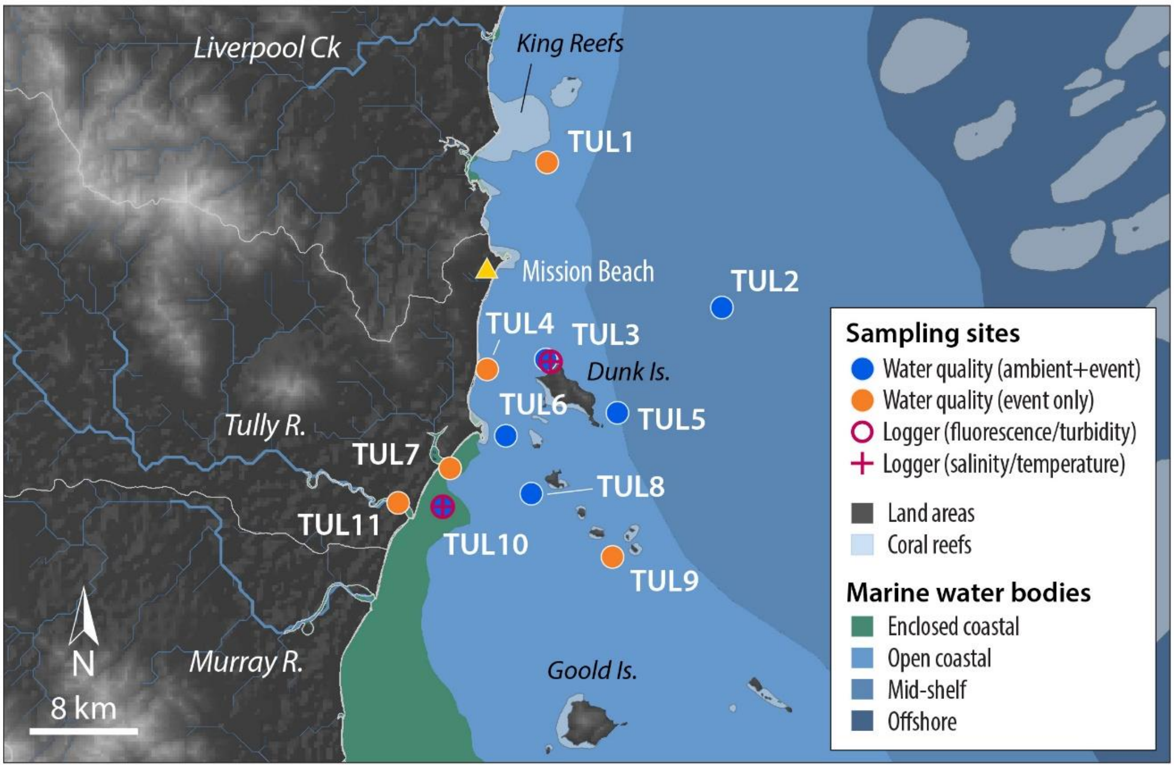


Figure 5-42: Sampling sites in the Tully focus region, shown with the water body boundaries.

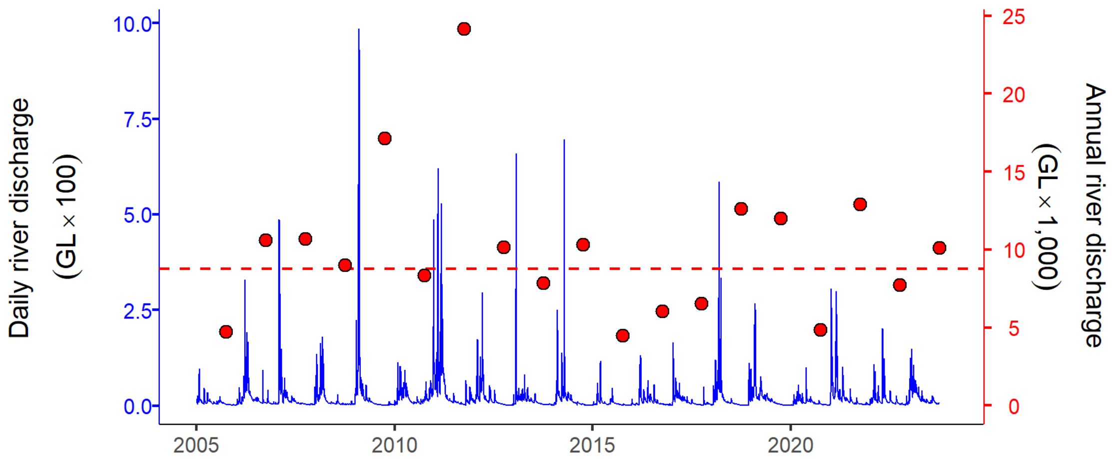


Figure 5-43: Combined discharge for Tully (Euramo gauge) and Herbert (Ingham gauge) Rivers. Daily (blue) and water year (October to September, red) discharge is shown. Red dashed line represents the long-term median of the combined annual discharge. Please note as this is the combined discharge, high flows in one river will not necessarily be visible in the graph.

The combined discharge volume of the Tully and Herbert Rivers for the 2022–23 water year was close to the long-term median (Figure 5-43).

The combined discharge and loads calculated for the 2022–23 water year from the Tully, Murray, and Herbert Basins were close to the long-term median (Figure 5-44). Over the 17-year period from 2006–07:

- discharge ranged from 4,491 GL (2014–15) to 24,166 GL (2010–11);
- TSS loads ranged from 260 kt (2014–15) to 1,827 kt (2010–11);
- DIN loads ranged from 1,082 t (2014–15) to 5,875 t (2010–11); and
- PN loads ranged from 796 t (2014–15) to 5,307 t (2010–11).

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

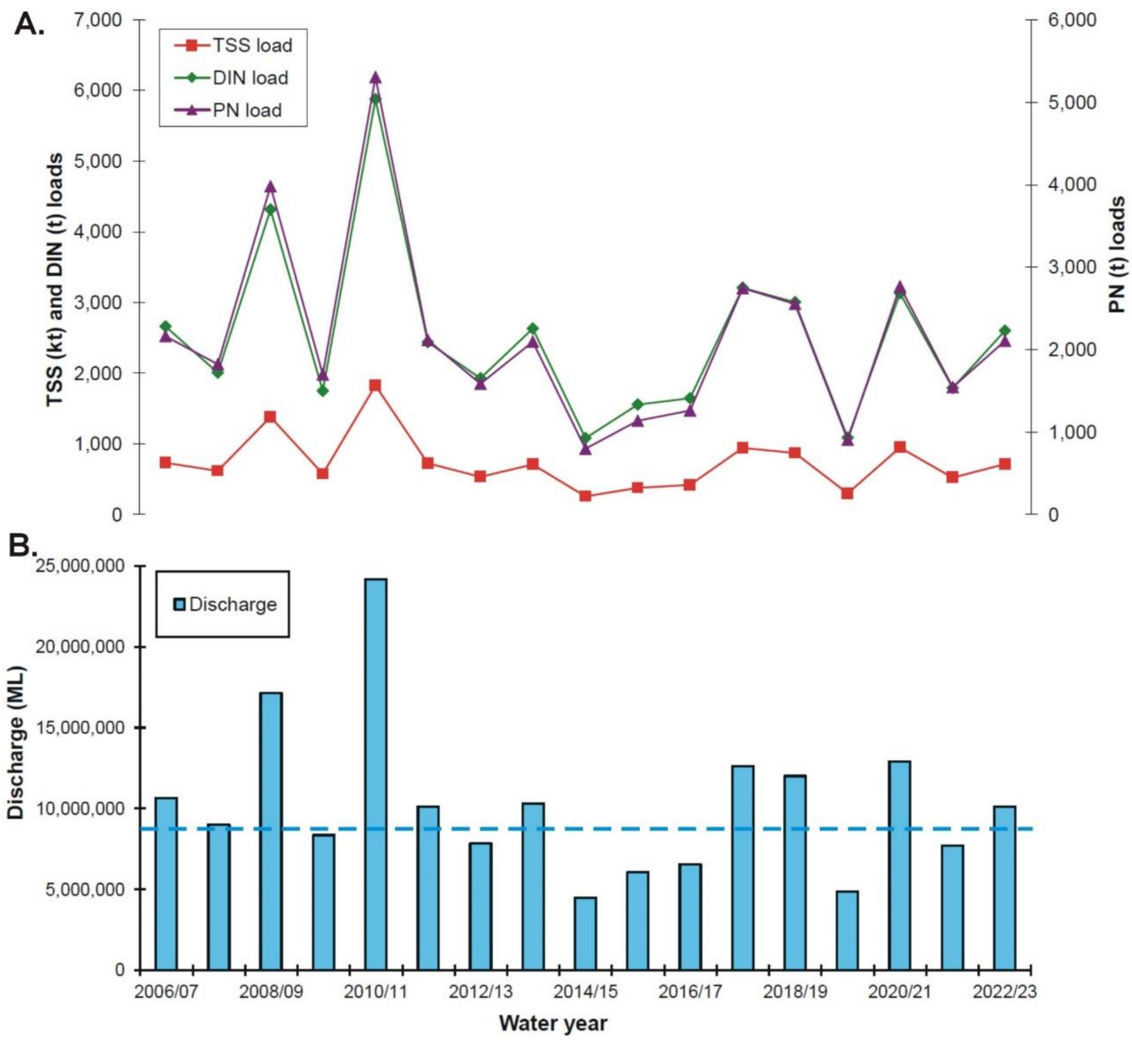


Figure 5-44: Loads of (A) TSS, DIN, and PN and (B) discharge for the Tully, Murray, and Herbert Basins from 2006 to 2023. The loads reported here are a combination of 'best estimates' for each basin based on 'up-scaled discharge data from gauging stations, monitoring data (Tully and Herbert Rivers), the DIN model developed in Lewis et al. (2014) and annual mean concentrations and discharge from monitoring data or Source Catchments modelling data. The dotted line represents the long-term median for basin discharge. Note the different scales on the two y-axes.

Ambient water quality and the in situ *Water Quality Index*

Water quality showed trends along the sampling transect (cross-shelf gradient in northerly direction). Sites located nearest to the river mouth (distance from river mouth = 0 km) had high concentrations of NO_x and particulate nutrients (PN and PP), which declined with distance away from the river mouth, reaching low levels in mid-shelf waters (Figure 5-45, Table C - 2). Concentrations of Chl-*a* and TSS showed a similar pattern to nutrient concentrations and tended to decline with distance from the river mouth. Secchi depths were low at sites near the river mouth (water clarity was poor) and increased (water clarity improved) with distance from the river mouth. These spatial patterns are generally consistent with those that are typically observed in the region.

This year, seasonal differences in NO_x were observed, where concentrations (especially near the river mouth) were much higher during the wet than the dry season. Concentrations of Chl-*a* and PN were generally similar between wet and dry seasons. Concentrations of TSS and

PP were higher in the dry season compared to the wet season, and Secchi depths were lower (water clarity was worse) during the dry season (Figure 5-45).

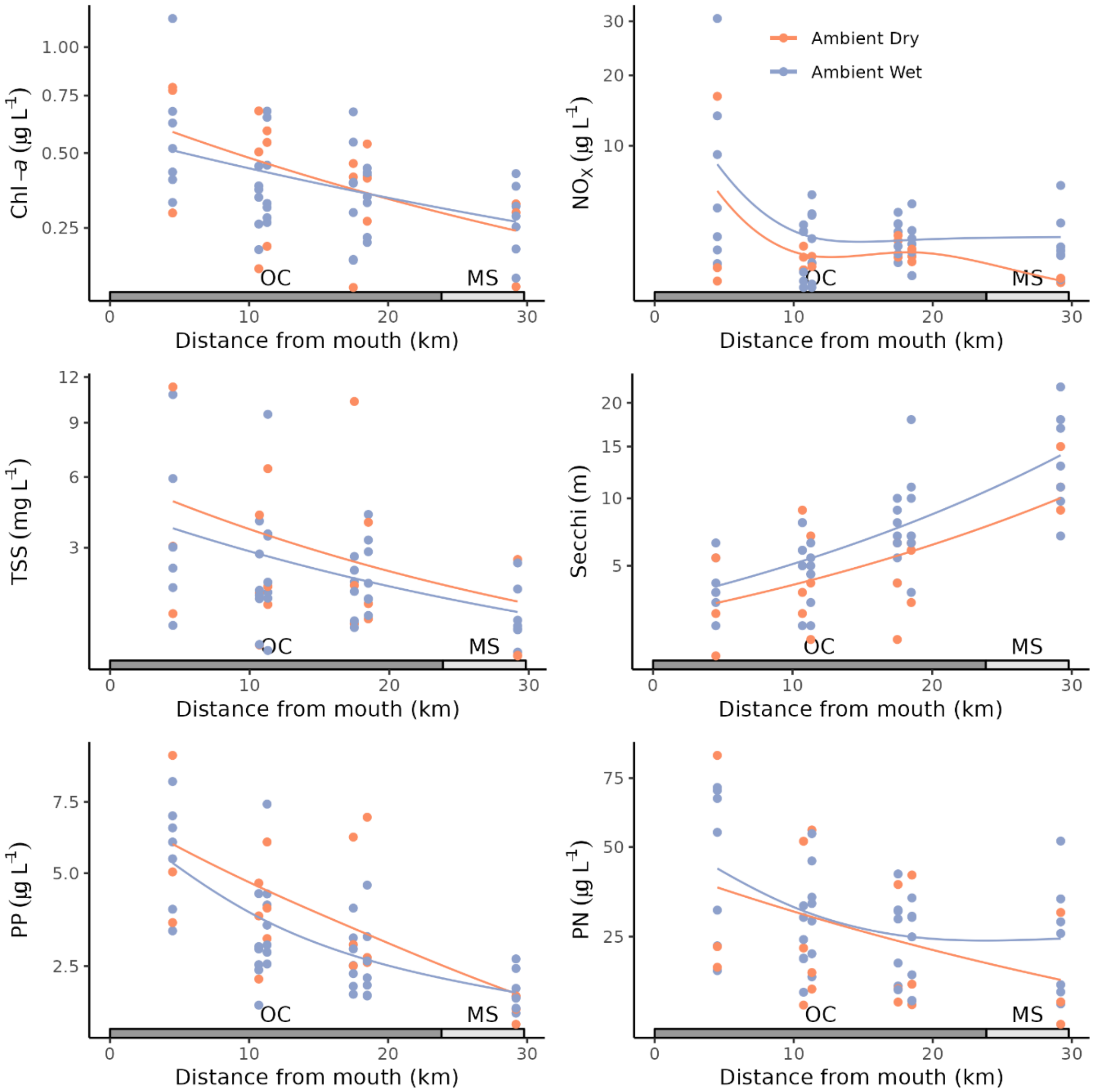


Figure 5-45: Water quality variables measured during ambient and event sampling in 2022–23 along the Tully focus region transect. Chlorophyll *a* (Chl-*a*), nitrate/nitrite (NO_x), total suspended solids (TSS), Secchi depth, particulate nitrogen (PN), and particulate phosphorus (PP) are shown with distance from the Tully River mouth. Water body classifications are shown along the x-axes: open coastal (OC) and mid-shelf (MS). Note the y-axes are logarithmic scales. Fitted lines are generalised additive models.

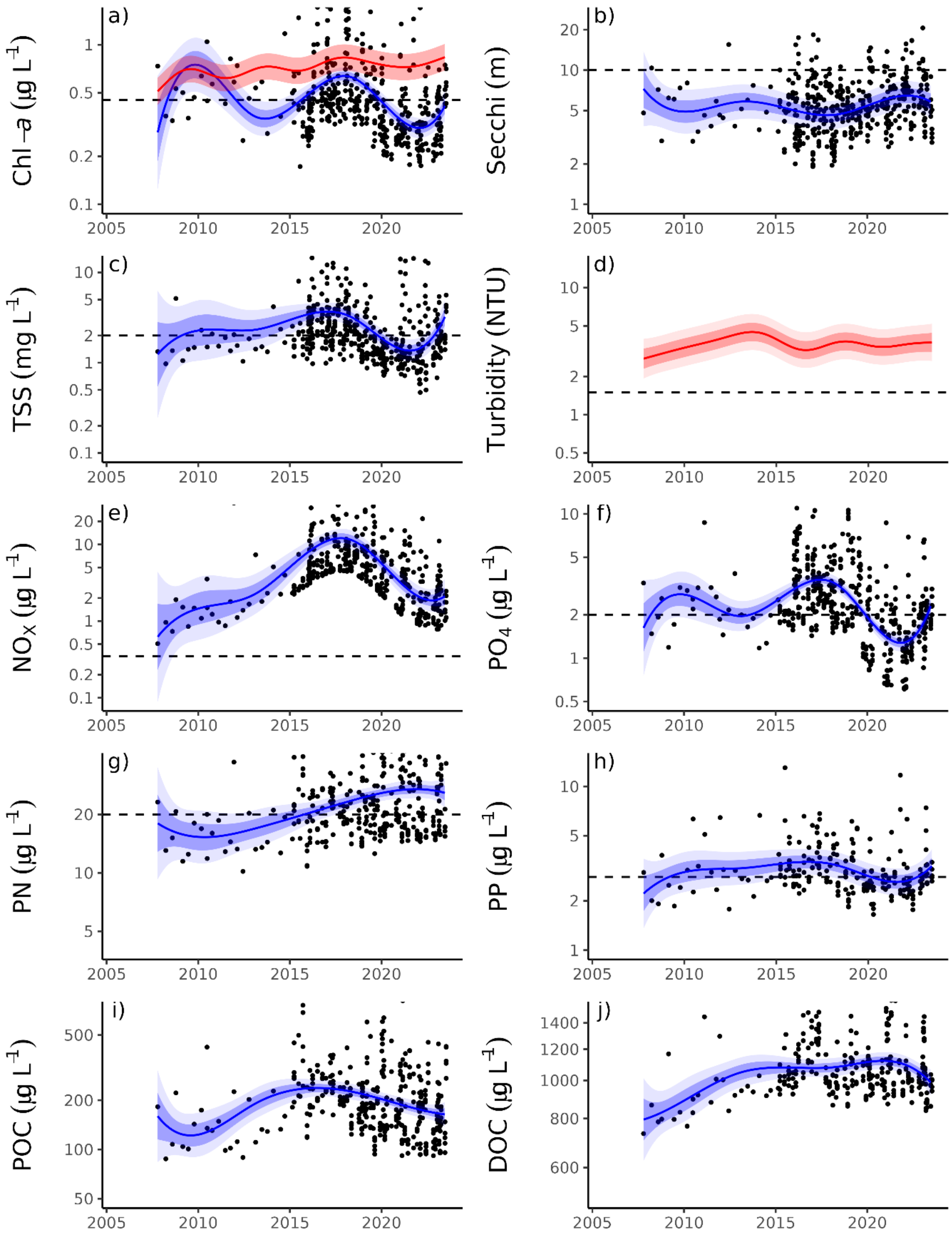


Figure 5-46: Temporal trends in water quality variables for the Tully focus region: a) chlorophyll *a* (Chl-*a*), b) Secchi depth, c) total suspended solids (TSS), d) turbidity, e) nitrate/nitrite (NO_x), f) phosphate (PO_4), g) particulate nitrogen (PN), h) particulate phosphorus (PP), i) particulate organic carbon (POC) and j) dissolved organic carbon (DOC). Generalised additive mixed effect models (trends) are represented by blue lines with shaded areas defining 95% confidence intervals of those trends accounting for the effects of wind, waves, tides, and seasons after applying x-z detrending. Trends of records from ECO FLNTUSB instruments are represented in red, and individual records can be found in Figure C - 1. Dashed horizontal reference lines indicate annual guidelines.

Distinct long-term trends (since 2005) were observed in some water quality variables, while others showed little change (Figure 5-46). Site-specific statistics and comparison to GVs for all variables are available in Table C - 2.

Concentrations of Chl-*a* have shown large fluctuations above and below the GVs since monitoring began in 2005 (Figure 5-46a). Over the period 2015–2023, mean concentration of Chl-*a* has remained stable (not improved or declined overall) despite a large oscillation over this 8-year period. Chl-*a* in 2022–23 was just below (met) the local GVs. Chlorophyll fluorescence measured by FLNTU instruments (Figure 5-46a) does not reflect these trends and has been generally stable and well above GVs since monitoring began in 2007. The differences between FLNTU chlorophyll fluorescence and Chl-*a* concentration reflect differences in sampling location and measurement method.

Secchi depth gradually declined (i.e., water clarity worsened) from 2005 until 2015, remaining below (not meeting) the GVs. Over the period 2015–2023, mean Secchi depth has remained stable (not improved or declined overall) despite some oscillations over this 8-year period (Figure 5-46b). Secchi depth in 2022–23 was below (not meeting) the local GVs.

Concentrations of TSS have fluctuated above and below the GVs since monitoring began in 2005. Over the period 2015–2023, mean concentration of TSS has remained stable (not improved or declined overall) despite an oscillation over this 8-year period. TSS concentrations in 2022–23 were just slightly below (met) the local water quality GVs (Figure 5-46c). TSS is currently trending upwards again and will likely exceed GVs next year if this trend continues.

Turbidity has remained relatively stable and well above the GVs since monitoring began in 2005 (Figure 5-46d). Over the period 2015–2023, turbidity has remained stable (not improved or declined overall) despite small oscillations over this 8-year period. Turbidity in 2022–23 was above (not meeting) the GVs.

Concentrations of NO_x steadily increased and remained above the local GVs from 2005 until 2015 (Figure 5-46e). Over the period 2015–2023, mean concentration of NO_x has shown a large and steady decrease. NO_x in 2022–23 was above (not meeting) the local GVs.

Concentrations of PO_4 fluctuated generally above the local GVs from 2005 until 2015 (Figure 5-46f). Over the period 2015–2023, mean concentration of PO_4 has remained stable (not improved or declined overall) despite a large oscillation during this 8-year period. PO_4 in 2022–23 was just below (met) the local GVs.

Concentrations of PN have generally increased since monitoring began in 2005 and started exceeding local GVs around 2015 (Figure 5-46g). Over the period 2015–2023, mean concentration of PN has shown a large and steady increase. PN in 2022–23 was above (not meeting) the local GVs.

Concentrations of PP have remained relatively stable and close to the local GVs since monitoring began in 2005 (Figure 5-46h). Over the period 2015–2023, mean concentration of PP has remained stable (not improved or declined overall) despite showing some minor variability over this 8-year period. PP in 2022–23 was below (met) the local GVs.

Concentrations of POC have shown some variability over the period 2005–2017 (Figure 5-46i). Over the period 2015–2023, mean concentration of POC has decreased, similar to all other focus regions. Concentrations of DOC increased over the period 2007–2015 but have stabilised since 2015 (Figure 5-46j).

The WQ Index is calculated using two different formulations to communicate the a) long-term trend in water quality (based on the pre-2015 sampling design) and b) annual condition of water quality (based on the post-2015 sampling design, which increased the power to detect change). Section 2.5 and Appendix B contain details of the calculations for both Index formulations.

The long-term WQ Index for the Tully region has shown the most variability of any focus region since the inception of the MMP. The period 2007–2014 was characterised by a large (i.e., changing over two grades) decline in water quality, driven by declines in all indicators with the exception of NO_x (Figure 5-47a). The period 2014–2020 showed some variability, but water quality did not improve or decline overall. Over the last three years, a preliminary trend of improvement in water quality has been observed (Figure 5-47a). This improving trend is driven by improvements in Chl-*a*, PN, and PP indicators.

The annual condition WQ Index has scored water quality as 'moderate' or 'poor' since its inception (2015–present), with the 2022–23 year receiving a 'moderate' score (Figure 5-47b). This version of the Index scores water quality parameters against GVs relevant to the season when samples are collected (wet versus dry GVs). It is important to note that the two versions of the WQ Index are designed to answer separate questions and therefore differences in scores between the versions are expected.

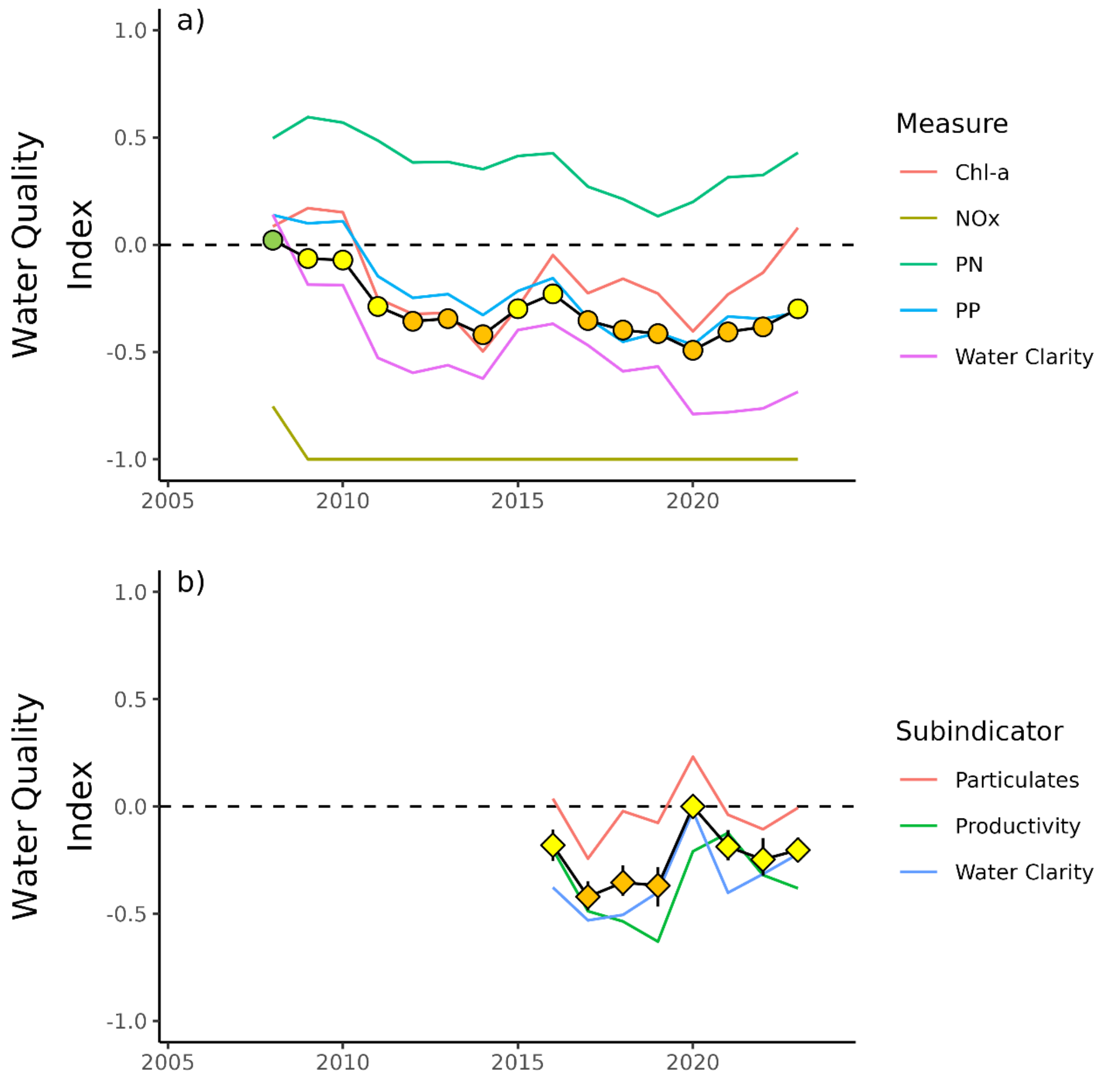


Figure 5-47: The Water Quality Index (WQ Index) for the Tully focus region. The WQ Index uses two formulations to communicate: a) long-term trend (based on pre-2015 sampling design) and b) the annual condition (based on post-2015 sampling design). WQ Index colour coding: ■ / ◆– 'very good'; ■ / ◆ – 'good'; ■ / ◆ – 'moderate; ■ / ◆ – 'poor'; ■ / ◆ – 'very poor'. Indicators or sub-indicators that are used to calculate the WQ Index are shown as coloured lines on each plot. Error bars (vertical black lines) on the WQ Index represent the 95% quantile intervals. Calculations for both formulations are described in Appendix B.

Event water quality

No event sampling was conducted in the 2022–23 wet season in the Tully focus region.

5.3 Burdekin region

Three sites were sampled in this focus region three times per year until the end of 2014. Following the implementation of the revised MMP water quality sampling design in 2015, 15 sites are now sampled in this focus region up to nine times per year. Six sites are sampled during both the dry and wet seasons and nine additional sites are sampled during major flood events (Table A - 1). The monitoring sites are located along a transect away from the river mouth in a north-westerly direction, representing a gradient in water quality. Eight sites are in open coastal waters, two sites are in the mid-shelf water body, and five sites are in enclosed coastal waters (Figure 5-48).

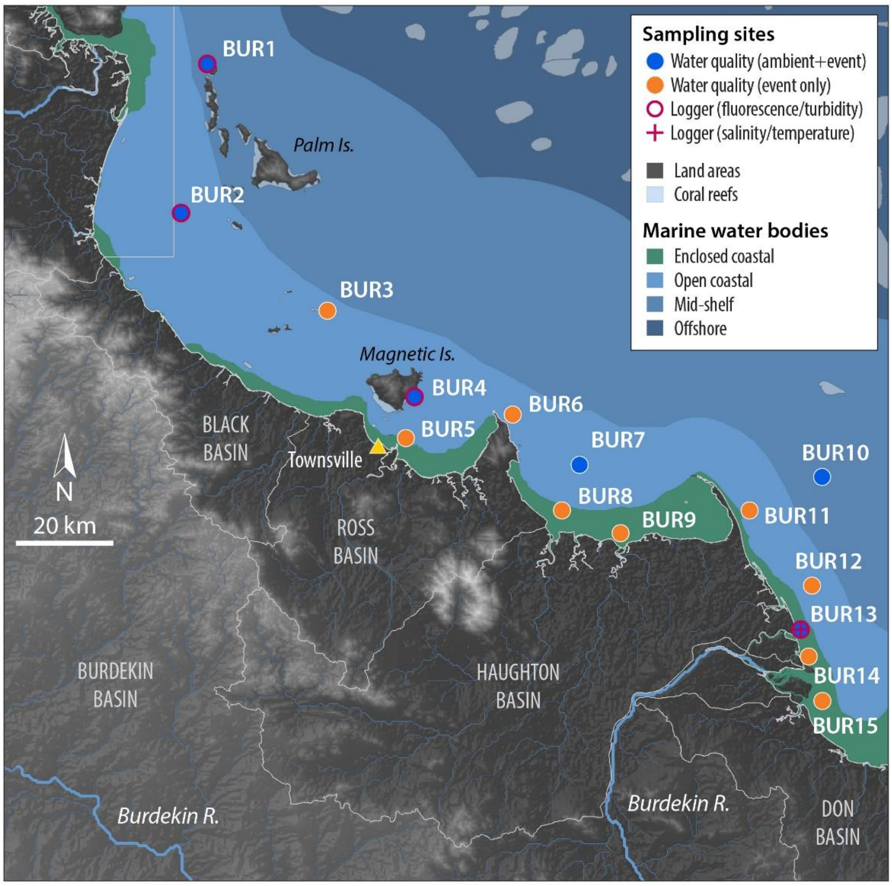


Figure 5-48: Sampling sites in the Burdekin focus region, shown with the water body boundaries.

The total discharge for the Burdekin region in 2022–23 was 2.2 times the long-term median (Figure 5-49; Table 3-1). The combined discharge and loads calculated for the 2022–23 water year from the Burdekin and Haughton Basins were in the lower range over the past decade (Figure 5-50). Over the 17-year period from 2006–7:

- discharge ranged from 1,036 GL (2014–15) to 37,470 GL (2010–11);
- TSS loads ranged from 290 kt (2013–14) to 15,024 kt (2007–08);
- DIN loads ranged from 275 t (2014–15) to 4,019 t (2010–11); and
- PN loads ranged from 586 t (2013–14) to 22,083 t (2007–08).

During the very large discharge years (2007–08, 2008–09, 2010–11 and 2018–19), the Burdekin and Haughton Basins (dominated by the Burdekin Basin) produced by far the highest loads of TSS and PN compared to any of the other focus regions. In contrast, the DIN loads are either similar to or lower than the basins of the Wet Tropics and Mackay-Whitsunday regions during the high discharge years and much lower during the lower discharge years.

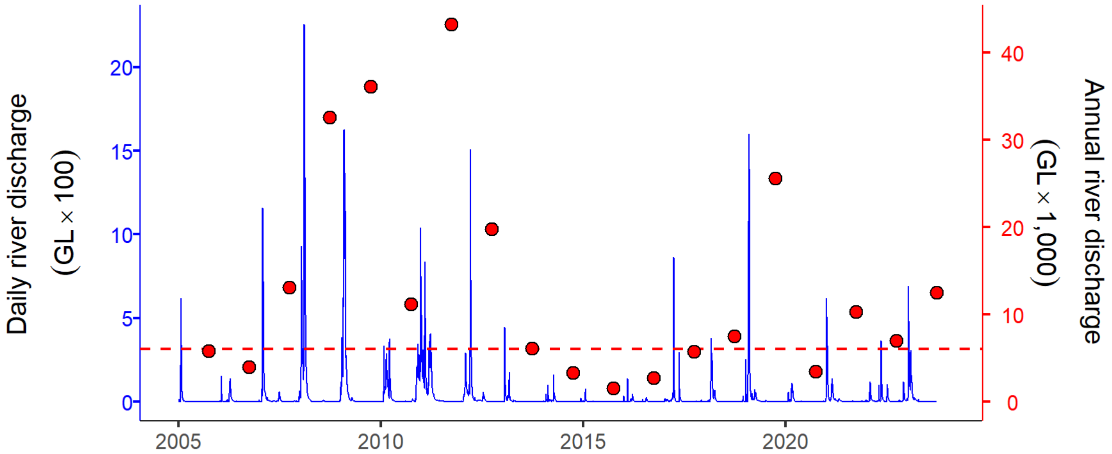


Figure 5-49: Total discharge for the Burdekin region (Table 3-1). Daily (blue) and water year (October to September, red) discharge is shown. Red dashed line represents the long-term median annual discharge.

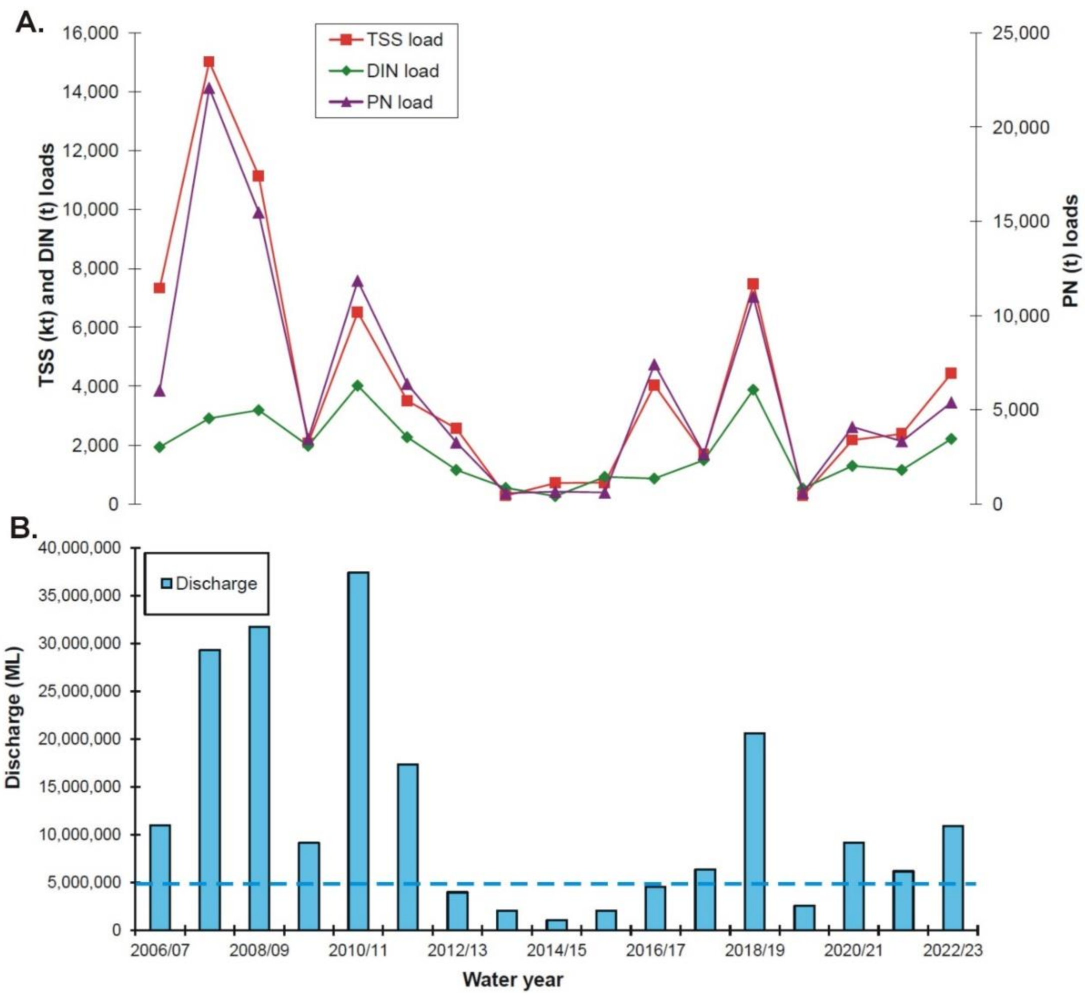


Figure 5-50: Loads of (A) TSS, DIN, and PN and (B) discharge for the Burdekin and Haughton Basins from 2006 to 2023. The loads reported here are a combination of 'best estimates' for each basin based on 'up-scaled discharge data from gauging stations, monitoring data (Burdekin River), and annual mean concentrations and discharge from monitoring data or Source Catchments modelling data. Dotted line represents the long-term median for basin discharge. Note the different scales on the two y-axes.

Ambient water quality and the in situ *Water Quality Index*

Water quality showed trends along the sampling transect (cross-shelf gradient in northerly direction). Sites located nearest to the river mouth (distance from river mouth = 0 km) had high concentrations of NO_x and particulate nutrients (PN and PP), which declined with distance away from the river mouth, reaching low levels at sites furthest from the river mouth (Figure 5-51, Table C - 2). Concentrations of Chl-*a* and TSS showed a similar pattern to nutrient concentrations and tended to decline with distance from the river mouth. Secchi depths were low at sites near the river mouth (water clarity was poor) and increased (water clarity improved) with distance from the river mouth. These spatial patterns are generally consistent with those that are typically observed in the region.

This year, clear seasonal differences in NO_x, TSS, Secchi depth, PN, and PP were observed, where concentrations (especially near the river mouth) were much higher during the wet than the dry season (with the exception of Secchi depth, which showed increased water clarity during the dry season). These seasonal differences tended to become less pronounced further offshore (e.g., concentrations of NO_x, TSS, and Secchi depth during wet and dry seasons were similar at sites furthest from the river mouth). Concentrations of Chl-*a* were generally higher during the wet season, although showed some variability over the transect (Figure 5-51).

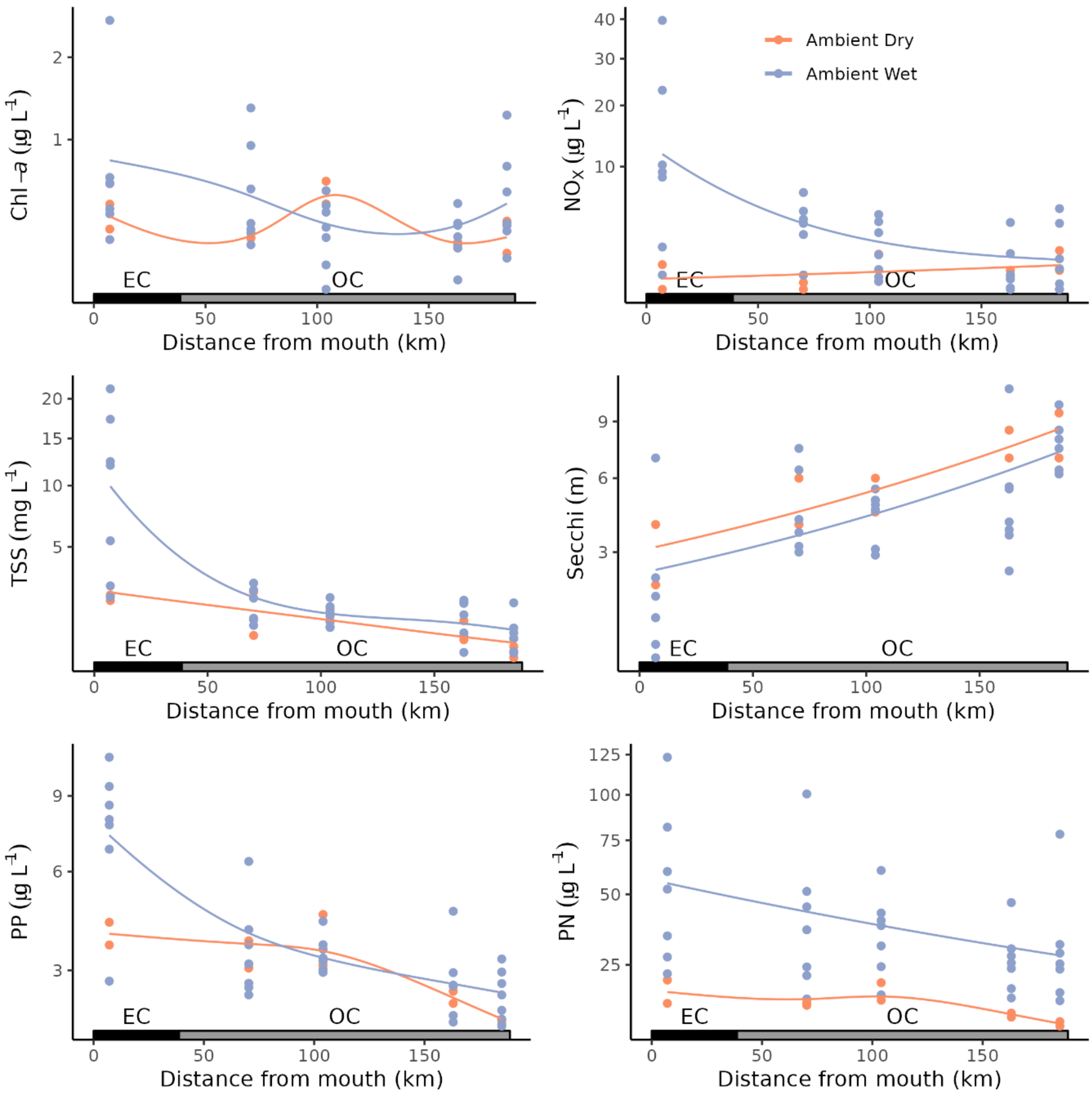


Figure 5-51: Water quality variables measured during ambient and event sampling in 2022–23 along the Burdekin focus region transect. Chlorophyll *a* (Chl-*a*), nitrate/nitrite (NO_x), total suspended solids (TSS), Secchi depth, particulate nitrogen (PN), and particulate phosphorus (PP) are shown with distance from the Burdekin River mouth. Water body classifications are shown along the x-axes: Enclosed coastal (EC) and open coastal (OC). Note the y-axes are logarithmic scales. Fitted lines are generalised additive models.

Distinct long-term trends (since 2005) were observed in some water quality variables, while others showed little change (Figure 5-52). Site-specific statistics and comparison to GVs for all variables are available in Table C - 1.

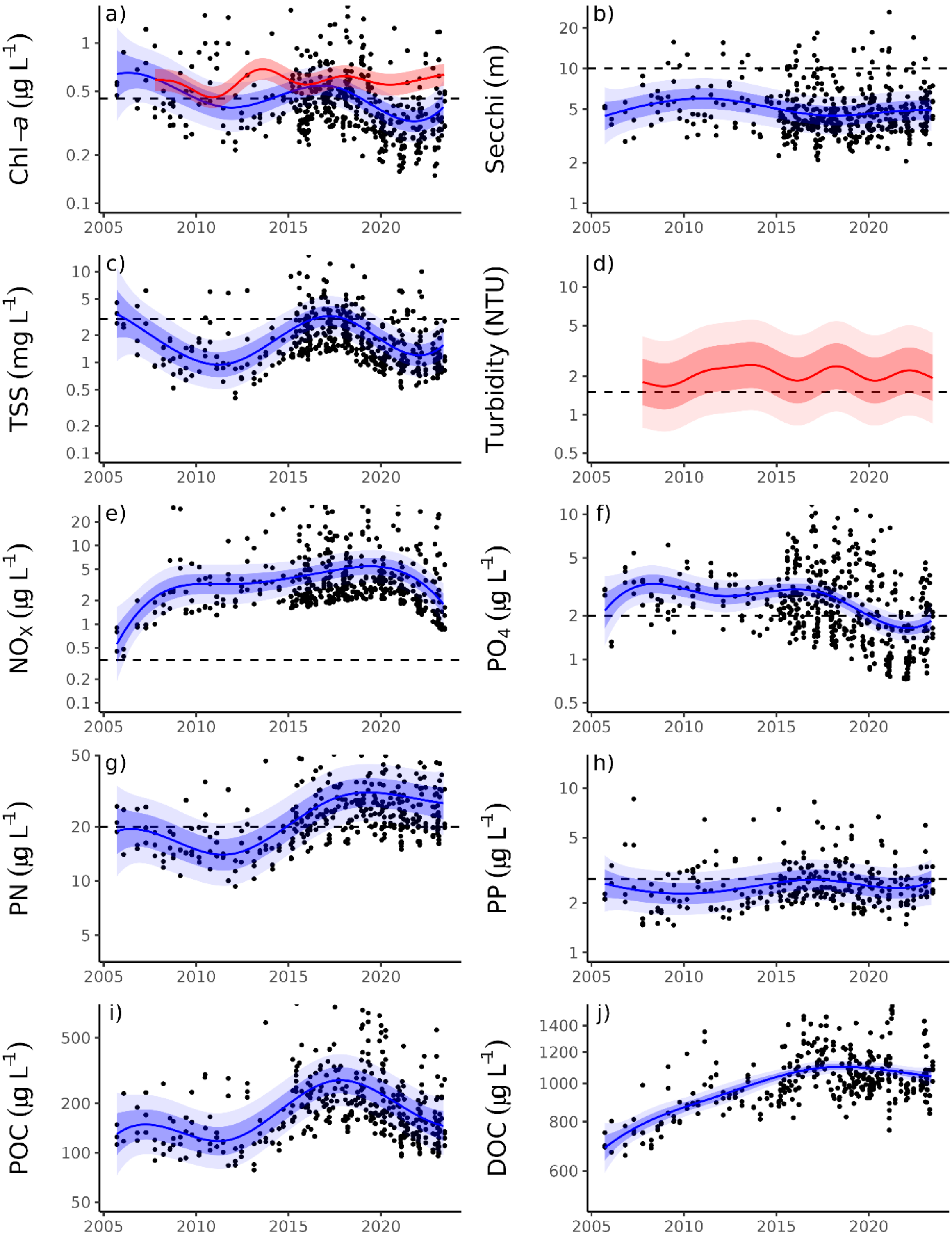


Figure 5-52: Temporal trends in water quality variables for the Burdekin focus region: a) chlorophyll *a* (Chl-*a*), b) Secchi depth, c) total suspended solids (TSS), d) turbidity, e) nitrate/nitrite (NO_x), f) phosphate (PO_4), g) particulate nitrogen (PN), h) particulate phosphorus (PP), i) particulate organic carbon (POC) and j) dissolved organic carbon (DOC). Generalised additive mixed effect models (trends) are represented by blue lines with shaded areas defining 95% confidence intervals of those trends accounting for the effects of wind, waves, tides, and seasons after applying x-z detrending. Trends of records from ECO FLNTUSB instruments are represented in red, and individual records can be found in Figure C - 1. Dashed horizontal reference lines indicate annual guidelines.

Concentrations of Chl-*a* have shown large fluctuations above and below the GVs since monitoring began in 2005 (Figure 5-52a). Over the period 2015–2023, mean concentration of Chl-*a* has remained stable (not improved or declined overall) despite a large oscillation over this 8-year period. Chl-*a* in 2022–23 was just below (met) the local GVs. Chlorophyll fluorescence measured by FLNTU instruments (Figure 5-52a) does not reflect these trends and has been fluctuating above GVs since monitoring began in 2007. The differences between FLNTU chlorophyll fluorescence and Chl-*a* concentration reflect differences in sampling location and measurement method.

Secchi depth has remained relatively stable and below (not meeting) the GVs since monitoring began in 2005 (Figure 5-52b). Over the period 2015–2023, mean Secchi depth has remained stable (not improved or declined overall) despite small oscillations over this 8-year period. Secchi depth in 2022–23 was below (not meeting) the local GVs.

Concentrations of TSS have fluctuated above and below the GVs since monitoring began in 2005. Over the period 2015–2023, mean concentration of TSS has remained stable (not improved or declined overall) despite an oscillation over this 8-year period (Figure 5-52c). TSS concentrations in 2022–23 were below (met) the local water quality GVs.

Turbidity has remained relatively stable and above the GVs since monitoring began in 2005 (Figure 5-52d). Over the period 2015–2023, turbidity has decreased slightly (i.e., water clarity has improved) despite oscillations over this 8-year period. Turbidity in 2022–23 was above (not meeting) the GVs.

Concentrations of NO_x steadily increased and remained well above the local GVs from 2005 until 2015 (Figure 5-52e). Over the period 2015–2023, mean concentration of NO_x has decreased slightly. NO_x in 2022–23 was above (not meeting) the local GVs.

Concentrations of PO_4 were generally stable and well above the local GVs from 2005 until 2015 (Figure 5-52f). Over the period 2015–2023, mean concentration of PO_4 has steadily decreased. PO_4 in 2022–23 was just below (met) the local GVs.

Concentrations of PN have shown large fluctuations above and below the GVs since monitoring began in 2005 (Figure 5-52g). Over the period 2015–2023, mean concentration of PN has remained stable (not improved or declined overall) despite an increase in the early years of this 8-year period. PN in 2022–23 was just below (met) the local GVs.

Concentrations of PP have remained relatively stable and generally below the local GVs since monitoring began in 2005 (Figure 5-52h). Over the period 2015–2023, mean concentration of PP has remained stable (not improved or declined overall) despite showing some minor variability over this 8-year period. PP in 2022–23 was below (met) the local GVs.

Concentrations of POC have shown large oscillations since monitoring began in 2005 (Figure 5-52i). Over the period 2015–2023, mean concentration of POC has decreased, similar to all other focus regions. Concentrations of DOC increased over the period 2005–2017 but have stabilised in recent years (Figure 5-52j).

The WQ Index is calculated using two different formulations to communicate the a) long-term trend in water quality (based on the pre-2015 sampling design) and b) annual condition of water quality (based on the post-2015 sampling design, which increased the power to detect change). Section 2.5 and Appendix B contain details of the calculations for both Index formulations.

The long-term WQ Index has shown a small (i.e., changing by a single grade) overall decline in water quality from the period 2010–2018, driven by PN and PP indicators (Figure 5-53a). The Index then stabilised for ~three years and has shown a trend of improvement over the last two years (Figure 5-53a). This improving trend is driven primarily by improvements in Chl-*a* and PN indicators.

The annual condition WQ Index has generally scored water quality as ‘moderate’ (with one year of ‘good’) since its inception (2015–present), with the 2022–23 year receiving a ‘moderate’ score (Figure 5-53b). This version of the Index scores water quality parameters against GVs relevant to the season when samples are collected (wet versus dry GVs).

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

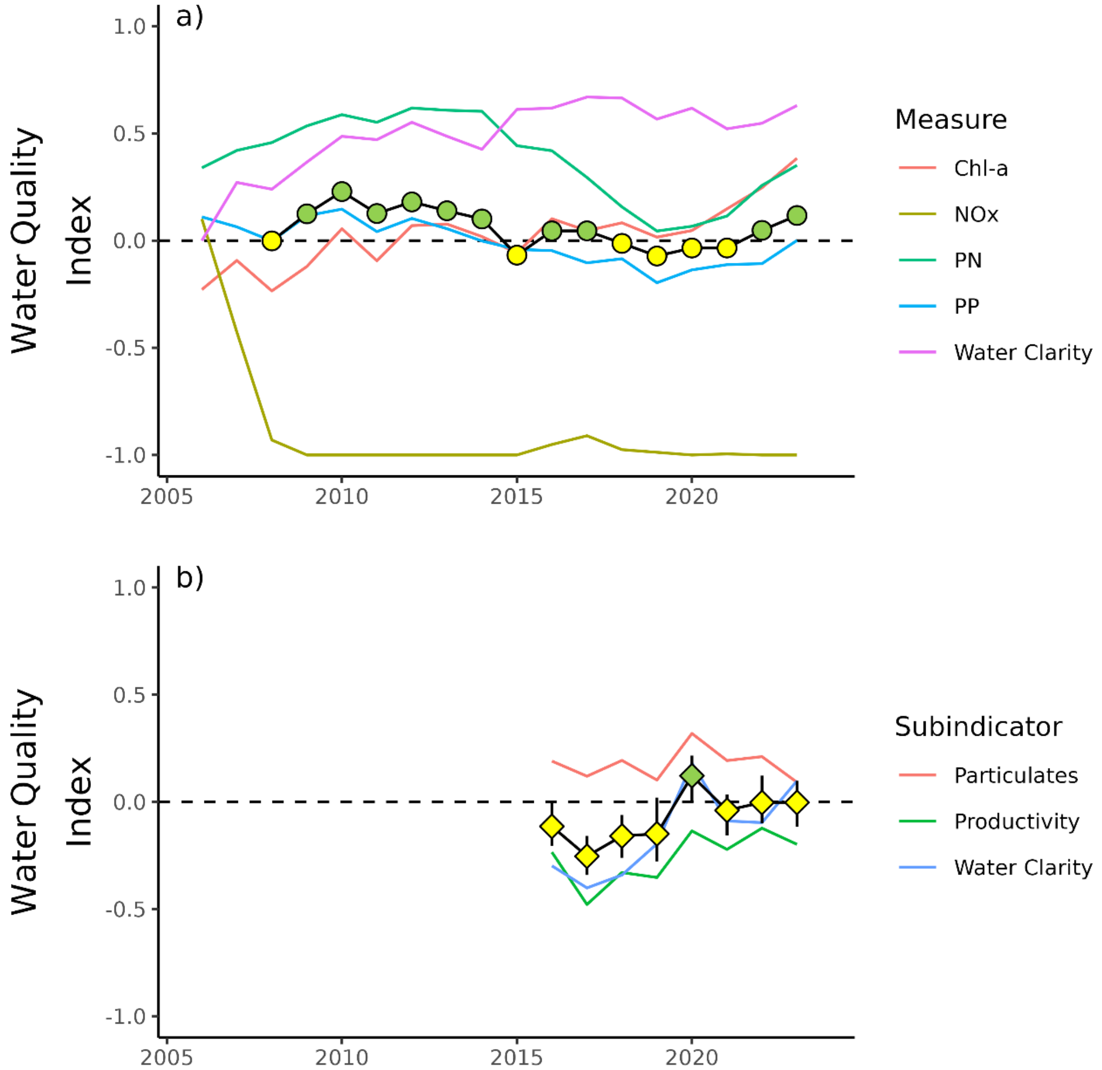


Figure 5-53: The Water Quality Index (WQ Index) for the Burdekin focus region. The WQ Index uses two formulations to communicate: a) long-term trend (based on pre-2015 sampling design) and b) the annual condition (based on post-2015 sampling design). WQ Index colour coding: / – ‘very good’; / – ‘good’; / – ‘moderate; / – ‘poor’; / – ‘very poor’. Indicators or sub-indicators that are used to calculate the WQ Index are shown as coloured lines on each plot. Error bars (vertical black lines) on the WQ Index represent the 95% quantile intervals. Calculations for both formulations are described in Appendix B.

Event water quality

No event sampling was conducted in the 2022–23 wet season in the Burdekin focus region.

5.4 Mackay-Whitsunday region

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

Three sites were sampled in this focus region three times per year until the end of 2014. From 2015, 11 sites have been sampled in this focus region up to five times per year, with five sites sampled during both the dry and wet seasons and six additional sites sampled during major flood events (Table A - 1). The sites are located along a transect from the O'Connell River mouth to open coastal waters, representing a gradient in water quality. Ten sites are within open coastal waters and one site is in enclosed coastal waters (Figure 5-54).

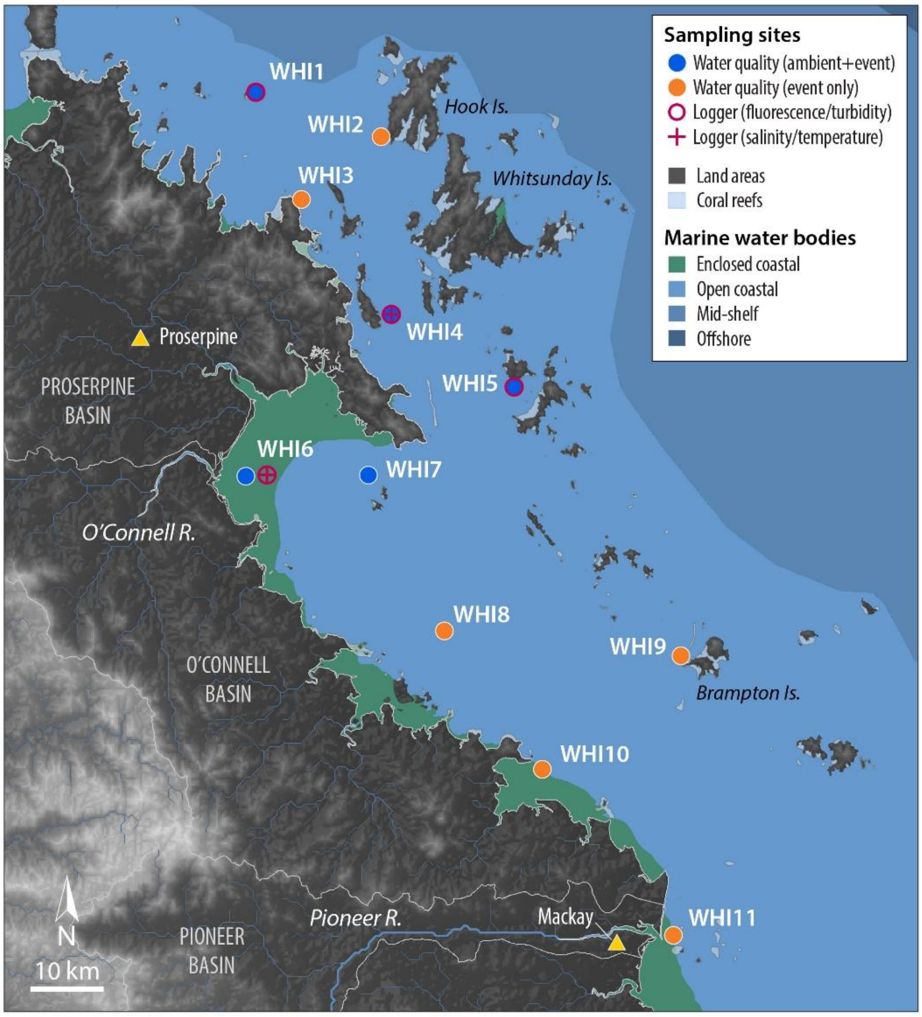


Figure 5-54: Sampling sites in the Mackay-Whitsunday focus region, shown with the water body boundaries.

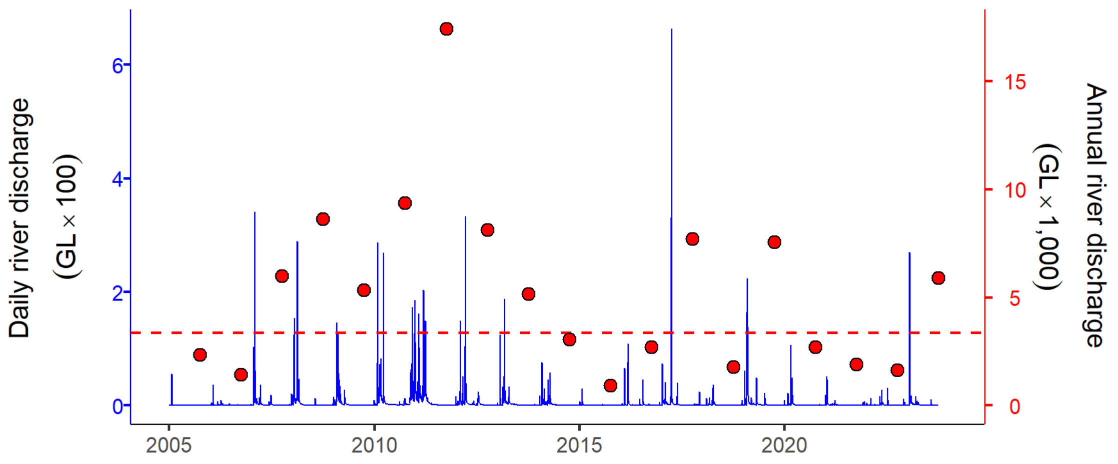


Figure 5-55: Combined discharge for the Mackay-Whitsunday focus region. Daily (blue) and water year (October to September, red) discharge is shown. Red dashed line represents the long-term median of the combined annual discharges. SeeTable 2-3 for a list of flow gauge data used. Please note as this is the combined discharge, high flows in one river will not necessarily be visible in the graph.

Annual discharge for the Mackay-Whitsunday region in the 2022–23 water year was 1.7 times above the long-term median (Figure 5-51, Table 3-1) and was the highest discharge in the region since 2018–19. Annual discharges from the individual basins were higher (2.2. times the long-term median) in the northern Proserpine and O'Connell Basins and were just above the long-term median in the Pioneer and Plane Basin (Table 3-1).

The combined discharge and loads calculated for the 2022–23 water year from the Proserpine, O'Connell, Pioneer, and Plane Basins (Figure 5-56) were in the upper range of values recorded over the past decade. Over the 17-year period from 2006–07:

- discharge ranged from 919 GL (2014–15) to 17,425 GL (2010–11);
- TSS loads ranged from 120 kt (2014–15) to 3,163 kt (2010–11);
- DIN loads ranged from 242 t (2014–15) to 3,814 t (2010–11); and
- PN loads ranged from 356 t (2014–15) to 8,564.

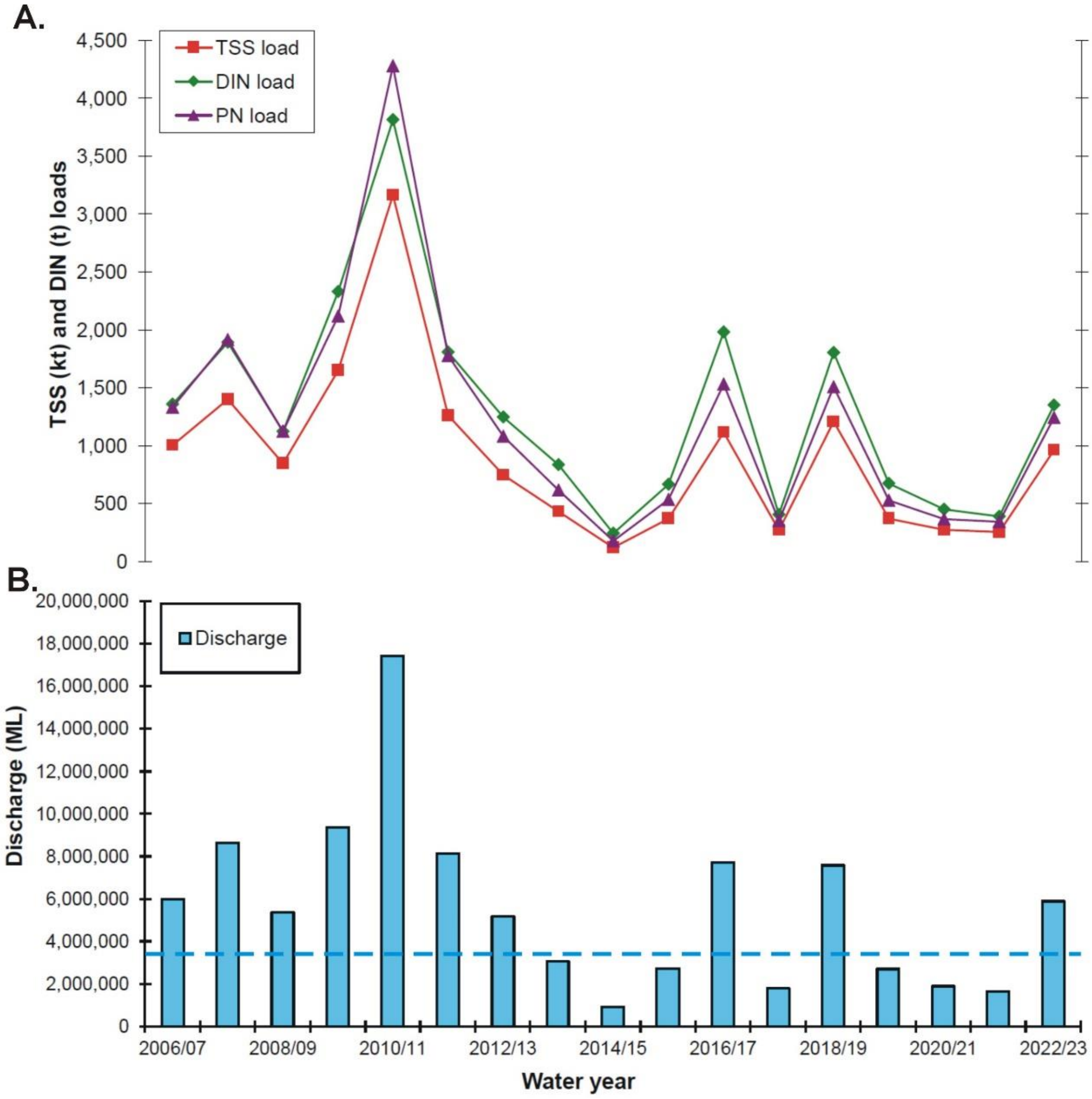


Figure 5-56: Loads of (A) TSS, DIN and PN and (B) discharge for the Proserpine, O'Connell, Pioneer, and Plane Basins from 2006 to 2023. The loads reported here are a combination of 'best estimates' for each basin based on 'up-scaled discharge data from gauging stations, monitoring data (O'Connell and Pioneer Rivers and Sandy Creek), and annual mean concentrations and discharge from monitoring data or Source Catchments modelling data. Dotted line represents the long-term median for basin discharge. Note the different scales on the two y-axes.

Ambient water quality and the in situ *Water Quality Index*

Water quality showed trends along the sampling transect (O'Connell River mouth to open coastal waters). The site located in the enclosed coastal water body (distance from river mouth = 0 km) had high concentrations of Chl-*a*, NO_x, TSS, and particulate nutrients (PN and PP), which declined with distance away from the river mouth (Figure 5-57, Table C - 2). Secchi depths were low at sites near the river mouth (water clarity was poor) and increased (water clarity improved) with distance from the river mouth. These spatial patterns are generally consistent with those that are typically observed in the region.

This year, clear seasonal differences in Chl-*a*, NO_x, and TSS were observed, where concentrations (especially near the river mouth) were greater during the wet than the dry season. These seasonal differences tended to become less pronounced further offshore (e.g., concentrations of NO_x during wet and dry seasons were similar at sites furthest from the river mouth). Concentrations of PN and PP were higher near the river mouth during the wet season but were generally didn't show seasonal differences other sites along the transect (Figure 5-57). Secchi depth showed poorer water clarity near the river mouth during the wet season but otherwise didn't show seasonal differences. Concentrations of TSS were higher at most sites during the dry season.

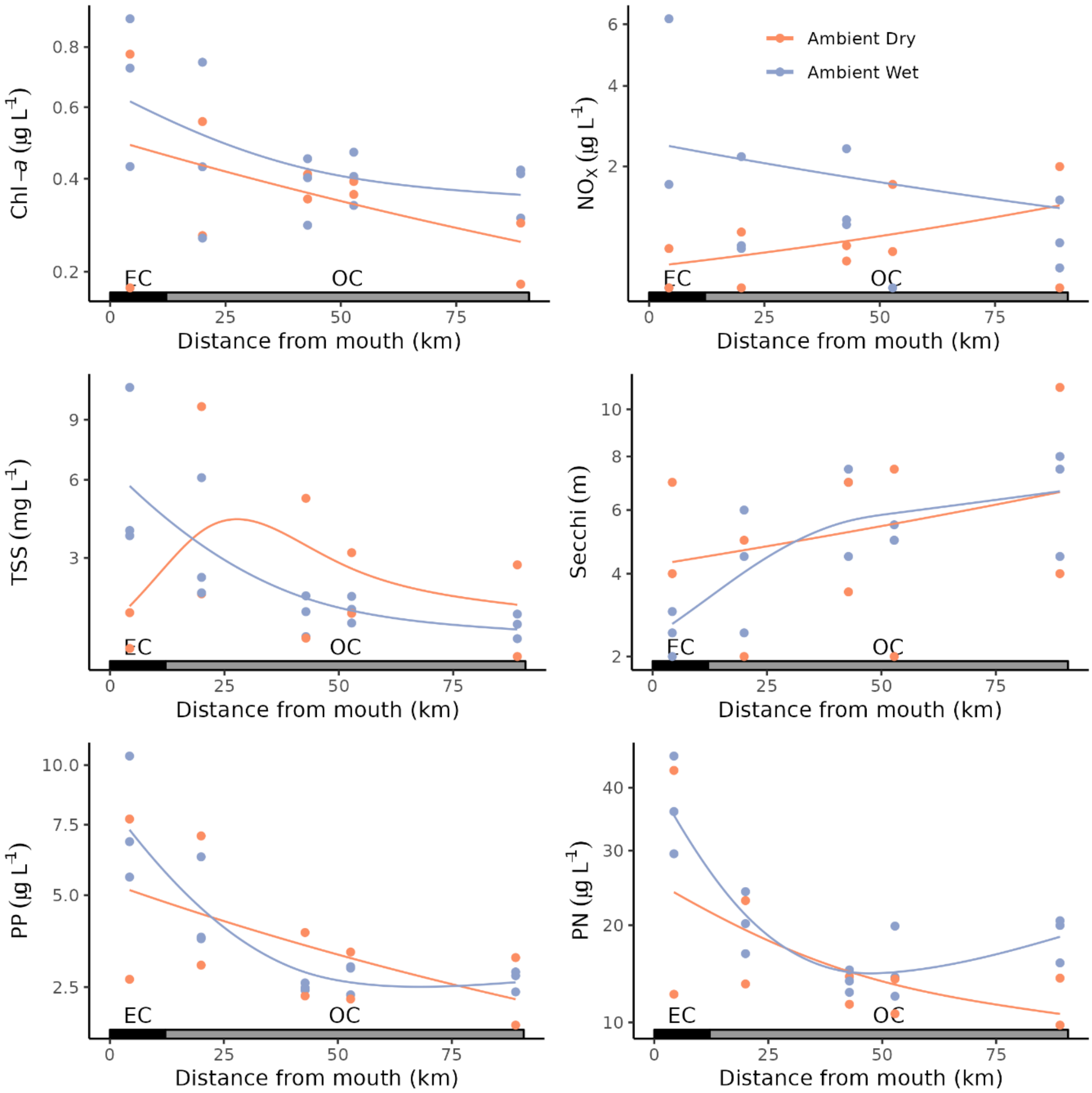


Figure 5-57: Water quality variables measured during ambient and event sampling in 2022–23 along the Mackay-Whitsunday focus region transect. Chlorophyll *a* (Chl-*a*), nitrate/nitrite (NO_x), total suspended solids (TSS), Secchi depth, particulate nitrogen (PN), and particulate phosphorus (PP) are shown with distance from the O'Connell River mouth. Water body classifications are shown along the x-axes: Enclosed coastal (EC) and open coastal (OC). Note the y-axes are logarithmic scales. Fitted lines are generalised additive models.

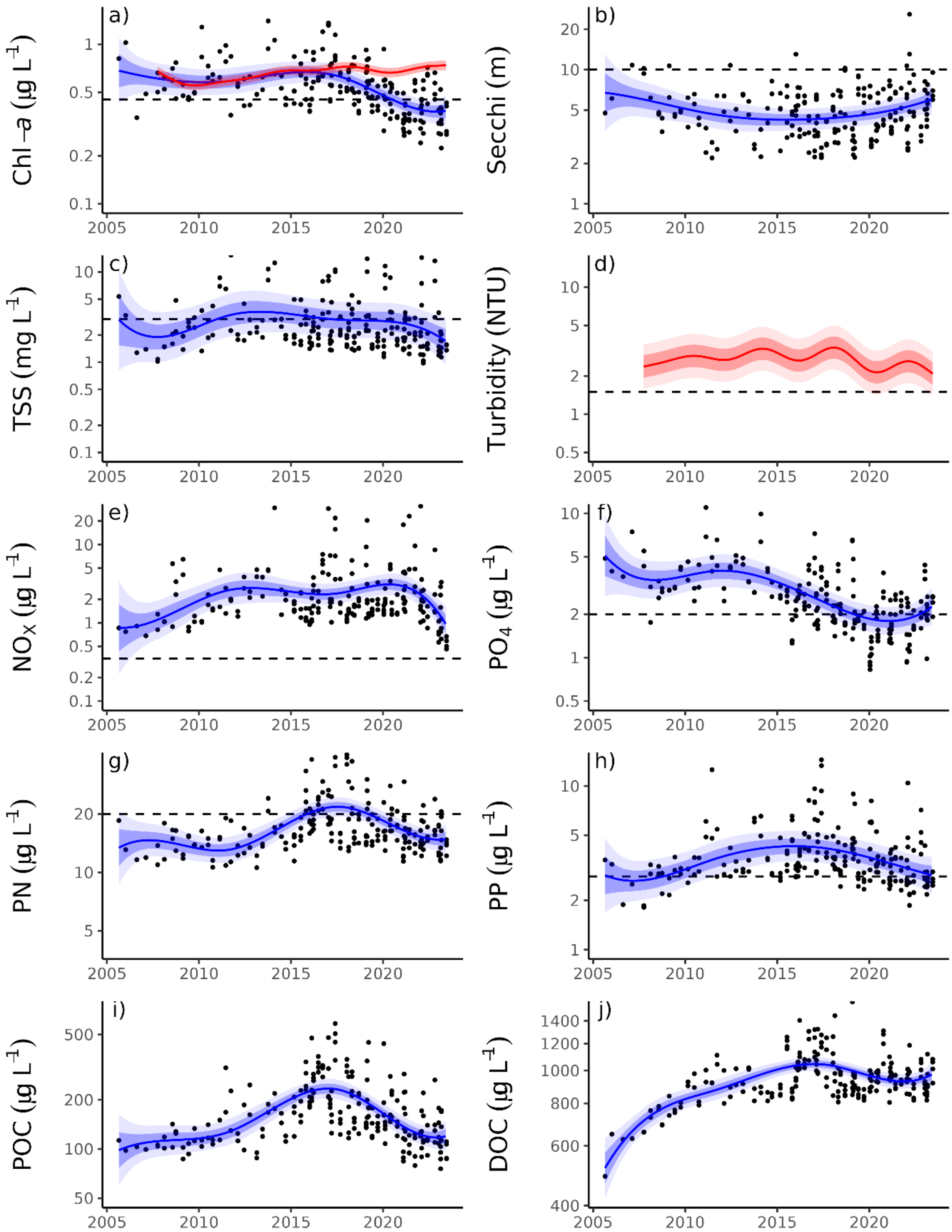


Figure 5-58: Temporal trends in water quality variables for the Mackay-Whitsunday focus region: a) chlorophyll *a* (Chl-*a*), b) Secchi depth, c) total suspended solids (TSS), d) turbidity, e) nitrate/nitrite (NO_x), f) phosphate (PO_4), g) particulate nitrogen (PN), h) particulate phosphorus (PP), i) particulate organic carbon (POC) and j) dissolved organic carbon (DOC). Generalised additive mixed effect models (trends) are represented by blue lines with shaded areas defining 95% confidence intervals of those trends accounting for the effects of wind, waves, tides, and seasons after applying x-z detrending. Trends of records from ECO FLNTUSB instruments are represented in red, and individual records can be found in Figure C - 1. Dashed horizontal reference lines indicate annual guidelines.

Distinct long-term trends (since 2005) were observed in some water quality variables, while others showed little change (Figure 5-58). Site-specific statistics and comparison to GVs for all variables are available in Table C - 1.

Concentrations of Chl-*a* were generally stable and well above the GVs over the period 2005–2015 (Figure 5-58a). Over the period 2015–2023, mean concentration of Chl-*a* has steadily decreased overall. Chl-*a* in 2022–23 was below (met) the local GVs. Chlorophyll fluorescence measured by FLNTU instruments (Figure 5-58a) has been relatively stable and well above GVs since monitoring began in 2007. The differences between FLNTU chlorophyll fluorescence and Chl-*a* concentration reflect differences in sampling location and measurement method.

Secchi depth gradually decreased (i.e., water clarity worsened) over the period 2005–2015 and has remained below (not meeting) GVs since monitoring began in 2005 (Figure 5-58b). Over the period 2015–2023, mean Secchi depth has gradually increased (i.e., water clarity has improved). Secchi depth in 2022–23 was below (not meeting) the local GVs.

Concentrations of TSS have fluctuated above and below the GVs since monitoring began in 2005, although tend to be more stable than other focus regions. Over the period 2015–2023, mean concentration of TSS has declined (water clarity has improved) in a steady trend (Figure 5-58c). TSS concentrations in 2022–23 were slightly above (exceeded) the local water quality GVs.

Turbidity has oscillated but remained above the GVs since monitoring began in 2005 (Figure 5-58d). Over the period 2015–2023, turbidity has decreased overall (i.e., water clarity has improved) despite oscillations over this 8-year period. Turbidity in 2022–23 was above (not meeting) the GVs.

Concentrations of NO_x steadily increased and remained well above the local GVs from 2005 until 2015 (Figure 5-58e). Over the period 2015–2023, mean concentration of NO_x has decreased, especially in recent years. NO_x in 2022–23 was above (not meeting) the local GVs.

Concentrations of PO_4 were generally stable and well above the local GVs from 2005 until 2015 (Figure 5-58f). Over the period 2015–2023, mean concentration of PO_4 has decreased overall despite a small upward trend in recent years. PO_4 in 2022–23 was just above (not meeting) the local GVs.

Concentrations of PN have shown fluctuations above and below the GVs since monitoring began in 2005 (Figure 5-58g). Over the period 2015–2023, mean concentration of PN has steadily decreased over this 8-year period. PN in 2022–23 was below (met) the local GVs.

Concentrations of PP increased and were generally above local GVs from the period 2005-2015 (Figure 5-58h). Over the period 2015–2023, mean concentration of PP has decreased steadily. PP in 2022–23 was just above (not meeting) the local GVs.

Concentrations of POC have shown a large oscillation since monitoring began in 2005 (Figure 5-58i). Over the period 2015–2023, mean concentration of POC has decreased, similar to all other focus regions. Concentrations of DOC increased over the period 2005–2017 but have stabilised in recent years (Figure 5-58j).

The WQ Index is calculated using two different formulations to communicate the a) long-term trend in water quality (based on the pre-2015 sampling design) and b) annual condition of water quality (based on the post-2015 sampling design, which increased the power to detect change). Section 2.5 and Appendix B contain details of the calculations for both Index formulations.

The long-term WQ Index has shown a small (i.e., changing by a single grade) overall decline in water quality from period 2007–2018, driven by water clarity, PN, and PP indicators (Figure 5-59a). This trend then stabilised and has reversed in recent years. Over the last four years, a trend of improvement in water quality has been observed (Figure 5-59a). This improving trend is driven primarily by improvements in water clarity, Chl-*a*, PN, and PP indicators.

The annual condition WQ Index has scored water quality as 'moderate' or 'poor' since its inception (2015–present), with the 2022–23 year receiving a 'moderate' score (Figure 5-59b). This version of the Index scores water quality parameters against GVs relevant to the season when samples are collected (wet versus dry GVs).

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

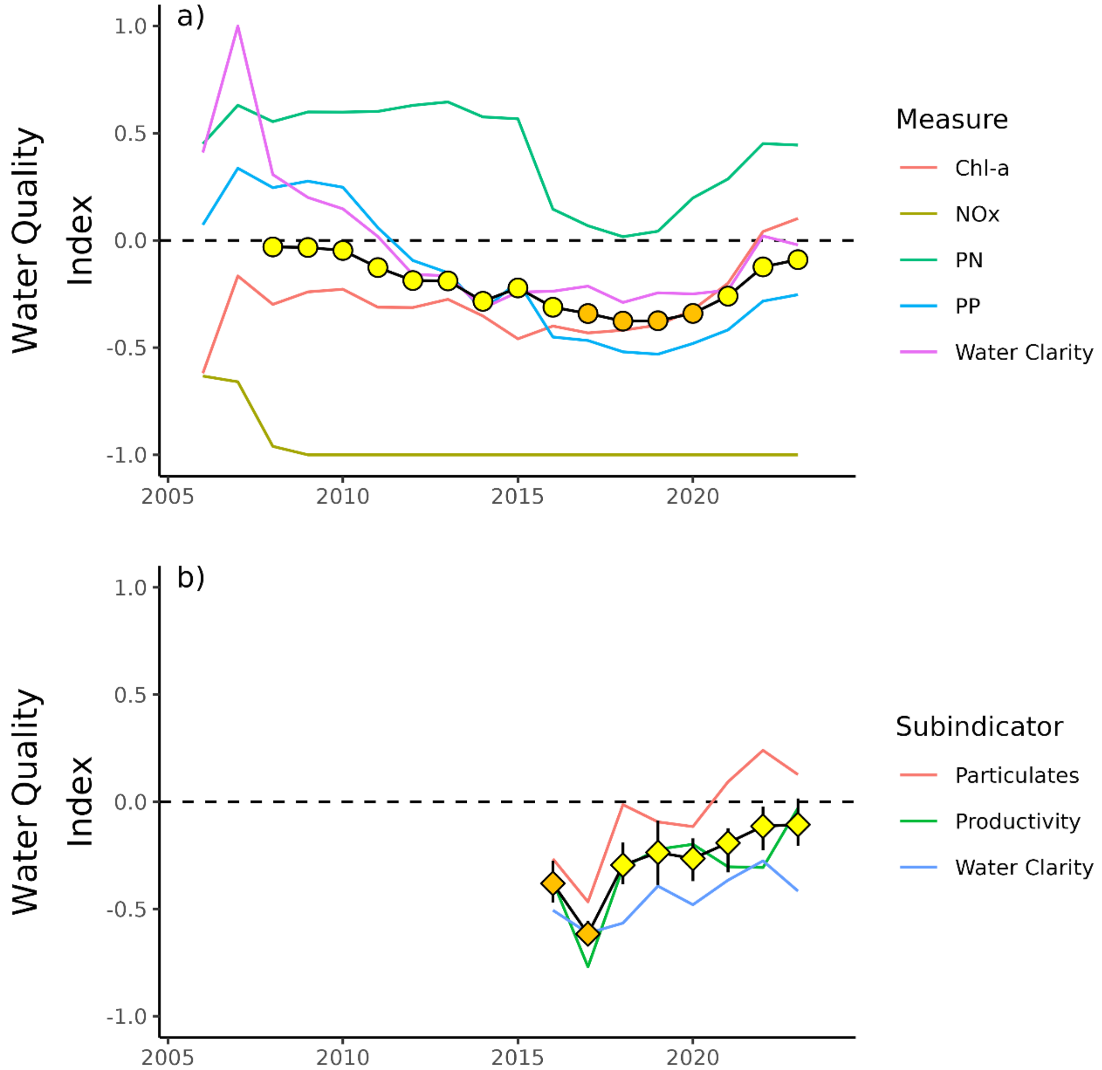


Figure 5-59: The Water Quality Index (WQ Index) for the Mackay-Whitsunday focus region. The WQ Index uses two formulations to communicate: a) long-term trend (based on pre-2015 sampling design) and b) the annual condition (based on post-2015 sampling design). WQ Index colour coding: ■ / ◆ – 'very good'; ■ / ◆ – 'good'; ■ / ◆ – 'moderate; ■ / ◆ – 'poor'; ■ / ◆ – 'very poor'. Indicators or sub-indicators that are used to calculate the WQ Index are shown as coloured lines on each plot. Error bars (vertical black lines) on the WQ Index represent the 95% quantile intervals. Calculations for both formulations are described in Appendix B.

Event water quality

High discharge occurred in the Proserpine and O'Connell Basins in January 2023 as highlighted by the O'Connell River gauge at Stafford's Crossing (Figure 5-60). Despite considerable rainfall in the Mackay area and surrounds, the rainfall event did not result in large flows in the Pioneer River (Figure 5-60). The event peaked on 16 January 2023 and the resultant flood plume was subject to event sampling on 21 and 22 January.

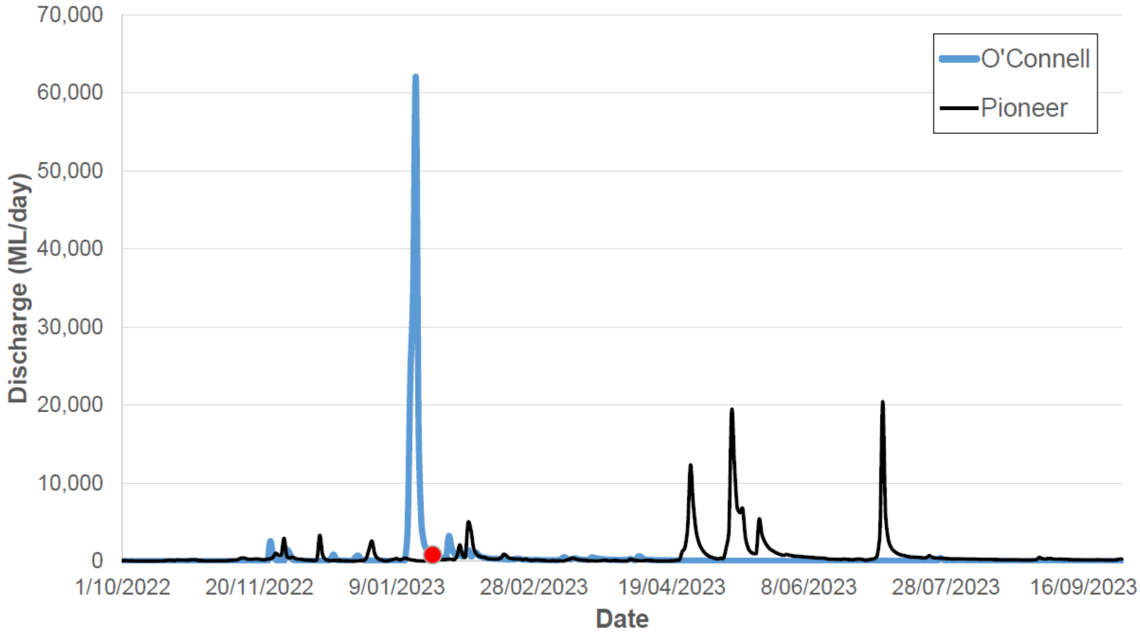


Figure 5-60: Discharge from the O'Connell River at Stafford's Crossing (blue line) and Pioneer River at Dumbleton Weir Tailwater (black line) flow gauges for the 2022–23 water year. The date of offshore sampling by JCU is marked as a red dot.

The sampling sites are shown in Figure 5-61. Ambient and event monitoring sites for the Mackay-Whitsunday region were all sampled at surface and bottom depths with additional sites to capture a broader area.

Selected results from the water column profiling of salinity and light are shown in Figure 5-62. The profiles of salinity show the increasing influence of the river flood plume in the upper ~5 to 10 m of the water column at the sites within Repulse Bay. In contrast, the more distant sites from the river (e.g., MWE8 Anchor Islands and WHI9 Brampton Island) showed less plume influence. The light profiles showed increasing PAR available at greater water column depths from the river mouth to the more offshore sites, while the satellite true colour images and Forel-Ule processed images show the brown turbid waters (Reef WT1) from the sites near or at the river mouth, becoming greener (i.e., Reef WT2) in the sites that were further offshore but still under the influence of plume waters, and becoming bluer (i.e., Reef WT3 and RT4) in the areas not clearly influenced by the plume (i.e., based on salinity profiles) (Figure 5-63).

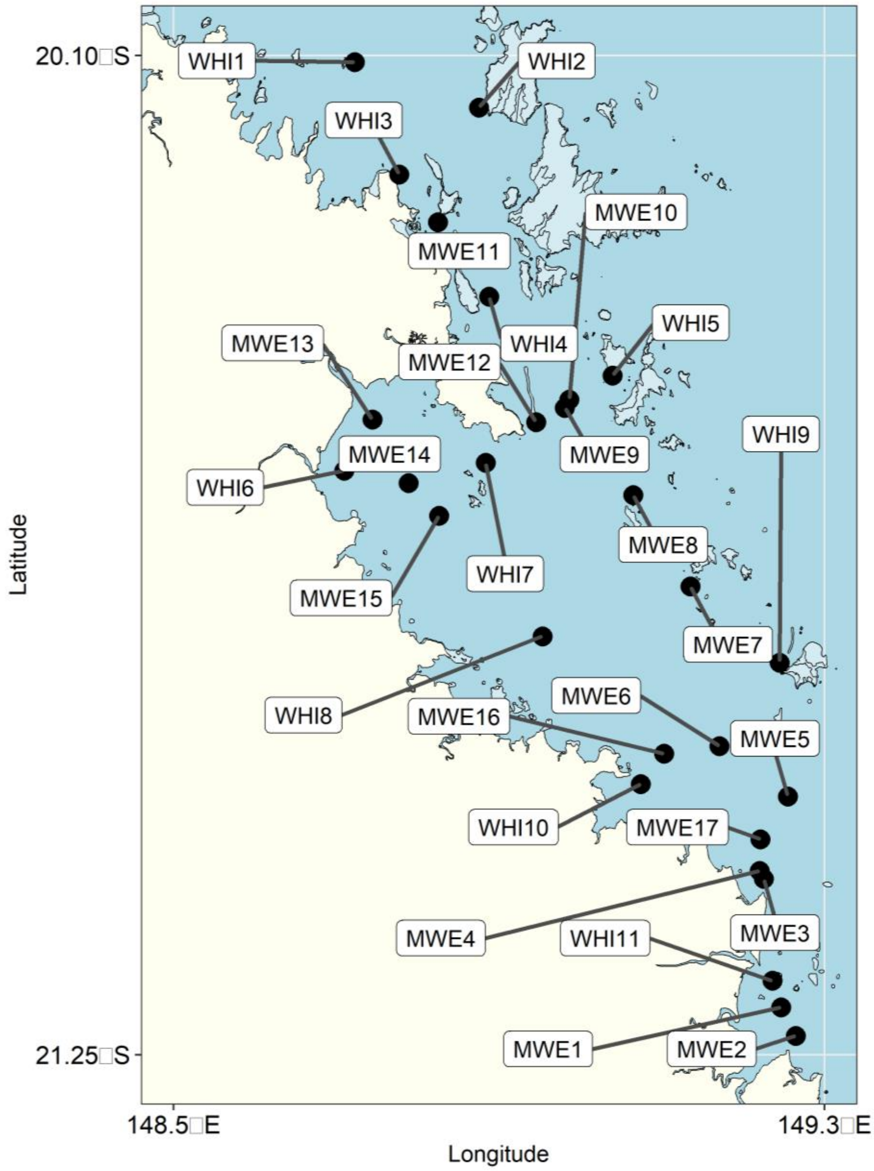


Figure 5-61: Map showing sites sampled for the event sampling in the Mackay-Whitsunday region on 21–22 January 2023. The site codes correspond to the suspended sediment and nutrient data gathered in the plume.

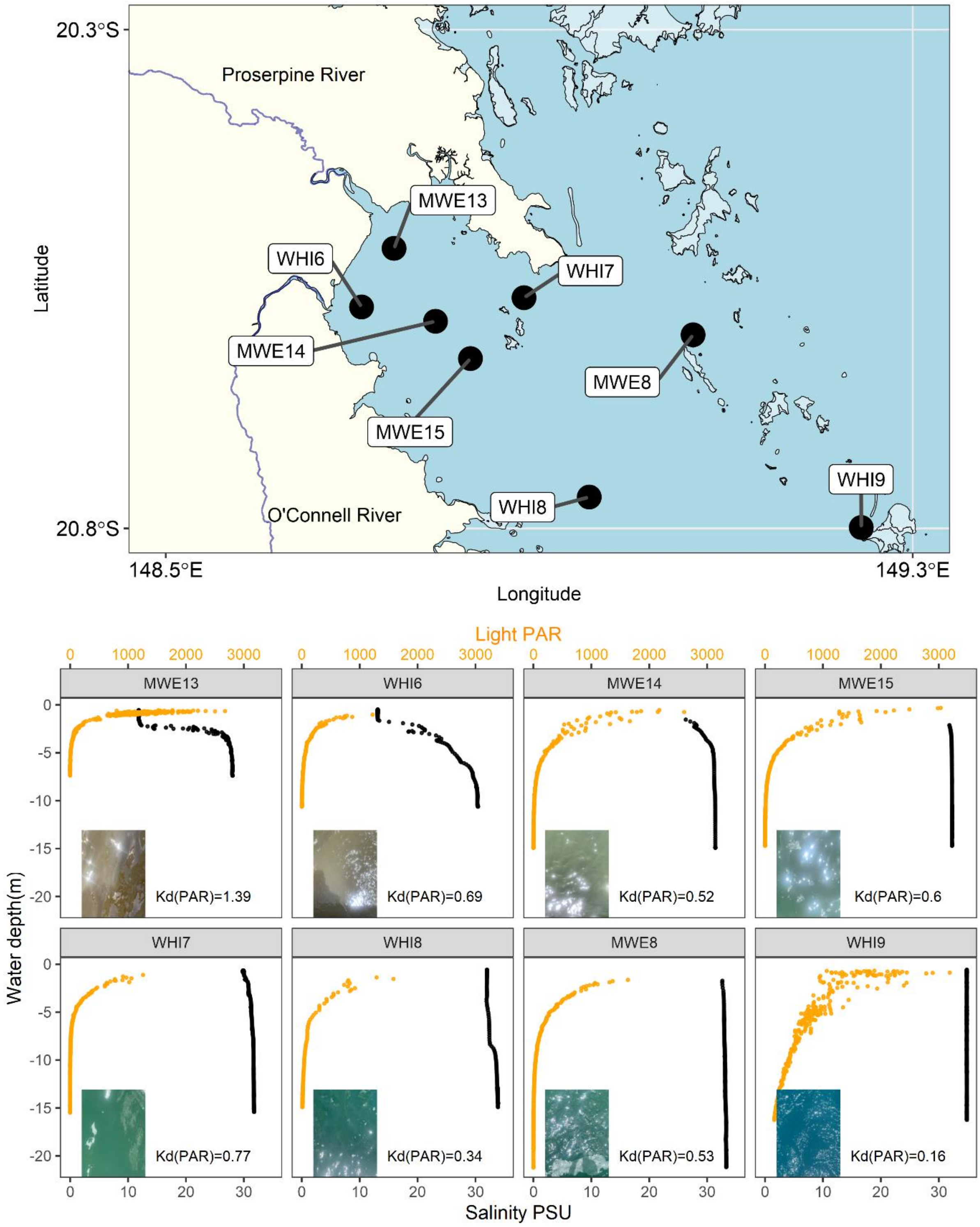


Figure 5-62: Top panel: Map of the Mackay-Whitsunday region with a focus offshore from the mouths of the Proserpine (MWE13) and O'Connell (WHI6) Rivers showing the plume sampling sites. Lower panels: Plots of the water column profiles of salinity (black lines) and light (orange lines with K_D values written in text) at the selected sites shown on the map along with corresponding water colour photos.

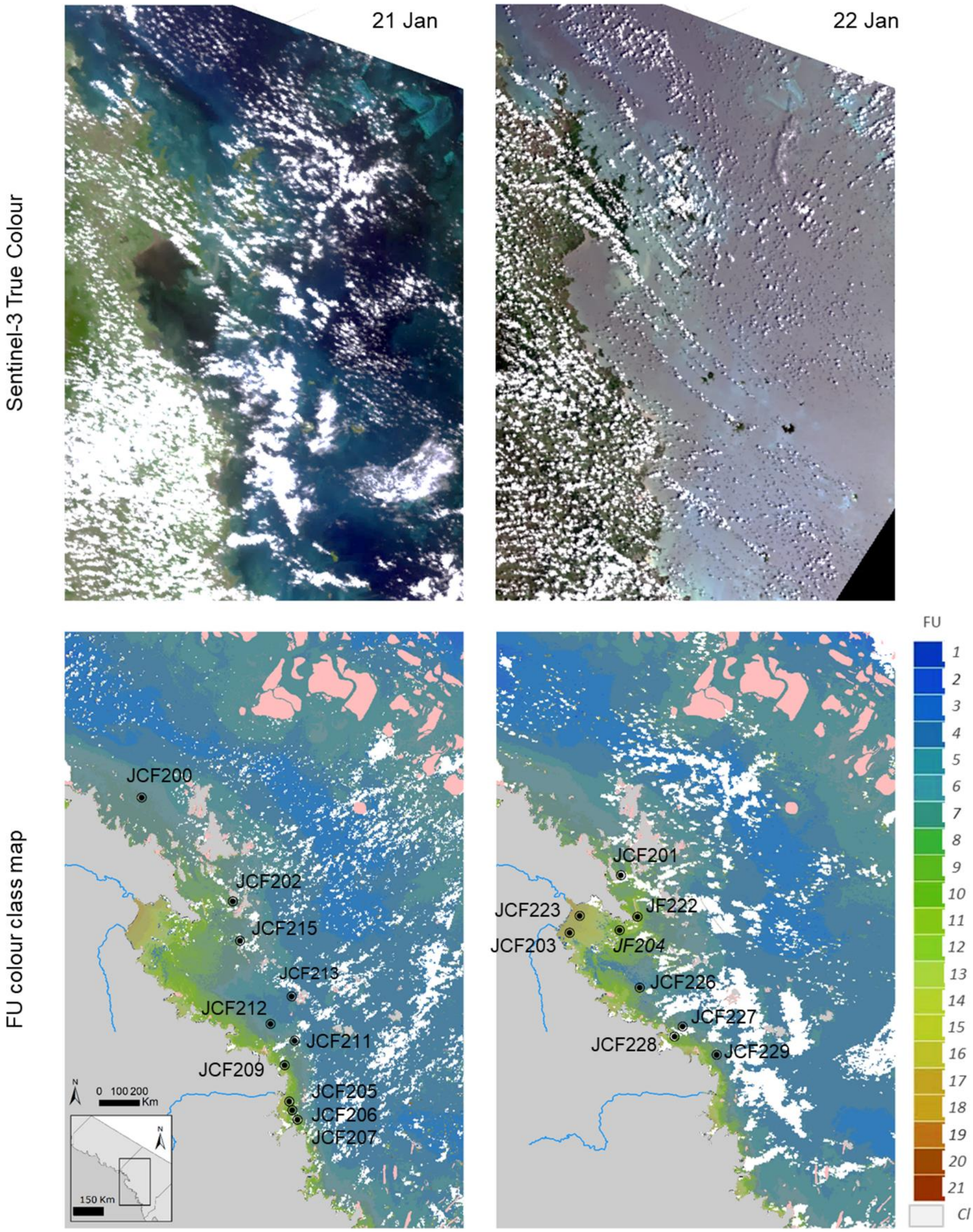


Figure 5-63: Satellite true colour images (top panels) from the Mackay-Whitsunday region that coincided with the flood plume sampling on 21–22 January 2023 and the corresponding processed imagery showing the Forel-Ule classes (bottom panels). The site codes correspond to the pesticide samples collected in the plume.

As the sampling was conducted 5–6 days after the flood peak (earlier sampling was prevented by weather), the plume was well-dispersed throughout the offshore waters of the Mackay-Whitsunday region as shown by the salinity profiles (Figure 5-62). This timeline of sampling (i.e., ~1 week after the peak) allowed the primary productivity of the offshore waters to be likely near peak levels. However, due to the mixing of the waters and the ‘flashiness’ of the river flows (i.e., the elevated river flow quickly receded), the vast majority of samples were collected from the >30 salinity zone and so the salinity gradient was not fully captured in this event.

The water quality concentrations of the samples are highly variable over this range (Figure 5-64 and Figure 5-65). The water quality samples also reflect that the plume was well-dispersed in the offshore waters with little difference between the surface and depth samples (Figure 5-64 and Figure 5-65). The concentrations in the plumes are generally comparable to those measured previously in 2017 following Tropical Cyclone Debbie where sampling occurred approximately 10 days after the river peak discharge. A possible exception was that TSS concentrations recorded in the plume following Tropical Cyclone Debbie were significantly higher than the samples collected in 2023. This may be explained by the rough seastate conditions which occurred during the 2017 sampling. In general, the TSS, PN, and Chl-*a* concentrations are consistent to plume sampling from other regions, although, it appears that NO_x, DIP, and PP are typically higher at comparable salinity values when compared to plumes from the Wet Tropics and Burdekin regions.

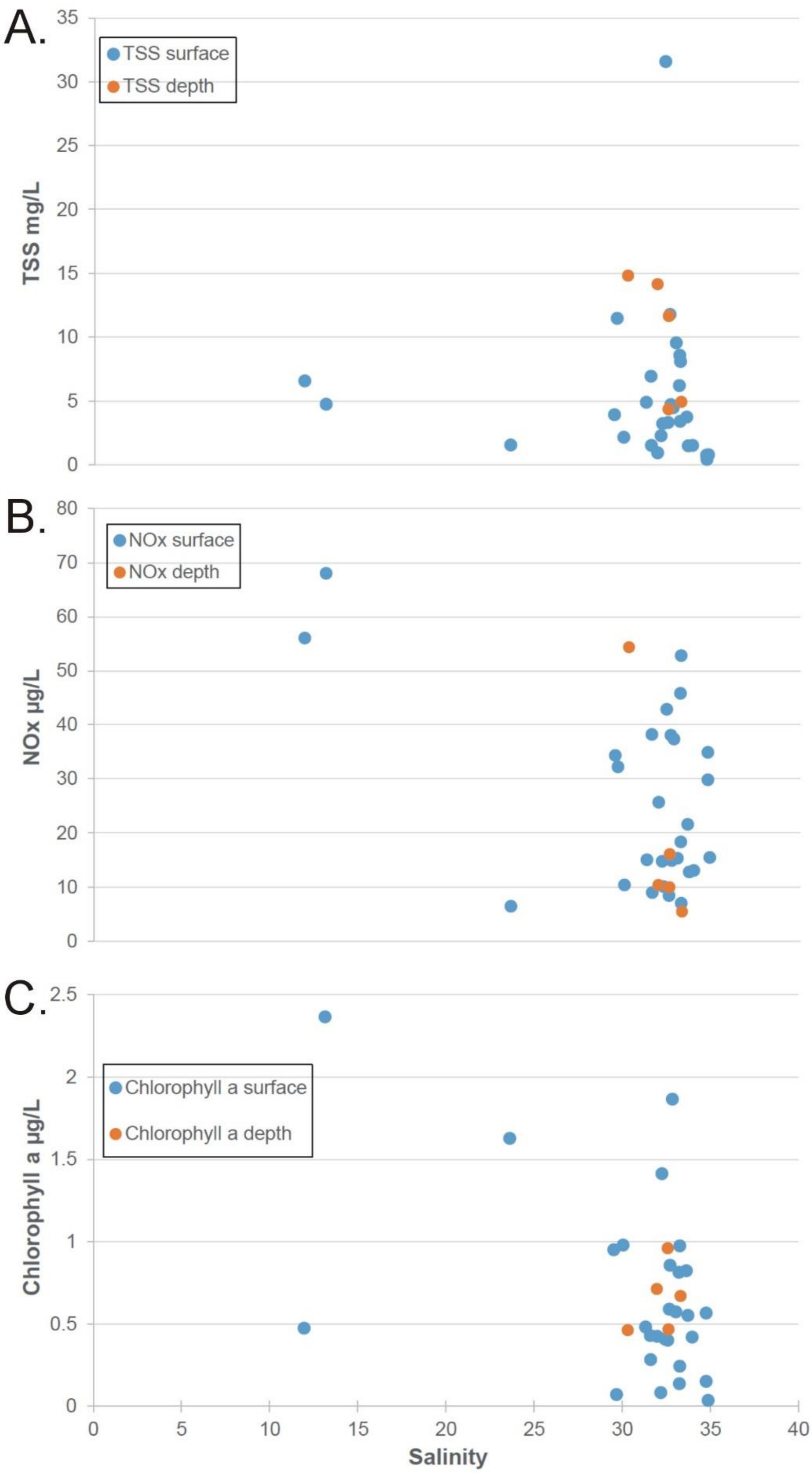


Figure 5-64: Water quality data from the Mackay-Whitsunday region under the influence of flood plumes over the 2022–23 wet season including (A) TSS, (B) NO_X, and (C) Chl-*a* plotted over the salinity gradient. Surface samples are plotted as blue circles and depth samples as red circles.

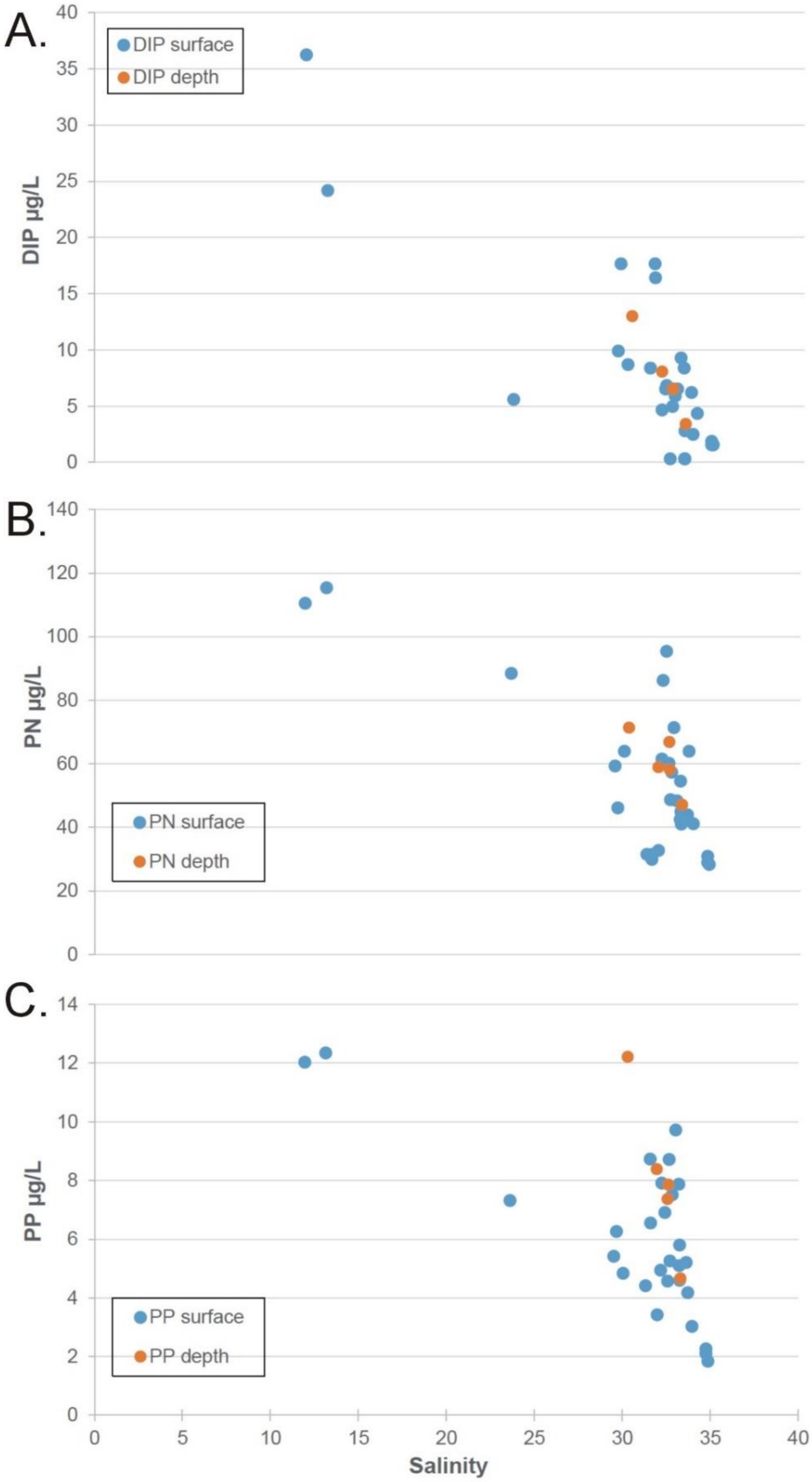


Figure 5-65: Water quality data from the Mackay-Whitsunday region under the influence of flood plumes over the 2022–23 wet season including (A) DIP, (B) PN, and (C) PP plotted over the salinity gradient. Surface samples are plotted as blue circles and depth samples as red circles.

Pesticide residue samples were also collected in the Mackay-Whitsunday event sampling campaign in January 2023. Several pesticides were detected in the plume waters and the most commonly detected pesticides are plotted along the salinity gradient in Figure 5-66, with 2,4-D, atrazine, diuron, imidacloprid, metolachlor, tebuthiuron, and hexazinone detected in the majority (>90%) of samples. The concentrations of all pesticides were well below GVs, which is expected since the plume was sampled after the peak flows and most of the samples were collected from waters that were well-diluted (i.e., salinities >30). While there were limited samples that cover the salinity gradient, the data suggest a general conservative mixing of pesticide concentrations which is consistent with previous measurements. The variability in the concentrations of pesticides collected from the two lower salinity values reflect the two different rivers sampled with generally lower concentrations in the O'Connell River mouth (salinity = 13) compared to the sample from the Proserpine River mouth (salinity = 12).

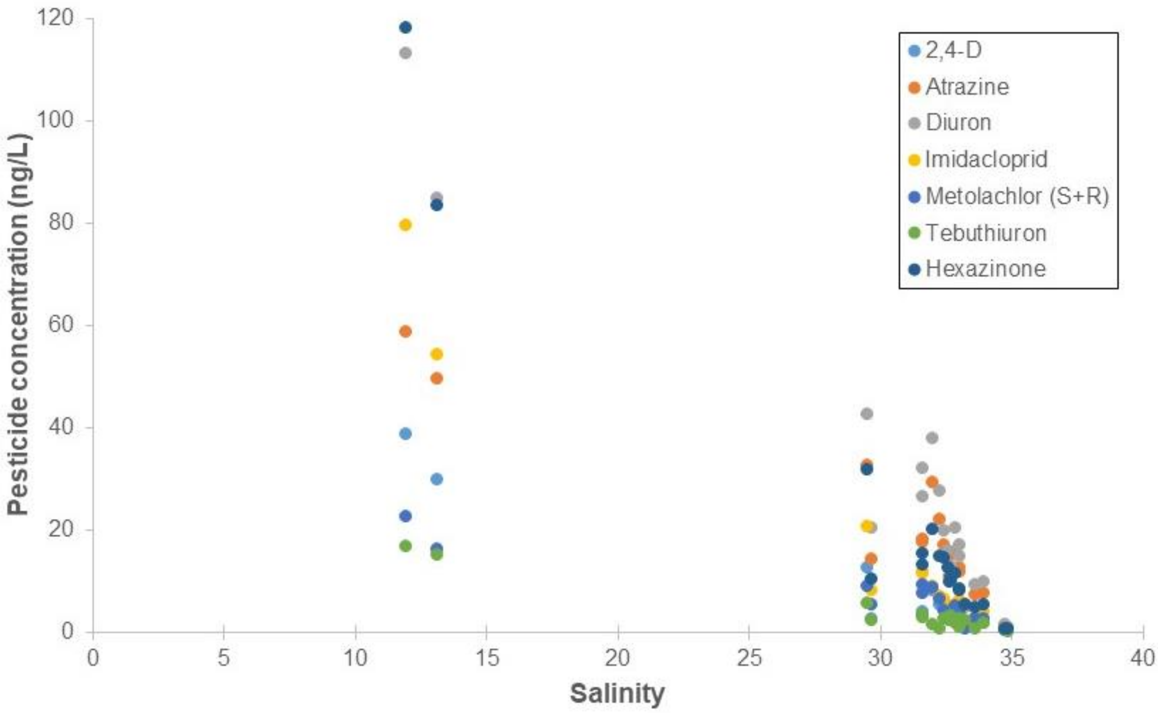


Figure 5-66: Concentrations of pesticides measured across the salinity gradient in the Mackay-Whitsunday event sampling in January 2023.

6 Conclusions

Environmental conditions over the 2022–23 wet season included rainfall and river discharge just above the long-term median for the total Reef discharge. There was no cyclone activity for the Reef although several weak tropical lows resulted in high rainfall and river discharge events in some locations.

In 2022–23, the long-term WQ Index showed trends of improvement in water quality in all regions where this score is able to be generated. In addition, the annual condition WQ Index scored water quality as either ‘good’ or ‘moderate’ in all focus regions in 2022–23.

Recent trend analysis based on the previous eight years of monitoring data (presented in the GAMMs) indicates that nearly all water quality indicators are showing signs of stability or improvement in all focus regions. The only exception to this trend was PN in the Tully focus region, which showed a trend of deterioration over the last eight years. In the Mackay-Whitsunday region, all water quality indicators showed a trend of improvement since 2015. These findings are likely a product of near-median river discharge over the last ~4 years in most focus regions, with few major flood events or cyclones impacting most of the Reef catchments in recent years.

In 2022–23, Chl-*a* was the only indicator that met GVs in all focus regions. PO_4, PN, PP, and TSS met GVs in most focus regions. NO_x and Secchi depth did not meet GVs in most focus regions, despite recent trends of improvement in these indicators. This year, trend analysis showed that NO_x is improving in all focus regions (with the exception of the Barron Daintree), although it remains well above GVs (except in the Annan-Endeavour focus region) and substantial improvement is needed for GVs may be met.

This report presents some positive results and trends of improvement for many parameters in the Reef lagoon for the 2022–23 water year. It is important to interpret these trends cautiously, and further work is needed to determine to what extent oceanographic and climatic drivers contribute to observed trends. Associated trends in catchment load reductions from the Great Barrier Reef Catchment Loads Monitoring Program (Water Quality & Investigations (2023)) are an important line of evidence that need to be established before trends in inshore water quality can be related to catchment land use practices.

The main findings for each NRM region are highlighted below and the results are separated into ambient (routine sampling during wet and dry seasons) and event-based monitoring (sampling during flood events). Table 6-1 provides a high-level summary by NRM region.

Table 6-1: Summary of results for some of the primary indicators measured in the MMP Inshore Water Quality program, 2022–23. *Arrows indicate difference relative to long-term patterns: → area exposed in 2021–22 similar (difference ≤ 5%) to long-term patterns, ↘ decrease in area exposed (difference > 5%), ↗ increase in area exposed (difference >5 %), coral reef, seagrass.

	Drivers and Pressures		Remote sensing mapping and modelling		Water Quality Index	
NRM region	**Cyclone activity (timing)**	**River discharge (relative to long-term median; <1.5 is blue, 1.5-2 is orange and >2 is red)**	**Area (in %) exposed to a potential risk***	**Area (in %) exposed to the highest potential risk (categories III and IV)***	**Annual 2022–23**	**Long-term**
Reef-wide	NA	<1.5	Reef: 11% → • **Note** ↗ (+6%) in seagrass area exposed to cat. Of risk III. Likely related to ↗ in Cape York regions.	Reef: 3% → <2% → , 33% → →Only inshore Reef waters and habitats, with the largest proportion in the enclosed coastal waters.	NA	NA
Cape York	NA	>2.0	Cape York: 11% → • **Note** ↗ (+10%) in coral area exposed to lowest cat. of risk (II). ↗ (+9%) in seagrass area exposed to cat. Of risk III.	Cape York: 3% → 2% → , 26% ↗ → Only inshore Cape York waters and habitats, with the largest proportion in the enclosed coastal waters.	Good	NA
Wet Tropics	NA	<1.5	Wet Tropics: 11% →	Wet Tropics: 2% → <2% → , -29% ↘ → Only inshore Wet Tropics waters and habitats, with the largest proportion in the enclosed coastal waters.	Moderate	**Declined** 2008–2018, **improved** past 5 years and showing signs of **improvement** in

	Drivers and Pressures		Remote sensing mapping and modelling		Water Quality Index	
NRM region	**Cyclone activity (timing)**	**River discharge (relative to long-term median; <1.5 is blue, 1.5-2 is orange and >2 is red)**	**Area (in %) exposed to a potential risk***	**Area (in %) exposed to the highest potential risk (categories III and IV)***	**Annual 2022–23**	**Long-term**
						all focus regions in 2022–23
Burdekin	NA	>2.0	Burdekin: 10 % →	Burdekin: 3% →  <2% → ,  48% → → Only inshore Burdekin waters and habitats, with the largest proportion in the enclosed coastal waters.	Moderate	**Declined** gradually from 2010–2018, **improved** over the last 2 years
Mackay-Whitsunday	NA	1.5–2.0	Mackay-Whitsunday: 10 % → **Note** ↘ (-16%) in seagrass area exposed to lowest cat. of risk (II).	Mackay-Whitsunday: 3% →  <2% → ,  40% → → Only inshore Mackay-Whitsunday waters and habitats, with the largest proportion in the enclosed coastal waters.	Moderate	**Declined** since 2008, **improved** over the last 4 years
Fitzroy	NA	<1.5	Fitzroy: 7% → • **Note** ↘ (-122% and -8%)in seagrass area exposed the categories of risk II and IV	Fitzroy: 3% →  2% → ,  36% → → Only inshore Fitzroy waters and habitats, with the largest proportion in the enclosed coastal waters.	Good (see Appendix D)	**Improved** from 2008–2015, **improved** over last 2 years (see Appendix D)

	Drivers and Pressures		Remote sensing mapping and modelling		Water Quality Index	
NRM region	**Cyclone activity (timing)**	**River discharge (relative to long-term median; <1.5 is blue, 1.5-2 is orange and >2 is red)**	**Area (in %) exposed to a potential risk***	**Area (in %) exposed to the highest potential risk (categories III and IV)***	**Annual 2022–23**	**Long-term**
Burnett-Mary	NA	<1.5	Burnett-Mary: 2% → **Note** ↘ (-23%) in seagrass area exposed to lowest cat. of risk (II).	Burnett-Mary: <1% →  <1% → ,  27% → → Only inshore Burnett-Mary waters and habitats, with the largest exposure to cat. IV (47%) in open coastal waters.	NA	NA

6.1 Cape York

The annual condition WQ Index for the Cape York region was 'good' for the 2022–23 water year. The Annan-Endeavour and Pascoe focus regions had 'good' scores for the annual WQ Index, while the Normanby and Stewart focus regions were 'moderate'. No long-term trends have been evaluated yet in the Cape York region.

Discharge from rivers in the Cape York region was between 1.5 and 1.9 times above the long-term median discharge for all focus regions, except for the Normanby which had discharge 3.1 times the long-term median. As a result of the high discharge, the Normanby saw flooding across Princess Charlotte Bay throughout most of January, February, and March with floodwaters flowing over 100 km to the east beyond the outer reefs and to the north past the Stewart River transect. In contrast, the Pascoe, Stewart, Annan-Endeavour focus regions had consistent high discharge but only minor flooding compared to some years.

Ambient water quality - Enclosed coastal, open coastal and mid-shelf waters:

- Chl-*a*, TSS, and PP met the water quality GVs at most sites.
- NO_x exceeded the GVs at most sites and focus regions except for the Annan-Endeavour.
- Secchi depth was less than (did not meet) the GVs at most sites and focus regions. However, monitoring occurred primarily during the wet season and means are compared against annual GVs.
- PN and PO_4 comparisons against GVs were mixed, with some sites and focus regions meeting the GVs (Table 6-2).
- Mean and median turbidity and Chl-*a* estimated from FLNTU data met the annual and wet season GVs at Dawson and Forrester Reef sites.

Table 6-2: Water quality indicator summary for Cape York. Performance relative to guideline values is shown as: generally exceeding (✗) or meeting (✓) guideline values across all sites. Mixed results across sites are indicated by both signs.

Water quality indicator	Pascoe	Stewart	Normanby	Annan-Endeavour
NO_x	✗	✗	✗ ✓	✓
PO_4	✗ ✓	✗ ✓	✗ ✓	✗ ✓
PN	✗	✗	✗ ✓	✓
PP	✓	✓	✓	✓
TSS	✓	✓	✗ ✓	✓
Secchi depth	✗	✗	✗	✗ ✓
Chl-*a*	✗ ✓	✓	✗ ✓	✓

Event water quality

- Targeted flood sampling conducted on 14 and 25 January 2023 coincided with the first major flood event of the year, an above-average magnitude event with a total discharge over the month of January of 2,226 GL measured at the Kalpowar gauge. Satellite images show the majority of sediment was discharged from the Kennedy River. By late January, the flood plume travelled over 100 km to the north along the coast past Cliff Isles and the Stewart River transect. After a short decline, discharge from the Normanby River increased again mid-February, remaining at flood levels until mid-March. For this second period of maintained flooding, a total discharge volume of 3,363 GL was measured at the Kalpowar gauge. Satellite images during this event show turbid floodwater inundating Cliff Isles and Corbett Reef to the north and extending over 100 km to the east beyond the outer reefs.
- Event samples collected in early January showed that most parameters were significantly elevated compared to ambient conditions. Across the transect, NO_x increased by a factor of 10. DOC concentrations doubled compared to ambient concentrations. PN and PP concentrations were also close to double the ambient concentrations. Chl-*a* concentrations were elevated in the enclosed coastal and open coastal water bodies (maximum 0.98 µg L^{-1}) but remained low (<0.15 µg L^{-1}) at mid-shelf and offshore sites. On 14 January, TSS was 112 and 36 mg L^{-1}, respectively, at the mouth of the Kennedy and Normanby Rivers. By 25 January, TSS concentrations at the river mouths had decreased to 28 and 9 mg L^{-1} respectively. NO_x, DOC, PN, and PP (but not DIP) remained elevated across the transect. Chl-*a* remained elevated at open coastal water body sites and was particularly high in the enclosed coastal water body (>2 µg L^{-1}), where decreasing TSS conditions promoted increased phytoplankton growth.
- In the Cape York region, 89% of the area was not exposed to a potential risk category, in keeping with long-term patterns (93%), and only 1% (692 km^2) of the region was exposed to the highest risk category IV. Approximately 14% (1,443 km^2) of the region's coral reefs and 60% (1,602 km^2) of the region's seagrasses were exposed to a potential risk (combined risk categories II–IV). There was an increase in the coral area exposed to the lowest potential risk category (II: +10%) and an increase in the seagrass area exposed to the potential risk category (III: +9%). Only the inshore Cape York waters, seagrass and coral habitats were exposed to the highest categories of potential risk (III and IV), with the largest proportion located in the region's enclosed coastal waters. Mid-shelf and offshore Cape York reefs and seagrasses were exposed to the lower potential risk category II or to no/very low risk.

6.2 Wet Tropics

Discharge from the Daintree, Mossman, and Barron basins was 2.1 times greater than the long-term median in 2022–23, after near-median discharge in the previous two years. Discharge from the Russell-Mulgrave and Johnstone basins was very close to the long-term median in 2022–23, after near-median discharge in the previous two years. Discharge from the Tully-Murray-Herbert basins was also very close to the long-term median in 2022–23 after below average discharge in the previous year and 1.5 times higher discharge in 2020–21.

Ambient water quality - Enclosed coastal, open coastal, and mid-shelf waters:

- NO_x and Secchi depth did not meet water quality GVs for any focus region in the Wet Tropics (Table 6-3).
- PO_4, PP, TSS, and Chl-*a* met GVs for all focus regions in the Wet Tropics.
- PN met GVs for two of the three focus regions in the Wet Tropics.
- Over the period from 2015–2023, NO_x and Chl-*a* showed a trend of improvement in two of the three focus regions in the Wet Tropics. Most other indicators showed a trend of stability (no net improvement or deterioration). PN was the **only** indicator which showed a trend of deterioration in a single focus region (Tully region).
- Water Quality Index scores have shown a trend of improvement over the past two to five years (depending on the region). For the 2022–23 water year, the annual condition Water Quality Index score was 'moderate'.

Table 6-3: Water quality indicator summary for the three focus regions of the Wet Tropics. Performance relative to guideline values is shown as: generally exceeding (✗) or meeting (✓) guideline values across all sites. The trend of the indicator (2015–present) is shown as: deteriorating (↘), improving (↗) or stable (→).

Water quality indicator	Barron-Daintree	Russel-Mulgrave	Tully
NO_x	✗ →	✗ ↗	✗ ↗
PO_4	✓ ↗	✓ →	✓ →
PN	✓ →	✓ →	✗ ↘
PP	✓ →	✓ →	✓ →
TSS	✓ ↗	✓ →	✓ →
Secchi depth	✗ →	✗ ↗	✗ →
Chl-*a*	✓ ↗	✓ ↗	✓ →

Wet season and event water quality

- In the Wet Tropics 89% of the region was not exposed to a potential risk, in keeping with long-term patterns, and only 1% (or 352 km²) of the region was exposed to the highest risk category IV. Approximately 3% (78 km^2) of the region's coral reefs and 98% (227 km^2) of the region's seagrasses were exposed to a potential risk (combined risk categories II–IV). Marine habitat areas exposed to respective risk categories II, III, or IV were overall similar to the long-term areas but there was a shift in the seagrass area exposed from higher potential risk (IV: -14% and III: -15%) to lower potential risk (II: +29%). Only the inshore Wet Tropics waters, seagrass, and coral habitats were exposed to the highest categories of potential risk (III and IV), with the largest proportion located in the region's enclosed coastal waters. Mid-shelf and offshore Wet Tropics reefs and mid-shelf Wet Tropics seagrasses were largely exposed to no/very low risk (>98%).

6.3 Burdekin

The combined discharge and loads calculated for the 2022–23 water year from the Burdekin and Haughton basins were around 2.2 times the long-term median, following two years of above-median discharge (1.2 times higher in 2021–22 and 1.8 times higher in 2020–21).

Ambient water quality - Enclosed coastal, open coastal, and mid-shelf waters:

- NO_x and Secchi depth did not meet water quality GVs in the Burdekin region (Table 6-4).
- PO_4, PN, PP, TSS, and Chl-*a* met GVs in the Burdekin region.
- Over the period from 2015–2023, NO_x and PO_4 showed a trend of improvement in the Burdekin region. All other indicators showed a trend of stability (no net improvement or deterioration). No indicators showed a trend of deterioration.
- Water Quality Index scores have shown a long-term trend of deterioration from 2010–2018 followed by a period of stability. The last two years have shown an improving trend driven by improvements in PN and Chl-*a*. For the 2022–23 water year, the annual condition Water Quality Index score was 'moderate'.

Table 6-4: Water quality indicator summary for the Burdekin region. Performance relative to guideline values is shown as: generally exceeding (✖) or meeting (✔) guideline values across all sites. The trend of the indicator (2015–present) is shown as: deteriorating (↘), improving (↗) or stable (→).

Water quality indicator	Burdekin
NO_x	✖ ↗
PO_4	✔ ↗
PN	✔ →
PP	✔ →
TSS	✔ →
Secchi depth	✖ →
Chl-*a*	✔ →

Wet season and event water quality

- In the Burdekin region, approximately 90% of the area was not exposed to a potential risk in keeping with long-term patterns (90%), and only 1% (or 694 km^2) of the region was exposed to the highest risk category IV. Approximately 1% (20 km^2) of the region's coral reefs and 90% (634 km^2) of the region's seagrasses were exposed to a potential risk (combined risk categories II–IV). Marine habitat areas exposed to respective risk categories II, III, or IV were similar to the long-term areas. Only the inshore Burdekin waters, seagrass, and coral habitats were exposed to the highest categories of potential risk (III and IV), with the largest proportion located in the region’s enclosed coastal waters. Mid-shelf Burdekin seagrasses and mid-shelf and offshore Burdekin reefs were largely exposed to no/very low risk (>94%).

6.4 Mackay-Whitsunday

The combined discharge and loads calculated for the 2022–23 water year from the Proserpine, O'Connell, Pioneer, and Plane Basins were around 2.0 times the long-term median values following three years of well below-median discharge.

Ambient water quality - Enclosed coastal and open coastal waters:

- NO_x, PO_4, PP, TSS, and Secchi depth did not meet water quality GVs in the Mackay-Whitsunday region (Table 6-5).
- PN and Chl-*a* met GVs in the Mackay-Whitsunday region.
- Over the period from 2015–2023, all indicators showed a trend of improvement in the Mackay-Whitsunday region. No indicators showed a trend of stability or deterioration.
- Water Quality Index scores showed a long-term trend of deterioration from 2007–2018. The trend then stabilised and has started to improve over the last four years, driven by improvements in PN, PP, water clarity, and Chl-*a*. For the 2022–23 water year, the annual condition Water Quality Index score was 'moderate'.

Table 6-5: Water quality indicator summary for Mackay-Whitsunday. Performance relative to guideline values is shown as: generally exceeding (✗) or meeting (✓) guideline values across all sites. The trend of the indicator (2015–present) is shown as: deteriorating (↘), improving (↗) or stable (–).

Water quality indicator	Mackay-Whitsunday
NO_x	✗ ↗
PO_4	✗ ↗
PN	✓ ↗
PP	✗ ↗
TSS	✗ ↗
Secchi depth	✗ ↗
Chl-*a*	✓ ↗

Wet season and event water quality

- There was a major flood event in the Proserpine and O'Connell Basins of the Mackay-Whitsunday region during the 2022–23 wet season.
- In the Mackay-Whitsunday region, 89% of the area was not exposed to a potential risk in keeping with long-term patterns (87%) and only 1% (or 514 km^2) of the region was exposed to the highest risk category IV. Approximately 4% (133 km^2) of the region's

coral reefs and 84% (258 km^2) of the region's seagrasses were exposed to a potential risk. Marine habitat areas exposed to respective risk categories II, III, or IV were overall similar to the long-term areas but there was a shift in the seagrass area exposed from lowest potential risk (II: -16%) to no/very low potential risk (+13%). Only inshore waters, seagrasses, and coral habitats were exposed to the highest categories of potential risk (III and IV), with the largest proportion located in the region's enclosed coastal waters. Mid-shelf and offshore Mackay-Whitsunday reefs were all exposed to no/very low risk (100%).

7 References

Álvarez-Romero JG, Devlin MJ, Teixeira da Silva E, Petus C, Ban N, Pressey RJ, Kool J, Roberts S, Cerdeira WA, Brodie J (2013). A novel approach to model exposure of coastal-marine ecosystems to riverine flood plumes based on remote sensing techniques. Journal of Environmental Management 119:194-207.

Australian and Queensland governments, (2003). Reef Water Quality Protection Plan for catchments adjacent to the Great Barrier Reef World Heritage Area. The State of Queensland and Commonwealth of Australia. Queensland Department of Premier and Cabinet, Brisbane. 43 pp.

Australian and Queensland governments, (2018a). Reef 2050 Water Quality Improvement Plan 2017-2022. Queensland government, Brisbane, Australia.

Australian and Queensland governments, (2018b). Paddock to Reef Integrated Monitoring, Modelling and Reporting Program: Program Design 2018-2022. Queensland government, Brisbane, Australia.

Bainbridge ZT, Wolanski E, Álvarez-Romero JG, Lewis SE, Brodie JE (2012). Fine sediment and nutrient dynamics related to particle size and floc formation in a Burdekin River flood plume, Australia. Marine Pollution Bulletin, The Catchment to Reef Continuum: Case studies from the Great Barrier Reef 65, 236–248. doi:10.1016/j.marpolbul.2012.01.043

Brinkman R, Herzfeld M, Andrewartha J, Rizwi F, Steinberg C, Spagnol S (2011). Hydrodynamics at the whole of GBR scale. AIMS Final Project Report MTSRF Project 2.5i.1, June 2011. Report to Reef and Rainforest Research Centre. Australian Institute of Marine Science, Townsville. 42 pp.

Brodie J, Waterhouse J, Schaffelke B, Furnas M, Maynard J, Collier C, Lewis S, Warne M, Fabricius K, Devlin M, McKenzie L, Yorkston H, Randall L, Bennett J, Brando V (2013). Scientific Consensus Statement. Chapter 3: Relative risks to the Great Barrier Reef from degraded water quality The State of Queensland. Published by the Reef Water Quality Protection Plan Secretariat, July 2013. http://www.reefplan.qld.gov.au/about/scientific-consensus-statement/water-quality-risks.aspx

Brooks A, Spencer J, Olley J, Pietsch T, Borombovits D, Curwen G, Shellberg J, Howley C, Gleeson A, Simon A, Bankhead N, Klimetz D, Eslami-Endargoli L, Bourgeault A (2013) An empirically-based sediment budget for the Normanby Basin: sediment sources, sinks, and drivers on the Cape York Savannah, Australian Rivers Institute, Griffith University, Final report for the Australian Government Caring for Our Country - Reef Rescue Program.

Bureau of Meteorology [BOM] (2011). Climate averages, average monthly wind velocity over Australia. Australian Government, Bureau of Meteorology, viewed 7 December 2017, http://www.bom.gov.au/jsp/ncc/climate_averages/wind-velocity/index.jsp?period=jan#maps

Bureau of Meteorology [BOM] (2022). Rainfall data, accessed online October 2022, http://www.bom.gov.au/climate/data/

Bureau of Meteorology [BOM] (2017). eReefs Catchments: simulations, nowcasts, and forecasts of water quantity and quality flowing to the Great Barrier Reef. Final Report, eReefs Project Phase 3, Great Barrier Reef Foundation, Brisbane, QLD Australia.

Cape York NRM and South Cape York Catchments (2016). Eastern Cape York Water Quality Improvement Plan. Cape York Natural Resource Management and South Cape York Catchments, Cooktown, Queensland, Australia.

Carstensen J, Klais R, Cloern, JE (2015). Phytoplankton blooms in estuarine and coastal waters: Seasonal patterns and key species. Estuarine, Coastal and Shelf Science 162*:* 98-109.

Commonwealth of Australia (2018). Reef 2050 Long-Term Sustainability Plan. http://www.environment.gov.au/marine/gbr/publications/reef-2050-long-term-sustainability-plan.

De'ath G, Fabricius KE (2008) Water quality of the Great Barrier Reef: distributions, effects on reef biota and trigger values for the protection of ecosystem health. Final Report to the Great Barrier Reef Marine Park Authority. Australian Institute of Marine Science, Townsville. 104 pp.

De'ath G, Fabricius KE (2010). Water quality as a regional driver of coral biodiversity and macroalgae on the Great Barrier Reef. Ecological Applications 20: 840–850.

Department of Environment and Resource Management (2009). Queensland Water Quality Guidelines, Version 3. 167 p. Available at www.derm.qld.gov.au. ISBN 978-0-9806986-0-2.

Department of Regional Development, Manufacturing and Water (DRMW) (2023). River discharge data. https://water-monitoring.information.qld.gov.au/ Accessed October 2023.

Devlin M, McKinna LW, Álvarez-Romero J, Petus C, Abott B, Harkness P, Brodie J (2012) Mapping the pollutants in surface plume waters in the Great Barrier Reef, Australia. Marine Pollution Bulletin 65: 224-235. doi:10.1016/j.marpolbul.2012.03.001

Devlin MJ, Teixeira da Silva E, Petus C, Wenger A, Zeh D, Tracey D, Álvarez-Romero J, Brodie J (2013). Combining water quality and remote sensed data across spatial and temporal scales to measure wet season chlorophyll-*a* variability: Great Barrier Reef lagoon (Queensland, Australia). Ecological Processes 2.

Devlin M, Petus C, Teixeira da Silva E, Tracey D, Wolff N, Waterhouse J, Brodie J (2015). Water quality and river plume monitoring in the Great Barrier Reef: An Overview of Methods Based on Ocean Colour Satellite Data. Remote Sensing 7: 12909-12941.

Folkers A, Rohde K, Delaney K, Flet, I (2014). Mackay-Whitsunday Water Quality Improvement Plan 2014-2021. Reef Catchments and Australian Government. http://reefcatchments.com.au/files/2015/06/WATER-QUALITY-IMPROVEMENT-PLAN-MACKAY-WHITSUNDAY-ISAAC-2014-2021_DRAFT.pdf

Great Barrier Reef Marine Park Authority (2010). Water Quality Guidelines for the Great Barrier Reef Marine Park. Revised Edition 2010. Great Barrier Reef Marine Park Authority, Townsville. 100pp.

Great Barrier Reef Marine Park Authority (2014). Great Barrier Reef Region Strategic Assessment. Great Barrier Reef Marine Park Authority, Townsville.

Great Barrier Reef Marine Park Authority (2019). Great Barrier Reef Outlook Report 2019, Great Barrier Reef Marine Park Authority, Townsville.

Great Barrier Reef Marine Park Authority (2022), Great Barrier Reef Marine Monitoring Program quality assurance and quality control manual 2020–21, Great Barrier Reef Marine Park Authority, Townsville.

Grill G, Lehner B, Thieme M. *et al.* (2019). Mapping the world's free-flowing rivers. Nature 569, 215–221. https://doi.org/10.1038/s41586-019-1111-9

Gruber R, Waterhouse J, Logan M, Petus C, Tracey D, Lewis S, Howley C, Tonin H, Skuza M, Doyle J, Costello P, Davidson J, Gunn K, Wright M, Zagorskis I, Kroon F, Neilen A (2018). Marine Monitoring Program: Annual Report for inshore water quality monitoring

2016-2017. Report for the Great Barrier Reef Marine Park Authority, Great Barrier Reef Marine Park Authority, Townsville.

Gruber R, Waterhouse J, Logan M, Petus C, Howley C, Lewis S, Tracey D, Langlois L, Tonin H, Skuza M, Costello P, Davidson J, Gunn K, Lefevre C, Moran D, Robson B, Shanahan M, Zagorskis I, Shellberg J, Neilen A (2020). Marine Monitoring Program: Annual Report for Inshore Water Quality Monitoring 2018–19. Report for the Great Barrier Reef Marine Park Authority, Great Barrier Reef Marine Park Authority, Townsville, 262pp.

Howley C, (2020) Natural and Anthropogenic Drivers of Water Quality in the Normanby Basin and Princess Charlotte Bay, Northern Australia. PhD Dissertation. Griffith University, Australian Rivers Institute, School of Environment, Brisbane, Qld (199pp).

Jenks GF, Caspall FC (1971). Error on Choroplethic Maps: Definition, Measurement Reduction. Annals of the Association of American Geographers 61: 217-44.

Kaserzon S, Shiels R, Elisei G, Paxman C, Li Y, Carswell C, Xia S, Prasad P, Gallen M, Reeks T, Thompson K, Taucare G, Marano K, Gorji S, Mueller J, Prazeres M, Walker K (2023). Herbicide analysis for the inshore Great Barrier Reef Marine Monitoring Program (MMP) – 25 August 2023. Report for the Great Barrier Reef Marine Park Authority.

Kuhnert PM, Liu Y, Henderson B, Dambacher J, Lawrence E, Kroon FJ (2015). Review of the Marine Monitoring Program (MMP). Final Report for the Great Barrier Reef Marine Park Authority, CSIRO, Australia: 278

Lewis S, Brodie J, Endo G, Lough J, Furnas M, Bainbridge Z (2014). Synthesizing historical land use change, fertiliser and pesticide usage and pollutant load data in the regulated catchments to quantify baseline and changing Loads exported to the Great Barrier Reef. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Technical Report 14/20, James Cook University, Townsville, 105 pp.

Lloyd-Jones LR, Kuhnert PM, Lawrence E, Lewis SE, Waterhouse J, Gruber RK, Kroon FJ (2022). Sampling re-design increases power to detect change in the Great Barrier Reef's inshore water quality. PLOS ONE 17(7): e0271930. https://doi.org/10.1371/journal.pone.0271930

Margvelashvili N, Andrewartha J, Baird M, Herzfeld M, Jones E, Mongin M, Rizwi F, Robson BJ, Skerratt J, Wild-Allen K, Steven A (2018). Simulated fate of catchment-derived sediment on the Great Barrier Reef shelf. Marine Pollution Bulletin 135: 954-962.

McCloskey GL, Baheerathan R, Dougall C, Ellis R, Bennett FR, Waters D, Darr S, Fentie B, Hateley LR, Askildsen M (2021). Modelled estimates of fine sediment and particulate nutrients delivered from the Great Barrier Reef catchments. Marine Pollution Bulletin 165: 112163 https://doi.org/10.1016/j.marpolbul.2021.112163.

McKenzie LJ, Collier CJ, Langlois LA, Yoshida RL. 2023, Marine Monitoring Program: Annual Report for Inshore Seagrass Monitoring 2021–22. Report for the Great Barrier Reef Marine Park Authority, Great Barrier Reef Marine Park Authority, Townsville. 172pp.

Moran D, Robson B, Gruber R, Waterhouse J, Logan M, Petus C, Howley C, Lewis S, James C, Tracey D, Mellors J, O'Callaghan M, Bove U, Davidson J, Glasson K, Jaworski S, Lefevre C, Nordborg M, Vasile R, Zagorskis I, Shellberg J. (2023). Marine Monitoring Program: Annual Report for Inshore Water Quality Monitoring 2021–22. Report for the Great Barrier Reef Marine Park Authority, Great Barrier Reef Marine Park Authority, Townsville.

NQ Dry Tropics (2016). Burdekin Region Water Quality Improvement Plan 2016, NQ Dry Tropics, Townsville. https://www.nqdrytropics.com.au/wqip2016/

Novoa S, Wernand MR, Van der Woerd HJ, (2013). The Forel-Ule scale revisited spectrally: preparation protocol, transmission measurements and chromaticity. Journal of the European Optical Society-Rapid Publications 8, 13057.

Petus C, Devlin M, Thompson A, McKenzie L, Teixeira da Silva E, Collier C, Tracey D, Martin K (2016). Estimating the exposure of coral reefs and seagrass meadows to land-sourced contaminants in river flood plumes of the Great Barrier Reef: validating a simple Satellite Risk Framework with Environmental Data. Remote Sensing 8: 210.

Petus C, Devlin M, da Silva E, Lewis S, Waterhouse J, Wenger A, Bainbridge Z, Tracey D (2018) Defining wet season water quality target concentrations for ecosystem conservation using empirical light attenuation models: a case study in the Great Barrier Reef (Australia). Journal of Environmental Management 213: 1-16.

Petus C, Waterhouse J, Lewis S, Vacher M, Tracey D, Devlin M. (2019). A flood of information: Using Sentinel-3 water colour products to assure continuity in the monitoring of water quality trends in the Great Barrier Reef (Australia). Journal of Environmental Management 248: 109255.

Pinheiro JC, Bates DM (2000). Mixed-effects models in S and S-PLUS, Statistics and Computing Series, Springer-Verlag, New York, NY.

Puignou Lopez O, Lewis S, James C, Davis A, Mackay S. (in review). Hydrology of the Great Barrier Reef catchment area along a latitudinal gradient: Upscaling discharge to reflect catchment inputs. Journal of Hydrology.

Queensland Land Use Mapping Program [QLUMP] (2015). Land use mapping for the Cape York NRM region, prepared by DNRM.

R Core Team (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL: https://www.R-project.org/

Schaffelke B, Carleton J, Skuza M, Zagorskis I, Furnas MJ (2012). Water quality in the inshore Great Barrier Reef lagoon: Implications for long-term monitoring and management. Marine Pollution Bulletin 65:249-260. DOI: 10.1016/j.marpolbul.2011.10.031

Shellberg J, Brooks A (2013). Alluvial Gully Prevention and Rehabilitation Options for Reducing Sediment Loads in the Normanby Catchment and Northern Australia. Australian Rivers Institute, Griffith University, Final report for the Australian Government Caring for Our Country - Reef Rescue Program.

Shellberg JG, Spencer J, Brooks AP, Pietsch TJ (2016). Degradation of the Mitchell River fluvial megafan by alluvial gully erosion increased by post-European land use change, Queensland, Australia. Geomorphology, 266, 105-120.

Skerratt JH, Mongin M, Baird ME, Wild-Allen KA, Robson BJ, Schaffelke B, Davies CH, Richardson AJ, Margvelashvili N, Soja-Wozniak M, Steven ADL (2019). Simulated nutrient and plankton dynamics in the Great Barrier Reef (2011–2016). Journal of Marine Systems, 192, 51-74.

Spencer J, Brooks A, Curwen G, Tews K (2016). A Disturbance Index Approach for Assessing Water Quality Threats in Eastern Cape York. A report to South Cape York Catchments and Cape York NRM for the Cape York Water Quality Improvement Plan, by the Australian Rivers Institute, Griffith University, 42 pp

State of Queensland (2020). Environmental Protection (Water and Wetland Biodiversity) Policy 2019: Environmental Values and Water Quality Objectives, Eastern Cape York Basins https://environment.des.qld.gov.au/management/water/policy/cape-york-eastern-basins

Steven AD, Baird ME, Brinkman R, Ca, NJ, Cox SJ, Herzfeld M, Hodge J, Jones E, King E, Margvelashvili N, Robillot C, (2019). eReefs: An operational information system for managing the Great Barrier Reef. Journal of Operational Oceanography, pp.1-17.

Terrain NRM (2015). Wet Tropics Water Quality Improvement Plan 2015-2020. Terrain NRM, Innisfail. https://www.wettropicsplan.org.au/regional-themes/water/wqip/

Thai P, Paxman C, Prasad P, Elisei G, Reeks T, Eaglesham G, Yeh R, Tracey D, Grant S, Mueller J (2020). Marine Monitoring Program: Annual report for inshore pesticide monitoring 2018-2019. Report for the Great Barrier Reef Marine Park Authority, Great Barrier Reef Marine Park Authority, Townsville, 69pp.

Thompson A, Davidson J, Logan M, Thompson C. (2023). Marine Monitoring Program Annual Report for Inshore Coral Reef Monitoring: 2021–22. Report for the Great Barrier Reef Marine Park Authority, Great Barrier Reef Marine Park Authority, Townsville.143 pp.

Van der Woerd JH, Wernand RM (2018). Hue-angle product for low to medium spatial resolution optical satellite sensors. Remote Sensing 10, 180.

Van der Woerd JH, Wernand RM, Peters M, Brockmann C (2016). True colour analysis of natural waters with SeaWiFS, MODIS, MERIS and OLCI by SNAP, Ocean Optics conference. At Victoria BC Canada XXIII.

Water Quality & Investigations (2023). Great Barrier Reef Catchment Loads Monitoring Program: Loads and yields for sediment and nutrients, and Pesticide Risk Metric results (2020–2021) for rivers that discharge to the Great Barrier Reef. Department of Environment and Science, Brisbane, Australia.

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

Waterhouse J, Burton J, Garzon-Garcia A, Lewis S, Brodie J, Bainbridge Z, Robson R, Burford MA, Gruber RK, Dougall C (2018). Synthesis of knowledge and concepts - Bioavailable Nutrients: Sources, delivery and impacts in the Great Barrier Reef, July 2018. Supporting Concept Paper for the Bioavailable Nutrients Workshop, 15 March 2018. Reef and Rainforest Research Centre, 84pp.

Waterhouse J, Gruber R, Logan M, Petus C, Howley C, Lewis S, Tracey D, James C, Mellors J, Tonin H, Skuza M, Costello P, Davidson J, Gunn K, Lefevre C, Moran D, Robson B, Shanahan M, Zagorskis I, Shellberg J (2021). Marine Monitoring Program: Annual Report for Inshore Water Quality Monitoring 2019–20. Report for the Great Barrier Reef Marine Park Authority, Great Barrier Reef Marine Park Authority, Townsville.

Waterhouse J, Petus C, Lewis S, James C, O'Callaghan M, Tracey D, Doyle J, Patel F, Uthicke S (2023). Pilot study to investigate options for water quality sampling as part of the Reef Trust Partnership Crown of Thorns Starfish Control Program, Final Report July 2023. Report for the Reef Trust Partnership. TropWATER Report No. 23/50. 92 pp. James Cook University, Townsville.

Wells SC, Cole SJ, Moore RJ, Black KB, Khan U, Hapuarachchi P, Gamage N, Hasan M, MacDonald A, Bari M, Tuteja NK (2018). Forecasting the water flows draining to the Great Barrier Reef using the G2G Distributed Hydrological Model. Technical Report (Contract No. 112-2015-16), Centre for Ecology & Hydrology Wallingford, OX10 8BB, UK.

Wernand MR, Hommersom A, Van der Woerd HJ (2012). MERIS-based ocean colour classification with the discrete Forel–Ule scale. Ocean Science Discussions 9, 2817–2849.

Wernand MR, Van der Woerd HJ, Gieskes WWC (2013). Trends in ocean colour and chlorophyll concentration from 1889 to present. PLoS One, 0063766.

Wijffels S, Beggs H, Griffin C, Middleton J, Cahill M, King E, Jones E, Feng M, Benthuysen J, Steinberg C, Sutton P (2018). A fine spatial-scale sea surface temperature atlas of the Australian regional seas (SSTAARS): Seasonal variability and trends around Australasia and New Zealand revisited. Journal of Marine Systems. 187. 10.1016/j.jmarsys.2018.07.005.

Wood SN (2006). Generalized additive models: An introduction with R. Chapman & Hall/CRC Publisher, City.

Wood SN (2011). Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. Journal of the Royal Statistical Society (B) 73: 3-36.

Appendix A: Water quality site locations and frequency of monitoring

Table A - 1: Description of the water quality sites sampled by AIMS, JCU and CYWP during 2022–23. The proposed number of visits is shown in black text, while the actual number of visits is shown in parentheses in red text. Actual visits can differ from proposed due to poor weather limiting site access.

Site location	Logger Deployment		Ambient sampling at fixed sites: proposed (actual)		Event-based sampling
NRM region	**Turbidity and chlorophyll**	**Salinity**	**Number of times site is visited/year by AIMS**	**Number of times site is visited/year by JCU/ CYWP**	**Additional surface-sampling/year by JCU/ CYWP**
Cape York					
Normanby-Kennedy transect					
Kennedy mouth					2
Kennedy inshore					2
Cliff Islands				4 (Sampling 2 depths) (3)	2
Bizant River mouth					2
Normanby River mouth					2
Normanby inshore				4 (Sampling 2 depths) (3)	2
NR-03				4 (Sampling 2 depths) (2)	2
NR-04				4 (Sampling 2 depths) (2)	2
NR-05				4 (Sampling 2 depths) (3)	1
Corbett Reef				4 (Sampling 2 depths) (3)	2
Pascoe transect					
Pascoe mouth north					1
Pascoe mouth south				5 (Sampling 2 depths) (4)	
PR-N2				5 (Sampling 2 depths) (5)	
PR-N3					
PR-N4				5 (Sampling 2 depths) (0)	
PR-N5					
PR-N6					
PR-S2.5				5 (Sampling 2 depths) (5)	
Middle Reef				5 (Sampling 2 depths) (5)	
PR-S5				5 (Sampling 2 depths) (5)	1
Annan and Endeavour transect					

Site location	Logger Deployment		Ambient sampling at fixed sites: proposed (actual)		Event-based sampling
NRM region	Turbidity and chlorophyll	Salinity	Number of times site is visited/year by AIMS	Number of times site is visited/year by JCU/ CYWP	Additional surface-sampling/year by JCU/ CYWP
Annan mouth					
Walker Bay				5 (Sampling 2 depths) (5)	
Dawson Reef	√			5 (Sampling 2 depths) (5)	2
Endeavour mouth					1
Endeavour north shore				5 (Sampling 2 depths) (5)	
Endeavour offshore				5 (Sampling 2 depths) (5)	
Egret and Boulder Reef				5 (Sampling 2 depths) (5)	
Forrester Reef	√				
Stewart transect					
Stewart mouth					
SR-02				5 (Sampling 2 depths) (5)	
SR-03				5 (Sampling 2 depths) (5)	
SR-04				5 (Sampling 2 depths) (5)	
Hannah Island				5 (Sampling 2 depths) (4)	
Wet Tropics					
Cairns Long-term transect					
Cape Tribulation*			3 (Sampling 2 depths) (3)		
Port Douglas*			3 (Sampling 2 depths) (3)		
Double Island*			3 (Sampling 2 depths) (3)		
Yorkey's Knob*			3 (Sampling 2 depths) (3)		
Fairlead Buoy*			3 (Sampling 2 depths) (3)		
Green Island*			3 (Sampling 2 depths) (3)		
Russell-Mulgrave Focus Region					
Fitzroy Island West	√		5 (Sampling 2 depths) (5)		
RM2					
RM3			5 (Sampling 2 depths) (5)	5 (Sampling 2 depths) (5)	
RM4					
High Island East					
Normanby Island					
Frankland Group West (Russell Island)*	√		5 (Sampling 2 depths) (5)	5 (Sampling 2 depths) (5)	

Site location	Logger Deployment		Ambient sampling at fixed sites: proposed (actual)		Event-based sampling
NRM region	Turbidity and chlorophyll	Salinity	Number of times site is visited/year by AIMS	Number of times site is visited/year by JCU/ CYWP	Additional surface-sampling/year by JCU/ CYWP
High Island West*	√	√	5 (Sampling 2 depths) (5)	5 (Sampling 2 depths) (5)	
Palmer Point					
Russell-Mulgrave River mouth mooring	√	√	5 (Sampling 2 depths) (5)	5 (Sampling 2 depths) (5)	
Russell-Mulgrave River mouth					
Russell-Mulgrave junction [River]					
Tully Focus Region					
King Reef					
East Clump Point			5 (Sampling 2 depths) (5)	5 (Sampling 2 depths) (6)	
Dunk Island North*	√	√	5 (Sampling 2 depths) (5)	5 (Sampling 2 depths) (6)	
South Mission Beach					
Dunk Island South East			5 (Sampling 2 depths) (5)	5 (Sampling 2 depths) (6)	
Between Tam O'Shanter and Timana			5 (Sampling 2 depths) (5)	5 (Sampling 2 depths) (6)	
Hull River mouth					
Bedarra Island			5 (Sampling 2 depths) (5)	5 (Sampling 2 depths) (6)	
Triplets					
Tully River mouth mooring	√	√	5 (Sampling 2 depths) (5)	5 (Sampling 2 depths) (6)	
Tully River					
Burdekin					
Burdekin Focus Region					
Pelorus and Orpheus Island West*	√		4 (Sampling 2 depths) (4)	5 (Sampling 2 depths) (5)	
Pandora Reef*	√		4 (Sampling 2 depths) (4)	5 (Sampling 2 depths) (5)	
Cordelia Rocks					
Magnetic Island (Geoffrey Bay)*	√		4 (Sampling 2 depths) (4)	5 (Sampling 2 depths) (5)	
Inner Cleveland Bay					
Cape Cleveland					
Haughton 2			4 (Sampling 2 depths) (4)	5 (Sampling 2 depths) (5)	

Site location	Logger Deployment		Ambient sampling at fixed sites: proposed (actual)		Event-based sampling
NRM region	**Turbidity and chlorophyll**	**Salinity**	**Number of times site is visited/year by AIMS**	**Number of times site is visited/year by JCU/ CYWP**	**Additional surface-sampling/year by JCU/ CYWP**
Haughton River mouth					
Barratta Creek					
Yongala IMOS NRS	√	√	4 (Sampling 2 depths) (4)		
Cape Bowling Green					
Plantation Creek					
Burdekin River mouth mooring	√	√	4 (Sampling 2 depths) (4)	5 (Sampling 2 depths) (5)	
Burdekin Mouth 2					
Burdekin Mouth 3					
Mackay-Whitsunday					
Whitsunday focus Region					
Double Cone Island*	√		5 (Sampling 2 depths) (5)		1
Hook Island W					
North Molle Island					
Pine Island*	√	√	5 (Sampling 2 depths) (5)		1
Seaforth Island	√		5 (Sampling 2 depths) (5)		1
OConnell River mouth	√	√	5 (Sampling 2 depths) (5)		1
Repulse Islands dive mooring			5 (Sampling 2 depths) (5)		1
Rabbit Island NE					
Brampton Island					
Sand Bay					
Pioneer River mouth					

*Sites which were part of the MMP sampling design from 2005–2015.

Appendix B: Water quality monitoring methods

B-1 Comparison with Reef Water Quality Guideline values

The Water Quality Guidelines provide a useful framework to interpret the water quality measurements obtained through the MMP. Table B - 1 gives a summary of the Guideline Values (GVs) for water quality variables in four cross-shelf water bodies (Great Barrier Reef Marine Park Authority, 2010).

At present, the Water Quality Guidelines do not define GVs for dissolved inorganic nutrients (nitrate and phosphate) in the Reef lagoon as these nutrients are rapidly cycled through uptake and release by biota and are variable on small spatial and temporal scales (Furnas *et al.*, 2005, 2011). Due to this high variability, their concentrations did not show as clear spatial patterns or correlations with coral reef attributes as the other water quality parameters that were included in the Guidelines and are considered to be more representative of nutrient availability integrated over time (De'ath and Fabricius, 2010). However, the Queensland Water Quality Guidelines (Department of Environment and Resource Management [DERM], 2009) identify GVs for dissolved inorganic nutrients in marine water bodies. Guideline values for dissolved inorganic nutrients and turbidity (in enclosed coastal waters) were drawn from Queensland Water Quality Guidelines or provided by the Reef Authority. Site-specific GVs for all water quality variables are shown in Appendix C Table C - 9.

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

		Enclosed coastal		Open coastal		Mid-shelf		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*	$mg\ L^{-1}$	5.0	15.0	2.0	2.0	2.0	2.0	0.7	0.7
Turbidity	NTU	10.0^{QLD}	6.0^{QLD}	1.5**	1.5**	1.5**	1.5**	<1^{QLD}	<1^{QLD}
Secchi depth	m	1.0	1.5	10.0	10.0	10.0	10.0	17.0	17.0
NO_x	$\mu g\ L^{-1}$	10.0^{QLD}	3.0^{QLD}	0.35***	0.35***	0.35***	0.35***	2.0^{QLD}	2.0^{QLD}
PO_4	$\mu g\ L^{-1}$	5.0^{QLD}	6.0^{QLD}	4.0^{QLD}	6.0^{QLD}	4.0^{QLD}	6.0^{QLD}	4.0^{QLD}	5.0^{QLD}

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

* Seasonal adjustments to these parameters are used to produce seasonal (wet and dry) guidelines for producing satellite exposure maps (Table B-4).

** Turbidity trigger value (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 QA/QC Reports and Schaffelke *et al.*, 2009).

*** NO_x GVs for open coastal and mid-shelf sites are provided by the Reef Authority.

B-2 Calculation of the Water Quality Index

In the Great Barrier Reef Report Cards published prior to 2016, water quality assessments were based on the MMP broad-scale monitoring using ocean colour remote sensing imagery that covers a larger area than the fixed sampling locations reported here (Brando *et al.*, 2011). However, the current design of the MMP focuses on interpreting trends in site-specific water quality within key focus regions.

The Water Quality Index (WQ Index) is an interpretation tool developed by AIMS to visualise trends in the suite of water quality variables measured and to compare monitored water quality to existing Water Quality Guidelines (Department of Environment and Resource Management, 2009; Great Barrier Reef Marine Park Authority, 2010). The WQ Index uses a set of five key indicators:

- Water clarity,
- Chl-*a* concentrations,
- PN concentrations,
- PP concentrations, and
- NO_x concentrations.

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

TSS concentration, turbidity, and Secchi depth are indicators of the clarity of the water, which is influenced by a number of factors, including wind, waves, tides, and river inputs of particulate material. Chl-a concentration is widely used as a proxy for phytoplankton biomass as a measure of the productivity of a system or its eutrophication status and is used to indicate nutrient availability (Brodie et al., 2007). Particulate nutrients (PN, PP) are an indicator of nutrient stocks in the water column (predominantly bound in phytoplankton and other organic particles as well as adsorbed to fine sediment particles) but are less affected by small-scale variability in space and time than dissolved nutrients (Furnas et al., 2005, 2011). Nitrate is included as an indicator of dissolved nutrient concentrations in the coastal zone, which tend to be rapidly used by phytoplankton. Guideline values for NO_x were provided by the Reef Authority as available NO_x GVs from the Queensland Water Quality Guidelines (Department of Environment and Resource Management [DERM], 2009) are the 80th percentiles, which are considered to be high and not representative of values normally found in the Reef lagoon.

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

Long-term trend: This version of the WQ Index is based on the pre-2015 MMP sampling design and uses only the original sites (located in the open coastal water body) and three sampling dates per year. This sampling design had low temporal and spatial resolution and was aimed at detecting Long-term trends in inshore water quality. To compensate for less frequent sampling, four-year running means are used to reduce the effect of sampling date on the Index. Monitoring data are compared against broad water body GVs that do not include wet and dry season GVs (Table B - 1). Steps in the calculation of this version of the WQ Index are:

1. Calculate four-year mean values for each of the seven indicators (i.e., all values from 2005–08, 2006–09, 2007–10, et cetera).
2. Calculate the proportional deviations (ratios) of these running mean values (V) from the associated guideline value (GV) (Table B - 1) as the difference of binary logarithms of values and guidelines:

$$\text{Ratio} = \log_2(GV) - \log_2(V)$$

   for values where exceeding the GV constitutes a "fail". For values where exceeding the GV constitutes a "pass" (i.e., Secchi depth), the right side of this equation would be reversed.
3. Binary logarithm transformations are useful for exploring data on powers of 2 scales, and thus are ideal for generating ratios of two numbers in a manner that will be symmetrical around 0. Ratios of 1 and -1 signify a doubling and a halving, respectively, compared to the guideline. Hence, a ratio of 0 indicates a running mean that is the same as its GV, ratios <0 signify running means that exceeded the GV and ratios >0 signify running means that complied with the GV.
4. Ratios exceeding 1 or -1 (more than twice or half the GV) are capped at 1 to bind the WQ Index scales to the region -1 to 1.
5. A combined water clarity ratio is generated by averaging the ratios of TSS and turbidity from loggers (where available).
6. The WQ Index for each site per four-year period is calculated by averaging the ratios of PP, PN, NO_x, Chl-*a*, and water clarity.
7. In accordance with other Great Barrier Reef Report Card indicators, the WQ Index scores (ranging from -1 to 1) are converted to a 'traffic light' colour scheme for reporting whereby:
   - < -2/3 to -1 equates to 'very poor' and is coloured red
   - < -1/3 to -2/3 equates to 'poor' and is coloured orange
   - < 0 to -1/3 equates to 'moderate' and is coloured yellow
   - 0 to 0.5 equates to 'good' and is coloured light green
   - 0.5 to 1 equates to 'very good' and is coloured dark green.
8. For the focus region summaries, the Index scores of all sampling locations within a focus region (for example, all sites in the Tully focus region) are averaged and converted into the colour scheme as above. For regional summaries, the Index scores of all sampling locations within a region (for example, all sites in the Wet Tropics region) are averaged and converted as above.

Annual condition: This version of the WQ Index is based on the post-2015 MMP sampling design and uses all samples from open coastal and mid-shelf water bodies each year. (Note that the WQ Index in reports prior to the 2018–19 report included enclosed coastal sites, see below). Due to high spatial and temporal sampling, a running mean is not used. Monitoring data are compared against site-specific GVs that include wet and dry season GVs (Table C - 9). Steps in the calculation of this version of the WQ Index are:

1. For each of the seven indicators, the annual, wet and dry season (aggregations) means and medians (statistic) are calculated per year.
2. Guidelines from the Reef Authority are consulted to select the appropriate aggregation (annual, wet, or dry season) and statistic (mean or median) for each site and indicator (Table C - 9).
3. Calculate the proportional deviations (ratios) of these aggregation statistics from the associated GVs as the difference of base 2 logarithms of values and GVs:

$$\text{Ratio} = \log_2(GV) - \log_2(V)$$

for values where exceeding the GV constitutes a “fail”. For values where exceeding the GV constitutes a “pass” (i.e., Secchi depth), the right side of this equation would be reversed.

4. Ratios exceeding 1 or -1 (more than twice or half the GV) are capped at 1 to bind the WQ Index scales to the region -1 to 1.
5. Ratios of several indicators are combined to create a hierarchical structure. Three groups were created by averaging ratios as follows:
   - water clarity (average of Secchi depth, TSS, and turbidity from loggers ratios),
   - productivity (average of Chl-*a* and NO_x ratios), and
   - particulate nutrients (average of PN and PP ratios).
6. The WQ Index for each site is calculated by averaging the ratios of water clarity, productivity, and particulate nutrients.
7. In accordance with other Reef Report Card indicators, the WQ Index scores (ranging from -1 to 1) are converted to a ‘traffic light’ colour scheme for reporting whereby:
   - < -2/3 to -1 equates to ‘very poor’ and is coloured red
   - < -1/3 to -2/3 equates to ‘poor’ and is coloured orange
   - < 0 to -1/3 equates to ‘moderate’ and is coloured yellow
   - 0 to 0.5 equates to ‘good’ and is coloured light green
   - 0.5 to 1 equates to ‘very good’ and is coloured dark green.
8. For the focus region summaries, the Index scores of all sampling locations within a focus region (for example, all sites in the Tully focus region) are averaged and converted into the colour scheme as above. For regional summaries, the Index scores of all sampling locations within a region (for example, all sites in the Wet Tropics region) are averaged and converted as above.
9. As of the 2018–19 report, this version of the Index now includes error bars, which propagate error in the Index via bootstrapping. Aggregation uncertainty is propagated through the spatial (site > focus region > region) and measure (measure > sub-indicator > indicator) hierarchies by repeatedly re-sampling (100 times with replacement) and aggregating bootstrapping. Each aggregation yields 100 estimates of each mean, and thus error bars represent the 95% quantile confidence intervals.

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

B-3 Monitoring of Reef water quality trends using remote sensing data

Remote sensing imagery is a useful assessment tool in the monitoring of turbid water masses and river flood plumes (hereafter river plumes) in the Reef lagoon. Ocean colour imagery provides synoptic-scale information regarding the movement, frequency of occurrence and composition of turbid waters in the Reef lagoon. Combined with *in situ* water quality sampling and modelling, the use of remote sensing is a valid and practical way to estimate wet season marine conditions as well as the extent and frequency of water type exposure on Reef ecosystems, including river plumes and resuspension events.

Until 2020, marine areas exposed to wet season water types were mapped using MODIS true colour images and a wet season (WS) water colour classification method, composed of 6 colours. This method is extensively presented in Álvarez-Romero *et al.* (2013) and used in, for example, Devlin *et al.* (2013) and Petus *et al.* (2014b, 2016, 2018 and 2019). Since 2020–21, the use of Sentinel-3 Ocean Land Colour Instrument (OLCI) satellite imagery and another colour scale (the Forel-Ule (FU) colour scale) was adopted, as the quality of the MODIS images was declining (Petus *et al.*, 2019).

The FU colour scale is an historical colour scale standard to determine the colour and classifies worldwide bodies of water (Novoa *et al.*, 2013). It is composed of 22 colours; going from indigo blue to cola brown, and is applicable for all natural waters (inland, estuarine, inshore and offshore) and all environmental conditions, including wet and dry season conditions (Wernand *et al.*, 2012, 2013; Van der Woerd *et al.*, 2016; Van der Woerd and Wernand, 2018). MODIS-Aqua WS and Sentinel-3 FU colour class maps showed very similar patterns over the 2017–18 wet season in a case study focusing on Wet Tropics and Burdekin regions of the Reef (Petus *et al.*, 2019 and Figure 2-2b and Table 2-2). This suggested that Sentinel-3 FU water colour products can be used to assure continuity in the monitoring of Reef water quality trends.

Production of the Reef water type maps

Previous methods used Daily MODIS Level-0 data acquired from the NASA Ocean Colour website, 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 typical wet season water masses types (including river plumes) in the Reef lagoon (Álvarez-Romero *et al.* 2013).

For this report, Reef water type maps were produced using daily Sentinel-3 OLCI Level 2 (hereafter, Sentinel-3 or S3) imagery reclassified to 21 distinct colour classes defined by their colour properties and using the Forel-Ule colour classification scale.

- Sentinel-3 imagery of the study area was downloaded on the EUMETSAT Data centre (URL: https://www.eumetsat.int/eumetsat-data-centre). Sentinel-3 are atmospherically corrected
- The imagery was processed with the FU Satellite Toolbox implemented in the Sentinel Application Platform (https://step.esa.int/main/toolboxes/snap/) and using automated tools (python scripts and ArcGIS toolboxes) developed through MMP funding

The FU satellite algorithm converts satellite normalised multi-band reflectance information into a discrete set of FU numbers using uniform colourimetric functions (Van der Woerd *et al.*, 2016, Van der Woerd and Wernand, 2018). The derivation of the colour of natural waters is based on the calculation of Tristimulus values of the three primaries (X, Y, Z) that specify the colour stimulus of the human eye. The algorithm is validated by a set of hyperspectral measurements from inland, coastal and marine waters (Van der Woerd *et al.*, 2016, Van der Woerd and Wernand, 2018). Technical details about the FU scale algorithm are synthetised through the European citclops (URL: http://www.citclops.eu/) and Eye on Water project webpages (https://www.eyeonwater.org/).

Production of weekly Reef water type maps

Weekly Reef water type composites are then created to minimise the image area contaminated by dense cloud cover and intense sun glint (Álvarez-Romero *et al.*, 2013).

- The maximum FU value of each pixel/week is used to keep the colour class with the highest turbidity level for each wet season week.
- The weekly composite maps are then cleaned to remove single or small clusters of cells sometimes misclassified by the FU satellite algorithm in the offshore regions of the Great Barrier Reef (including, for example, around coral reefs due to bottom interference and residual glint contamination). The aim of cleaning is to minimise the image area contaminated by dense cloud cover and intense sun glint, and to remove shallow water interference around reefs. In all cases the effect of these phenomena can be that offshore waters are misclassified as, for example, Reef WT1 waters (FU ≥ 10, previously primary waters). To minimise these effects an automated process is applied to the rasters that has the effect of sequentially infilling contiguous water-type areas one colour class at a time from FU1 through to FU21 using Python 2.7.3 (Python

Software Foundation, 2012) and ArcGIS 10.7 (ESRI, 2019). Infilling was achieved using the following steps: 1) Raster to Polygon conversion (not simplified), 2) Union (no gaps) then 3) removal, using Erase, of an external polygon, and 4) Polygon to Raster conversion. This process generates a separate raster mask (values 1 or 0) for each colour class, and the final cleaned raster is created by adding the component raster masks. Whilst this process is effective at removing noise offshore it can occasionally have the effect of removing areas of turbid coastal and plume water if they are not directly connected to the coast. To counter this, a final step is included in the cleaning process whereby waters classified as FU classes ≥10 i.e., in the cleaned raster are replaced with pixels of FU classes ≥10 in the original raster, using Con (Spatial Analyst). Thus, pixels adjacent to the coast that are classified as highly turbid water are kept and pixels within otherwise contiguous water types offshore are removed.

Production of annual, multi-annual, and typical wet and dry Reef frequency maps

- Four distinct Reef water type (WT) are defined by grouping the FU colour classes 1–3 (Reef WT4, equivalent to marine waters in the WS scale), FU colour classes 4–5 (reef WT3, equivalent to WS Tertiary water type), FU colour classes 6–9 (Reef WT2, equivalent to WS Secondary water type) and FU≥10 (Reef WT1, equivalent to wet season primary water type), as defined in Petus et al. (2019). The Reef water types are fully described in Table 2-2.
- Weekly Reef water type composites are thus overlaid in ArcGIS (i.e., presence/absence of one Reef water type), normalised (0–1) to compute each year a seasonal normalised frequency maps of occurrence of each Reef water type individually and of the Reef WT1–2 combined. Pixel (or cell) values of these maps range from 0 to 1; with a value of 1 meaning that one pixel has been exposed 22 weeks out of 22 weeks of the wet season.
- Annual frequency maps are then overlaid in ArcGIS to create multi-annual normalised frequency composites of occurrence of Reef water types. Multi-annual composites are calculated over different time frames, using the archive of MODIS-Aqua (2002–03 to 2019–20) and Sentinel-3 (2020–21 to 2022–23) water type maps. In order to combine the MODIS-Aqua and Sentinel-3 frequency composites, the MODIS frequency rasters were resampled to the same spatial resolution as the Sentinel imagery (0.00329 decimal degrees) using the Nearest Interpolation methods in ArcMAP 10.6 (Resample toll, Data Management)

Multi-annual frequency composites include: (i) a long-term period (2002–03 to 2021–22: 16 wet seasons) and (ii) a typical recovery period for Reef corals (2012–2017).

Composite frequency maps are also produced to represent typical wet year and dry year conditions. To account for broad-scale spatial variability in wet season river flows, wet- and dry-year maps are first produced separately by averaging frequency maps from the four wettest and driest years in each NRM region (Table B - 2). The wet-year maps for each NRM region are combined into a single composite Reef-wide map using the maximum value of the input rasters. This method captures wet-year plume conditions across the entire Reef even if the most significant plume events originate outside the NRM (for example, if Fitzroy plumes are dominant in the Mackay-Whitsunday region the top-quartile discharges from the Fitzroy are already included in the composite raster). Conversely, the dry-year maps are combined into a Reef-wide composite map using the minimum value of the input rasters, which thus represents the least extensive plume from an average of the driest years in each NRM region.

Except for the coral recovery period, reference maps (long-term, wet and dry frequency maps) were all updated in 2023 to ensure they remains valid as a representative period and to improve their accuracy as more satellite data are available. The previous update was in 2019.

The daily, weekly, and wet season frequency maps are used to illustrate the wet season conditions for every year, to assess the extent of river flood plumes and resuspension events in the Reef and to compare seasonal with long-term trends, as well as trend in water composition during typical dry and wet years. Results are presented in the main report and in Appendix C-6.

Table B - 2: Wettest and driest years used to compute the typical wet and typical dry composite frequency maps in each NRM region. All years are in the top/bottom quartiles, except 2005 and 2007 for Cape York which are under the long-term median.

Region	Wet years				Dry years			
Cape York	2021	2006	2011	2019	2003	2016	2005	2007
Wet Tropics	2018	2009	2019	2011	2003	2020	2015	2005
Burdekin	2019	2008	2009	2011	2015	2016	2004	2003
Mackay-Whitsunday	2012	2008	2010	2011	2004	2015	2003	2006
Fitzroy	2008	2010	2013	2011	2006	2005	2007	2004
Burnett-Mary	2012	2022	2013	2011	2021	2006	2007	2005

Susceptibility assessment

Frequency maps are compared with ecological health information collected through the coral reef and seagrass components of the MMP (e.g., McKenzie *et al.*, 2019, Thompson *et al.*, 2019) to better understand the susceptibility of the seagrass meadow and coral reef ecosystems to water quality conditions.

Composition of Reef water types

The classification of four Reef water types allows mapping of large Reef waterbodies with different colour characteristics and concentrations of optically active components (TSS, CDOM, and Chl-*a*), water quality indicators (e.g. nutrients levels; Devlin et al., 2015; Petus et al., 2019), and light attenuation levels (Petus et al., 2018) typically found in the Reef during the wet season (Table 2-2). Match-up of *in situ* concentrations of water quality parameters and the four Reef water types are performed to validate this concept and quantify the range and average of water quality concentrations found in each Reef water type.

Match-ups between sampled date and corresponding weekly Reef water type maps are performed at site location basis using the *extract tool of* the raster package (Hijmans *et al.*, 2015) with bilinear interpolation method in R 3.2.4 or the Extract Multi Values to Point (Spatial Analyst) in ArcMap (from 2020). The R tool interpolates from the values of the four nearest raster cells (R Core Team, 2019) while the ArcMap tool extract cell values at the exact location (used from 2020). Several land-based pollutants are investigated through match-ups between *in situ* data and the six colour class maps, including NO_x, DIP, PP, PN, TSS, Chl-*a*, CDOM and K_D or Secchi depth. Boxplots of water quality parameters across water types (Figure 4-3) and MODIS WS colour classes (Table B - 2) as well as the mean long-term concentrations of water quality parameters across the three wet season water types in all focus regions (Figure B - 2) are presented. Work is currently underway to break down the turbid WT1 into a greater number of water types and identify Sentinel-3 Forel-Ule colour classes equivalent to the former MODIS colour classes 1 to 4.

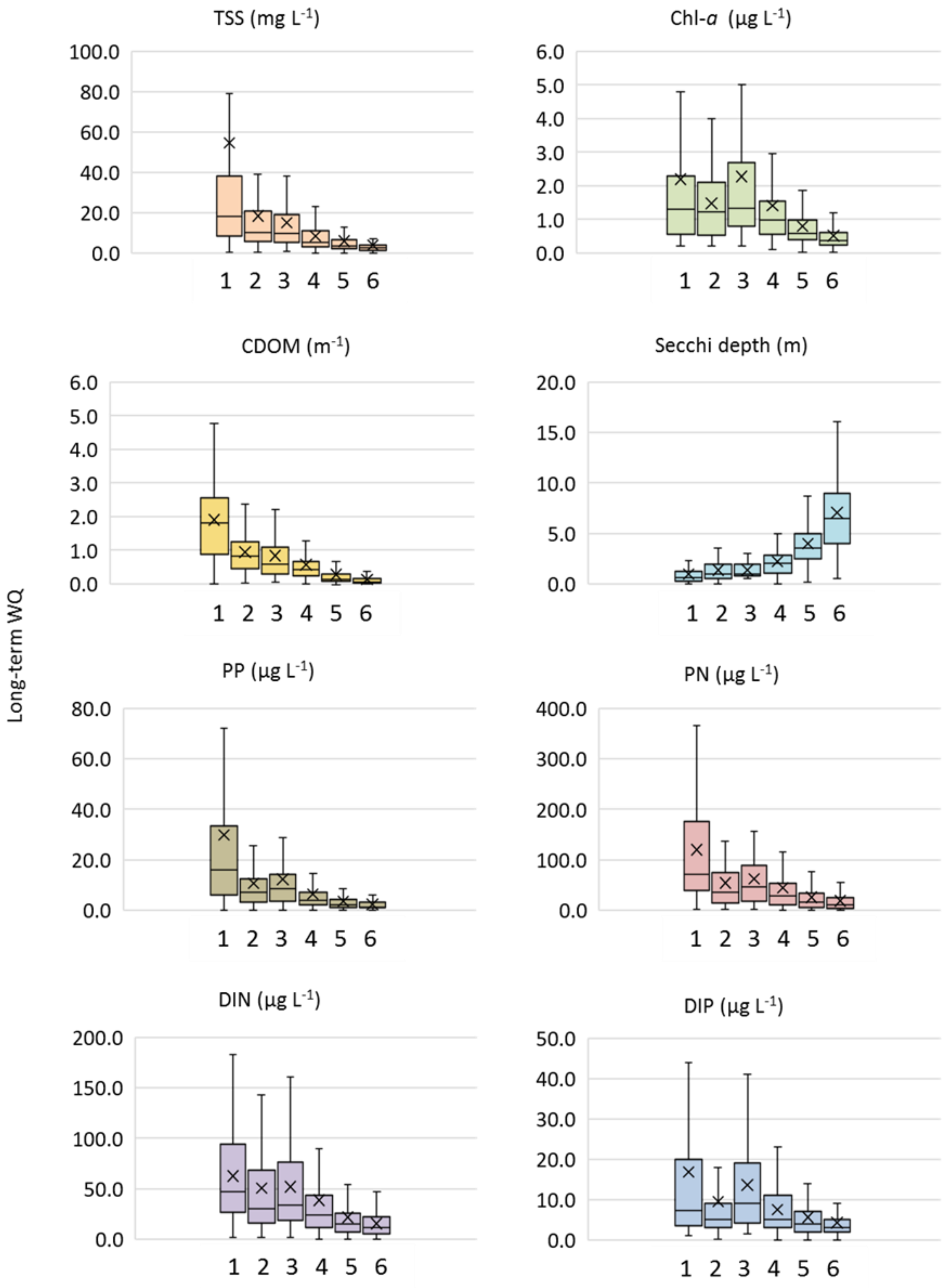


Figure B - 1: Long-term water quality (WQ) concentrations and Secchi disk depth boxplots for each wet season colour class. The mean is plotted as a cross (x) and its numerical value is indicated. The interquartile range is delimited by the box and the median by the line inside the box. Whiskers indicate variability outside the upper and lower quartiles. Data beyond the whiskers range are considered outliers and are not plotted. Long-term water quality values are reviewed and updated every 4 years (and/or in the case of extremely wet year or specific event patterns) to ensure the water type characterization remains valid as a representative period, and to improve its accuracy as more field data are collected every wet seasons. The last update was in 2019, using all field data available (from 2004–2019). Work is underway to update this figure.

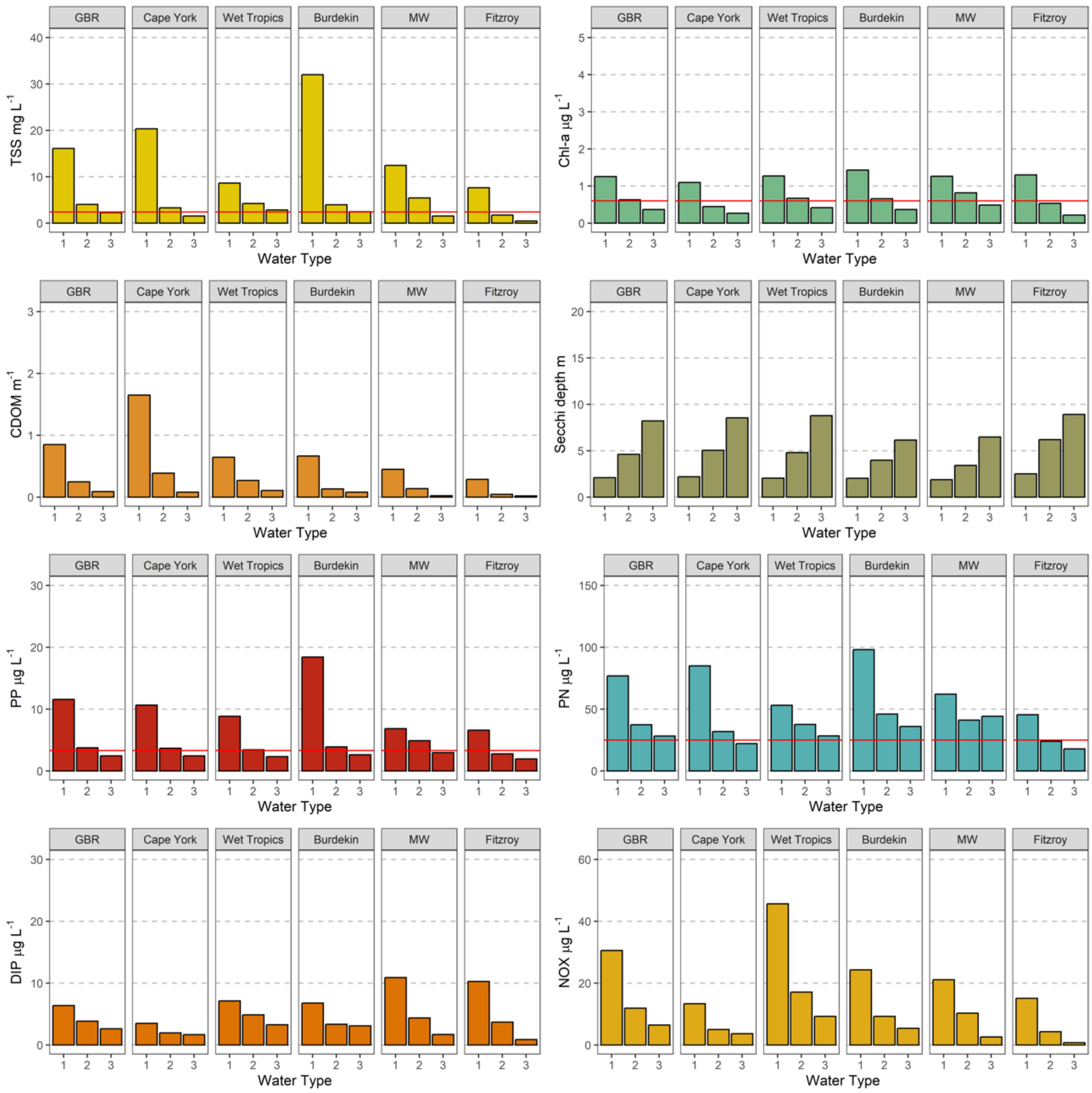


Figure B - 2: Mean long-term (2004–2023) concentrations of water quality parameters across the three wet season water types in all focus regions . Red lines show the Reef-wide wet season GVs (Table B-4). The Burdekin region has the greatest average TSS, PP, and PN concentrations in the Reef water type 1, which exceeded the long-term Reef-scale average. The greatest mean NOx and CDOM concentrations are measured in the Reef water type 1 of the Wet Tropics and Cape York regions, respectively. The greatest mean Chl-a concentrations are measured in the Reef water type 1 of the Burdekin region, but concentrations are more uniform across region. Mean long-term concentrations of water quality parameters include samples collected from the enclosed coastal water body (Table B - 1), where high TSS, PN, and PP concentrations are likely to contribute to exceedances of the Reef-wide GVs.

Detailed summaries of water quality parameters (mean, standard deviation, minimum, maximum, and number of values for each parameter across colour classes and water types) for the long-term are provided in Appendix C-4. Long-term water quality values are calculated using all surface data (<0.2 m) collected between December and April by JCU (since 2004), AIMS, and the CYWP (since 2016–17) in the whole of the Reef.

Exposure maps and exposure assessment

Information on the long-term water chemistry concentrations measured in the Reef water type are compared to published water quality guideline values and, combined with frequency maps of occurrence of wet season colour classes, are used in a *"magnitude x likelihood"* risk management framework to develop surface exposure maps (also referred to as potential risk maps in some Reef studies). Different frameworks have been used to estimate the exposure and potential risk from exposure, and are described in Petus *et al.* (2014a, 2016), Waterhouse *et al.* (2017), Gruber *et al.* (2019), and used in the MMP reports before 2015–16. In a collaborative effort between the MMP monitoring providers (JCU water quality and seagrass teams and the AIMS coral monitoring team), an updated exposure assessment framework was developed in 2015–16 (modified from Petus *et al.*, 2016), where the 'potential risk' corresponds to an exposure to above guideline concentrations of land-based pollutant during wet season conditions and focuses on the TSS, Chl-*a*, PP, and PN concentrations.

- The *'magnitude of the exposure'* corresponds to the long-term concentration of pollutants (proportional exceedance of the guideline) mapped through the Reef WT1, WT2 and WT3 (primary, secondary and tertiary water types).
- The *'likelihood of the exposure'* is estimated by calculating the frequency of occurrence of each Reef 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 Reef water type and calculated as below. For each cell (500 m x 500 m):

For each pollutant (Poll.) the exposure in the Reef WT1, WT2, WT3 (primary or secondary or tertiary): $Poll\_expo_{water\ type}$ is calculated:

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

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

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

where $water\ type$ is the Reef WT1, WT2 or WT3 (primary, secondary and tertiary water types), $[Poll.]_{water\ type}$ is long-term mean TSS, Chl-*a*, PN, or PP concentration measured in each respective wet season water types and $guideline$ is the Reef-wide wet season GV from De'ath and Fabricius (2008) for TSS, Chl-*a*, PP, and PN (Table B-4).

Table B - 3: Reef-wide wet season guideline values used to calculate the exposure score for satellite exposure maps. These guidelines are based on seasonal adjustments to Reef-wide annual guidelines (Great Barrier Reef Marine Park Authority, 2010), where wet season guidelines are +20% for TSS, PN, and PP, and +40% for Chl-*a* of annual guidelines (De'ath and Fabricius 2008).

Parameter	Unit	Reef-wide
Chlorophyll *a*	$\mu g\ L^{-1}$	0.63
Particulate nitrogen	$\mu g\ L^{-1}$	25
Particulate phosphorus	$\mu g\ L^{-1}$	3.3
Suspended solids	$mg\ L^{-1}$	2.4

These GVs are compared against the mean long-term concentrations to calculate the exposure score in the satellite exposure maps (proportional exceedance of the guideline). Mean long-term concentrations of water quality parameters are calculated using all available surface water quality data in all Reef marine regions and water bodies (Table B-5). The variability in the number of samples between regions and water types is primarily driven by the sampling design which was reviewed in 2014. The small number of samples in the Burnett-Mary region reflects the geographic extent of the MMP; with a majority of the samples collected by JCU in the 2011 and 2013 flood events when the design of the event monitoring was more opportunistic across the whole Reef. The relatively small number of samples in offshore waters reflects the geographic focus of the MMP design which is largely constrained to the open coastal and mid-shelf waters. The last update in the mean long-term concentrations was in the 2022–23 reporting year (Gruber et al., 2020), using field data collected from 2004 to 2019. Note also that the long-term and Reef- wide concentrations of water quality parameters are used rather than the seasonal and/or regional mean concentrations in water type to avoid bias due to differential regional and seasonal sampling distribution.

Table B - 4: Number of collected *in situ* samples used in exposure scoring by region and water type. Samples include all wet season (Dec–April) surface samples since 2004 (from JCU) and since the 2016–17 water year (AIMS and the CYWP) and up to April 2022.

Region	Reef Water type	SDD	TSS	CHL	CDOM	NO_x	DIP	PP	PN
Cape York	WT1	157	208	218	160	214	218	102	80
	WT2	225	295	301	180	301	301	188	170
	WT3	126	176	181	109	178	178	120	111
	Marine	8	13	13	4	13	13	5	4
Wet Tropics	WT1	185	406	399	388	356	356	57	58
	WT2	400	623	637	574	611	615	228	229
	WT3	203	289	296	239	273	274	143	143
	Marine	25	33	35	29	33	33	19	19
Burdekin	WT1	102	157	156	113	151	155	63	73
	WT2	202	258	260	194	258	260	99	106
	WT3	61	97	96	71	81	82	40	40
	Marine	21	33	39	23	28	29	20	19
Mackay-Whitsunday	WT1	28	45	42	43	45	45	20	20
	WT2	73	134	129	98	127	132	74	75
	WT3	20	39	39	27	33	34	27	27
	Marine	7	13	13	8	9	10	6	6
Fitzroy	WT1	22	103	104	78	105	105	17	17
	WT2	27	64	78	65	82	84	22	22
	WT3	8	20	25	11	16	17	8	8
	Marine	0	6	6	1	6	6	0	0
Burnett-Mary	WT1	7	16	16	7	7	16	0	0
	WT2	5	9	9	5	5	9	0	0
	WT3	0	2	2	0	0	0	0	0
	Marine	0	8	8	1	3	3	0	0
Reef-wide	WT1	501	935	935	789	878	895	259	248
	WT2	932	1383	1414	1116	1384	1401	611	602
	WT3	418	623	639	457	581	585	338	329
	Marine	61	106	114	66	92	94	50	48

For each pollutant, the total exposure ($Poll\_expo$) is calculated at the exposure for each of the Reef 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:

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

For example, using the long-term mean Chl-*a* values measured during high flow conditions in the Reef WT1, WT2, and WT3:

$$Chla\_exp_{WT1} = \frac{1.45-0.63}{0.63} \times frequency_{water\ type\ (0-1, cell-specific)}$$

$$Chla\_exp_{WT2} = \frac{0.65-0.63}{0.63} \times frequency_{water\ type\ (0-1, cell-specific)}$$

$Chla\_exp_{WT3}$ = 0 as Chl-*a* levels are below the guideline for Chl-*a*;

The total exposure for Chl-*a*:

$$Chla\_expo = Chla\_expo_{WT1} + Chla\_expo_{WT2} + Chla\_expo_{WT3}$$

- The overall exposure scores are then grouped into four potential classes (I–IV) based on a “Natural Break (or Jenks)” classification. Jenks is a statistical procedure, embedded in ArcGIS that analyses the distribution of values in the data and finds the most evident breaks in it (i.e., the steep or marked breaks; Jenks and Caspall, 1971). The Jenks classification determine the best arrangement of values into different classes by reducing the variance within classes and maximising the variance between classes.

The exposure classes are defined by applying the Jenks classification to the mean long-term exposure map (2003–2022), because this map presented the highest number of observations. Using the 2003–2018 mean exposure map, categories were defined as [>0–0.9] = cat. I, [0.9–3.5] = cat. II, [3.2–7.9] = cat III and >7.9 = cat IV. Category I and areas mapped as “exposure = 0 (no exposure)”, are re-grouped into a unique category I (no or very low exposure). These categories are to all exposure composites created (seasonal, coral recovery period, typical wet and dry periods).

The methods presented above are slightly different than methods used in previous wet season’s reports (2016–17 and 2017–18 wet seasons) where (i) seasonal mean concentrations of water quality parameters across water types were used to produce the seasonal exposure map and (ii) exposure maps were reclassified using four equally-distributed colour classes. Changes in 2019 (using only long-term mean concentrations of water quality parameters and a Jenk’s classification of the exposure maps) were made in response to: (i) concerns that water quality concentrations collected in a specific wet season would likely get biased toward the sample size and the location and timing of sampling in this particular wet season conditions and (ii) that the equally-distributed categories were not responsive enough to changes in environmental pressures of each year.

Exposure maps are produced for the whole of the Reef, for all focus regions and over different time frames: for the current reporting wet season (using the Sentinel-3 FU imagery), and over several multi-years period (using the archive of MODIS WS imagery): the long-term (2002–03 to 2021–22: 20 wet seasons), over a documented recovery period for coral reefs (2012–2017 period) and representation of typical wet-year and dry-year conditions. Except for the coral recovery period, reference maps (long-term, wet and dry frequency maps) were all updated in

2023 to ensure they remain valid as a representative period and to improve their accuracy as more satellite data are available. The last update was in 2019.

- Finally, assessments of ecosystem exposure are made through the calculation of the areas (km^2) and percentages (%) of each region, coral reefs and seagrass meadows affected by different categories of exposure. The area and percentage are calculated as a relative measure between regions and waterbodies. The difference in percentages between the current year and in the long-term is also calculated. Figure B - 3 presents the marine boundaries used for the Marine Park, each NRM region, the Reef waterbodies and the seagrass and coral reefs ecosystems. The area (km^2) and percentages of seagrass and coral reefs in the Reef and regional waterbodies is indicated in Figure B - 3. We assumed in this study that the seagrass shapefile can be used as a representation of the actual seagrass distribution. It is known, however, that absence on the composite map does not definitively equate to absence of seagrass and may also indicate un-surveyed areas.

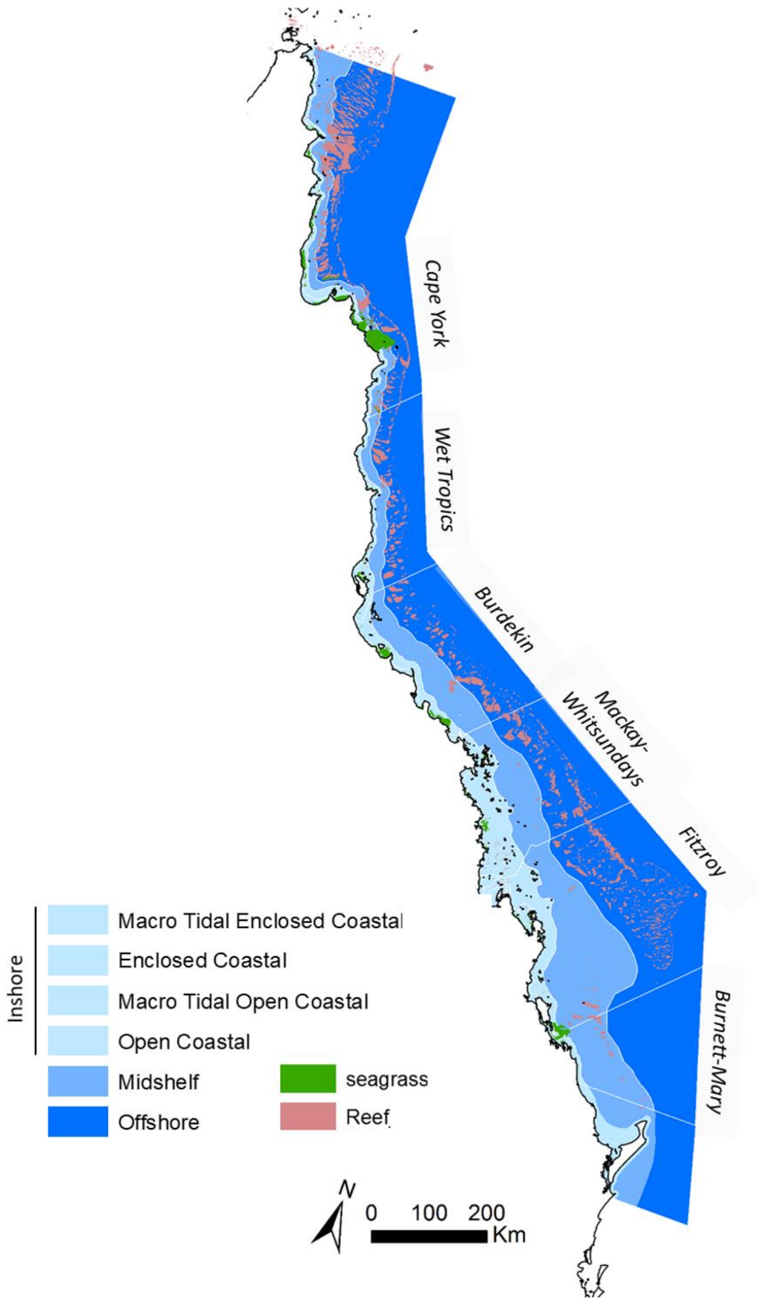


Figure B - 3: Boundaries used for the Marine Park, each NRM region, and the coral reefs and seagrass ecosystems. Coral reef and NRM layers derived from the Reef Authority, supplied 2013. Seagrass layer is a composite of surveys conducted by Department of Agriculture and Fisheries, QLD.

B-4 References

Álvarez-Romero JG, Devlin MJ, Teixeira da Silva E, Petus C, Ban N, Pressey RJ, Kool J, Roberts S, Cerdeira WA, Brodie J (2013). A novel approach to model exposure of coastal-marine ecosystems to riverine flood plumes based on remote sensing techniques. Journal of Environmental Management 119: 194-207.

Brando VE, Blondeau-Patissier D, Schroeder T, Dekker AG, Clementson L (2011). Reef Rescue Marine Monitoring Program: Assessment of terrestrial run-off entering the Reef and inshore marine water quality monitoring using earth observation data. Final Report for 2010/11 Activities. CSIRO, Canberra. 201 pp.

Brodie, J., De'ath, G., Devlin, M., Furnas, M., Wright, M., (2007). Spatial and temporal patterns of near-surface chlorophyll a in the Great Barrier Reef lagoon. Marine and Freshwater Research 58, 342–353.

De'ath G, Fabricius KE (2008) Water quality of the Great Barrier Reef: distributions, effects on reef biota and trigger values for the protection of ecosystem health. Final Report to the Great Barrier Reef Marine Park Authority. Australian Institute of Marine Science, Townsville. 104 pp.

De'ath G, Fabricius KE (2010). Water quality as a regional driver of coral biodiversity and macroalgae on the Great Barrier Reef. Ecological Applications 20: 840–850.

Department of Environment and Resource Management (DERM) (2009). Queensland Water Quality Guidelines, Version 3. 167 p. Available at www.derm.qld.gov.au. ISBN 978-0-9806986-0-2.

Devlin MJ, Wenger A, Petus C, da Silva ET, DeBose J, Álvarez-Romero J (2013). Reef Rescue Marine Monitoring Program. Final report of JCU activities 2011/12: flood plumes and extreme weather monitoring for the Great Barrier Reef Marine Park Authority (Report). James Cook University.

Devlin M, Petus C, Teixeira da Silva E, Tracey D, Wolff N, Waterhouse J, Brodie J (2015). Water quality and river plume monitoring in the Great Barrier Reef: An Overview of Methods Based on Ocean Colour Satellite Data. Remote Sensing 7: 12909-12941.

Furnas MJ, Mitchell AW, Skuza M, Brodie J (2005). In the other 90%: Phytoplankton responses to enhanced nutrient availability in the Great Barrier Reef lagoon. Marine Pollution Bulletin 51: 253-256.

Furnas M, Alongi D, 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. doi:10.1016/j.csr.2011.09.007

Great Barrier Reef Marine Park Authority (GBRMPA) (2010). Water Quality Guidelines for the Great Barrier Reef Marine Park. Revised Edition 2010. Great Barrier Reef Marine Park Authority, Townsville. 100 pp.

Gruber R, Waterhouse J, Logan M, Petus C, Howley C, Lewis S, Tracey D, Langlois L, Tonin H, Skuza M, Costello P, Davidson J, Gunn K, Lefevre C, Shanahan M, Wright M, Zagorskis I, Kroon F, Neilen A (2019). Marine Monitoring Program: Annual Report for Inshore Water Quality Monitoring 2017-18. Report for the Great Barrier Reef Marine Park Authority, Great Barrier Reef Marine Park Authority, Townsville, 304pp.

Gruber R, Waterhouse J, Logan M, Petus C, Howley C, Lewis S, Tracey D, Langlois L, Tonin H, Skuza M, Costello P, Davidson J, Gunn K, Lefevre C, Moran D, Robson B, Shanahan M, Zagorskis I, Shellberg J, Neilen A (2020). Marine Monitoring Program: Annual Report for Inshore Water Quality Monitoring 2018–19. Report for the Great Barrier Reef Marine Park Authority, Great Barrier Reef Marine Park Authority, Townsville, 262pp.

Hijmans RJ, Etten J van, Mattiuzzi M, Sumner M, Greenberg JA, Lamigueiro OP, Bevan A, Racine, EB, Shortridge A (2015). raster: Geographic Data Analysis and Modelling.

Jenks GF and Caspall FC (1971). Error on Choroplethic Maps: Definition, Measurement Reduction. Annals of the Association of American Geographers 61: 217-44.

McKenzie LJ, Collier CJ, Langlois LA, Yoshida RL, Uusitalo J, Smith N, Waycott M (2019). Marine Monitoring Program: Annual Report for inshore seagrass monitoring 2017-2018. Report for the Great Barrier Reef Marine Park Authority, Great Barrier Reef Marine Park Authority, Townsville, 188 pp.

Petus C, Teixera da Silva E, Devlin M, Álvarez-Romero J, Wenger A (2014a). Using MODIS data for mapping of water types within flood plumes in the Great Barrier Reef, Australia: towards the production of river plume risk maps for reef and seagrass ecosystems. Journal of Environmental Management 137: 163-177.

Petus C, Collier C, Devlin M, Rasheed M, McKenna S (2014b). Using MODIS data for understanding changes in seagrass meadow health: A case study in the Great Barrier Reef (Australia). Marine Environmental Research 98: 68-85.

Petus C, Devlin M, Thompson A, McKenzie L, Teixeira da Silva E, Collier C, Tracey D, Martin K (2016). Estimating the exposure of coral reefs and seagrass meadows to land-sourced contaminants in river flood plumes of the Great Barrier Reef: validating a simple Satellite Risk Framework with Environmental Data. Remote Sensing, 8, 210.

Petus C, Devlin M, da Silva E, Lewis S, Waterhouse J, Wenger A, Bainbridge Z and Tracey D (2018) Defining wet season water quality target concentrations for ecosystem conservation using empirical light attenuation models: a case study in the Great Barrier Reef (Australia). Journal of Environmental Management 213: 1-16.

Petus C, Waterhouse J, Lewis S, Vacher M, Tracey D, Devlin M. (2019). A flood of information: Using Sentinel-3 water colour products to assure continuity in the monitoring of water quality trends in the Great Barrier Reef (Australia). Journal of Environmental Management 248: 109255.

R Core Team (2019). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL: https://www.R-project.org/

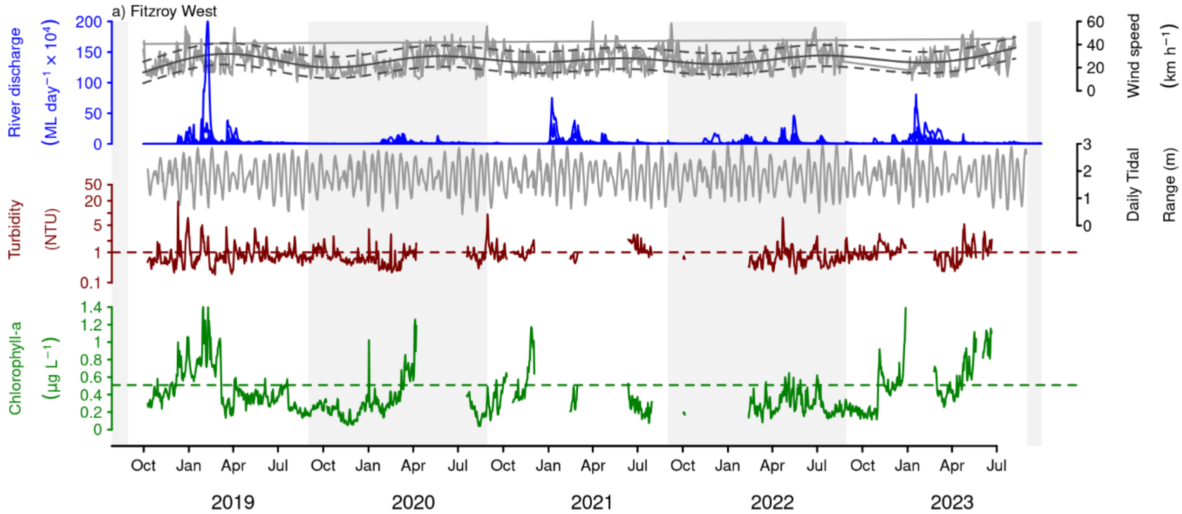
Schaffelke B, Thompson A, Carleton J, Davidson J, Doyle J, Furnas M, Gunn K, Skuza M, Wright M, Zagorskis I (2009). Reef Rescue Marine Monitoring Program. Final Report of AIMS Activities 2008/09. Report for Reef and Rainforest Research Centre. Australian Institute of Marine Science, Townsville. 146 pp.

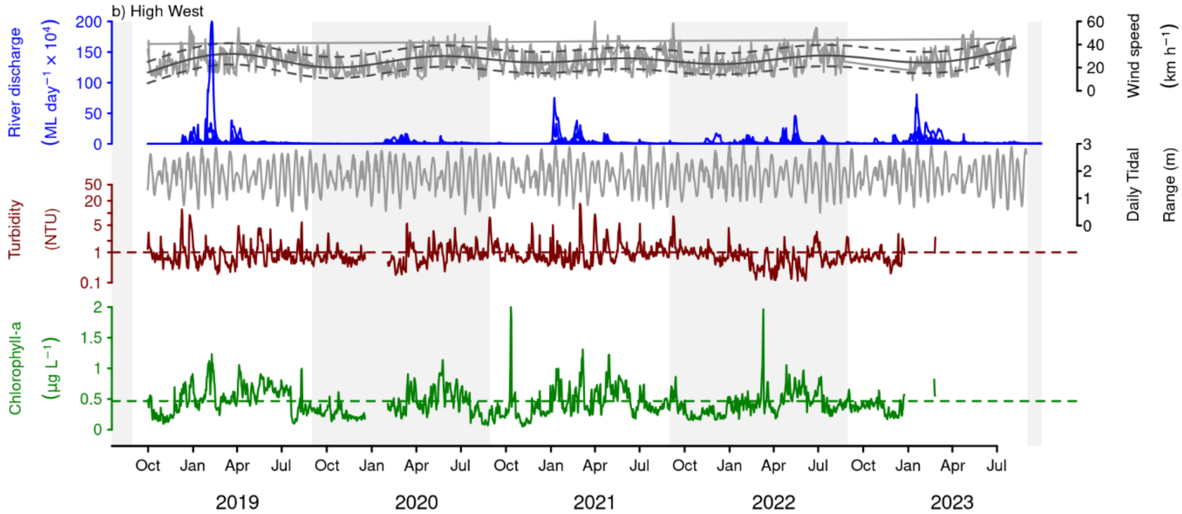
Thompson A, Costello P, Davidson J, Logan M, Coleman G (2019). Marine Monitoring Program: Annual report for inshore coral reef monitoring 2017-18. Great Barrier Reef Marine Park Authority, Townsville.127pp.

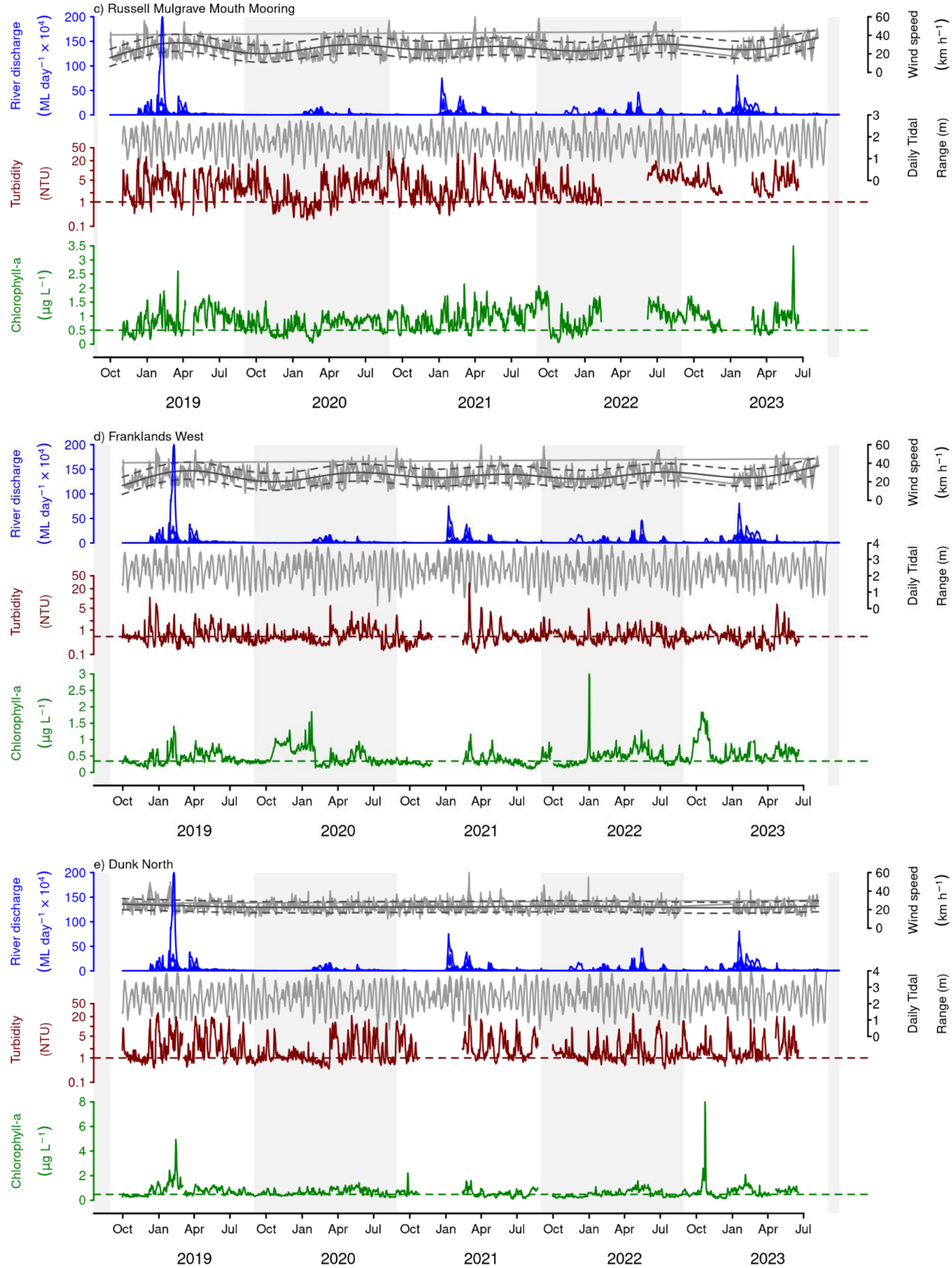
Waterhouse J, Lønborg C, Logan M, Petus C, Tracey D, Lewis S, Tonin H, Skuza M, da Silva E, Carreira C, Costello P, Davidson J, Gunn K, Wright M, Zagorskis I, Brinkman R, Schaffelke B (2017) Marine Monitoring Program: Annual Report for inshore water quality monitoring 2015-2016. Report for the Great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

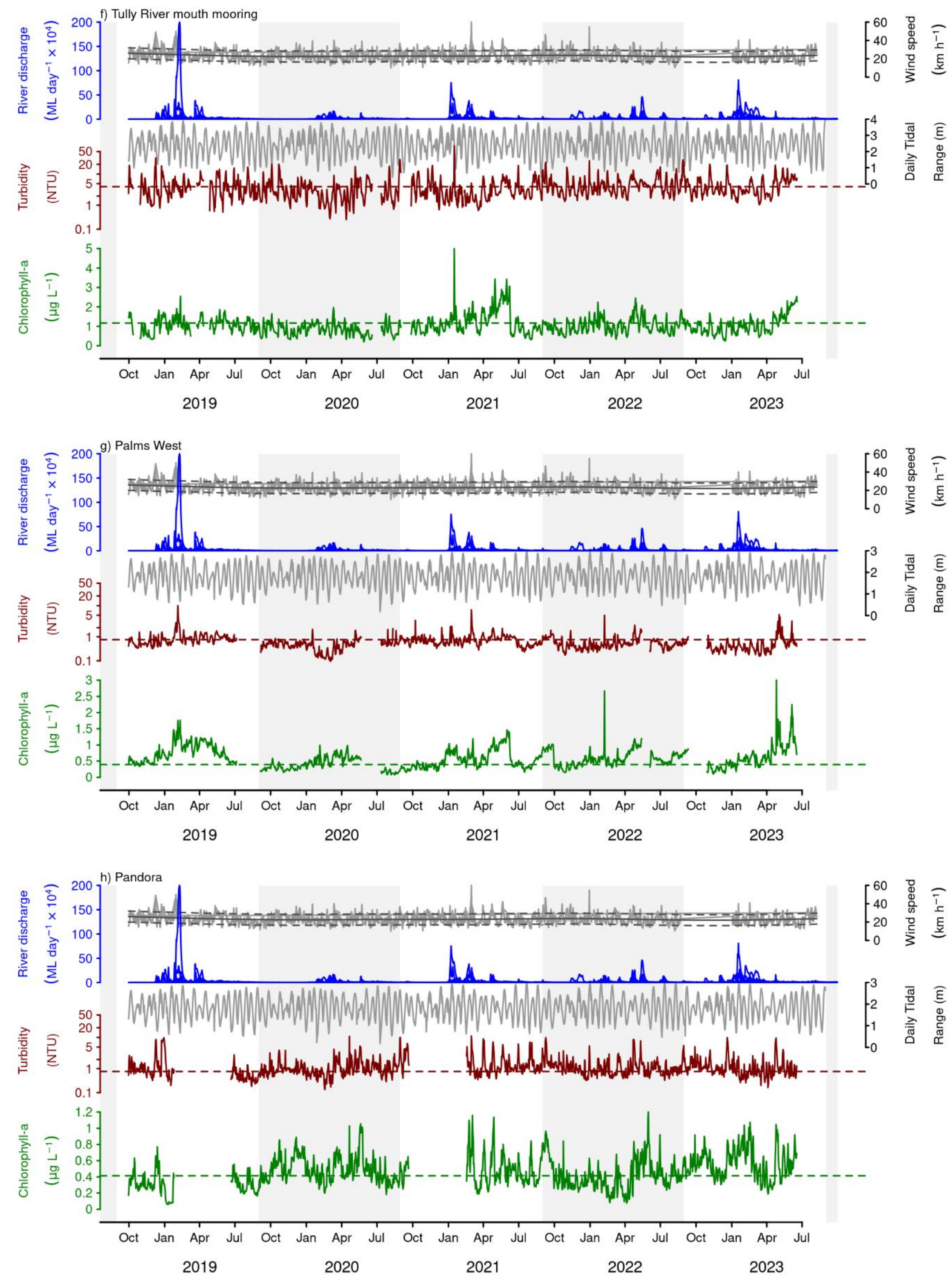
Appendix C: Additional information

C-1 Time-series of turbidity and chlorophyll

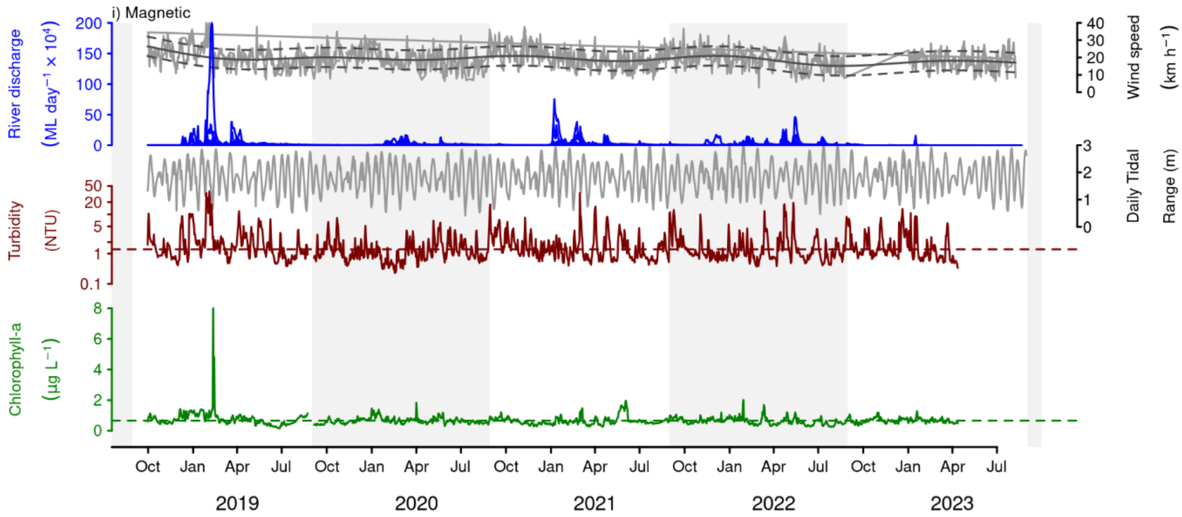


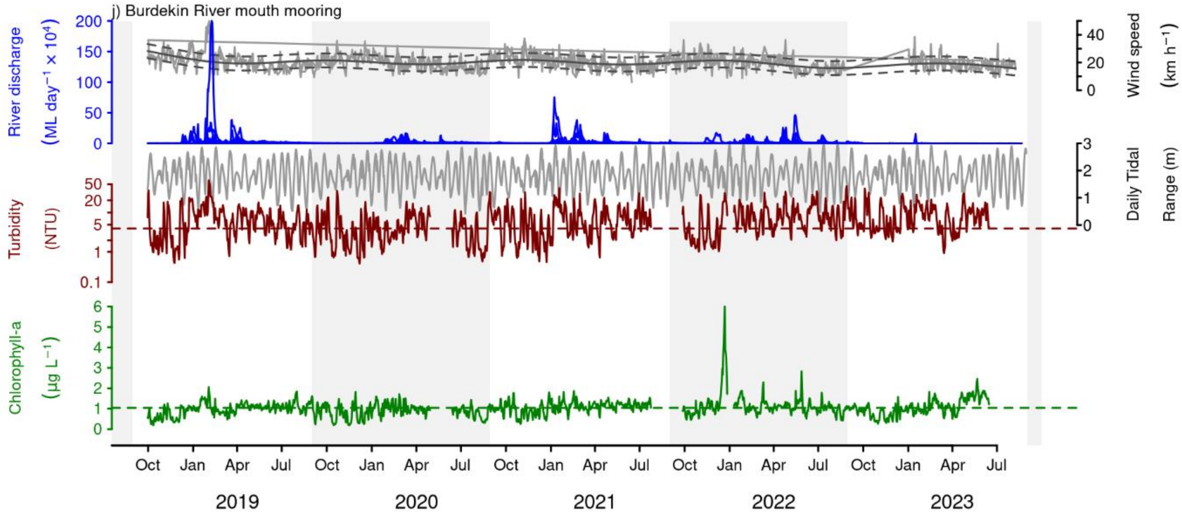


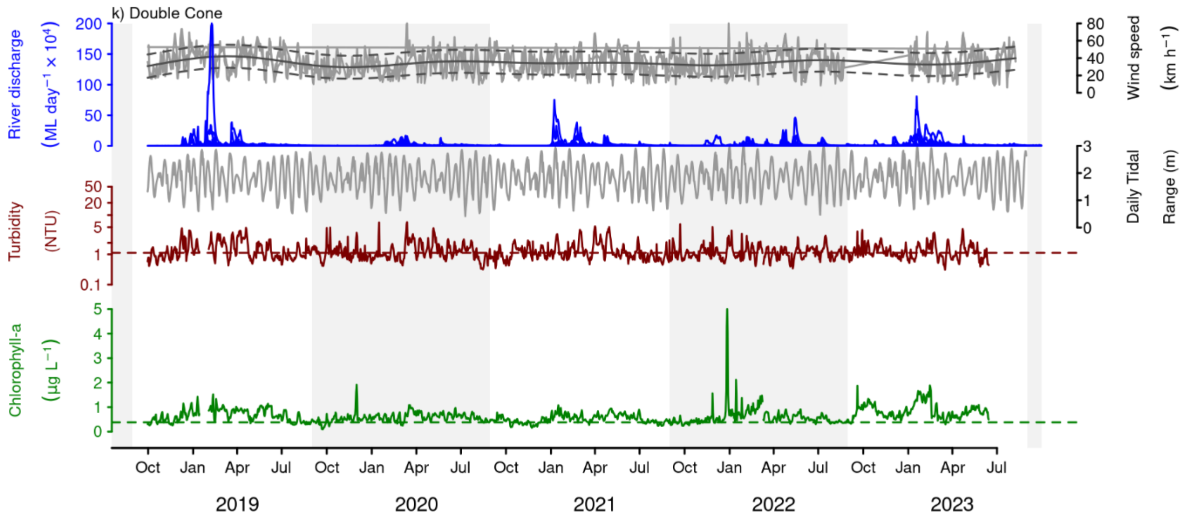

c) Russell Mulgrave Mouth Mooring
d) Franklands West
e) Dunk North
River discharge (ML day⁻¹ × 10⁴)
Turbidity (NTU)
Chlorophyll-a (µg L⁻¹)
Wind speed (km h⁻¹)
Daily Tidal Range (m)
Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul
2019 2020 2021 2022 2023

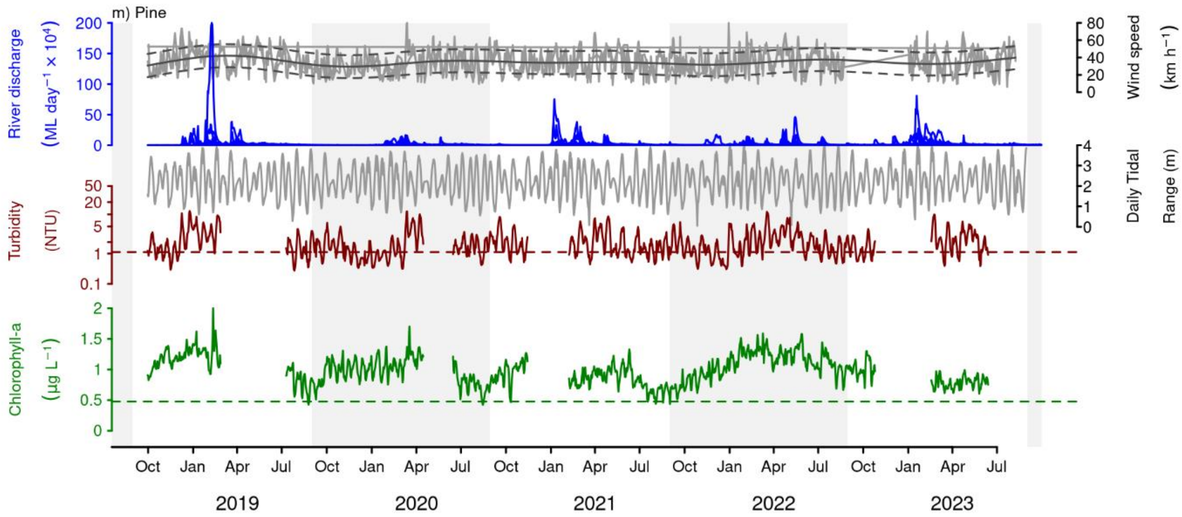


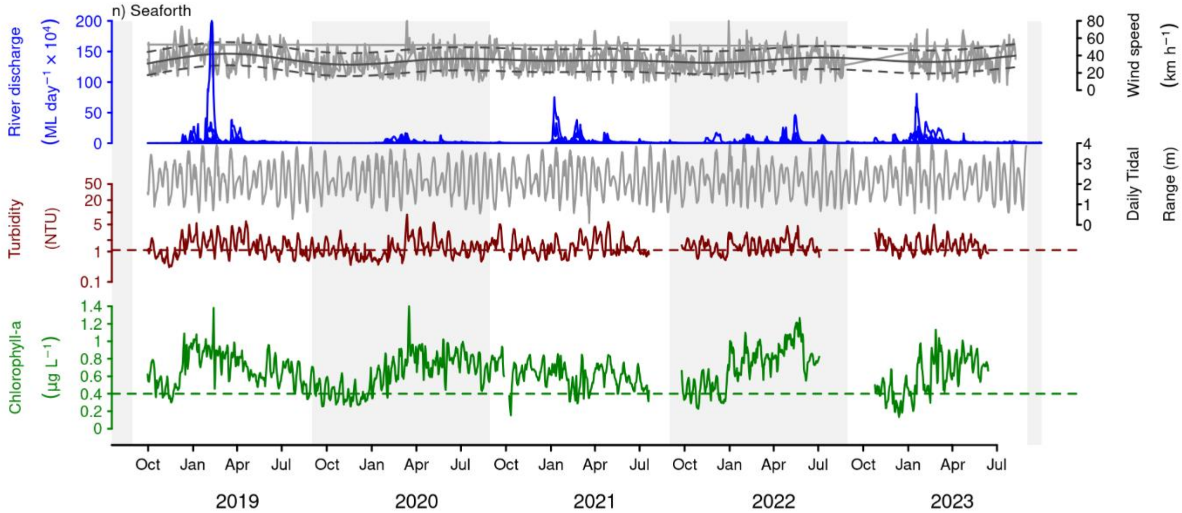
f) Tully River mouth mooring
g) Palms West
h) Pandora
River discharge
(ML day⁻¹ × 10⁴)
Turbidity
(NTU)
Chlorophyll-a
(µg L⁻¹)
Wind speed
(km h⁻¹)
Daily Tidal
Range (m)
Oct
Jan
Apr
Jul
2019
2020
2021
2022
2023

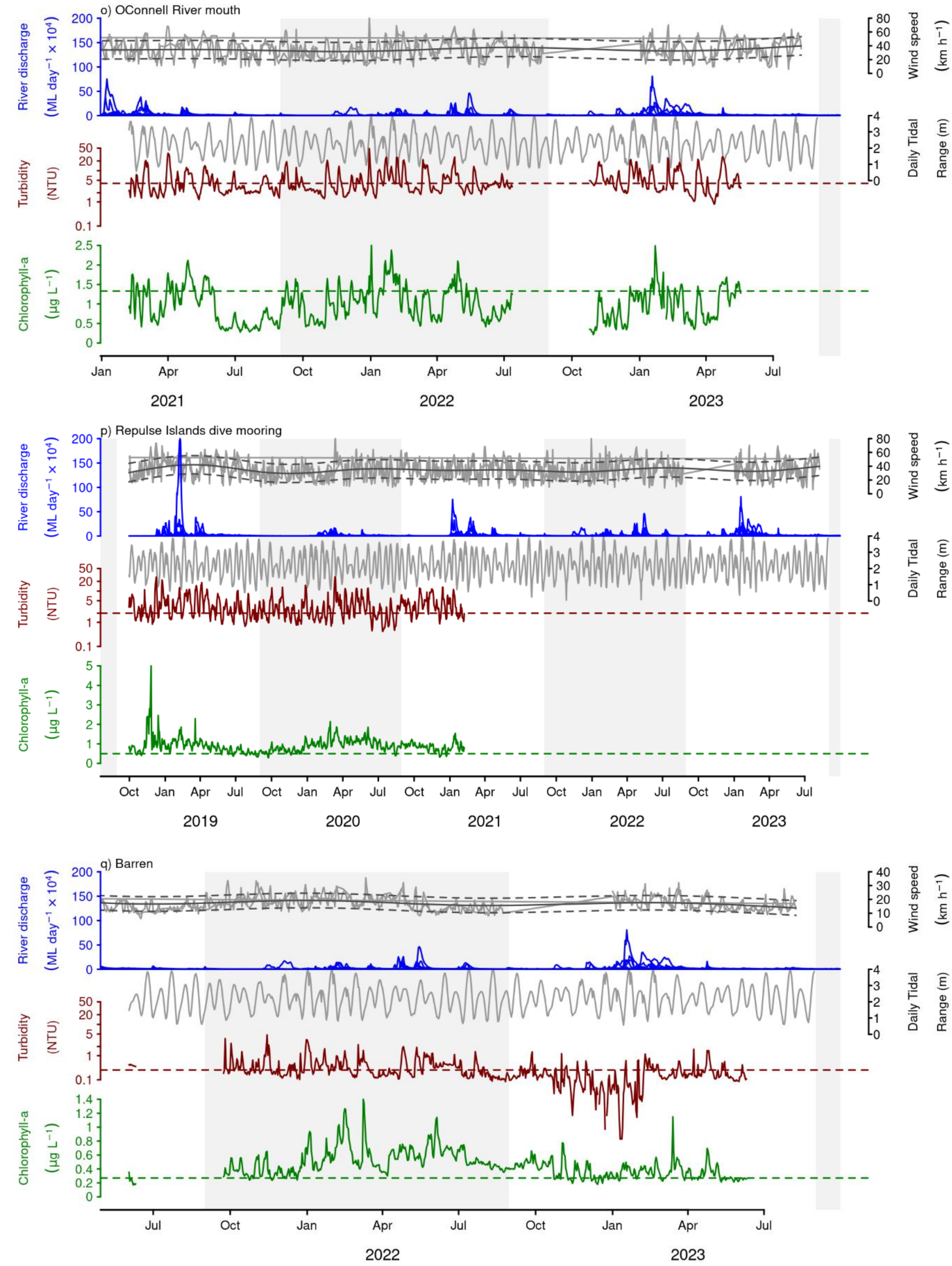

i) Magnetic
River discharge
(ML day⁻¹ × 10⁴)
Turbidity
(NTU)
Chlorophyll-a
(µg L⁻¹)
Wind speed
(km h⁻¹)
Daily Tidal
Range (m)
Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul
2019 2020 2021 2022 2023


j) Burdekin River mouth mooring
River discharge
(ML day⁻¹ × 10⁴)
Turbidity
(NTU)
Chlorophyll-a
(µg L⁻¹)
Wind speed
(km h⁻¹)
Daily Tidal
Range (m)
Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul
2019 2020 2021 2022 2023


k) Double Cone
River discharge
(ML day⁻¹ × 10⁴)
Turbidity
(NTU)
Chlorophyll-a
(µg L⁻¹)
Wind speed
(km h⁻¹)
Daily Tidal
Range (m)
Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul
2019 2020 2021 2022 2023


m) Pine
River discharge
(ML day⁻¹ × 10⁴)
Turbidity
(NTU)
Chlorophyll-a
(µg L⁻¹)
Wind speed
(km h⁻¹)
Daily Tidal
Range (m)
Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul
2019 2020 2021 2022 2023


n) Seaforth
River discharge
(ML day⁻¹ × 10⁴)
Turbidity
(NTU)
Chlorophyll-a
(µg L⁻¹)
Wind speed
(km h⁻¹)
Daily Tidal
Range (m)
Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul
2019 2020 2021 2022 2023


o) OConnell River mouth
p) Repulse Islands dive mooring
q) Barren
River discharge (ML day⁻¹ × 10⁴)
Turbidity (NTU)
Chlorophyll-a (µg L⁻¹)
Wind speed (km h⁻¹)
Daily Tidal Range (m)
Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul
2021 2022 2023
Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul
2019 2020 2021 2022 2023
Jul Oct Jan Apr Jul Oct Jan Apr Jul
2022 2023

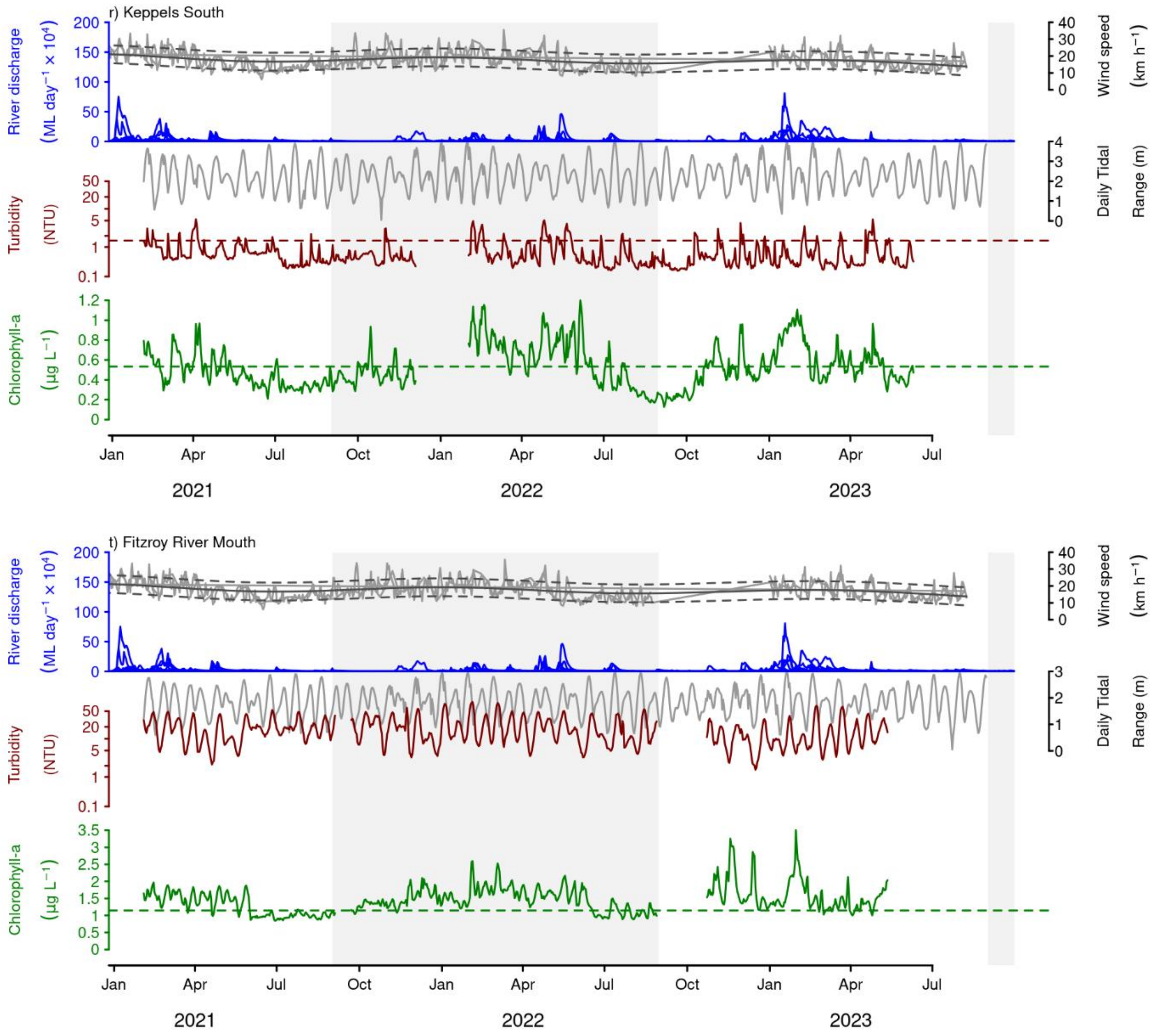


Figure C - 1: Time-series of daily means of chlorophyll fluorescence and turbidity measured by moored ECO FLNTUSB instruments coloured dashed lines represent the water quality GVs. Daily river discharge from the nearest river, daily wind speeds from the nearest weather stations, and daily tidal range from the nearest tidal gauge are also shown. Locations of loggers are shown in Figure 2-1, Section 5, and Figure D - 1 and panels continue on additional pages below: a) Fitzroy West; b) High West; c) Russell-Mulgrave Mouth Mooring; d) Franklands West; e) Dunk North; f) Tully Mouth Mooring; g) Palms West; h) Pandora; i) Magnetic; j) Burdekin Mouth Mooring; k) Double Cone; m) Pine; n) Seaforth; o) O'Connell River, p) Repulse Island (discontinued in 2021), q) Barren, r) Keppels South, and t) Fitzroy River Mouth.

C-2 Time-series of temperature and salinity

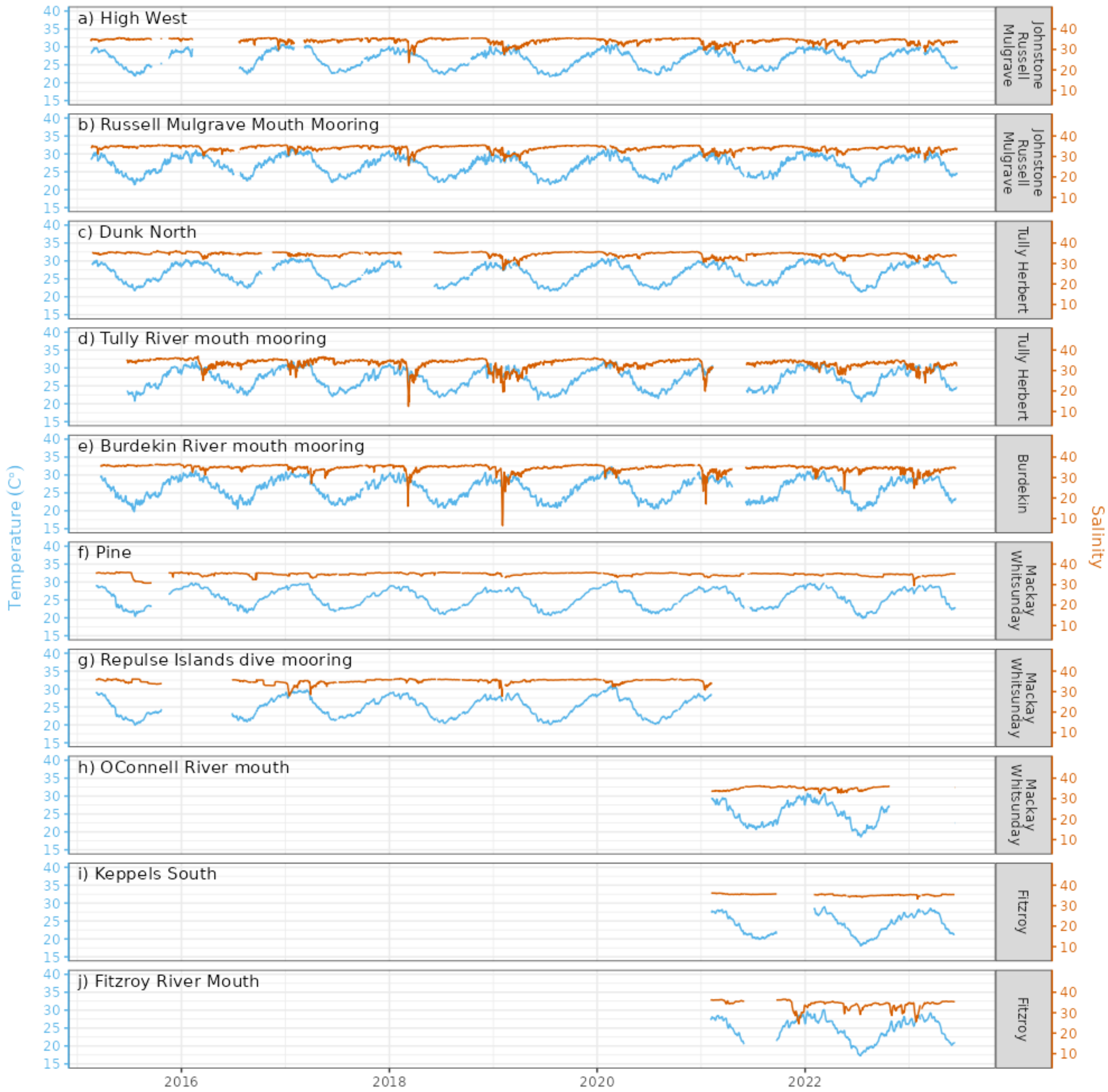


Figure C - 2: Time-series of daily means of temperature and salinity derived from moored loggers (Sea-Bird Electronics SBE37s). Sub-figures represent instrument locations at: a) High West, b) Russel Mulgrave Mouth Mooring, c) Dunk North, d) Tully River Mouth Mooring, e) Burdekin Mouth Mooring, f) Pine, g) Repulse, h) O'Connell River mouth, i) Keppels South, and j) Fitzroy River mouth.

C-3 Summary statistics for all sites

Table C - 1: Summary statistics for water quality parameters at individual monitoring sites from 1 October 2022 to 30 September 2023. N = number of sampling occasions. See Section 2 for descriptions of each analyte and its abbreviation. Mean and median values that exceed available Water Quality Guidelines (DERM, 2009; Great Barrier Reef Marine Park Authority, 2010; State of Queensland, 2020) are shaded in red. Averages that exceed wet season guidelines are shaded in yellow. DOF is direction of failure ('H' = high values fail, while 'L' = low values fail).

Region	Site	Measure	N	Mean	Median	Quantiles				Guideline Values				
						Q5	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
Cape York	PRN03 (PRN03)	DIN (µg L^{-1})	1	1.96	1.96	1.96	1.96	1.96	1.96					
		DOC (µg L^{-1})	1	1618	1618	1618	1618	1618	1618					
		DON (µg L^{-1})	1	74.77	74.77	74.77	74.77	74.77	74.77					
		DOP (µg L^{-1})	1	4.96	4.96	4.96	4.96	4.96	4.96					
		Chl-a (µg L^{-1})	1	0.22	0.22	0.22	0.22	0.22	0.22	H	Median	0.36	0.25	0.46
		NO$_x$ (µg L^{-1})	1	0.28	0.28	0.28	0.28	0.28	0.28	H	Median	0.35	0.32	0.45
		PN (µg L^{-1})	1	18.44	18.44	18.44	18.44	18.44	18.44	H	Mean		16	
		PN (µg L^{-1})	1	18.44	18.44	18.44	18.44	18.44	18.44	H	Median	18		20
		PO$_4$ (µg L^{-1})	1	0.31	0.31	0.31	0.31	0.31	0.31	H	Median	1.4	1.86	0.93
		POC (mg L^{-1})	1	106	106	106	106	106	106					
		PP (µg L^{-1})	1	1.34	1.34	1.34	1.34	1.34	1.34	H	Mean		2.3	
		PP (µg L^{-1})	1	1.34	1.34	1.34	1.34	1.34	1.34	H	Median	2.6		3
		Secchi (m)	1	3.80	3.80	3.80	3.80	3.80	3.80	L	Mean	10		
		Secchi (m)	1	3.80	3.80	3.80	3.80	3.80	3.80	L	Median			
		SiO$_4$ (mg L^{-1})	1	508	508	508	508	508	508					
		TSS (mg L^{-1})	1	0.80	0.80	0.80	0.80	0.80	0.80	H	Mean		1.6	
		TSS (mg L^{-1})	1	0.80	0.80	0.80	0.80	0.80	0.80	H	Median	1.9		1.7
	PRN02 (PRN02)	DIN (µg L^{-1})	4	8.58	3.92	2.14	3.08	12.21	21.53					
		DOC (µg L^{-1})	4	1405	1202	1083	1128	1600	2010					
		DON (µg L^{-1})	4	86	84	69	75	95	104					
		DOP (µg L^{-1})	4	4.49	4.18	3.24	3.65	5.20	6.18					
		Chl-a (µg L^{-1})	4	0.27	0.26	0.19	0.22	0.32	0.36	H	Median	0.36	0.25	0.46

Region	Site	Measure	N	Mean	Median	Quantiles				Guideline Values				
						Q5	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		NOx (µg L⁻¹)	4	0.63	0.49	0.28	0.28	0.92	1.18	H	Median	0.35	0.32	0.45
		PN (µg L⁻¹)	4	24.50	25.64	18.09	21.24	28.22	29.32	H	Mean		16	
		PN (µg L⁻¹)	4	24.50	25.64	18.09	21.24	28.22	29.32	H	Median	18		20
		PO_4 (µg L⁻¹)	4	1.01	1.24	0.45	0.87	1.24	1.24	H	Median	1.4	1.86	0.93
		POC (mg L⁻¹)	4	129	126	92	104	152	168					
		PP (µg L⁻¹)	4	2.21	2.26	1.52	1.67	2.77	2.82	H	Mean		2.3	
		PP (µg L⁻¹)	4	2.21	2.26	1.52	1.67	2.77	2.82	H	Median	2.6		3
		Secchi (m)	4	3.30	3.30	2.31	2.64	3.96	4.29	L	Mean	10		
		Secchi (m)	4	3.30	3.30	2.31	2.64	3.96	4.29	L	Median			
		SiO_4 (mg L⁻¹)	4	927	269	144	179	1412	2633					
		TSS (mg L⁻¹)	4	1.22	0.80	0.38	0.44	1.84	2.66	H	Mean		1.6	
		TSS (mg L⁻¹)	4	1.22	0.80	0.38	0.44	1.84	2.66	H	Median	1.9		1.7
	Pascoe River mouth north (PRN01)	DIN (µg L⁻¹)	1	19.04	19.04	19.04	19.04	19.04	19.04					
		DOC (µg L⁻¹)	1	1177	1177	1177	1177	1177	1177					
		DON (µg L⁻¹)	1	78.97	78.97	78.97	78.97	78.97	78.97					
		DOP (µg L⁻¹)	1	3.41	3.41	3.41	3.41	3.41	3.41					
		Chl-a (µg L⁻¹)	1	0.14	0.14	0.14	0.14	0.14	0.14	H	Median			0.7
		NOx (µg L⁻¹)	1	0.98	0.98	0.98	0.98	0.98	0.98	H	Median			1.5
		PN (µg L⁻¹)	1	16.64	16.64	16.64	16.64	16.64	16.64	H	Mean			
		PN (µg L⁻¹)	1	16.64	16.64	16.64	16.64	16.64	16.64	H	Median			
		PO_4 (µg L⁻¹)	1	0.93	0.93	0.93	0.93	0.93	0.93	H	Median			3
		POC (mg L⁻¹)	1	90	90	90	90	90	90					
		PP (µg L⁻¹)	1	1.67	1.67	1.67	1.67	1.67	1.67	H	Mean			
		PP (µg L⁻¹)	1	1.67	1.67	1.67	1.67	1.67	1.67	H	Median			
		Secchi (m)	1	4.30	4.30	4.30	4.30	4.30	4.30	L	Mean			
		Secchi (m)	1	4.30	4.30	4.30	4.30	4.30	4.30	L	Median			3
		SiO_4 (mg L⁻¹)	1	167	167	167	167	167	167					

Region	Site	Measure	N	Mean	Median	Quantiles				Guideline Values				
						Q5	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		TSS (mg L⁻¹)	1	0.54	0.54	0.54	0.54	0.54	0.54	H	Median			4
	Pascoe River mouth south (PRS01)	DIN (µg L⁻¹)	4	11.94	6.51	1.65	2.41	19.29	29.82					
		DOC (µg L⁻¹)	4	2521	2711	1219	1832	3285	3557					
		DON (µg L⁻¹)	4	90.97	86.74	80.24	83.64	96.61	107.63					
		DOP (µg L⁻¹)	4	5.42	5.11	2.32	3.72	7.00	8.95					
		Chl-a (µg L⁻¹)	4	0.16	0.17	0.09	0.11	0.22	0.22	H	Median			0.7
		NO_x (µg L⁻¹)	4	8.26	3.08	0.32	0.45	14.00	23.45	H	Median			1.5
		PN (µg L⁻¹)	4	63.18	69.44	32.36	44.71	84.17	85.25	H	Mean			
		PN (µg L⁻¹)	4	63.18	69.44	32.36	44.71	84.17	85.25	H	Median			
		PO_4 (µg L⁻¹)	4	1.78	1.24	0.71	0.99	2.35	3.61	H	Median			3
		POC (mg L⁻¹)	4	533	574	202	329	752	806					
		PP (µg L⁻¹)	4	4.76	5.23	2.81	3.81	5.90	6.05	H	Mean			
		PP (µg L⁻¹)	4	4.76	5.23	2.81	3.81	5.90	6.05	H	Median			
		Secchi (m)	4	1.73	2.20	0.67	1.18	2.38	2.47	L	Mean			
		Secchi (m)	4	1.73	2.20	0.67	1.18	2.38	2.47	L	Median			3
		SiO_4 (mg L⁻¹)	4	3172	3763	786	2244	4336	4730					
		TSS (mg L⁻¹)	4	13.35	14.77	2.59	6.74	20.52	22.11	H	Median			4
	PRS05 (PRS05)	DIN (µg L⁻¹)	6	5.18	3.54	1.14	1.82	10.15	10.89					
		DOC (µg L⁻¹)	6	1183	1117	977	1001	1432	1454					
		DON (µg L⁻¹)	6	72.48	72.72	59.92	66.71	78.48	84.57					
		DOP (µg L⁻¹)	6	4.97	5.46	3.17	4.34	5.88	5.88					
		Chl-a (µg L⁻¹)	6	0.35	0.37	0.19	0.23	0.44	0.50	H	Median	0.27		
		NO_x (µg L⁻¹)	6	1.57	0.86	0.28	0.28	3.43	3.64	H	Median	0.35		
		PN (µg L⁻¹)	6	16.81	18.19	12.27	12.94	19.04	20.09	H	Mean			
		PN (µg L⁻¹)	6	16.81	18.19	12.27	12.94	19.04	20.09	H	Median	18		
		PO_4 (µg L⁻¹)	6	1.48	1.55	0.46	0.46	2.40	2.46	H	Median	0.62		
		POC (mg L⁻¹)	6	91	94	64	72	114	114					

Region	Site	Measure	N	Mean	Median	Quantiles				Guideline Values				
						Q5	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		PP (µg L⁻¹)	6	1.80	1.90	1.35	1.43	1.98	2.18	H	Mean			
		PP (µg L⁻¹)	6	1.80	1.90	1.35	1.43	1.98	2.18	H	Median	2		
		Secchi (m)	6	8.60	8.15	7.53	7.60	8.90	10.70	L	Mean	10		
		Secchi (m)	6	8.60	8.15	7.53	7.60	8.90	10.70	L	Median			
		SiO_4 (mg L⁻¹)	6	122	110	50	95	151	209					
		TSS (mg L⁻¹)	6	1.01	1.01	0.80	0.88	1.08	1.24	H	Mean			
		TSS (mg L⁻¹)	6	1.01	1.01	0.80	0.88	1.08	1.24	H	Median	1.5		
	PRS2.5 (PRS2.5)	DIN (µg L⁻¹)	5	7.21	6.02	3.29	3.50	11.39	11.85					
		DOC (µg L⁻¹)	5	1357	1251	1112	1177	1544	1698					
		DON (µg L⁻¹)	5	88	78	69	70	105	121					
		DOP (µg L⁻¹)	5	4.46	4.72	3.89	3.93	4.83	4.92					
		Chl-a (µg L⁻¹)	5	0.39	0.41	0.21	0.25	0.54	0.55	H	Median	0.36	0.25	0.46
		NO_x (µg L⁻¹)	5	1.87	0.74	0.50	0.52	3.43	4.17	H	Median	0.35	0.32	0.45
		PN (µg L⁻¹)	5	26.08	25.74	19.31	21.92	31.56	31.85	H	Mean		16	
		PN (µg L⁻¹)	5	26.08	25.74	19.31	21.92	31.56	31.85	H	Median	18		20
		PO_4 (µg L⁻¹)	5	1.44	1.32	0.70	0.93	2.01	2.25	H	Median	1.4	1.86	0.93
		POC (mg L⁻¹)	5	152	133	106	121	186	213					
		PP (µg L⁻¹)	5	2.66	2.51	2.12	2.35	3.12	3.18	H	Mean		2.3	
		PP (µg L⁻¹)	5	2.66	2.51	2.12	2.35	3.12	3.18	H	Median	2.6		3
		Secchi (m)	5	5.36	6.40	2.78	4.22	6.64	6.76	L	Mean	10		
		Secchi (m)	5	5.36	6.40	2.78	4.22	6.64	6.76	L	Median			
		SiO_4 (mg L⁻¹)	5	442	145	107	115	844	999					
		TSS (mg L⁻¹)	5	2.17	1.37	1.07	1.17	2.59	4.68	H	Mean		1.6	
		TSS (mg L⁻¹)	5	2.17	1.37	1.07	1.17	2.59	4.68	H	Median	1.9		1.7
	Middle Reef (PRBB)	DIN (µg L⁻¹)	5	5.10	5.39	2.72	4.35	6.17	6.85					
		DOC (µg L⁻¹)	5	1224	1149	960	1049	1440	1520					
		DON (µg L⁻¹)	5	81	81	62	65	96	99					

Region	Site	Measure	N	Mean	Median	Quantiles				Guideline Values				
						Q5	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		DOP (µg L⁻¹)	5	5.11	5.42	4.03	4.49	5.76	5.85					
		Chl-a (µg L⁻¹)	5	0.40	0.46	0.16	0.28	0.53	0.59	H	Median	0.27		
		NO_x (µg L⁻¹)	5	1.23	0.56	0.49	0.49	2.14	2.48	H	Median	0.35		
		PN (µg L⁻¹)	5	20.02	21.64	13.26	14.82	24.80	25.58	H	Mean			
		PN (µg L⁻¹)	5	20.02	21.64	13.26	14.82	24.80	25.58	H	Median	18		
		PO_4 (µg L⁻¹)	5	1.11	0.93	0.68	0.87	1.46	1.64	H	Median	0.62		
		POC (mg L⁻¹)	5	105	99	82	87	116	140					
		PP (µg L⁻¹)	5	1.86	1.72	1.45	1.56	2.15	2.44	H	Mean			
		PP (µg L⁻¹)	5	1.86	1.72	1.45	1.56	2.15	2.44	H	Median	2		
		Secchi (m)	5	7.60	6.80	6.30	6.30	8.70	9.90	L	Mean	10		
		Secchi (m)	5	7.60	6.80	6.30	6.30	8.70	9.90	L	Median			
		SiO_4 (mg L⁻¹)	5	150	111	82	104	218	233					
		TSS (mg L⁻¹)	5	0.84	0.81	0.73	0.78	0.88	1.03	H	Mean			
		TSS (mg L⁻¹)	5	0.84	0.81	0.73	0.78	0.88	1.03	H	Median	1.5		
	Hannah Island (SR05)	DIN (µg L⁻¹)	4	2.78	2.57	2.21	2.32	3.16	3.65					
		DOC (µg L⁻¹)	4	1409	1114	1087	1089	1610	2143					
		DON (µg L⁻¹)	4	80	73	66	68	89	105					
		DOP (µg L⁻¹)	4	5.17	5.30	4.12	4.65	5.74	6.02					
		Chl-a (µg L⁻¹)	4	0.28	0.27	0.19	0.20	0.35	0.37	H	Median	0.27		
		NO_x (µg L⁻¹)	4	0.69	0.61	0.28	0.28	1.07	1.21	H	Median	0.35		
		PN (µg L⁻¹)	4	22.35	19.29	15.04	16.84	26.64	33.95	H	Mean			
		PN (µg L⁻¹)	4	22.35	19.29	15.04	16.84	26.64	33.95	H	Median	18		
		PO_4 (µg L⁻¹)	4	1.05	0.97	0.40	0.68	1.38	1.80	H	Median	0.62		
		POC (mg L⁻¹)	4	108	92	78	80	129	159					
		PP (µg L⁻¹)	4	2.25	1.79	1.43	1.56	2.76	3.73	H	Mean			
		PP (µg L⁻¹)	4	2.25	1.79	1.43	1.56	2.76	3.73	H	Median	2		
		Secchi (m)	4	6.81	6.63	5.33	5.42	8.13	8.56	L	Mean	10		

Region	Site	Measure	N	Mean	Median	Quantiles				Guideline Values				
						Q5	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		Secchi (m)	4	6.81	6.63	5.33	5.42	8.13	8.56	L	Median			
		SiO_4 (mg L⁻¹)	4	282	163	67	89	427	664					
		TSS (mg L⁻¹)	4	1.17	1.09	0.50	0.74	1.56	1.94	H	Mean			
		TSS (mg L⁻¹)	4	1.17	1.09	0.50	0.74	1.56	1.94	H	Median	1.5		
	Burkitt Island (SR04)	DIN (µg L⁻¹)	5	1.89	1.75	1.23	1.36	2.53	2.58					
		DOC (µg L⁻¹)	5	1381	1140	1008	1021	1865	1872					
		DON (µg L⁻¹)	5	79.01	66.57	52.27	58.06	98.78	119.36					
		DOP (µg L⁻¹)	5	5.57	6.04	4.24	5.36	6.07	6.16					
		Chl-a (µg L⁻¹)	5	0.25	0.20	0.15	0.16	0.33	0.40	H	Median	0.36	0.25	0.46
		NO_x (µg L⁻¹)	5	0.42	0.42	0.28	0.28	0.56	0.56	H	Median	0.35	0.32	0.45
		PN (µg L⁻¹)	5	19.94	17.14	11.94	14.04	27.90	28.68	H	Mean		16	
		PN (µg L⁻¹)	5	19.94	17.14	11.94	14.04	27.90	28.68	H	Median	18		20
		PO_4 (µg L⁻¹)	5	0.77	0.62	0.37	0.56	1.11	1.21	H	Median	1.4	1.86	0.93
		POC (mg L⁻¹)	5	92.99	76.75	66.44	72.45	119.09	130.20					
		PP (µg L⁻¹)	5	2.27	1.99	1.45	1.77	2.76	3.37	H	Mean		2.3	
		PP (µg L⁻¹)	5	2.27	1.99	1.45	1.77	2.76	3.37	H	Median	2.6		3
		Secchi (m)	5	7.04	7.10	5.32	5.98	8.28	8.52	L	Mean	10		
		Secchi (m)	5	7.04	7.10	5.32	5.98	8.28	8.52	L	Median			
		SiO_4 (mg L⁻¹)	5	288	212	72	114	509	532					
		TSS (mg L⁻¹)	5	0.93	0.89	0.66	0.75	1.16	1.20	H	Mean		1.6	
		TSS (mg L⁻¹)	5	0.93	0.89	0.66	0.75	1.16	1.20	H	Median	1.9		1.7
	SR03 (SR03)	DIN (µg L⁻¹)	5	2.73	2.24	1.16	1.92	3.77	4.56					
		DOC (µg L⁻¹)	5	1488	1144	980	1020	2091	2203					
		DON (µg L⁻¹)	5	84	77	53	66	110	112					
		DOP (µg L⁻¹)	5	5.95	5.73	4.92	5.30	6.47	7.31					
		Chl-a (µg L⁻¹)	5	0.31	0.34	0.15	0.19	0.40	0.47	H	Median	0.36	0.25	0.46
		NO_x (µg L⁻¹)	5	0.84	0.49	0.36	0.41	1.22	1.72	H	Median	0.35	0.32	0.45

Region	Site	Measure	N	Mean	Median	Quantiles				Guideline Values				
						Q5	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		PN (µg L^{-1})	5	21.92	21.94	15.64	18.34	26.84	26.84	H	Mean		16	
		PN (µg L^{-1})	5	21.92	21.94	15.64	18.34	26.84	26.84	H	Median	18		20
		PO_4 (µg L^{-1})	5	0.96	0.93	0.43	0.81	1.18	1.46	H	Median	1.4	1.86	0.93
		POC (mg L^{-1})	5	110	105	95	102	124	125					
		PP (µg L^{-1})	5	2.75	2.72	2.03	2.30	3.21	3.50	H	Mean		2.3	
		PP (µg L^{-1})	5	2.75	2.72	2.03	2.30	3.21	3.50	H	Median	2.6		3
		Secchi (m)	5	4.50	4.60	3.02	3.08	5.78	6.02	L	Mean	10		
		Secchi (m)	5	4.50	4.60	3.02	3.08	5.78	6.02	L	Median			
		SiO_4 (mg L^{-1})	5	356	298	98	121	565	699					
		TSS (mg L^{-1})	5	1.41	1.33	0.70	0.94	2.02	2.05	H	Mean		1.6	
		TSS (mg L^{-1})	5	1.41	1.33	0.70	0.94	2.02	2.05	H	Median	1.9		1.7
	SR02 (SR02)	DIN (µg L^{-1})	5	5.26	3.71	1.15	1.76	9.06	10.61					
		DOC (µg L^{-1})	5	1691	1124	1083	1110	2162	2977					
		DON (µg L^{-1})	5	101	97	72	77	111	148					
		DOP (µg L^{-1})	5	5.73	6.19	4.46	5.30	6.30	6.40					
		Chl-a (µg L^{-1})	5	0.42	0.33	0.21	0.23	0.51	0.83	H	Median			0.4
		NO_x (µg L^{-1})	5	2.78	2.03	0.31	0.39	5.49	5.68	H	Median			1.5
		PN (µg L^{-1})	5	31.02	27.19	20.96	22.07	40.12	44.75	H	Mean			
		PN (µg L^{-1})	5	31.02	27.19	20.96	22.07	40.12	44.75	H	Median			
		PO_4 (µg L^{-1})	5	1.30	1.47	0.42	0.51	1.94	2.17	H	Median			2
		POC (mg L^{-1})	5	167	121	118	120	220	254					
		PP (µg L^{-1})	5	3.20	3.17	2.24	2.38	3.77	4.43	H	Mean			
		PP (µg L^{-1})	5	3.20	3.17	2.24	2.38	3.77	4.43	H	Median			
		Secchi (m)	5	3.78	3.40	2.52	2.88	4.78	5.32	L	Mean			
		Secchi (m)	5	3.78	3.40	2.52	2.88	4.78	5.32	L	Median			3.1
		SiO_4 (mg L^{-1})	5	474	274	84	126	789	1098					
		TSS (mg L^{-1})	5	1.13	1.05	1.03	1.03	1.21	1.30	H	Mean			

Region	Site	Measure	N	Mean	Median	Quantiles				Guideline Values				
						Q5	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		TSS (mg L⁻¹)	5	1.13	1.05	1.03	1.03	1.21	1.30	H	Median			5
	Corbett Reef (NR06)	DIN (µg L⁻¹)	3	6.23	1.72	0.80	1.11	10.45	14.82					
		DOC (µg L⁻¹)	3	1111	1003	969	980	1220	1329					
		DON (µg L⁻¹)	3	64	65	58	60	69	71					
		DOP (µg L⁻¹)	3	5.24	5.65	4.47	4.86	5.70	5.72					
		Chl-a (µg L⁻¹)	3	0.32	0.33	0.17	0.22	0.42	0.46	H	Median	0.26		
		NO_x (µg L⁻¹)	3	3.33	0.28	0.28	0.28	5.76	8.50	H	Median	0.42		
		PN (µg L⁻¹)	3	18.54	18.29	13.75	15.26	21.77	23.51	H	Median	16		
		PO_4 (µg L⁻¹)	3	1.70	1.32	0.90	1.04	2.29	2.78	H	Median	0.39		
		POC (mg L⁻¹)	3	96.43	91.11	87.15	88.47	103.33	109.45					
		PP (µg L⁻¹)	3	2.30	2.76	1.48	1.90	2.79	2.80	H	Mean			
		PP (µg L⁻¹)	3	2.30	2.76	1.48	1.90	2.79	2.80	H	Median	1.9		
		Secchi (m)	3	10.13	9.40	8.86	9.04	11.08	11.92	L	Mean	17		
		Secchi (m)	3	10.13	9.40	8.86	9.04	11.08	11.92	L	Median			
		SiO_4 (mg L⁻¹)	3	165	184	89	121	213	227					
		TSS (mg L⁻¹)	3	1.09	0.96	0.48	0.64	1.51	1.79	H	Mean			
		TSS (mg L⁻¹)	3	1.09	0.96	0.48	0.64	1.51	1.79	H	Median	0.5		
	NR05 (NR05)	DIN (µg L⁻¹)	3	2.45	1.82	0.88	1.19	3.58	4.47					
		DOC (µg L⁻¹)	3	1269	1041	969	993	1499	1728					
		DON (µg L⁻¹)	3	72	61	54	56	86	98					
		DOP (µg L⁻¹)	3	5.26	5.26	4.57	4.80	5.73	5.96					
		Chl-a (µg L⁻¹)	3	0.25	0.22	0.21	0.21	0.28	0.31	H	Median	0.27		
		NO_x (µg L⁻¹)	3	0.44	0.35	0.29	0.31	0.56	0.67	H	Median	0.35		
		PN (µg L⁻¹)	3	16.24	16.04	13.97	14.66	17.78	18.65	H	Mean			
		PN (µg L⁻¹)	3	16.24	16.04	13.97	14.66	17.78	18.65	H	Median	18		
		PO_4 (µg L⁻¹)	3	1.03	1.08	0.81	0.90	1.18	1.22	H	Median	0.62		
		POC (mg L⁻¹)	3	81	81	75	77	86	88					

Region	Site	Measure	N	Mean	Median	Quantiles				Guideline Values				
						Q5	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		PP (µg L^{-1})	3	1.78	1.42	1.37	1.38	2.10	2.44	H	Mean			
		PP (µg L^{-1})	3	1.78	1.42	1.37	1.38	2.10	2.44	H	Median	2		
		Secchi (m)	3	7.70	6.30	5.58	5.82	9.30	10.80	L	Mean	10		
		Secchi (m)	3	7.70	6.30	5.58	5.82	9.30	10.80	L	Median			
		SiO_4 (mg L^{-1})	3	243	191	98	129	348	426					
		TSS (mg L^{-1})	3	0.62	0.74	0.19	0.37	0.90	0.97	H	Mean			
		TSS (mg L^{-1})	3	0.62	0.74	0.19	0.37	0.90	0.97	H	Median	1.5		
	NR04 (NR04)	DIN (µg L^{-1})	1	2.73	2.73	2.73	2.73	2.73	2.73					
		DOC (µg L^{-1})	1	1022	1022	1022	1022	1022	1022					
		DON (µg L^{-1})	1	59	59	59	59	59	59					
		DOP (µg L^{-1})	1	5.73	5.73	5.73	5.73	5.73	5.73					
		Chl-a (µg L^{-1})	1	0.38	0.38	0.38	0.38	0.38	0.38	H	Median	0.36	0.25	0.46
		NO_x (µg L^{-1})	1	0.35	0.35	0.35	0.35	0.35	0.35	H	Median	0.35	0.32	0.45
		PN (µg L^{-1})	1	16.34	16.34	16.34	16.34	16.34	16.34	H	Mean		16	
		PN (µg L^{-1})	1	16.34	16.34	16.34	16.34	16.34	16.34	H	Median	18		20
		PO_4 (µg L^{-1})	1	1.08	1.08	1.08	1.08	1.08	1.08	H	Median	1.4	1.86	0.93
		POC (mg L^{-1})	1	86.26	86.26	86.26	86.26	86.26	86.26					
		PP (µg L^{-1})	1	2.31	2.31	2.31	2.31	2.31	2.31	H	Mean		2.3	
		PP (µg L^{-1})	1	2.31	2.31	2.31	2.31	2.31	2.31	H	Median	2.6		3
		Secchi (m)	1	8.10	8.10	8.10	8.10	8.10	8.10	L	Mean	10		
		Secchi (m)	1	8.10	8.10	8.10	8.10	8.10	8.10	L	Median			
		SiO_4 (mg L^{-1})	1	231	231	231	231	231	231					
		TSS (mg L^{-1})	1	1.96	1.96	1.96	1.96	1.96	1.96	H	Mean		1.6	
		TSS (mg L^{-1})	1	1.96	1.96	1.96	1.96	1.96	1.96	H	Median	1.9		1.7
	Cliff Isles (CI01)	DIN (µg L^{-1})	3	3.08	3.36	2.04	2.48	3.74	3.93					
		DOC (µg L^{-1})	3	1394	1161	1156	1157	1584	1796					
		DON (µg L^{-1})	3	87	79	74	76	98	107					

Region	Site	Measure	N	Mean	Median	Quantiles				Guideline Values				
						Q5	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		DOP (µg L⁻¹)	3	5.37	6.04	3.95	4.65	6.22	6.32					
		Chl-a (µg L⁻¹)	3	0.29	0.26	0.24	0.25	0.32	0.36	H	Median	0.36	0.25	0.46
		NO_x (µg L⁻¹)	3	0.82	0.91	0.34	0.53	1.12	1.23	H	Median	0.35	0.32	0.45
		PN (µg L⁻¹)	3	30.81	21.14	20.78	20.90	38.78	47.60	H	Mean		16	
		PN (µg L⁻¹)	3	30.81	21.14	20.78	20.90	38.78	47.60	H	Median	18		20
		PO_4 (µg L⁻¹)	3	1.60	1.70	1.15	1.33	1.89	1.98	H	Median	1.4	1.86	0.93
		POC (mg L⁻¹)	3	138	143	100	114	163	173					
		PP (µg L⁻¹)	3	2.81	2.40	2.18	2.25	3.28	3.72	H	Mean		2.3	
		PP (µg L⁻¹)	3	2.81	2.40	2.18	2.25	3.28	3.72	H	Median	2.6		3
		Secchi (m)	3	4.20	4.60	3.52	3.88	4.60	4.60	L	Mean	10		
		Secchi (m)	3	4.20	4.60	3.52	3.88	4.60	4.60	L	Median			
		SiO_4 (mg L⁻¹)	3	325	236	227	230	403	486					
		TSS (mg L⁻¹)	3	1.35	1.49	1.00	1.16	1.57	1.61	H	Mean		1.6	
		TSS (mg L⁻¹)	3	1.35	1.49	1.00	1.16	1.57	1.61	H	Median	1.9		1.7
	NR03 (NR03)	DIN (µg L⁻¹)	3	4.83	2.63	1.05	1.58	7.64	10.15					
		DOC (µg L⁻¹)	3	1508	1202	1019	1080	1874	2210					
		DON (µg L⁻¹)	3	88	82	75	78	97	105					
		DOP (µg L⁻¹)	3	5.57	5.88	4.21	4.77	6.44	6.72					
		Chl-a (µg L⁻¹)	3	0.38	0.43	0.24	0.30	0.47	0.49	H	Median	0.36	0.25	0.46
		NO_x (µg L⁻¹)	3	1.06	0.46	0.42	0.43	1.57	2.12	H	Median	0.35	0.32	0.45
		PN (µg L⁻¹)	3	25.01	23.99	18.32	20.21	29.60	32.41	H	Mean		16	
		PN (µg L⁻¹)	3	25.01	23.99	18.32	20.21	29.60	32.41	H	Median	18		20
		PO_4 (µg L⁻¹)	3	1.19	1.08	0.67	0.81	1.55	1.78	H	Median	1.4	1.86	0.93
		POC (mg L⁻¹)	3	127	115	93	101	150	168					
		PP (µg L⁻¹)	3	3.03	2.69	2.46	2.54	3.46	3.84	H	Mean		2.3	
		PP (µg L⁻¹)	3	3.03	2.69	2.46	2.54	3.46	3.84	H	Median	2.6		3
		Secchi (m)	3	3.70	3.70	1.99	2.56	4.84	5.41	L	Mean	10		

Region	Site	Measure	N	Mean	Median	Quantiles				Guideline Values				
						Q5	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		Secchi (m)	3	3.70	3.70	1.99	2.56	4.84	5.41	L	Median			
		SiO_4 (mg L^{-1})	3	418	319	135	196	621	771					
		TSS (mg L^{-1})	3	1.60	1.81	0.66	1.04	2.20	2.40	H	Mean		1.6	
		TSS (mg L^{-1})	3	1.60	1.81	0.66	1.04	2.20	2.40	H	Median	1.9		1.7
	Normanby inshore (NR02)	DIN (µg L^{-1})	3	9.15	2.03	1.90	1.95	14.93	21.37					
		DOC (µg L^{-1})	3	1707	1489	1008	1168	2203	2559					
		DON (µg L^{-1})	3	91	93	60	71	112	121					
		DOP (µg L^{-1})	3	6.45	5.42	4.17	4.58	8.11	9.46					
		Chl-a (µg L^{-1})	3	0.70	0.69	0.63	0.65	0.75	0.78	H	Median			0.7
		NO_x (µg L^{-1})	3	1.68	0.42	0.29	0.34	2.77	3.95	H	Median			1
		PN (µg L^{-1})	3	44.43	47.28	38.82	41.64	47.80	48.05	H	Mean			
		PN (µg L^{-1})	3	44.43	47.28	38.82	41.64	47.80	48.05	H	Median			
		PO_4 (µg L^{-1})	3	1.65	1.70	0.87	1.15	2.17	2.40	H	Median			2
		POC (mg L^{-1})	3	230	239	191	207	254	262					
		PP (µg L^{-1})	3	5.91	5.82	5.33	5.49	6.31	6.55	H	Mean			
		PP (µg L^{-1})	3	5.91	5.82	5.33	5.49	6.31	6.55	H	Median			
		Secchi (m)	3	1.30	1.50	0.96	1.14	1.50	1.50	L	Mean			
		Secchi (m)	3	1.30	1.50	0.96	1.14	1.50	1.50	L	Median			1.5
		SiO_4 (mg L^{-1})	3	549	479	211	300	784	936					
		TSS (mg L^{-1})	3	4.81	5.29	3.52	4.11	5.61	5.77	H	Mean			
		TSS (mg L^{-1})	3	4.81	5.29	3.52	4.11	5.61	5.77	H	Median			6
	Endeavour offshore (ER03)	DIN (µg L^{-1})	5	3.11	2.03	0.92	1.60	3.71	7.28					
		DOC (µg L^{-1})	5	1156	1079	896	962	1291	1550					
		DON (µg L^{-1})	5	72	62	54	55	80	108					
		DOP (µg L^{-1})	5	5.51	4.96	4.71	4.89	6.22	6.78					
		Chl-a (µg L^{-1})	5	0.24	0.18	0.14	0.17	0.35	0.36	H	Median	0.36	0.25	0.46
		NO_x (µg L^{-1})	5	0.83	0.28	0.28	0.28	0.87	2.42	H	Median	0.35	0.32	0.45

Region	Site	Measure	N	Mean	Median	Quantiles				Guideline Values				
						Q5	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		PN (µg L⁻¹)	5	15.32	15.14	12.58	14.50	16.26	18.12	H	Mean		16	
		PN (µg L⁻¹)	5	15.32	15.14	12.58	14.50	16.26	18.12	H	Median	18		20
		PO_4 (µg L⁻¹)	5	1.42	1.24	1.11	1.21	1.73	1.83	H	Median	1.4	1.86	0.93
		POC (mg L⁻¹)	5	79	77	67	72	83	96					
		PP (µg L⁻¹)	5	1.90	1.64	1.29	1.43	2.15	2.99	H	Mean		2.3	
		PP (µg L⁻¹)	5	1.90	1.64	1.29	1.43	2.15	2.99	H	Median	2.6		3
		Secchi (m)	5	8.40	7.60	5.16	6.24	10.96	12.04	L	Mean	10		
		Secchi (m)	5	8.40	7.60	5.16	6.24	10.96	12.04	L	Median			
		SiO_4 (mg L⁻¹)	5	150	97	79	80	217	275					
		TSS (mg L⁻¹)	5	0.95	0.79	0.24	0.61	1.11	1.98	H	Mean		1.6	
		TSS (mg L⁻¹)	5	0.95	0.79	0.24	0.61	1.11	1.98	H	Median	1.9		1.7
	Endeavour north shore (ER02b)	DIN (µg L⁻¹)	5	2.58	2.10	0.92	0.97	3.33	5.56					
		DOC (µg L⁻¹)	5	1158	1086	930	1043	1250	1482					
		DON (µg L⁻¹)	5	73	71	59	59	86	87					
		DOP (µg L⁻¹)	5	5.02	5.11	4.18	4.18	5.67	5.95					
		Chl-a (µg L⁻¹)	5	0.23	0.19	0.16	0.18	0.28	0.33	H	Median	0.36	0.25	0.46
		NO_x (µg L⁻¹)	5	0.69	0.28	0.28	0.28	0.81	1.78	H	Median	0.35	0.32	0.45
		PN (µg L⁻¹)	5	17.46	17.64	16.06	16.42	18.38	18.80	H	Mean		16	
		PN (µg L⁻¹)	5	17.46	17.64	16.06	16.42	18.38	18.80	H	Median	18		20
		PO_4 (µg L⁻¹)	5	1.95	1.70	1.42	1.52	2.51	2.60	H	Median	1.4	1.86	0.93
		POC (mg L⁻¹)	5	99	96	89	93	103	114					
		PP (µg L⁻¹)	5	2.14	2.16	1.79	1.83	2.29	2.61	H	Mean		2.3	
		PP (µg L⁻¹)	5	2.14	2.16	1.79	1.83	2.29	2.61	H	Median	2.6		3
		Secchi (m)	5	6.18	5.30	4.64	4.76	7.38	8.82	L	Mean	10		
		Secchi (m)	5	6.18	5.30	4.64	4.76	7.38	8.82	L	Median			
		SiO_4 (mg L⁻¹)	5	189	204	78	95	270	299					
		TSS (mg L⁻¹)	5	1.08	1.05	0.41	0.88	1.34	1.74	H	Mean		1.6	

Region	Site	Measure	N	Mean	Median	Quantiles				Guideline Values				
						Q5	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		TSS (mg L^{-1})	5	1.08	1.05	0.41	0.88	1.34	1.74	H	Median	1.9		1.7
	Egret and Boulder Reef (AE04)	DIN (µg L^{-1})	5	2.30	2.07	1.22	1.83	2.71	3.70					
		DOC (µg L^{-1})	5	1137	1040	921	951	1370	1405					
		DON (µg L^{-1})	5	63	56	50	51	67	90					
		DOP (µg L^{-1})	5	5.28	5.11	4.18	4.88	5.93	6.30					
		Chl-a (µg L^{-1})	5	0.22	0.23	0.15	0.16	0.27	0.31	H	Median	0.27		
		NO_x (µg L^{-1})	5	0.31	0.28	0.28	0.28	0.33	0.37	H	Median	0.35		
		PN (µg L^{-1})	5	13.59	12.64	11.51	11.57	15.77	16.46	H	Mean			
		PN (µg L^{-1})	5	13.59	12.64	11.51	11.57	15.77	16.46	H	Median	18		
		PO_4 (µg L^{-1})	5	1.33	1.16	1.04	1.13	1.64	1.69	H	Median	0.62		
		POC (mg L^{-1})	5	71.86	71.30	62.35	65.68	78.61	81.34					
		PP (µg L^{-1})	5	2.09	1.52	1.16	1.21	2.74	3.81	H	Mean			
		PP (µg L^{-1})	5	2.09	1.52	1.16	1.21	2.74	3.81	H	Median	2		
		Secchi (m)	5	12.43	11.80	9.77	10.26	14.34	15.96	L	Mean	10		
		Secchi (m)	5	12.43	11.80	9.77	10.26	14.34	15.96	L	Median			
		SiO_4 (mg L^{-1})	5	119	75	69	71	129	251					
		TSS (mg L^{-1})	5	0.90	0.43	0.09	0.23	1.84	1.88	H	Mean			
		TSS (mg L^{-1})	5	0.90	0.43	0.09	0.23	1.84	1.88	H	Median	1.5		
	Dawson Reef (AR03b)	DIN (µg L^{-1})	5	2.87	2.66	1.62	1.67	4.03	4.37					
		DOC (µg L^{-1})	5	1422	1291	964	1025	1717	2113					
		DON (µg L^{-1})	5	82	76	48	53	97	133					
		DOP (µg L^{-1})	5	5.57	5.26	4.24	4.89	6.22	7.25					
		Chl-a (µg L^{-1})	5	0.23	0.24	0.11	0.11	0.32	0.37	H	Median	0.36	0.25	0.46
		NO_x (µg L^{-1})	5	0.52	0.49	0.28	0.28	0.69	0.85	H	Median	0.35	0.32	0.45
		PN (µg L^{-1})	5	16.84	12.54	10.76	11.12	24.50	25.28	H	Mean		16	
		PN (µg L^{-1})	5	16.84	12.54	10.76	11.12	24.50	25.28	H	Median	18		20
		PO_4 (µg L^{-1})	5	1.55	1.39	1.15	1.33	1.80	2.07	H	Median	1.4	1.86	0.93

Region	Site	Measure	N	Mean	Median	Quantiles				Guideline Values				
						Q5	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		POC (mg L⁻¹)	5	95	70	60	61	129	154					
		PP (µg L⁻¹)	5	1.73	1.41	1.13	1.27	2.38	2.43	H	Mean		2.3	
		PP (µg L⁻¹)	5	1.73	1.41	1.13	1.27	2.38	2.43	H	Median	2.6		3
		Secchi (m)	5	10.22	10.10	8.14	9.16	10.92	12.78	L	Mean	10		
		Secchi (m)	5	10.22	10.10	8.14	9.16	10.92	12.78	L	Median			
		SiO_4 (mg L⁻¹)	5	199	114	73	88	338	384					
		TSS (mg L⁻¹)	5	1.06	0.69	0.18	0.44	1.33	2.68	H	Mean		1.6	
		TSS (mg L⁻¹)	5	1.06	0.69	0.18	0.44	1.33	2.68	H	Median	1.9		1.7
	Walker Bay (AR02b)	DIN (µg L⁻¹)	5	3.04	3.33	2.30	2.49	3.45	3.62					
		DOC (µg L⁻¹)	5	1293	1223	1125	1185	1399	1531					
		DON (µg L⁻¹)	5	73	74	71	71	75	76					
		DOP (µg L⁻¹)	5	6.07	5.96	4.55	5.44	6.60	7.80					
		Chl-a (µg L⁻¹)	5	0.24	0.22	0.15	0.18	0.30	0.37	H	Median	0.36	0.25	0.46
		NO_x (µg L⁻¹)	5	0.48	0.32	0.28	0.28	0.64	0.90	H	Median	0.35	0.32	0.45
		PN (µg L⁻¹)	5	22.31	20.89	18.09	18.24	26.85	27.48	H	Mean		16	
		PN (µg L⁻¹)	5	22.31	20.89	18.09	18.24	26.85	27.48	H	Median	18		20
		PO_4 (µg L⁻¹)	5	1.52	1.47	1.13	1.27	1.77	1.95	H	Median	1.4	1.86	0.93
		POC (mg L⁻¹)	5	116	110	93	105	137	137					
		PP (µg L⁻¹)	5	2.04	2.05	1.29	1.78	2.27	2.78	H	Mean		2.3	
		PP (µg L⁻¹)	5	2.04	2.05	1.29	1.78	2.27	2.78	H	Median	2.6		3
		Secchi (m)	5	7.88	8.30	5.10	6.30	9.10	10.60	L	Mean	10		
		Secchi (m)	5	7.88	8.30	5.10	6.30	9.10	10.60	L	Median			
		SiO_4 (mg L⁻¹)	5	256	126	83	99	424	549					
		TSS (mg L⁻¹)	5	1.11	1.15	0.87	0.98	1.28	1.28	H	Mean		1.6	
		TSS (mg L⁻¹)	5	1.11	1.15	0.87	0.98	1.28	1.28	H	Median	1.9		1.7
Wet Tropics		DIN (µg L⁻¹)	3	4.31	3.61	3.54	3.56	4.91	5.56					
		DOC (µg L⁻¹)	3	922	926	880	895	950	962					

Region	Site	Measure	N	Mean	Median	Quantiles				Guideline Values				
						Q5	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
	Cape Tribulation (C1)	DON (µg L^{-1})	3	69	68	63	64	74	77					
		DOP (µg L^{-1})	3	5.42	5.34	5.20	5.25	5.57	5.69					
		Chl-a (µg L^{-1})	3	0.32	0.30	0.18	0.22	0.41	0.46	H	Mean	0.45		
		Chl-a (µg L^{-1})	3	0.32	0.30	0.18	0.22	0.41	0.46	H	Median		0.32	0.63
		NO$_x$ (µg L^{-1})	3	0.97	1.02	0.54	0.70	1.25	1.36	H	Median	0.35		
		PN (µg L^{-1})	3	13.02	12.42	10.06	10.84	15.08	16.40	H	Mean	20		
		PN (µg L^{-1})	3	13.02	12.42	10.06	10.84	15.08	16.40	H	Median		16	25
		PO$_4$ (µg L^{-1})	3	1.45	1.94	0.54	1.01	1.98	2.01	H	Median	2		
		POC (mg L^{-1})	3	84	71	49	57	108	126					
		PP (µg L^{-1})	3	2.64	2.78	1.79	2.12	3.19	3.39	H	Mean	2.8		
		PP (µg L^{-1})	3	2.64	2.78	1.79	2.12	3.19	3.39	H	Median		2.3	3.3
		Secchi (m)	3	6.17	5.00	2.75	3.50	8.60	10.40	L	Mean	10		
		Secchi (m)	3	6.17	5.00	2.75	3.50	8.60	10.40	L	Median			
		SiO$_4$ (mg L^{-1})	3	180	114	73	87	260	333					
		TSS (mg L^{-1})	3	1.03	0.97	0.33	0.54	1.51	1.79	H	Mean	2		
		TSS (mg L^{-1})	3	1.03	0.97	0.33	0.54	1.51	1.79	H	Median		1.6	2.4
	Port Douglas (C4)	DIN (µg L^{-1})	3	2.89	2.63	2.40	2.48	3.26	3.57					
		DOC (µg L^{-1})	3	907	912	893	899	916	918					
		DON (µg L^{-1})	3	76	81	62	68	84	86					
		DOP (µg L^{-1})	3	5.65	5.65	5.44	5.51	5.79	5.86					
		Chl-a (µg L^{-1})	3	0.36	0.40	0.22	0.28	0.45	0.47	H	Median	0.3	0.32	0.63
		NO$_x$ (µg L^{-1})	3	0.69	0.63	0.32	0.42	0.95	1.10	H	Median	0.31		
		PN (µg L^{-1})	3	13.46	13.63	12.05	12.58	14.37	14.74	H	Median	14	16	25
		PO$_4$ (µg L^{-1})	3	1.32	1.24	0.82	0.96	1.66	1.87	H	Median	2		
		POC (mg L^{-1})	3	102	104	94	97	108	110					
		PP (µg L^{-1})	3	2.95	3.08	2.60	2.76	3.16	3.20	H	Median	2	2.3	3.3
		Secchi (m)	3	4.50	4.50	4.05	4.20	4.80	4.95	L	Median	13		

Region	Site	Measure	N	Mean	Median	Quantiles				Guideline Values				
						Q5	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		SiO_4 (mg L⁻¹)	3	114	74	69	71	150	188					
		TSS (mg L⁻¹)	3	1.71	1.42	1.22	1.29	2.08	2.40	H	Median	1.2	1.6	2.4
	Double Island (C5)	DIN (µg L⁻¹)	3	3.19	2.70	2.29	2.42	3.85	4.43					
		DOC (µg L⁻¹)	3	917	946	846	879	961	968					
		DON (µg L⁻¹)	3	68	68	64	65	71	73					
		DOP (µg L⁻¹)	3	5.81	5.88	5.40	5.56	6.07	6.16					
		Chl-a (µg L⁻¹)	3	0.32	0.26	0.21	0.23	0.41	0.48	H	Median	0.3	0.32	0.63
		NO_x (µg L⁻¹)	3	0.55	0.56	0.37	0.43	0.67	0.72	H	Median	0.31		
		PN (µg L⁻¹)	3	12.28	12.67	10.89	11.48	13.16	13.40	H	Median	14	16	25
		PO_4 (µg L⁻¹)	3	1.16	1.08	0.39	0.62	1.69	1.99	H	Median	2		
		POC (mg L⁻¹)	3	82.59	83.26	71.91	75.69	89.62	92.80					
		PP (µg L⁻¹)	3	2.16	2.10	1.74	1.86	2.44	2.61	H	Median	2	2.3	3.3
		Secchi (m)	3	8.00	8.00	7.10	7.40	8.60	8.90	L	Median	13		
		SiO_4 (mg L⁻¹)	3	126	122	55	77	174	200					
		TSS (mg L⁻¹)	3	0.78	0.76	0.68	0.71	0.86	0.91	H	Median	1.2	1.6	2.4
	Green Island (C11)	DIN (µg L⁻¹)	3	6.28	6.23	6.01	6.08	6.46	6.58					
		DOC (µg L⁻¹)	3	897	904	864	878	917	924					
		DON (µg L⁻¹)	3	75	74	59	64	86	92					
		DOP (µg L⁻¹)	3	5.39	5.50	5.08	5.22	5.59	5.64					
		Chl-a (µg L⁻¹)	3	0.21	0.16	0.13	0.14	0.27	0.33	H	Median	0.3	0.32	0.63
		NO_x (µg L⁻¹)	3	1.20	0.91	0.44	0.60	1.75	2.17	H	Median	0.31		
		PN (µg L⁻¹)	3	10.07	9.38	9.32	9.34	10.67	11.31	H	Median	14	16	25
		PO_4 (µg L⁻¹)	3	2.06	1.70	1.29	1.42	2.63	3.10	H	Median	2		
		POC (mg L⁻¹)	3	50	49	43	45	56	59					
		PP (µg L⁻¹)	3	1.46	1.37	1.22	1.27	1.63	1.76	H	Median	2	2.3	3.3
		Secchi (m)	3	11.00	10.00	8.20	8.80	13.00	14.50	L	Median	13		
		SiO_4 (mg L⁻¹)	3	87.62	55.97	42.00	46.66	122.25	155.39					

Region	Site	Measure	N	Mean	Median	Quantiles				Guideline Values				
						Q5	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		TSS (mg L^{-1})	3	0.27	0.20	0.20	0.20	0.34	0.40	H	Median	1.2	1.6	2.4
	Yorkey's Knob (C6)	DIN (µg L^{-1})	3	3.79	3.15	2.90	2.98	4.47	5.13					
		DOC (µg L^{-1})	3	1022	1024	964	984	1060	1079					
		DON (µg L^{-1})	3	80	81	58	66	95	102					
		DOP (µg L^{-1})	3	6.01	6.19	5.08	5.45	6.61	6.82					
		Chl-a (µg L^{-1})	3	0.48	0.45	0.30	0.35	0.60	0.68	H	Mean	0.45		
		Chl-a (µg L^{-1})	3	0.48	0.45	0.30	0.35	0.60	0.68	H	Median		0.32	0.63
		NO_x (µg L^{-1})	3	0.69	0.84	0.40	0.55	0.86	0.87	H	Median	0.35		
		PN (µg L^{-1})	3	15.85	14.42	13.47	13.79	17.63	19.24	H	Mean	20		
		PN (µg L^{-1})	3	15.85	14.42	13.47	13.79	17.63	19.24	H	Median		16	25
		PO_4 (µg L^{-1})	3	1.55	1.78	0.94	1.22	1.92	1.99	H	Median	2		
		POC (mg L^{-1})	3	124	121	105	111	137	145					
		PP (µg L^{-1})	3	3.78	3.92	3.26	3.48	4.11	4.21	H	Mean	2.8		
		PP (µg L^{-1})	3	3.78	3.92	3.26	3.48	4.11	4.21	H	Median		2.3	3.3
		Secchi (m)	3	3.67	3.00	3.00	3.00	4.20	4.80	L	Mean	10		
		Secchi (m)	3	3.67	3.00	3.00	3.00	4.20	4.80	L	Median			
		SiO_4 (mg L^{-1})	3	207	206	115	146	268	299					
		TSS (mg L^{-1})	3	2.08	2.06	1.88	1.94	2.22	2.30	H	Mean	2		
		TSS (mg L^{-1})	3	2.08	2.06	1.88	1.94	2.22	2.30	H	Median		1.6	2.4
	Fairlead Buoy (C8)	DIN (µg L^{-1})	3	3.41	2.56	1.55	1.88	4.76	5.86					
		DOC (µg L^{-1})	3	969	990	911	937	1005	1013					
		DON (µg L^{-1})	3	72	71	68	69	75	78					
		DOP (µg L^{-1})	3	5.73	5.81	5.53	5.62	5.85	5.88					
		Chl-a (µg L^{-1})	3	0.42	0.29	0.29	0.29	0.52	0.63	H	Mean	0.45		
		Chl-a (µg L^{-1})	3	0.42	0.29	0.29	0.29	0.52	0.63	H	Median		0.32	0.63
		NO_x (µg L^{-1})	3	0.36	0.32	0.28	0.29	0.42	0.47	H	Median	0.35		
		PN (µg L^{-1})	3	17.41	15.64	13.66	14.32	20.14	22.39	H	Mean	20		

Region	Site	Measure	N	Mean	Median	Quantiles				Guideline Values				
						Q5	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		PN (µg L⁻¹)	3	17.41	15.64	13.66	14.32	20.14	22.39	H	Median		16	25
		PO_4 (µg L⁻¹)	3	1.39	1.78	0.60	0.99	1.87	1.92	H	Median	2		
		POC (mg L⁻¹)	3	147	132	109	117	174	194					
		PP (µg L⁻¹)	3	4.13	3.85	3.04	3.31	4.89	5.41	H	Mean	2.8		
		PP (µg L⁻¹)	3	4.13	3.85	3.04	3.31	4.89	5.41	H	Median		2.3	3.3
		Secchi (m)	3	3.33	3.50	2.60	2.90	3.80	3.95	L	Mean	10		
		Secchi (m)	3	3.33	3.50	2.60	2.90	3.80	3.95	L	Median			
		SiO_4 (mg L⁻¹)	3	135	93	89	90	171	210					
		TSS (mg L⁻¹)	3	2.74	2.64	1.86	2.12	3.33	3.68	H	Mean	2		
		TSS (mg L⁻¹)	3	2.74	2.64	1.86	2.12	3.33	3.68	H	Median		1.6	2.4
	Fitzroy West (RM1)	DIN (µg L⁻¹)	5	4.07	3.68	2.21	2.86	4.56	7.02					
		DOC (µg L⁻¹)	5	929	915	889	904	966	970					
		DON (µg L⁻¹)	5	74.41	76.41	62.54	68.79	81.21	83.10					
		DOP (µg L⁻¹)	5	6.41	5.57	4.55	5.20	7.15	9.57					
		Chl-a (µg L⁻¹)	5	0.24	0.20	0.14	0.17	0.29	0.38	H	Mean	0.45		
		Chl-a (µg L⁻¹)	5	0.24	0.20	0.14	0.17	0.29	0.38	H	Median		0.32	0.63
		NO_x (µg L⁻¹)	5	1.30	0.60	0.30	0.36	1.87	3.38	H	Median	0.35		
		Turbidity (NTU)	225	1.23	1.05	0.49	0.75	1.67	2.43	H	Median	1		
		PN (µg L⁻¹)	5	12.76	12.03	11.02	11.43	14.28	15.05	H	Mean	20		
		PN (µg L⁻¹)	5	12.76	12.03	11.02	11.43	14.28	15.05	H	Median		16	25
		PO_4 (µg L⁻¹)	5	1.92	1.24	1.10	1.15	2.52	3.59	H	Median	2		
		POC (mg L⁻¹)	5	81	72	68	69	92	103					
		PP (µg L⁻¹)	5	2.03	2.20	1.44	1.64	2.43	2.44	H	Mean	2.8		
		PP (µg L⁻¹)	5	2.03	2.20	1.44	1.64	2.43	2.44	H	Median		2.3	3.3
		Secchi (m)	5	7.50	7.50	4.45	5.80	9.20	10.55	L	Mean	10		
		Secchi (m)	5	7.50	7.50	4.45	5.80	9.20	10.55	L	Median			

Region	Site	Measure	N	Mean	Median	Quantiles				Guideline Values				
						Q5	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		SiO_4 (mg L⁻¹)	5	141	98	78	78	216	237					
		TSS (mg L⁻¹)	5	0.71	0.55	0.12	0.32	0.94	1.61	H	Mean	2		
		TSS (mg L⁻¹)	5	0.71	0.55	0.12	0.32	0.94	1.61	H	Median		1.6	2.4
	RM3 (RM3)	DIN (µg L⁻¹)	9	4.86	4.45	2.25	2.74	5.99	9.39					
		DOC (µg L⁻¹)	9	992	1004	892	937	1023	1115					
		DON (µg L⁻¹)	9	82	78	60	72	90	111					
		DOP (µg L⁻¹)	9	6.49	6.19	5.03	5.50	6.30	9.55					
		Chl-a (µg L⁻¹)	9	0.41	0.35	0.24	0.27	0.51	0.73	H	Median	0.3	0.32	0.63
		NO_x (µg L⁻¹)	9	1.61	0.74	0.31	0.37	2.44	4.96	H	Median	0.31		
		PN (µg L⁻¹)	9	20.93	17.62	13.95	15.36	28.61	29.63	H	Median	14	16	25
		PO_4 (µg L⁻¹)	9	2.09	1.86	0.87	1.33	2.73	3.65	H	Median	2		
		POC (mg L⁻¹)	9	137	124	116	117	156	171					
		PP (µg L⁻¹)	9	2.46	2.78	1.37	2.04	2.80	3.06	H	Median	2	2.3	3.3
		Secchi (m)	9	10.22	10.00	5.40	6.90	14.10	15.60	L	Median	13		
		SiO_4 (mg L⁻¹)	9	161	146	67	105	238	265					
		TSS (mg L⁻¹)	9	1.19	0.87	0.37	0.51	1.61	2.75	H	Median	1.2	1.6	2.4
	High West (RM8)	DIN (µg L⁻¹)	9	5.12	3.89	2.53	3.12	8.09	9.31					
		DOC (µg L⁻¹)	9	978	987	873	926	1020	1095					
		DON (µg L⁻¹)	9	77	73	69	72	81	91					
		DOP (µg L⁻¹)	9	7.12	5.73	4.97	5.11	8.32	11.99					
		Chl-a (µg L⁻¹)	9	0.37	0.34	0.19	0.24	0.47	0.61	H	Mean	0.45		
		Chl-a (µg L⁻¹)	9	0.37	0.34	0.19	0.24	0.47	0.61	H	Median		0.32	0.63
		NO_x (µg L⁻¹)	9	1.72	1.54	0.45	0.78	2.79	3.54	H	Median	0.35		
		Turbidity (NTU)	119	0.91	0.81	0.51	0.65	1.06	1.65	H	Median	1		
		PN (µg L⁻¹)	9	25.44	23.25	12.39	14.06	36.35	42.70	H	Mean	20		
		PN (µg L⁻¹)	9	25.44	23.25	12.39	14.06	36.35	42.70	H	Median		16	25

Region	Site	Measure	N	Mean	Median	Quantiles				Guideline Values				
						Q5	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		PO_4 (µg L^{-1})	9	2.52	2.63	0.94	1.83	3.25	4.37	H	Median	2		
		POC (mg L^{-1})	9	151	154	88	117	193	196					
		PP (µg L^{-1})	9	2.70	2.82	2.05	2.31	2.95	3.29	H	Mean	2.8		
		PP (µg L^{-1})	9	2.70	2.82	2.05	2.31	2.95	3.29	H	Median		2.3	3.3
		Secchi (m)	9	7.83	9.00	3.60	5.40	10.20	10.80	L	Mean	10		
		Secchi (m)	9	7.83	9.00	3.60	5.40	10.20	10.80	L	Median			
		SiO_4 (mg L^{-1})	9	188	121	86	115	321	330					
		TSS (mg L^{-1})	9	1.33	1.37	0.52	0.87	1.94	2.13	H	Mean	2		
		TSS (mg L^{-1})	9	1.33	1.37	0.52	0.87	1.94	2.13	H	Median		1.6	2.4
	Russell Mulgrave Mouth Mooring (RM10)	DIN (µg L^{-1})	9	8.76	4.97	2.80	4.12	12.57	19.97					
		DOC (µg L^{-1})	9	1042	1029	925	984	1114	1185					
		DON (µg L^{-1})	9	85	79	70	76	98	111					
		DOP (µg L^{-1})	9	6.28	5.57	5.33	5.47	7.05	8.39					
		Chl-a (µg L^{-1})	9	0.42	0.39	0.27	0.32	0.49	0.65	H	Mean	0.45		
		Chl-a (µg L^{-1})	9	0.42	0.39	0.27	0.32	0.49	0.65	H	Median		0.32	0.63
		NO_x (µg L^{-1})	9	4.74	0.98	0.31	0.41	7.55	15.45	H	Median	0.35		
		Turbidity (NTU)	220	4.99	3.91	1.79	2.45	6.35	13.26	H	Median	1		
		PN (µg L^{-1})	9	31.87	25.70	15.60	17.82	43.16	58.53	H	Mean	20		
		PN (µg L^{-1})	9	31.87	25.70	15.60	17.82	43.16	58.53	H	Median		16	25
		PO_4 (µg L^{-1})	9	2.32	2.40	1.56	1.84	2.73	3.10	H	Median	2		
		POC (mg L^{-1})	9	210	217	129	153	255	303					
		PP (µg L^{-1})	9	3.82	3.94	2.66	3.46	4.22	4.85	H	Mean	2.8		
		PP (µg L^{-1})	9	3.82	3.94	2.66	3.46	4.22	4.85	H	Median		2.3	3.3
		Secchi (m)	9	4.50	4.50	2.68	3.20	5.60	6.65	L	Mean	10		
		Secchi (m)	9	4.50	4.50	2.68	3.20	5.60	6.65	L	Median			
		SiO_4 (mg L^{-1})	9	389	392	92	141	689	735					

Region	Site	Measure	N	Mean	Median	Quantiles				Guideline Values				
						Q5	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		TSS (mg L⁻¹)	9	2.08	1.98	1.07	1.38	2.58	3.38	H	Mean	2		
		TSS (mg L⁻¹)	9	2.08	1.98	1.07	1.38	2.58	3.38	H	Median		1.6	2.4
	Franklands West (RM7)	DIN (µg L⁻¹)	9	4.82	4.20	2.53	3.42	6.85	7.16					
		DOC (µg L⁻¹)	9	984	976	883	920	1033	1115					
		DON (µg L⁻¹)	9	81	79	71	74	88	96					
		DOP (µg L⁻¹)	9	6.98	5.65	4.96	5.51	8.36	11.80					
		Chl-a (µg L⁻¹)	9	0.33	0.34	0.18	0.19	0.43	0.51	H	Median	0.3	0.32	0.63
		NO_x (µg L⁻¹)	9	1.49	1.19	0.31	0.56	1.78	3.84	H	Median	0.31		
		Turbidity (NTU)	289	0.79	0.66	0.34	0.47	0.93	1.48	H	Median	0.6		
		PN (µg L⁻¹)	9	21.77	16.29	11.12	13.26	32.28	38.04	H	Median	14	16	25
		PO_4 (µg L⁻¹)	9	2.34	1.78	0.68	1.38	3.19	4.96	H	Median	2		
		POC (mg L⁻¹)	9	123	108	69	83	162	185					
		PP (µg L⁻¹)	9	2.24	2.30	1.42	2.03	2.58	2.82	H	Median	2	2.3	3.3
		Secchi (m)	9	9.33	8.00	6.40	7.30	12.00	12.00	L	Median	13		
		SiO_4 (mg L⁻¹)	9	186	160	72	104	251	341					
		TSS (mg L⁻¹)	9	0.86	0.81	0.38	0.62	1.24	1.31	H	Median	1.2	1.6	2.4
	Clump Point East (TUL2)	DIN (µg L⁻¹)	10	4.77	4.18	2.29	3.41	5.80	9.01					
		DOC (µg L⁻¹)	10	973	941	858	887	1033	1178					
		DON (µg L⁻¹)	10	83	77	65	66	101	112					
		DOP (µg L⁻¹)	10	7.47	5.88	5.15	5.57	7.85	14.21					
		Chl-a (µg L⁻¹)	10	0.27	0.29	0.12	0.18	0.33	0.40	H	Median	0.3	0.32	0.63
		NO_x (µg L⁻¹)	10	1.62	1.28	0.39	0.44	1.91	4.58	H	Median	0.31		
		PN (µg L⁻¹)	10	23.35	20.44	10.22	12.13	31.61	44.09	H	Median	14	16	25
		PO_4 (µg L⁻¹)	10	2.00	1.78	0.95	1.53	2.66	3.44	H	Median	2		
		POC (mg L⁻¹)	10	144	117	58	71	201	282					
		PP (µg L⁻¹)	10	1.89	1.85	1.45	1.61	2.11	2.56	H	Median	2	2.3	3.3

Region	Site	Measure	N	Mean	Median	Quantiles				Guideline Values				
						Q5	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		Secchi (m)	10	13.28	12.00	7.90	9.60	17.20	20.20	L	Median	13		
		SiO_4 (mg L^{-1})	10	133	128	44	83	178	240					
		TSS (mg L^{-1})	10	1.16	0.86	0.41	0.44	1.88	2.55	H	Median	1.2	1.6	2.4
	Dunk North (TUL3)	DIN (µg L^{-1})	10	5.83	6.09	3.27	4.03	7.71	8.26					
		DOC (µg L^{-1})	10	1035	979	883	924	1101	1328					
		DON (µg L^{-1})	10	79	80	65	69	86	97					
		DOP (µg L^{-1})	10	5.91	5.81	5.05	5.39	6.35	6.95					
		Chl-a (µg L^{-1})	10	0.36	0.39	0.14	0.17	0.48	0.62	H	Mean	0.45		
		Chl-a (µg L^{-1})	10	0.36	0.39	0.14	0.17	0.48	0.62	H	Median		0.32	0.63
		NO_x (µg L^{-1})	10	2.14	2.10	1.07	1.30	2.91	3.36	H	Median	0.35		
		Turbidity (NTU)	280	2.73	1.51	0.92	1.06	3.25	9.51	H	Median	1		
		PN (µg L^{-1})	10	24.71	24.26	13.10	14.39	32.93	40.18	H	Mean	20		
		PN (µg L^{-1})	10	24.71	24.26	13.10	14.39	32.93	40.18	H	Median		16	25
		PO_4 (µg L^{-1})	10	1.78	1.90	0.67	0.93	2.34	2.95	H	Median	2		
		POC (mg L^{-1})	10	161	159	102	112	202	245					
		PP (µg L^{-1})	10	3.06	2.70	1.98	2.28	3.33	5.19	H	Mean	2.8		
		PP (µg L^{-1})	10	3.06	2.70	1.98	2.28	3.33	5.19	H	Median		2.3	3.3
		Secchi (m)	10	6.20	6.50	2.63	4.00	8.20	9.55	L	Mean	10		
		Secchi (m)	10	6.20	6.50	2.63	4.00	8.20	9.55	L	Median			
		SiO_4 (mg L^{-1})	10	214	177	106	111	330	416					
		TSS (mg L^{-1})	10	2.44	1.74	0.88	0.93	2.35	6.90	H	Mean	2		
		TSS (mg L^{-1})	10	2.44	1.74	0.88	0.93	2.35	6.90	H	Median		1.6	2.4
	Dunk Island South East (TUL5)	DIN (µg L^{-1})	10	5.48	6.09	3.12	4.00	6.43	7.71					
		DOC (µg L^{-1})	10	1004	979	840	887	1094	1246					
		DON (µg L^{-1})	10	86	90	63	76	93	101					
		DOP (µg L^{-1})	10	6.74	5.77	5.05	5.26	7.90	10.73					

Region	Site	Measure	N	Mean	Median	Quantiles				Guideline Values				
						Q5	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		Chl-a (µg L⁻¹)	10	0.36	0.38	0.22	0.26	0.43	0.49	H	Mean	0.45		
		Chl-a (µg L⁻¹)	10	0.36	0.38	0.22	0.26	0.43	0.49	H	Median		0.32	0.63
		NO_x (µg L⁻¹)	10	1.70	1.47	0.56	0.92	2.16	3.52	H	Median	0.35		
		PN (µg L⁻¹)	10	22.93	20.96	12.03	12.43	30.90	38.32	H	Mean	20		
		PN (µg L⁻¹)	10	22.93	20.96	12.03	12.43	30.90	38.32	H	Median		16	25
		PO_4 (µg L⁻¹)	10	2.17	1.97	1.47	1.86	2.54	3.18	H	Median	2		
		POC (mg L⁻¹)	10	141	139	76	85	192	232					
		PP (µg L⁻¹)	10	3.07	2.60	1.88	2.05	3.48	5.89	H	Mean	2.8		
		PP (µg L⁻¹)	10	3.07	2.60	1.88	2.05	3.48	5.89	H	Median		2.3	3.3
		Secchi (m)	10	7.85	6.75	3.23	5.50	10.20	14.85	L	Mean	10		
		Secchi (m)	10	7.85	6.75	3.23	5.50	10.20	14.85	L	Median			
		SiO_4 (mg L⁻¹)	10	176	121	87	103	284	331					
		TSS (mg L⁻¹)	10	2.27	1.68	1.05	1.30	3.41	4.14	H	Mean	2		
		TSS (mg L⁻¹)	10	2.27	1.68	1.05	1.30	3.41	4.14	H	Median		1.6	2.4
	Between Tam O'Shanter and Timana (TUL6)	DIN (µg L⁻¹)	10	5.41	5.92	2.67	3.47	7.03	7.88					
		DOC (µg L⁻¹)	10	1145	1075	948	1010	1200	1526					
		DON (µg L⁻¹)	10	93	87	76	79	104	129					
		DOP (µg L⁻¹)	10	6.23	6.04	5.18	5.33	6.53	8.24					
		Chl-a (µg L⁻¹)	10	0.43	0.39	0.23	0.28	0.60	0.66	H	Mean	0.45		
		Chl-a (µg L⁻¹)	10	0.43	0.39	0.23	0.28	0.60	0.66	H	Median		0.32	0.63
		NO_x (µg L⁻¹)	10	1.89	1.10	0.31	0.74	3.52	4.41	H	Median	0.35		
		PN (µg L⁻¹)	10	32.21	31.00	15.36	17.23	47.32	55.13	H	Mean	20		
		PN (µg L⁻¹)	10	32.21	31.00	15.36	17.23	47.32	55.13	H	Median		16	25
		PO_4 (µg L⁻¹)	10	1.55	1.55	0.88	1.39	1.72	2.25	H	Median	2		
		POC (mg L⁻¹)	10	211	195	122	149	287	316					
		PP (µg L⁻¹)	10	4.08	3.73	2.67	2.96	4.70	6.79	H	Mean	2.8		
		PP (µg L⁻¹)	10	4.08	3.73	2.67	2.96	4.70	6.79	H	Median		2.3	3.3

Region	Site	Measure	N	Mean	Median	Quantiles				Guideline Values				
						Q5	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		Secchi (m)	10	4.35	4.50	1.73	2.80	5.70	6.78	L	Mean	10		
		Secchi (m)	10	4.35	4.50	1.73	2.80	5.70	6.78	L	Median			
		SiO_4 (mg L⁻¹)	10	404	316	132	176	606	820					
		TSS (mg L⁻¹)	10	3.15	1.85	0.86	1.46	4.09	8.13	H	Mean	2		
		TSS (mg L⁻¹)	10	3.15	1.85	0.86	1.46	4.09	8.13	H	Median		1.6	2.4
	Bedarra (TUL8)	DIN (µg L⁻¹)	9	4.87	4.62	2.53	3.46	6.33	6.96					
		DOC (µg L⁻¹)	9	1024	1014	908	915	1079	1215					
		DON (µg L⁻¹)	9	81	82	64	68	93	100					
		DOP (µg L⁻¹)	9	5.70	5.81	4.86	5.00	6.29	6.75					
		Chl-a (µg L⁻¹)	9	0.37	0.37	0.17	0.23	0.47	0.61	H	Mean	0.45		
		Chl-a (µg L⁻¹)	9	0.37	0.37	0.17	0.23	0.47	0.61	H	Median		0.32	0.63
		NO_x (µg L⁻¹)	9	1.42	1.19	0.34	0.57	2.46	2.72	H	Median	0.35		
		PN (µg L⁻¹)	9	25.21	22.44	12.54	17.61	30.84	44.19	H	Mean	20		
		PN (µg L⁻¹)	9	25.21	22.44	12.54	17.61	30.84	44.19	H	Median		16	25
		PO_4 (µg L⁻¹)	9	1.67	1.86	0.87	1.38	2.01	2.11	H	Median	2		
		POC (mg L⁻¹)	9	160	154	84	122	177	262					
		PP (µg L⁻¹)	9	3.06	2.89	1.91	2.34	4.00	4.57	H	Mean	2.8		
		PP (µg L⁻¹)	9	3.06	2.89	1.91	2.34	4.00	4.57	H	Median		2.3	3.3
		Secchi (m)	9	5.56	6.00	2.20	3.10	8.00	8.60	L	Mean	10		
		Secchi (m)	9	5.56	6.00	2.20	3.10	8.00	8.60	L	Median			
		SiO_4 (mg L⁻¹)	9	221	153	109	116	279	500					
		TSS (mg L⁻¹)	9	2.06	1.62	0.56	1.11	3.27	4.16	H	Mean	2		
		TSS (mg L⁻¹)	9	2.06	1.62	0.56	1.11	3.27	4.16	H	Median		1.6	2.4
	Tully River mouth mooring (TUL10)	DIN (µg L⁻¹)	10	11.06	5.65	2.23	3.70	18.40	28.45					
		DOC (µg L⁻¹)	10	1229	1160	1014	1041	1386	1610					
		DON (µg L⁻¹)	10	94	91	71	76	101	129					
		DOP (µg L⁻¹)	10	6.70	5.57	4.72	5.23	7.06	11.46					

Region	Site	Measure	N	Mean	Median	Quantiles				Guideline Values				
						Q5	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		Chl-a (µg L^{-1})	10	0.60	0.57	0.31	0.39	0.78	1.00	H	Median	1.1		
		NO_x (µg L^{-1})	10	7.99	3.10	0.59	0.92	14.39	24.30	H	Median	3		
		Turbidity (NTU)	293	4.72	3.51	1.60	2.36	6.83	10.20	H	Median	4		
		PN (µg L^{-1})	10	46.12	43.20	18.06	21.88	70.39	78.50	H	Median			
		PO_4 (µg L^{-1})	10	2.07	1.70	1.27	1.38	2.69	3.51	H	Median	3		
		POC (mg L^{-1})	10	299	284	147	173	415	477					
		PP (µg L^{-1})	10	5.86	5.75	3.44	3.85	7.24	8.91	H	Median			
		Secchi (m)	10	3.70	3.50	1.45	2.40	5.50	6.05	L	Median	1.6		
		SiO_4 (mg L^{-1})	10	758	612	145	316	956	1810					
		TSS (mg L^{-1})	10	4.32	3.02	1.00	1.64	6.90	11.08	H	Median	5		
Burdekin	Palms West (BUR1)	DIN (µg L^{-1})	9	4.65	3.61	1.93	2.74	6.57	9.42					
		DOC (µg L^{-1})	9	1016	1008	873	936	1036	1219					
		DON (µg L^{-1})	9	75	74	60	66	83	91					
		DOP (µg L^{-1})	9	5.90	5.81	5.06	5.34	6.52	6.98					
		Chl-a (µg L^{-1})	9	0.47	0.34	0.17	0.25	0.63	1.06	H	Median	0.35	0.32	0.63
		NO_x (µg L^{-1})	9	1.66	0.95	0.28	0.36	2.63	4.58	H	Median	0.28		
		Turbidity (NTU)	244	0.70	0.55	0.32	0.40	0.81	1.52	H	Median	0.8		
		PN (µg L^{-1})	9	26.82	23.74	10.56	13.76	29.66	59.42	H	Median	12	16	25
		PO_4 (µg L^{-1})	9	1.65	1.70	0.50	1.10	2.25	2.66	H	Median	1		
		POC (mg L^{-1})	9	137	124	61	89	144	263					
		PP (µg L^{-1})	9	2.31	2.08	1.78	1.85	2.79	3.16	H	Median	2.2	2.3	3.3
		Secchi (m)	9	7.96	8.00	6.28	6.76	8.90	9.80	L	Mean	10		
		Secchi (m)	9	7.96	8.00	6.28	6.76	8.90	9.80	L	Median			
		SiO_4 (mg L^{-1})	9	105	91	58	80	134	158					
		TSS (mg L^{-1})	9	0.78	0.73	0.35	0.42	0.94	1.57	H	Median	1.2	1.6	2.4

Region	Site	Measure	N	Mean	Median	Quantiles				Guideline Values				
						Q5	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
	Pandora (BUR2)	DIN (µg L⁻¹)	9	3.83	3.15	2.46	2.77	3.91	6.89					
		DOC (µg L⁻¹)	9	1099	1080	870	978	1208	1396					
		DON (µg L⁻¹)	9	85	76	64	70	95	123					
		DOP (µg L⁻¹)	9	5.78	5.88	4.71	5.22	6.26	6.72					
		Chl-a (µg L⁻¹)	9	0.26	0.23	0.14	0.21	0.33	0.41	H	Median	0.35	0.32	0.63
		NO_x (µg L⁻¹)	9	1.06	0.70	0.29	0.46	1.20	2.98	H	Median	0.28		
		Turbidity (NTU)	292	1.39	1.03	0.54	0.72	1.60	3.49	H	Median	0.8		
		PN (µg L⁻¹)	9	23.69	23.94	12.32	14.85	28.56	39.96	H	Median	12	16	25
		PO_4 (µg L⁻¹)	9	1.63	1.86	0.53	0.71	2.34	2.62	H	Median	1		
		POC (mg L⁻¹)	9	130	124	81	104	143	197					
		PP (µg L⁻¹)	9	2.67	2.61	1.89	2.12	2.76	3.98	H	Median	2.2	2.3	3.3
		Secchi (m)	9	5.72	5.50	2.88	3.72	7.60	10.00	L	Mean	10		
		Secchi (m)	9	5.72	5.50	2.88	3.72	7.60	10.00	L	Median			
		SiO_4 (mg L⁻¹)	9	159	118	63	98	259	296					
		TSS (mg L⁻¹)	9	1.27	1.26	0.53	0.75	1.94	2.02	H	Median	1.2	1.6	2.4
	Magnetic (BUR4)	DIN (µg L⁻¹)	9	5.04	3.92	2.45	2.51	7.31	9.32					
		DOC (µg L⁻¹)	9	1145	1100	995	1025	1299	1340					
		DON (µg L⁻¹)	9	93	92	71	80	95	126					
		DOP (µg L⁻¹)	9	5.76	5.81	4.18	4.55	6.88	7.62					
		Chl-a (µg L⁻¹)	9	0.36	0.40	0.09	0.21	0.50	0.60	H	Median	0.59	0.32	0.63
		NO_x (µg L⁻¹)	9	1.92	1.61	0.49	0.57	3.40	4.30	H	Median	0.28		
		Turbidity (NTU)	226	2.05	1.27	0.70	0.89	2.61	6.61	H	Median	1.3		
		PN (µg L⁻¹)	9	32.06	30.88	16.17	18.77	40.86	53.28	H	Median	17	16	25
		PO_4 (µg L⁻¹)	9	2.18	2.32	1.30	1.49	2.60	3.21	H	Median	1		
		POC (mg L⁻¹)	9	169	164	113	129	215	230					

Region	Site	Measure	N	Mean	Median	Quantiles				Guideline Values				
						Q5	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		PP (µg L⁻¹)	9	3.54	3.32	2.98	3.09	3.95	4.49	H	Mean	2.8		
		PP (µg L⁻¹)	9	3.54	3.32	2.98	3.09	3.95	4.49	H	Median		2.3	3.3
		Secchi (m)	9	4.60	4.80	2.98	3.94	5.20	5.80	L	Median	4		
		SiO_4 (mg L⁻¹)	9	273	213	97	139	434	513					
		TSS (mg L⁻¹)	9	1.47	1.42	1.05	1.16	1.74	2.01	H	Median	1.9	1.6	2.4
	Haughton 2 (BUR7)	DIN (µg L⁻¹)	9	6.50	5.88	2.14	2.77	9.00	12.48					
		DOC (µg L⁻¹)	9	1134	1129	1000	1038	1167	1322					
		DON (µg L⁻¹)	9	89	81	65	74	100	125					
		DOP (µg L⁻¹)	9	6.46	6.35	4.74	4.92	7.25	8.83					
		Chl-a (µg L⁻¹)	9	0.50	0.30	0.24	0.26	0.72	1.18	H	Mean	0.45		
		Chl-a (µg L⁻¹)	9	0.50	0.30	0.24	0.26	0.72	1.18	H	Median		0.32	0.63
		NO_x (µg L⁻¹)	9	2.73	2.91	0.35	0.60	4.42	6.02	H	Median	1		
		PN (µg L⁻¹)	9	36.10	24.37	14.75	15.62	47.46	80.78	H	Median	13	16	25
		PO_4 (µg L⁻¹)	9	2.29	2.01	0.96	1.24	2.69	4.74	H	Median	2		
		POC (mg L⁻¹)	9	191	196	104	111	242	330					
		PP (µg L⁻¹)	9	3.54	3.16	2.48	2.64	3.92	5.47	H	Median	2.1	2.3	3.3
		Secchi (m)	9	4.67	4.00	3.08	3.50	6.16	7.06	L	Mean	10		
		Secchi (m)	9	4.67	4.00	3.08	3.50	6.16	7.06	L	Median			
		SiO_4 (mg L⁻¹)	9	292	165	88	118	460	752					
		TSS (mg L⁻¹)	9	1.88	2.14	0.93	1.22	2.47	2.72	H	Median	1.2	1.6	2.4
	Yongala (BUR10)	DIN (µg L⁻¹)	4	3.72	3.03	2.68	2.84	4.33	5.73					
		DOC (µg L⁻¹)	4	926	923	921	921	930	936					
		DON (µg L⁻¹)	4	62	61	50	54	70	75					
		DOP (µg L⁻¹)	4	5.03	4.92	4.42	4.66	5.36	5.81					
		Chl-a (µg L⁻¹)	4	0.26	0.24	0.17	0.20	0.31	0.39	H	Median	0.33	0.32	0.63
		NO_x (µg L⁻¹)	4	0.94	0.53	0.29	0.30	1.41	2.16	H	Median	0.28		
		PN (µg L⁻¹)	4	12.58	12.31	10.43	10.90	14.15	15.11	H	Median	14	16	25

Region	Site	Measure	N	Mean	Median	Quantiles				Guideline Values				
						Q5	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		PO_4 (µg L⁻¹)	4	1.26	1.28	0.77	0.98	1.55	1.72	H	Median	1		
		POC (mg L⁻¹)	4	92	83	64	73	107	133					
		PP (µg L⁻¹)	4	2.02	1.98	1.64	1.71	2.31	2.46	H	Median	2	2.3	3.3
		Secchi (m)	4	13.13	13.00	11.73	12.40	13.80	14.70	L	Mean	10		
		Secchi (m)	4	13.13	13.00	11.73	12.40	13.80	14.70	L	Median			
		SiO_4 (mg L⁻¹)	4	59.94	52.21	21.43	23.58	93.20	109.26					
		TSS (mg L⁻¹)	4	0.30	0.30	0.25	0.26	0.35	0.36	H	Median	0.8	1.6	2.4
	Burdekin River mouth mooring (BUR13)	DIN (µg L⁻¹)	9	18.03	13.79	3.38	4.66	25.93	50.42					
		DOC (µg L⁻¹)	9	1600	1398	977	1092	1996	2669					
		DON (µg L⁻¹)	9	107	102	63	83	132	138					
		DOP (µg L⁻¹)	9	6.59	6.50	3.65	4.96	6.92	11.34					
		Chl-a (µg L⁻¹)	9	0.70	0.46	0.27	0.36	0.63	1.80	H	Median	1		
		NO_x (µg L⁻¹)	9	10.55	8.61	0.45	0.95	15.35	33.01	H	Median	4		
		Turbidity (NTU)	290	9.20	7.14	2.45	3.58	13.57	23.11	H	Median	4		
		PN (µg L⁻¹)	9	48.55	34.24	17.26	21.76	68.71	106.71	H	Mean			
		PN (µg L⁻¹)	9	48.55	34.24	17.26	21.76	68.71	106.71	H	Median			
		PO_4 (µg L⁻¹)	9	6.09	3.25	1.94	2.03	10.55	15.38	H	Median	1		
		POC (mg L⁻¹)	9	276	243	127	168	392	504					
		PP (µg L⁻¹)	9	6.90	7.78	3.11	4.07	8.93	10.22	H	Median			
		Secchi (m)	9	2.28	1.70	0.58	1.00	2.92	5.80	L	Median	1.5		
		SiO_4 (mg L⁻¹)	9	1033	495	142	172	1903	2814					
		TSS (mg L⁻¹)	9	8.64	5.43	2.10	2.25	14.39	19.75	H	Median	2		
Mackay Whitsunday	Double Cone (WHI1)	DIN (µg L⁻¹)	5	2.74	3.05	1.25	1.44	3.50	4.45					
		DOC (µg L⁻¹)	5	898	869	852	859	920	990					
		DON (µg L⁻¹)	5	67	67	56	58	71	81					
		DOP (µg L⁻¹)	5	5.05	4.88	4.68	4.77	5.11	5.81					

Region	Site	Measure	N	Mean	Median	Quantiles				Guideline Values				
						Q5	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		Chl-a (µg L⁻¹)	5	0.32	0.31	0.20	0.27	0.41	0.42	H	Median	0.36	0.32	0.63
		NO_x (µg L⁻¹)	5	0.97	0.74	0.32	0.42	1.49	1.87	H	Median	1		
		Turbidity (NTU)	289	1.38	1.16	0.69	0.91	1.78	2.55	H	Median	1.1		
		PN (µg L⁻¹)	5	16.03	15.72	10.64	13.26	20.09	20.43	H	Mean	14		
		PN (µg L⁻¹)	5	16.03	15.72	10.64	13.26	20.09	20.43	H	Median		16	25
		PO_4 (µg L⁻¹)	5	1.49	1.55	0.46	0.93	1.92	2.57	H	Median	1		
		POC (mg L⁻¹)	5	125	119	72	92	166	174					
		PP (µg L⁻¹)	5	2.59	2.76	1.85	2.26	2.92	3.14	H	Median	2.3	2.3	3.3
		Secchi (m)	5	7.00	7.50	4.10	4.40	8.60	10.40	L	Mean	10		
		Secchi (m)	5	7.00	7.50	4.10	4.40	8.60	10.40	L	Median			
		SiO_4 (mg L⁻¹)	5	81	77	64	69	95	99					
		TSS (mg L⁻¹)	5	1.44	1.26	0.74	0.92	1.74	2.52	H	Median	1.4	1.6	2.4
	Pine (WHI4)	DIN (µg L⁻¹)	5	4.89	4.03	1.86	3.33	7.16	8.06					
		DOC (µg L⁻¹)	5	952	953	882	911	984	1030					
		DON (µg L⁻¹)	5	70	68	60	63	76	82					
		DOP (µg L⁻¹)	5	4.97	4.49	4.34	4.34	5.50	6.19					
		Chl-a (µg L⁻¹)	5	0.39	0.39	0.34	0.36	0.42	0.46	H	Median	0.36	0.32	0.63
		NO_x (µg L⁻¹)	5	2.26	1.65	0.35	0.56	4.19	4.56	H	Median	1		
		Turbidity (NTU)	172	2.46	2.01	0.72	1.04	3.33	6.09	H	Median	1.1		
		PN (µg L⁻¹)	5	14.26	14.04	11.07	12.04	15.37	18.76	H	Mean	14		
		PN (µg L⁻¹)	5	14.26	14.04	11.07	12.04	15.37	18.76	H	Median		16	25
		PO_4 (µg L⁻¹)	5	2.51	2.56	1.95	2.00	2.79	3.25	H	Median	1		
		POC (mg L⁻¹)	5	109	111	64	70	137	161					
		PP (µg L⁻¹)	5	2.77	2.95	2.26	2.31	3.06	3.28	H	Median	2.3	2.3	3.3
		Secchi (m)	5	5.00	5.00	2.60	4.40	5.90	7.10	L	Mean	10		

Region	Site	Measure	N	Mean	Median	Quantiles				Guideline Values				
						Q5	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		Secchi (m)	5	5.00	5.00	2.60	4.40	5.90	7.10	L	Median			
		SiO_4 (mg L^{-1})	5	94	87	75	76	103	131					
		TSS (mg L^{-1})	5	1.89	1.59	1.33	1.46	2.16	2.92	H	Median	1.4	1.6	2.4
	Seaforth (WHI5)	DIN (µg L^{-1})	5	3.48	2.87	2.01	2.47	4.11	5.94					
		DOC (µg L^{-1})	5	948	963	880	909	982	1005					
		DON (µg L^{-1})	5	71	65	59	64	80	84					
		DOP (µg L^{-1})	5	5.33	5.11	4.71	4.89	5.92	6.01					
		Chl-a (µg L^{-1})	5	0.38	0.40	0.30	0.34	0.42	0.44	H	Median	0.36	0.32	0.63
		NO_x (µg L^{-1})	5	1.13	0.98	0.56	0.67	1.32	2.11	H	Median	1		
		Turbidity (NTU)	232	1.69	1.47	0.90	1.09	2.20	3.07	H	Median	1.1		
		PN (µg L^{-1})	5	13.49	13.84	11.83	12.51	14.43	14.84	H	Mean	14		
		PN (µg L^{-1})	5	13.49	13.84	11.83	12.51	14.43	14.84	H	Median		16	25
		PO_4 (µg L^{-1})	5	2.14	2.25	1.36	1.50	2.46	3.11	H	Median	1		
		POC (mg L^{-1})	5	106	118	85	89	118	119					
		PP (µg L^{-1})	5	2.74	2.49	2.33	2.41	2.85	3.62	H	Median	2.3	2.3	3.3
		Secchi (m)	5	5.90	7.00	3.70	4.30	7.10	7.40	L	Mean	10		
		Secchi (m)	5	5.90	7.00	3.70	4.30	7.10	7.40	L	Median			
		SiO_4 (mg L^{-1})	5	95.06	96.84	73.83	79.19	110.90	114.52					
		TSS (mg L^{-1})	5	2.13	1.54	1.00	1.01	2.57	4.54	H	Median	1.4	1.6	2.4
	OConnell River mouth (WHI6)	DIN (µg L^{-1})	5	5.60	3.22	1.56	2.15	7.22	13.85					
		DOC (µg L^{-1})	5	1137	1151	999	1028	1218	1289					
		DON (µg L^{-1})	5	89	89	67	73	98	118					
		DOP (µg L^{-1})	5	5.90	5.42	5.14	5.23	6.83	6.88					
		Chl-a (µg L^{-1})	5	0.60	0.73	0.22	0.38	0.80	0.88	H	Median	1.3		
		NO_x (µg L^{-1})	5	1.81	0.67	0.28	0.28	2.56	5.29	H	Median	4		

Region	Site	Measure	N	Mean	Median	Quantiles				Guideline Values				
						Q5	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		Turbidity (NTU)	205	6.49	4.35	1.52	2.44	10.00	18.77	H	Median	4		
		PN (µg L^{-1})	5	33.34	36.04	15.94	26.14	43.52	45.07	H	Mean			
		PN (µg L^{-1})	5	33.34	36.04	15.94	26.14	43.52	45.07	H	Median			
		PO_4 (µg L^{-1})	5	3.64	3.87	0.99	3.04	5.08	5.22	H	Median	3		
		POC (mg L^{-1})	5	275	257	117	210	344	446					
		PP (µg L^{-1})	5	6.65	6.85	3.26	5.01	8.26	9.88	H	Median			
		Secchi (m)	5	3.70	3.00	2.10	2.40	4.60	6.40	L	Median	1.6		
		SiO_4 (mg L^{-1})	5	240	227	125	162	306	380					
		TSS (mg L^{-1})	5	4.18	3.75	0.95	1.37	5.32	9.48	H	Median	5		
	Repulse Islands dive mooring (WHI7)	DIN (µg L^{-1})	5	3.99	3.89	2.29	3.07	4.85	5.86					
		DOC (µg L^{-1})	5	1011	982	889	938	1087	1158					
		DON (µg L^{-1})	5	73	71	62	66	80	88					
		DOP (µg L^{-1})	5	5.22	4.96	4.65	4.65	5.62	6.22					
		Chl-a (µg L^{-1})	5	0.45	0.43	0.27	0.27	0.59	0.71	H	Mean	0.45		
		Chl-a (µg L^{-1})	5	0.45	0.43	0.27	0.27	0.59	0.71	H	Median		0.32	0.63
		NO_x (µg L^{-1})	5	0.95	0.70	0.36	0.59	1.14	1.94	H	Median	0.25		
		PN (µg L^{-1})	5	19.56	20.20	14.18	16.09	23.32	24.02	H	Median	18	16	25
		PO_4 (µg L^{-1})	5	2.76	2.79	1.98	2.12	3.33	3.56	H	Median	2		
		POC (mg L^{-1})	5	177	181	109	126	234	235					
		PP (µg L^{-1})	5	4.77	3.75	3.16	3.57	6.45	6.91	H	Median	2.1	2.3	3.3
		Secchi (m)	5	4.00	4.50	2.10	2.40	5.20	5.80	L	Mean	10		
		Secchi (m)	5	4.00	4.50	2.10	2.40	5.20	5.80	L	Median			
		SiO_4 (mg L^{-1})	5	131	111	83	88	153	220					
		TSS (mg L^{-1})	5	4.44	2.42	1.97	1.99	6.82	9.01	H	Median	1.6	1.6	2.4
Fitzroy	North Keppel	DIN (µg L^{-1})	8	4.70	4.64	2.90	3.59	5.73	6.73					
		DOC (µg L^{-1})	8	1084	1032	962	998	1183	1253					

Region	Site	Measure	N	Mean	Median	Quantiles				Guideline Values				
						Q5	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
	Island (FTZ4)	DON (µg L⁻¹)	8	65	62	59	61	69	79					
		DOP (µg L⁻¹)	8	5.12	5.31	3.85	4.10	5.85	6.34					
		Chl-a (µg L⁻¹)	8	0.23	0.21	0.16	0.17	0.24	0.40	H	Mean	0.45		
		Chl-a (µg L⁻¹)	8	0.23	0.21	0.16	0.17	0.24	0.40	H	Median		0.32	0.63
		NO_x (µg L⁻¹)	8	0.77	0.77	0.42	0.60	0.97	1.07	H	Median	0.5		
		PN (µg L⁻¹)	8	14.17	12.68	11.05	11.74	16.55	19.27	H	Median	15	16	25
		PO_4 (µg L⁻¹)	8	1.41	1.51	0.81	1.38	1.63	1.70	H	Median	2		
		POC (mg L⁻¹)	8	102	86	65	68	137	160					
		PP (µg L⁻¹)	8	2.29	2.16	1.45	1.60	2.72	3.65	H	Median	2.5	2.3	3.3
		Secchi (m)	8	9.25	10.00	4.85	6.10	11.60	13.30	L	Median	10		
		SiO_4 (mg L⁻¹)	8	69.58	68.64	54.10	66.69	74.94	84.20					
		TSS (mg L⁻¹)	8	0.99	0.59	0.16	0.31	1.73	2.60	H	Median	1	1.6	2.4
	Barren (FTZ1)	DIN (µg L⁻¹)	8	5.05	5.01	3.64	4.06	5.75	6.76					
		DOC (µg L⁻¹)	8	1073	1066	988	1005	1130	1171					
		DON (µg L⁻¹)	8	66	64	57	61	72	79					
		DOP (µg L⁻¹)	8	5.28	4.88	4.13	4.27	6.06	7.23					
		Chl-a (µg L⁻¹)	8	0.17	0.17	0.13	0.14	0.20	0.22	H	Median	0.27	0.32	0.63
		NO_x (µg L⁻¹)	8	1.01	0.88	0.43	0.67	1.05	2.05	H	Median	0.5		
		Turbidity (NTU)	285	0.31	0.25	0.04	0.13	0.41	0.77	H	Median	0.3		
		PN (µg L⁻¹)	8	12.19	11.89	10.42	11.39	12.87	14.50	H	Median	12	16	25
		PO_4 (µg L⁻¹)	8	1.27	1.39	0.70	0.91	1.51	1.75	H	Median	2		
		POC (mg L⁻¹)	8	85	75	65	69	101	127					
		PP (µg L⁻¹)	8	1.82	1.82	1.27	1.51	1.95	2.49	H	Median	1.9	2.4	3.4
		Secchi (m)	8	11.38	11.00	7.70	9.40	13.20	15.95	L	Median	12		
		SiO_4 (mg L⁻¹)	8	57.58	57.94	41.57	44.31	70.63	74.08					
		TSS (mg L⁻¹)	8	0.52	0.25	0.17	0.18	0.47	1.60	H	Median	0.4	1.7	2.5

Region	Site	Measure	N	Mean	Median	Quantiles				Guideline Values				
						Q5	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
	Keppels South (FTZ2)	DIN (µg L^{-1})	8	5.16	4.25	3.26	3.55	6.27	8.82					
		DOC (µg L^{-1})	8	1071	1102	931	1018	1127	1177					
		DON (µg L^{-1})	8	65	62	57	59	72	77					
		DOP (µg L^{-1})	8	5.14	5.19	4.21	4.35	5.74	6.26					
		Chl-a (µg L^{-1})	8	0.23	0.19	0.16	0.17	0.27	0.38	H	Mean	0.45		
		Chl-a (µg L^{-1})	8	0.23	0.19	0.16	0.17	0.27	0.38	H	Median		0.32	0.63
		NO_x (µg L^{-1})	8	0.76	0.67	0.30	0.42	0.87	1.55	H	Median	0.5		
		Turbidity (NTU)	285	0.80	0.51	0.31	0.37	1.12	2.23	H	Mean	1.5		
		Turbidity (NTU)	285	0.80	0.51	0.31	0.37	1.12	2.23	H	Median			
		PN (µg L^{-1})	8	14.10	12.79	11.91	12.34	15.73	18.19	H	Mean	20		
		PN (µg L^{-1})	8	14.10	12.79	11.91	12.34	15.73	18.19	H	Median		16	25
		PO_4 (µg L^{-1})	8	1.30	1.39	0.68	1.02	1.63	1.68	H	Mean	2		
		PO_4 (µg L^{-1})	8	1.30	1.39	0.68	1.02	1.63	1.68	H	Median			
		POC (mg L^{-1})	8	100	87	70	76	122	159					
		PP (µg L^{-1})	8	2.26	2.12	1.73	1.91	2.52	3.07	H	Mean	2.8		
		PP (µg L^{-1})	8	2.26	2.12	1.73	1.91	2.52	3.07	H	Median		2.4	3.4
		Secchi (m)	8	9.25	10.00	5.38	7.00	11.40	12.65	L	Mean	10		
		Secchi (m)	8	9.25	10.00	5.38	7.00	11.40	12.65	L	Median			
		SiO_4 (mg L^{-1})	8	67	66	48	65	71	83					
		TSS (mg L^{-1})	8	0.64	0.52	0.23	0.35	0.73	1.39	H	Mean	2		
		TSS (mg L^{-1})	8	0.64	0.52	0.23	0.35	0.73	1.39	H	Median		1.7	2.5
	Pelican (FTZ3)	DIN (µg L^{-1})	8	5.08	4.32	2.43	2.80	7.00	9.46					
		DOC (µg L^{-1})	8	1174	1159	1004	1078	1285	1349					
		DON (µg L^{-1})	8	73	70	60	66	85	88					
		DOP (µg L^{-1})	8	5.65	4.99	4.31	4.48	6.27	8.65					

Region	Site	Measure	N	Mean	Median	Quantiles				Guideline Values				
						Q5	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		Chl-a (µg L^{-1})	8	0.34	0.28	0.15	0.19	0.50	0.61	H	Mean	0.45		
		Chl-a (µg L^{-1})	8	0.34	0.28	0.15	0.19	0.50	0.61	H	Median		0.32	0.63
		NO_x (µg L^{-1})	8	0.75	0.70	0.39	0.53	0.88	1.25	H	Median	0.5		
		PN (µg L^{-1})	8	16.53	18.01	10.47	11.02	20.28	22.66	H	Mean	20		
		PN (µg L^{-1})	8	16.53	18.01	10.47	11.02	20.28	22.66	H	Median		16	25
		PO_4 (µg L^{-1})	8	3.75	3.95	2.61	2.74	4.38	4.97	H	Mean	2		
		PO_4 (µg L^{-1})	8	3.75	3.95	2.61	2.74	4.38	4.97	H	Median			
		POC (mg L^{-1})	8	130	128	57	64	186	223					
		PP (µg L^{-1})	8	3.70	3.48	1.60	2.45	5.02	6.55	H	Mean	2.8		
		PP (µg L^{-1})	8	3.70	3.48	1.60	2.45	5.02	6.55	H	Median		2.4	3.4
		Secchi (m)	8	4.31	3.75	2.00	2.40	5.20	8.60	L	Mean	10		
		Secchi (m)	8	4.31	3.75	2.00	2.40	5.20	8.60	L	Median			
		SiO_4 (mg L^{-1})	8	142	155	81	100	177	193					
		TSS (mg L^{-1})	8	2.71	1.82	0.59	1.18	4.39	6.55	H	Mean	2		
		TSS (mg L^{-1})	8	2.71	1.82	0.59	1.18	4.39	6.55	H	Median		1.7	2.5
	Peak West (FTZ5)	DIN (µg L^{-1})	8	5.31	5.69	2.68	3.11	7.13	7.57					
		DOC (µg L^{-1})	8	1192	1178	988	1097	1318	1397					
		DON (µg L^{-1})	8	79	79	66	73	87	89					
		DOP (µg L^{-1})	8	6.16	4.99	4.21	4.48	6.83	11.04					
		Chl-a (µg L^{-1})	8	0.37	0.34	0.21	0.25	0.49	0.60	H	Mean	0.45		
		Chl-a (µg L^{-1})	8	0.37	0.34	0.21	0.25	0.49	0.60	H	Median		0.32	0.63
		NO_x (µg L^{-1})	8	1.11	0.89	0.50	0.55	1.36	2.33	H	Median	0.5		
		PN (µg L^{-1})	8	16.56	16.72	12.34	12.57	19.13	22.42	H	Mean	20		
		PN (µg L^{-1})	8	16.56	16.72	12.34	12.57	19.13	22.42	H	Median		16	25
		PO_4 (µg L^{-1})	8	4.28	3.91	2.19	3.07	5.61	6.95	H	Median	2		
		POC (mg L^{-1})	8	122	113	75	78	158	193					
		PP (µg L^{-1})	8	4.02	4.46	1.97	2.76	4.83	5.73	H	Mean	2.8		

Region	Site	Measure	N	Mean	Median	Quantiles				Guideline Values				
						Q5	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		PP (µg L^{-1})	8	4.02	4.46	1.97	2.76	4.83	5.73	H	Median		2.4	3.4
		Secchi (m)	8	3.44	2.75	2.18	2.50	4.60	5.65	L	Mean	10		
		Secchi (m)	8	3.44	2.75	2.18	2.50	4.60	5.65	L	Median			
		SiO_4 (mg L^{-1})	8	135	112	82	99	193	201					
		TSS (mg L^{-1})	8	3.20	3.05	0.90	1.21	4.31	6.44	H	Mean	2		
		TSS (mg L^{-1})	8	3.20	3.05	0.90	1.21	4.31	6.44	H	Median		1.7	2.5
	Fitzroy River Mouth (FTZ6)	DIN (µg L^{-1})	8	24.79	7.67	5.37	5.73	51.25	75.82					
		DOC (µg L^{-1})	8	1599	1380	1125	1162	2131	2371					
		DON (µg L^{-1})	8	98	95	73	80	122	126					
		DOP (µg L^{-1})	8	5.69	4.96	3.98	4.55	5.73	9.46					
		Chl-a (µg L^{-1})	8	0.67	0.64	0.27	0.37	0.95	1.22	H	Median	1		
		NO_x (µg L^{-1})	8	19.34	2.71	0.99	1.57	42.84	67.90	H	Median	3		
		Turbidity (NTU)	203	14.94	10.21	3.05	5.78	22.22	38.96	H	Median		7	15
		PN (µg L^{-1})	8	27.54	23.56	13.84	18.07	32.54	48.97	H	Median			
		PO_4 (µg L^{-1})	8	13.93	8.59	3.50	4.78	24.56	34.47	H	Median	3		
		POC (mg L^{-1})	8	269	180	108	132	330	608					
		PP (µg L^{-1})	8	7.63	6.52	2.72	4.44	8.36	15.85	H	Median			
		Secchi (m)	8	1.43	1.50	0.68	1.10	1.62	2.22	L	Median			
		SiO_4 (mg L^{-1})	8	475	169	113	128	965	1220					
		TSS (mg L^{-1})	8	12.71	5.52	2.32	3.09	17.76	37.38	H	Median			

Table C - 2: Summary of turbidity measurements from moored loggers (site locations in Section 5 and Figure D - 1 for the past three water years. N = number of daily means in the time-series; SE = standard error; '% d> Trigger' refers to the percentage of days each year with mean or median values above the site-specific water quality guideline values (Table C - 9). Red shading indicates the annual means or medians that exceeded guideline values. '% 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.

Subregion	Site	Oct 2020 - Sept 2021						Oct 2021 - Sept 2022						Oct 2022 - Sept 2023					
		N	Annual Mean	SE	Annual Median	%d > Trigger	%d > 5 NTU	N	Annual Mean	SE	Annual Median	%d > Trigger	%d > 5 NTU	N	Annual Mean	SE	Annual Median	%d > Trigger	%d > 5 NTU
Cape York	Dawson	225	1.39	0.15	0.64	41.78	3.56	253	1.11	0.08	0.64	37.15	1.98	136	1.00	0.13	0.60	59	6
	Forrester	222	0.31	0.01	0.25	3.60	0.00	224	0.37	0.01	0.29	14.73	0.00	100	0.28	0.01	0.24	1	0
Johnstone Russell Mulgrave	Fitzroy West	118	1.28	0.05	1.10	67.80	0.00	235	0.94	0.05	0.79	27.66	0.85	194	1.27	0.05	1.08	55.15	0.52
	High West	365	1.44	0.09	1.00	49.32	3.56	365	0.91	0.03	0.84	33.70	0.00	88	0.92	0.05	0.81	30.68	0.00
	Russell Mulgrave Mouth Mooring	365	3.99	0.24	2.43	90.68	22.19	250	4.91	0.25	3.73	98.00	39.20	189	5.02	0.28	3.67	100.00	32.80
	Franklands West	282	1.04	0.15	0.63	56.38	1.77	364	0.77	0.03	0.65	60.99	0.00	258	0.81	0.04	0.67	59.30	0.78
Tully Herbert	Dunk North	215	3.38	0.24	1.87	89.30	20.47	365	2.40	0.15	1.37	78.90	10.68	248	2.85	0.21	1.59	86.29	14.11
	Tully River mouth mooring	364	4.26	0.26	2.97	35.44	26.37	365	4.88	0.18	4.00	50.14	33.70	261	4.79	0.21	3.51	44.06	36.02
Burdekin	Palms West	365	0.93	0.03	0.85	56.44	0.27	326	0.69	0.02	0.63	19.63	0.31	232	0.69	0.04	0.53	18.97	0.43
	Pandora	226	1.90	0.12	1.23	87.17	7.52	365	1.34	0.06	1.05	71.51	2.19	260	1.38	0.08	1.01	70.00	2.69
	Magnetic	365	2.11	0.14	1.32	51.51	6.85	365	1.89	0.12	1.12	38.63	6.30	194	2.06	0.15	1.23	47.42	9.79
	Burdekin River mouth mooring	301	7.71	0.36	5.95	63.79	55.81	352	8.80	0.37	6.68	71.88	60.51	258	9.31	0.42	7.39	74.42	63.18
Mackay Whitsunday	Double Cone	365	1.43	0.04	1.15	54.25	1.10	364	1.31	0.03	1.19	57.14	0.27	257	1.37	0.04	1.16	57.59	0.00
	Pine	281	2.28	0.10	1.63	77.58	8.54	365	2.25	0.09	1.70	72.88	8.49	142	2.66	0.16	2.20	80.28	12.68
	Seaforth	292	1.62	0.05	1.28	64.38	0.68	276	1.63	0.04	1.47	75.00	0.00	231	1.69	0.05	1.48	79.22	0.43
	OConnell River mouth	236	4.98	0.32	3.07	37.71	29.24	285	5.54	0.33	3.38	40.70	29.82	204	6.50	0.39	4.38	54.41	43.63
	Repulse Islands dive mooring	130	4.56	0.27	3.46	78.46	36.15												

Subregion	Site	Oct 2020 - Sept 2021						Oct 2021 - Sept 2022						Oct 2022 - Sept 2023					
		N	Annual Mean	SE	Annual Median	%d > Trigger	%d > 5 NTU	N	Annual Mean	SE	Annual Median	%d > Trigger	%d > 5 NTU	N	Annual Mean	SE	Annual Median	%d > Trigger	%d > 5 NTU
Fitzroy	Barren	17	0.66	0.19	0.52	100.00	0.00	365	0.57	0.03	0.40	70.14	0.00	253	0.30	0.02	0.25	32.41	0.00
	Keppels South	238	0.90	0.04	0.67	11.76	0.42	307	0.90	0.05	0.57	15.31	0.33	253	0.85	0.05	0.56	14.62	0.40
	Fitzroy River Mouth	223	19.42	0.78	17.61		92.83	332	21.92	0.92	16.01		93.07	202	14.98	0.91	10.23		84.16

C-4 Data used to generate remote sensing maps

Table C - 3: Summary of water quality data collected across the Sentinel-3 Reef water types (WT) as part of the wet season event sampling of the MMP. Multi-year samples were collected between December–April by AIMS and CYWP since 2016–17 and by JCU since 2003–04 and up to 2022–23.

Reef region	Multi-year		TSS (mg L^{-1})	Chl-*a* (µg L^{-1})	CDOM (m^{-1})	SDD (m)	DIN (µg L^{-1})	DIP (µg L^{-1})	PP (µg L^{-1})	PN (µg L^{-1})
	WT1	mean	17.40	1.45	0.86	2.11	31.60	8.74	11.60	76.90
		SD	44.10	2.21	0.99	2.12	44.40	11.90	20.60	82.60
		min	0.00	0.07	0.00	0.00	0.24	0.00	0.00	0.00
		max	590.00	30.90	6.17	16.00	338.00	98.00	186.28	719.00
		count	935	935	789	501	878	895	259	248
	WT2	mean	4.63	0.65	0.25	4.61	12.10	4.40	3.75	37.50
		SD	7.00	0.75	0.41	2.77	23.50	5.22	4.01	23.40
		min	0.00	0.02	0.00	0.20	0.12	0.00	0.00	0.00
		max	130.00	12.50	3.50	17.00	363.00	63.00	58.00	210.50
		count	1383	1414	1116	932	1384	1401	611	602
	WT3	mean	2.35	0.37	0.09	8.22	6.51	2.76	2.46	28.30
		SD	3.94	0.40	0.18	4.14	10.50	3.24	3.80	21.30
		min	0.00	0.02	0.00	0.50	0.12	0.31	0.00	0.00
		max	31.00	5.34	2.00	22.00	77.00	21.00	49.00	268.00
		count	623	639	457	418	581	585	338	329
	WT4	mean	1.78	0.53	0.12	11.00	8.81	4.24	2.37	28.50
		SD	3.55	0.86	0.20	4.76	10.70	4.84	2.52	19.40

Multi-year			TSS (mg L^{-1})	Chl-*a* (µg L^{-1})	CDOM (m^{-1})	SDD (m)	DIN (µg L^{-1})	DIP (µg L^{-1})	PP (µg L^{-1})	PN (µg L^{-1})
		min	0.00	0.02	0.00	0.50	0.14	0.31	0.77	8.36
		max	30.00	5.34	1.25	20.00	63.00	20.00	15.30	119.24
		count	93	101	58	54	83	84	44	42

Table C - 4: Summary of water quality data collected in the Cape York region across the Sentinel-3 Reef water types (WT) as part of the wet season event sampling of the MMP. Multi-year samples were collected between December and April by CYWP since 2016–17 and up to 2022–23.

Region	Multi-year		TSS (mg L^{-1})	Chl-*a* (µg L^{-1})	CDOM (m^{-1})	SDD (m)	DIN (µg L^{-1})	DIP (µg L^{-1})	PP (µg L^{-1})	PN (µg L^{-1})
Cape York	WT1	mean	20.36	1.10	1.65	2.21	13.37	3.49	10.66	85.03
		SD	44.13	1.13	1.59	2.23	14.64	2.58	12.64	87.21
		min	0.00	0.08	0.00	0.10	0.28	0.00	0.00	0.00
		max	320.00	8.82	6.17	12.00	73.14	13.32	68.00	563.78
		count	208	218	160	157	214	218	102	80
	WT2	mean	3.33	0.45	0.39	5.04	5.00	1.95	3.69	31.94
		SD	5.61	0.47	0.64	2.93	7.85	1.47	6.11	21.15
		min	0.00	0.04	0.00	0.20	0.28	0.31	0.00	8.84
		max	60.00	3.26	3.50	16.00	76.86	8.00	58.00	144.93
		count	295	301	180	225	301	301	188	170
	WT3	mean	1.53	0.27	0.08	8.54	3.64	1.67	2.47	22.18
		SD	2.00	0.31	0.24	3.81	6.99	1.46	5.83	12.89
		min	0.05	0.02	0.00	0.65	0.28	0.31	0.00	8.84
		max	14.00	1.95	2.00	17.50	68.00	7.14	49.00	76.71
		count	176	181	109	126	178	178	120	111
	WT4	mean	1.43	0.22	0.03	10.35	8.20	3.00	1.63	20.75
		SD	0.80	0.35	0.05	6.15	7.11	1.50	1.34	7.23
		min	0.41	0.02	0.00	2.50	0.28	0.31	0.77	13.84
		max	2.66	1.28	0.10	19.40	18.14	5.56	4.00	27.86
		count	13	13	4	8	13	13	5	4

Table C - 5: Summary of water quality data collected in the Wet Tropics region across the Sentinel-3 Reef water types (WT) as part of the wet season event sampling of the MMP. Samples were collected between December and April by AIMS since 2016–17 and JCU since 2003–04 and up to and up to 2022–23.

	Multi-year		TSS (mg L^{-1})	Chl-*a* (µg L^{-1})	CDOM (m^{-1})	SDD (m)	DIN (µg L^{-1})	DIP (µg L^{-1})	PP (µg L^{-1})	PN (µg L^{-1})
Wet Tropics	WT1	mean	8.66	1.27	0.64	2.05	45.66	7.13	8.86	53.22
		SD	9.71	1.84	0.51	2.13	57.32	5.12	8.50	29.84
		min	0.00	0.08	0.00	0.00	0.24	0.00	1.25	12.84
		max	92.00	30.90	3.56	14.00	338.00	21.00	40.86	173.71
		count	406	399	388	185	356	356	57	58
	WT2	mean	4.23	0.67	0.27	4.80	17.07	4.87	3.44	37.66
		SD	4.91	0.65	0.39	2.87	31.34	4.60	2.33	23.05
		min	0.00	0.02	0.00	0.50	0.12	0.00	0.53	7.74
		max	33.00	11.24	2.74	17.00	363.00	22.00	19.52	210.50
		count	623	637	574	400	611	615	228	229
	WT3	mean	2.84	0.42	0.11	8.77	9.23	3.28	2.34	28.46
		SD	4.79	0.49	0.16	4.53	13.20	3.60	1.72	13.68
		min	0.00	0.02	0.00	0.50	0.12	0.31	0.66	0.00
		max	31.00	5.34	1.38	22.00	77.00	21.00	13.53	100.19
		count	289	296	239	203	273	274	143	143
	WT4	mean	2.07	0.43	0.17	10.99	10.42	3.25	3.06	27.07
		SD	2.57	0.61	0.25	4.47	14.31	3.05	3.59	14.40
		min	0.01	0.10	0.00	1.30	0.14	0.31	0.93	8.36
		max	11.94	3.42	1.25	19.00	63.00	12.00	15.29	54.91
		count	33	35	29	25	33	33	19	19

Table C - 6: Summary of water quality data collected in the Burdekin region across the Sentinel-3 Reef water types (WT) as part of the wet season event sampling of the MMP. Multi-years samples were collected between December and April by AIMS since 2016–17 and JCU since 2003–04 and up to 2022–23.

	Multi-year		TSS (mg L^{-1})	Chl-*a* (µg L^{-1})	CDOM (m^{-1})	SDD (m)	DIN (µg L^{-1})	DIP (µg L^{-1})	PP (µg L^{-1})	PN (µg L^{-1})
Burdekin	WT1	mean	32.00	1.43	0.66	2.03	24.28	6.78	18.43	98.16
		SD	83.22	1.84	0.84	2.23	37.50	6.92	36.89	113.01
		min	0.05	0.10	0.00	0.00	0.28	0.31	1.27	15.23
		max	590.00	13.78	3.48	16.00	323.00	46.00	186.28	719.00
		count	157	156	113	102	151	155	63	73
	WS2	mean	3.99	0.66	0.13	3.98	9.22	3.34	3.92	46.03
		SD	8.47	0.82	0.25	2.30	17.98	3.64	3.33	29.68
		min	0.05	0.07	0.00	0.20	0.12	0.31	0.97	0.00
		max	130.00	8.69	2.03	16.00	223.38	27.90	26.35	182.88
		count	258	260	194	202	258	260	99	106
	WS3	mean	2.47	0.37	0.08	6.16	5.38	3.11	2.62	36.03
		SD	2.71	0.22	0.15	3.41	5.86	3.42	3.06	41.72
		min	0.05	0.08	0.00	1.00	0.14	0.31	0.91	0.00
		max	16.00	1.14	1.11	17.00	31.00	20.00	20.57	268.00
		count	97	96	71	61	81	82	40	40
	WS4	mean	1.77	0.34	0.06	11.21	4.38	2.45	1.90	31.46
		SD	5.35	0.38	0.09	4.76	5.37	2.96	0.95	24.87
		min	0.00	0.10	0.00	0.50	0.14	0.31	0.95	11.14
		max	30.00	2.20	0.33	20.00	19.00	9.00	4.64	119.24
		count	33	39	23	21	28	29	20	19

Table C - 7: Summary of water quality data collected in the Mackay-Whitsunday region across the Sentinel-3 Reef water types (WT) as part of the wet season event sampling of the MMP. Multi-year samples were collected between December and April by AIMS since 2016–17 and JCU since 2003–04 and up to 2022–23.

Region	Multi-year		TSS (mg L^{-1})	Chl-*a* (µg L^{-1})	CDOM (m^{-1})	SDD (m)	DIN (µg L^{-1})	DIP (µg L^{-1})	PP (µg L^{-1})	PN (µg L^{-1})
Mackay-Whitsundays	WT1	mean	12.44	1.26	0.45	1.88	21.12	10.89	6.85	62.20
		SD	20.59	1.22	0.56	1.41	16.50	7.43	2.56	26.91
		min	0.57	0.07	0.03	0.20	0.28	0.31	2.85	27.24
		max	110.00	6.78	2.60	6.00	68.04	36.23	12.35	115.28
		count	45	42	43	28	45	45	20	20
	WT2	mean	5.44	0.82	0.14	3.42	10.30	4.38	4.91	41.11
		SD	6.79	0.58	0.15	2.06	11.54	3.35	2.20	16.54
		min	0.10	0.03	0.01	0.40	0.14	0.00	1.83	16.43
		max	41.00	3.88	0.88	11.00	52.78	15.00	10.74	79.36
		count	134	129	98	73	127	132	74	75
	WT3	mean	1.56	0.49	0.02	6.48	2.57	1.69	2.98	44.30
		SD	2.10	0.24	0.01	1.97	4.02	1.28	0.97	29.15
		min	0.19	0.10	0.01	4.00	0.12	0.31	1.72	16.54
		max	12.00	1.19	0.05	10.50	22.00	7.00	5.57	136.91
		count	39	39	27	20	33	34	27	27

Table C - 8: Summary of water quality data collected in the Fitzroy region across the Sentinel-3 Reef water types (WT) as part of the wet season event sampling of the MMP. Multi-year samples were collected between December and April by AIMS since 2021–22 and JCU since 2007–08 and up to 2022–23.

	Multi-year		TSS (mg L^{-1})	Chl-*a* (µg L^{-1})	CDOM (m^{-1})	SDD (m)	DIN (µg L^{-1})	DIP (µg L^{-1})	PP (µg L^{-1})	PN (µg L^{-1})
Fitzroy	WT1	mean	7.63	1.30	0.29	2.52	15.10	10.27	6.62	45.53
		SD	10.41	1.88	0.36	1.39	25.42	12.46	4.73	21.59
		min	0.69	0.24	0.04	0.25	0.28	0.93	2.53	26.74
		max	39.88	8.73	1.41	6.00	116.83	57.76	22.64	97.76
		count	22	22	17	22	22	22	17	17
	WT2	mean	1.73	0.53	0.05	6.20	4.30	3.69	2.79	24.11
		SD	1.10	0.60	0.03	2.98	7.27	4.81	1.08	7.29
		min	0.17	0.11	0.01	2.50	0.28	0.31	1.28	14.04
		max	3.60	2.21	0.13	12.00	22.00	19.00	4.92	39.88
		count	27	27	22	27	27	27	22	22
	WT3	mean	0.49	0.22	0.02	8.91	0.77	0.87	1.95	17.92
		SD	0.38	0.09	0.02	2.22	0.21	0.55	0.59	5.09
		min	0.05	0.10	0.00	5.50	0.49	0.31	1.27	12.94
		max	1.70	0.35	0.05	11.50	0.98	1.70	3.21	29.44
		count	16	16	7	8	8	8	8	8

C-5 Site-specific Guideline Values for MMP sites

Table C - 9: Site-specific Guideline Values (GVs) used for comparison with water quality monitoring data. These GVs are used to calculate the annual condition version of the WQ Index for each water quality sampling location and were provided by the Reef Authority. GVs are derived from the Water Quality Guidelines for the Great Barrier Reef Marine Park (Great Barrier Reef Marine Park Authority, 2010, see Table B - 1). Basin-level water quality objectives can be accessed online (Great Barrier Reef Marine Park Authority, Water quality guidelines for the Great Barrier Reef). Seasonal guideline values (i.e., wet vs. dry) are calculated as described in De'ath and Fabricius (2008). Guideline values for the Cape York region come from State of Queensland, (2020). See Appendix B for details on WQ Index calculation. DOF is direction of failure ('H' = high values fail, while 'L' = low values fail). Annual mean GVs are applied to annual mean values of monitoring data (and median GVs are applied to median data). Bold GVs are those applied to monitoring data.

GBRMPA group	GBRMPA sites	Measure	Water body	DOF	Annual Mean	Annual Median	Dry Median	Wet Median
30	ER01, AR01, PRN01, PRS01	Chl-*a* (µg L⁻¹)	Enclosed Coastal waters	H				**0.70**
		NO_x (µg L⁻¹)	Enclosed Coastal waters	H				**1.50**
		PN (µg L⁻¹)	Enclosed Coastal waters					
		PO_4 (µg L⁻¹)	Enclosed Coastal waters	H				**3.00**
		PP (µg L⁻¹)	Enclosed Coastal waters					
		Secchi (m)	Enclosed Coastal waters	L				**3.00**
		TSS (mg L⁻¹)	Enclosed Coastal waters	H				**4.00**
		Turbidity (NTU)	Enclosed Coastal waters	H		**10.00**		
40	KR01, KR02, BR01, NR01, NR02	Chl-*a* (µg L⁻¹)	Enclosed Coastal waters	H				**0.70**
		NO_x (µg L⁻¹)	Enclosed Coastal waters	H				**1.00**
		PN (µg L⁻¹)	Enclosed Coastal waters					
		PO_4 (µg L⁻¹)	Enclosed Coastal waters	H				**2.00**
		PP (µg L⁻¹)	Enclosed Coastal waters					
		Secchi (m)	Enclosed Coastal waters	L				**1.50**
		TSS (mg L⁻¹)	Enclosed Coastal waters	H				**6.00**
		Turbidity (NTU)	Enclosed Coastal waters	H		**11.00**		
50	ER02b, ER03, AR02b, AR03b, CI01, NR03, NR04, SR03, SR04, PRN02, PRN03, PRS02, PRS03, PRS2.5	Chl-*a* (µg L⁻¹)	Open Coastal waters	H		0.36	**0.25**	**0.46**
		NO_x (µg L⁻¹)	Open Coastal waters	H		0.35	**0.32**	**0.45**
		PN (µg L⁻¹)	Open Coastal waters	H		18.00		**20.00**
		PO_4 (µg L⁻¹)	Open Coastal waters	H		1.40	**1.86**	**0.93**
		PP (µg L⁻¹)	Open Coastal waters	H		2.60		**3.00**
		Secchi (m)	Open Coastal waters	L	**10.00**			
		TSS (mg L⁻¹)	Open Coastal waters	H		1.90		**1.70**
		Turbidity (NTU)	Open Coastal waters	H			**0.90**	**0.80**
60	AE04, ER05, NR05, SR05, SR06, PRN04,	Chl-*a* (µg L⁻¹)	Mid-shelf waters	H		**0.27**		
		NO_x (µg L⁻¹)	Mid-shelf waters	H		**0.35**		

GBRMPA group	GBRMPA sites	Measure	Water body	DOF	Annual Mean	Annual Median	Dry Median	Wet Median
	PRN05, PRN06, PRBB, PRS05	PN (µg L⁻¹)	Mid-shelf waters	H		**18.00**		
		PO_4 (µg L⁻¹)	Mid-shelf waters	H		**0.62**		
		PP (µg L⁻¹)	Mid-shelf waters	H		**2.00**		
		Secchi (m)	Mid-shelf waters	L	**10.00**			
		TSS (mg L⁻¹)	Mid-shelf waters	H		**1.50**		
		Turbidity (NTU)	Mid-shelf waters	H		**0.50**		
70	NR06, ER06	Chl-*a* (µg L⁻¹)	Offshore waters	H		**0.26**		
		NO_x (µg L⁻¹)	Offshore waters	H		**0.42**		
		PN (µg L⁻¹)	Offshore waters	H		**16.00**		
		PO_4 (µg L⁻¹)	Offshore waters	H		**0.39**		
		PP (µg L⁻¹)	Offshore waters	H		**1.90**		
		Secchi (m)	Offshore waters	L	**17.00**			
		TSS (mg L⁻¹)	Offshore waters	H		**0.50**		
		Turbidity (NTU)	Offshore waters	H		**0.50**		
1	C1, C6, C8, RM1, RM4, RM8, TUL1	Chl-*a* (µg L⁻¹)	Open Coastal waters	H	0.45		**0.32**	**0.63**
		NO_x (µg L⁻¹)	Open Coastal waters	H		**0.35**		
		PN (µg L⁻¹)	Open Coastal waters	H	20.00		**16.00**	**25.00**
		PO_4 (µg L⁻¹)	Open Coastal waters	H		**2.00**		
		PP (µg L⁻¹)	Open Coastal waters	H	2.80		**2.30**	**3.30**
		Secchi (m)	Open Coastal waters	L	**10.00**			
		TSS (mg L⁻¹)	Open Coastal waters	H	2.00		**1.60**	**2.40**
		Turbidity (NTU)	Open Coastal waters	H		**1.00**		
2	RM9, RM10, TUL3, TUL4, TUL5, TUL6, TUL8, TUL9	Chl-*a* (µg L⁻¹)	Open Coastal waters	H	0.45		**0.32**	**0.63**
		NO_x (µg L⁻¹)	Open Coastal waters	H		**0.35**		
		PN (µg L⁻¹)	Open Coastal waters	H	20.00		**16.00**	**25.00**
		PO_4 (µg L⁻¹)	Open Coastal waters	H		**2.00**		
		PP (µg L⁻¹)	Open Coastal waters	H	2.80		**2.30**	**3.30**
		Secchi (m)	Open Coastal waters	L	**10.00**			
		TSS (mg L⁻¹)	Open Coastal waters	H	2.00		**1.60**	**2.40**
		Turbidity (NTU)	Open Coastal waters	H		**1.00**		
3	C4, C5, C11, RM2, RM3, RM5, RM6, RM7, TUL2	Chl-*a* (µg L⁻¹)	Mid-shelf waters	H		0.30	**0.32**	**0.63**
		NO_x (µg L⁻¹)	Mid-shelf waters	H		**0.31**		
		PN (µg L⁻¹)	Mid-shelf waters	H		14.00	**16.00**	**25.00**

GBRMPA group	GBRMPA sites	Measure	Water body	DOF	Annual Mean	Annual Median	Dry Median	Wet Median
		PO_4 (µg L^{-1})	Mid-shelf waters	H		**2.00**		
		PP (µg L^{-1})	Mid-shelf waters	H		2.00	**2.30**	**3.30**
		Secchi (m)	Mid-shelf waters	L		**13.00**		
		TSS (mg L^{-1})	Mid-shelf waters	H		1.20	**1.60**	**2.40**
		Turbidity (NTU)	Mid-shelf waters	H		**0.60**		
4	RM12, TUL11	Chl-*a* (µg L^{-1})	Mid-estuarine waters	H		**2.00**		
		NO_x (µg L^{-1})	Mid-estuarine waters	H		**15.00**		
		PN (µg L^{-1})	Mid-estuarine waters					
		PO_4 (µg L^{-1})	Mid-estuarine waters	H		**3.00**		
		PP (µg L^{-1})	Mid-estuarine waters					
		Secchi (m)	Mid-estuarine waters	L		**1.50**		
		TSS (mg L^{-1})	Mid-estuarine waters	H		**7.00**		
		Turbidity (NTU)	Mid-estuarine waters	H		**5.00**		
5	TUL7, TUL10	Chl-*a* (µg L^{-1})	Lower estuarine waters	H		**1.10**		
		NO_x (µg L^{-1})	Lower estuarine waters	H		**3.00**		
		PN (µg L^{-1})	Lower estuarine waters					
		PO_4 (µg L^{-1})	Lower estuarine waters	H		**3.00**		
		PP (µg L^{-1})	Lower estuarine waters					
		Secchi (m)	Lower estuarine waters	L		**1.60**		
		TSS (mg L^{-1})	Lower estuarine waters	H		**5.00**		
		Turbidity (NTU)	Lower estuarine waters	H		**4.00**		
6	BUR1, BUR2	Chl-*a* (µg L^{-1})	Open Coastal waters	H		0.35	**0.32**	**0.63**
		NO_x (µg L^{-1})	Open Coastal waters	H		**0.28**		
		PN (µg L^{-1})	Open Coastal waters	H		12.00	**16.00**	**25.00**
		PO_4 (µg L^{-1})	Open Coastal waters	H		**1.00**		
		PP (µg L^{-1})	Open Coastal waters	H		2.20	**2.30**	**3.30**
		Secchi (m)	Open Coastal waters	L	**10.00**			
		TSS (mg L^{-1})	Open Coastal waters	H		1.20	**1.60**	**2.40**
		Turbidity (NTU)	Open Coastal waters	H		**0.80**		
7	BUR3	Chl-*a* (µg L^{-1})	Open Coastal waters	H	0.45		**0.32**	**0.63**
		NO_x (µg L^{-1})	Open Coastal waters	H		**0.28**		
		PN (µg L^{-1})	Open Coastal waters	H	20.00		**16.00**	**25.00**
		PO_4 (µg L^{-1})	Open Coastal waters	H		**1.00**		

GBRMPA group	GBRMPA sites	Measure	Water body	DOF	Annual Mean	Annual Median	Dry Median	Wet Median
		PP (µg L^{-1})	Open Coastal waters	H	2.80		**2.30**	**3.30**
		Secchi (m)	Open Coastal waters	L	**10.00**			
		TSS (mg L^{-1})	Open Coastal waters	H	2.00		**1.60**	**2.40**
		Turbidity (NTU)	Open Coastal waters	H		**0.80**		
8	BUR4	Chl-*a* (µg L^{-1})	Open Coastal waters	H		0.59	**0.32**	**0.63**
		NO$_x$ (µg L^{-1})	Open Coastal waters	H		**0.28**		
		PN (µg L^{-1})	Open Coastal waters	H		17.00	**16.00**	**25.00**
		PO$_4$ (µg L^{-1})	Open Coastal waters	H		**1.00**		
		PP (µg L^{-1})	Open Coastal waters	H	2.80		**2.30**	**3.30**
		Secchi (m)	Open Coastal waters	L		**4.00**		
		TSS (mg L^{-1})	Open Coastal waters	H		1.90	**1.60**	**2.40**
		Turbidity (NTU)	Open Coastal waters	H		**1.30**		
9	BUR5	Chl-*a* (µg L^{-1})	Open Coastal waters	H		0.60	**0.32**	**0.63**
		NO$_x$ (µg L^{-1})	Open Coastal waters	H		**0.50**		
		PN (µg L^{-1})	Open Coastal waters	H	20.00		**16.00**	**25.00**
		PO$_4$ (µg L^{-1})	Open Coastal waters	H		**2.00**		
		PP (µg L^{-1})	Open Coastal waters	H	2.80		**2.30**	**3.30**
		Secchi (m)	Open Coastal waters	L		**3.00**		
		TSS (mg L^{-1})	Open Coastal waters	H		5.00	**1.60**	**2.40**
		Turbidity (NTU)	Open Coastal waters	H		**3.00**		
10	BUR6, BUR7	Chl-*a* (µg L^{-1})	Open Coastal waters	H	0.45		**0.32**	**0.63**
		NO$_x$ (µg L^{-1})	Open Coastal waters	H		**1.00**		
		PN (µg L^{-1})	Open Coastal waters	H		13.00	**16.00**	**25.00**
		PO$_4$ (µg L^{-1})	Open Coastal waters	H		**2.00**		
		PP (µg L^{-1})	Open Coastal waters	H		2.10	**2.30**	**3.30**
		Secchi (m)	Open Coastal waters	L	**10.00**			
		TSS (mg L^{-1})	Open Coastal waters	H		1.20	**1.60**	**2.40**
		Turbidity (NTU)	Open Coastal waters	H	**2.00**			
11	BUR8, BUR9	Chl-*a* (µg L^{-1})	Enclosed Coastal waters	H		**1.00**		
		NO$_x$ (µg L^{-1})	Enclosed Coastal waters	H		**4.00**		
		PN (µg L^{-1})	Enclosed Coastal waters					
		PO$_4$ (µg L^{-1})	Enclosed Coastal waters	H		**1.00**		
		PP (µg L^{-1})	Enclosed Coastal waters					

GBRMPA group	GBRMPA sites	Measure	Water body	DOF	Annual Mean	Annual Median	Dry Median	Wet Median
		Secchi (m)	Enclosed Coastal waters	L		**1.50**		
		TSS (mg L⁻¹)	Enclosed Coastal waters	H		**2.00**		
		Turbidity (NTU)	Enclosed Coastal waters	H		**4.00**		
12	BUR10	Chl-*a* (µg L⁻¹)	Mid-shelf waters	H		0.33	**0.32**	**0.63**
		NO_x (µg L⁻¹)	Mid-shelf waters	H		**0.28**		
		PN (µg L⁻¹)	Mid-shelf waters	H		14.00	**16.00**	**25.00**
		PO_4 (µg L⁻¹)	Mid-shelf waters	H		**1.00**		
		PP (µg L⁻¹)	Mid-shelf waters	H		2.00	**2.30**	**3.30**
		Secchi (m)	Mid-shelf waters	L	**10.00**			
		TSS (mg L⁻¹)	Mid-shelf waters	H		0.80	**1.60**	**2.40**
		Turbidity (NTU)	Mid-shelf waters	H		**0.50**		
13	BUR11, BUR12	Chl-*a* (µg L⁻¹)	Open Coastal waters	H	0.45		**0.32**	**0.63**
		NO_x (µg L⁻¹)	Open Coastal waters	H		**1.00**		
		PN (µg L⁻¹)	Open Coastal waters	H	20.00		**16.00**	**25.00**
		PO_4 (µg L⁻¹)	Open Coastal waters	H		**2.00**		
		PP (µg L⁻¹)	Open Coastal waters	H	2.80		**2.30**	**3.30**
		Secchi (m)	Open Coastal waters	L	**10.00**			
		TSS (mg L⁻¹)	Open Coastal waters	H	2.00		**1.60**	**2.40**
		Turbidity (NTU)	Open Coastal waters	H		**2.00**		
14	BUR13, BUR14, BUR15	Chl-*a* (µg L⁻¹)	Enclosed Coastal waters	H		**1.00**		
		NO_x (µg L⁻¹)	Enclosed Coastal waters	H		**4.00**		
		PN (µg L⁻¹)	Enclosed Coastal waters					
		PO_4 (µg L⁻¹)	Enclosed Coastal waters	H		**1.00**		
		PP (µg L⁻¹)	Enclosed Coastal waters					
		Secchi (m)	Enclosed Coastal waters	L		**1.50**		
		TSS (mg L⁻¹)	Enclosed Coastal waters	H		**2.00**		
		Turbidity (NTU)	Enclosed Coastal waters	H		**4.00**		
15	WHI1, WHI2, WHI3, WHI4, WHI5	Chl-*a* (µg L⁻¹)	Open Coastal waters	H		0.36	**0.32**	**0.63**
		NO_x (µg L⁻¹)	Open Coastal waters	H		**1.00**		
		PN (µg L⁻¹)	Open Coastal waters	H	14.00		**16.00**	**25.00**
		PO_4 (µg L⁻¹)	Open Coastal waters	H		**1.00**		
		PP (µg L⁻¹)	Open Coastal waters	H		2.30	**2.30**	**3.30**
		Secchi (m)	Open Coastal waters	L	**10.00**			

GBRMPA group	GBRMPA sites	Measure	Water body	DOF	Annual Mean	Annual Median	Dry Median	Wet Median
		TSS (mg L⁻¹)	Open Coastal waters	H		1.40	**1.60**	**2.40**
		Turbidity (NTU)	Open Coastal waters	H		**1.10**		
16	WHI6	Chl-*a* (µg L⁻¹)	Enclosed Coastal waters	H		**1.30**		
		NO_x (µg L⁻¹)	Enclosed Coastal waters	H		**4.00**		
		PN (µg L⁻¹)	Enclosed Coastal waters					
		PO_4 (µg L⁻¹)	Enclosed Coastal waters	H		**3.00**		
		PP (µg L⁻¹)	Enclosed Coastal waters					
		Secchi (m)	Enclosed Coastal waters	L		**1.60**		
		TSS (mg L⁻¹)	Enclosed Coastal waters	H		**5.00**		
		Turbidity (NTU)	Enclosed Coastal waters	H		**4.00**		
17	WHI7, WHI10	Chl-*a* (µg L⁻¹)	Open Coastal waters	H	0.45		**0.32**	**0.63**
		NO_x (µg L⁻¹)	Open Coastal waters	H		**0.25**		
		PN (µg L⁻¹)	Open Coastal waters	H		18.00	**16.00**	**25.00**
		PO_4 (µg L⁻¹)	Open Coastal waters	H		**2.00**		
		PP (µg L⁻¹)	Open Coastal waters	H		2.10	**2.30**	**3.30**
		Secchi (m)	Open Coastal waters	L	**10.00**			
		TSS (mg L⁻¹)	Open Coastal waters	H		1.60	**1.60**	**2.40**
		Turbidity (NTU)	Open Coastal waters	H	**2.00**			
18	WHI8, WHI11	Chl-*a* (µg L⁻¹)	Open Coastal waters	H	0.45		**0.32**	**0.63**
		NO_x (µg L⁻¹)	Open Coastal waters	H		**1.00**		
		PN (µg L⁻¹)	Open Coastal waters	H	20.00		**16.00**	**25.00**
		PO_4 (µg L⁻¹)	Open Coastal waters	H		**2.00**		
		PP (µg L⁻¹)	Open Coastal waters	H	2.80		**2.30**	**3.30**
		Secchi (m)	Open Coastal waters	L	**10.00**			
		TSS (mg L⁻¹)	Open Coastal waters	H	2.00		**1.60**	**2.40**
		Turbidity (NTU)	Open Coastal waters	H	**2.00**			
19	WHI9	Chl-*a* (µg L⁻¹)	Open Coastal waters	H	0.45		**0.32**	**0.63**
		NO_x (µg L⁻¹)	Open Coastal waters	H		**0.25**		
		PN (µg L⁻¹)	Open Coastal waters	H		18.00	**16.00**	**25.00**
		PO_4 (µg L⁻¹)	Open Coastal waters	H		**2.00**		
		PP (µg L⁻¹)	Open Coastal waters	H		2.10	**2.30**	**3.30**
		Secchi (m)	Open Coastal waters	L	**10.00**			
		TSS (mg L⁻¹)	Open Coastal waters	H		1.60	**1.60**	**2.40**

GBRMPA group	GBRMPA sites	Measure	Water body	DOF	Annual Mean	Annual Median	Dry Median	Wet Median
		Turbidity (NTU)	Open Coastal waters	H	**1.00**			
20	WHI10.1, WHI10.2	Chl-*a* (µg L^{-1})	Open Coastal waters	H	0.45		**0.32**	**0.63**
		NO_x (µg L^{-1})	Open Coastal waters	H		**1.00**		
		PN (µg L^{-1})	Open Coastal waters	H	20.00		**16.00**	**25.00**
		PO_4 (µg L^{-1})	Open Coastal waters	H		**2.00**		
		PP (µg L^{-1})	Open Coastal waters	H	2.80		**2.30**	**3.30**
		Secchi (m)	Open Coastal waters	L	**10.00**			
		TSS (mg L^{-1})	Open Coastal waters	H	2.00		**1.60**	**2.40**
		Turbidity (NTU)	Open Coastal waters	H			**2.00**	**12.00**
	FTZ1	Chl-*a* (µg L^{-1})	Mid-shelf waters	H		0.27	**0.32**	**0.63**
		NO_x (µg L^{-1})	Mid-shelf waters	H		**0.50**		
		PN (µg L^{-1})	Mid-shelf waters	H		12.00	**16.00**	**25.00**
		PO_4 (µg L^{-1})	Mid-shelf waters	H		**2.00**		
		PP (µg L^{-1})	Mid-shelf waters	H		1.90	**2.40**	**3.40**
		Secchi (m)	Mid-shelf waters	L		**12.00**		
		TSS (mg L^{-1})	Mid-shelf waters	H		0.40	**1.70**	**2.50**
		Turbidity (NTU)	Mid-shelf waters	H		**0.30**		
	FTZ2,FTZ3	Chl-*a* (µg L^{-1})	Open Coastal waters	H	0.45		**0.32**	**0.63**
		NO_x (µg L^{-1})	Open Coastal waters	H		**0.50**		
		PN (µg L^{-1})	Open Coastal waters	H	20.00		**16.00**	**25.00**
		PO_4 (µg L^{-1})	Open Coastal waters	H	**2.00**			
		PP (µg L^{-1})	Open Coastal waters	H	2.80		**2.40**	**3.40**
		Secchi (m)	Open Coastal waters	L	**10.00**			
		TSS (mg L^{-1})	Open Coastal waters	H	2.00		**1.70**	**2.50**
		Turbidity (NTU)	Open Coastal waters	H	**1.50**			
	FTZ4	Chl-*a* (µg L^{-1})	Open Coastal waters	H	0.45		**0.32**	**0.63**
		NO_x (µg L^{-1})	Open Coastal waters	H		**0.50**		
		PN (µg L^{-1})	Open Coastal waters	H		15.00	**16.00**	**25.00**
		PO_4 (µg L^{-1})	Open Coastal waters	H		**2.00**		
		PP (µg L^{-1})	Open Coastal waters	H		2.50	**2.30**	**3.30**
		Secchi (m)	Open Coastal waters	L		**10.00**		
		TSS (mg L^{-1})	Open Coastal waters	H		1.00	**1.60**	**2.40**
		Turbidity (NTU)	Open Coastal waters	H		**0.50**		
	FTZ5	Chl-*a* (µg L^{-1})	Open Coastal waters	H	0.45		**0.32**	**0.63**

GBRMPA group	GBRMPA sites	Measure	Water body	DOF	Annual Mean	Annual Median	Dry Median	Wet Median
		NO_x (µg L^{-1})	Open Coastal waters	H		0.50		
		PN (µg L^{-1})	Open Coastal waters	H	20.00		16.00	25.00
		PO_4 (µg L^{-1})	Open Coastal waters	H		2.00		
		PP (µg L^{-1})	Open Coastal waters	H	2.80		2.40	3.40
		Secchi (m)	Open Coastal waters	L	10.00			
		TSS (mg L^{-1})	Open Coastal waters	H	2.00		1.70	2.50
		Turbidity (NTU)	Open Coastal waters	H	1.50			
	FTZ6	Chl-*a* (µg L^{-1})	Enclosed Coastal waters	H		1.00		
		NO_x (µg L^{-1})	Enclosed Coastal waters	H		3.00		
		PN (µg L^{-1})	Enclosed Coastal waters	H				
		PO_4 (µg L^{-1})	Enclosed Coastal waters	H		3.00		
		PP (µg L^{-1})	Enclosed Coastal waters	H				
		Secchi (m)	Enclosed Coastal waters	L				
		TSS (mg L^{-1})	Enclosed Coastal waters	H				
		Turbidity (NTU)	Enclosed Coastal waters	H			7.00	15.00

C-6 Regional exposure assessments for waterbodies

Figure C - 3: Areas (in km^2 and represented as horizontal bars) of seagrass (left) and coral reefs (right) in the a) Reef and regional waterbodies; b) Cape York, c) Wet Tropics, d) Burdekin, e) Mackay-Whitsunday, f) Fitzroy, g) Burnett-Mary. Percentages of total Reef habitats or total regional habitats are indicated in italics.

Table C - 10: Areas (km²) (and percentages, %) of the Reef lagoon (total 348,839 km²) and division by waterbodies (enclosed coastal, EC; open coastal, OC; mid-shelf, Mid; and offshore, Off) affected by the Reef WT1–2 combined, and the three Reef water types individually during the current wet season and for a range of reference periods.

Water type	Water body	Area of Reef affected in km² and %									
		2022–23 wet season		Long-term average		Average of coral recovery period (2012–2017)		Typical wet-year composite		Typical dry-year composite	
		km²	% (%WB)	km²	% (%WB)	km²	% (%WB)	km²	% (%WB)	km²	% (%WB)
WT1+2	Reef	**73,503**	**21%**	**63,296**	**18%**	**58,870**	**17%**	**88,326**	**25%**	**42,047**	**12%**
	EC	6,377	2% *(77%)*	6,366	2% *(77%)*	7,826	2% *(95%)*	6,367	2% *(77%*	6,366	2% *(77%*
	OC	32,060	9% *(97%)*	33,955	10% *>99%*	32,085	9% *(97%)*	34,765	10% *>99%*	28,672	8% *(87%*
	Mid	19,630	6% *(24%)*	19,234	6% *(23%)*	16,296	5% *(20%)*	35,707	10% *(44%*	6,566	2% *(8%*
	Off	15,437	4% *(7%)*	3,741	1% *(2%)*	2,664	1% *(1%)*	11,488	3% *(5%*	443	0% *(0%*
WT1	Reef	**13,577**	**4%**	**10,791**	**3%**	**10,140**	**3%**	**19,856**	**6%**	**7,363**	**2%**
	EC	6,229	2% *(76%)*	6,018	2% *(73%)*	6,147	2% *(75%)*	6,199	2% *(75%*	5,398	2% *(65%*
	OC	7,015	2% *(21%)*	4,773	1% *(14%)*	3,989	1% *(12%)*	11,402	3% *(35%*	1,965	1% *(6%*
	Mid	333	0% *(0%)*	0	0% *(0%)*	4	0% *(0%)*	2,254	1% *(3%*	0	0% *(0%*
	Off	1	0% *(0%)*	0	0% *(0%)*	0	0% *(0%)*	0	0% *(0%*	0	0% *(0%*
WT2	Reef	**71,733**	**21%**	**59,410**	**17%**	**55,074**	**16%**	**82,931**	**24%**	**39,382**	**11%**
	EC	4,861	1% *(59%)*	5,118	1% *(62%)*	6,431	2% *(78%)*	5,490	2% *(67%*	4,649	1% *(56%*
	OC	32,018	9% *(97%)*	33,768	10% *>99%*	31,894	9% *(97%)*	34,759	10% *>99%*	28,461	8% *(86%*

Water type	Water body	Area of Reef affected in km^2 and %									
		2022–23 wet season		**Long-term average**		**Average of coral recovery period (2012–2017)**		**Typical wet-year composite**		**Typical dry-year composite**	
		km^2	% (%WB)	km^2	% (%WB)	km^2	% (%WB)	km^2	% (%WB)	km^2	% (%WB)
	Mid	19,417	6% *(24%)*	17,031	5% *(21%)*	14,387	4% *(18%)*	32,193	9% *(39%)*	5,840	2% *(7%*
	Off	15,437	4% *(7%)*	3,493	1% *(2%)*	2,363	1% *(1%)*	10,489	3% *(5%)*	433	0% *(0%*
WT3	Reef	**216,283**	**62%**	**184,626**	**53%**	**165,582**	**47%**	**203,859**	**58%**	**135,874**	**39%**
WT3	EC	267	0% *(3%)*	36	0% *(0%)*	91	0% *(1%)*	168	0% *(2%)*	31	0% *(0%*
WT3	OC	26,631	8% *(81%)*	26,764	8% *(81%)*	25,620	7% *(78%)*	27,940	8% *(85%)*	25,874	7% *(78%*
WT3	Mid	80,989	23% *(99%)*	75,136	22% *(92%)*	71,728	21% *(87%)*	79,609	23% *(97%)*	53,525	15% *(65%*
WT3	Off	108,395	31% *(49%)*	82,691	24% *(37%)*	68,143	20% *(31%)*	96,142	28% *(43%)*	56,443	16% *(25%*

C-7 References

Cooper TF, Uthicke S, Humphrey C, Fabricius KE (2007). Gradients in water column nutrients, sediment parameters, irradiance and coral reef development in the Whitsunday Region, central Great Barrier Reef. Estuarine, Coastal and Shelf Science 74:458-470.

Cooper TF, Ridd PV, Ulstrup KE, Humphrey C, Slivkoff M, Fabricius KE (2008). Temporal dynamics in coral bioindicators for water quality on coastal coral reefs of the Great Barrier Reef. Marine and Freshwater Research 59:703-716.

De'ath G and Fabricius KE (2008) Water quality of the Great Barrier Reef: distributions, effects on reef biota and trigger values for the protection of ecosystem health. Final Report to the Great Barrier Reef Marine Park Authority. Australian Institute of Marine Science, Townsville. 104 pp.

Great Barrier Reef Marine Park Authority. Water quality guidelines for the Great Barrier Reef. Basin-level objectives for Wet Tropics, Townsville, and Mackay-Whitsundays regions. URL: http://www.gbrmpa.gov.au/our-work/threats-to-the-reef/declining-water-quality?a=1394. Accessed Jan 2019.

Great Barrier Reef Marine Park Authority (2010). Water Quality Guidelines for the Great Barrier Reef Marine Park. Revised Edition 2010. Great Barrier Reef Marine Park Authority, Townsville. 100pp.

State of Queensland (2020). Environmental Protection (Water and Wetland Biodiversity) Policy 2019: Environmental Values and Water Quality Objectives, Eastern Cape York Basins https://environment.des.qld.gov.au/management/water/policy/cape-york-eastern-basins.

Appendix D: Water Quality Monitoring in the Fitzroy NRM Region 2022–23

D-1 Acknowledgements

The Fitzroy Basin Marine Monitoring Program for Inshore Water Quality is funded by the partnership between the Australian Government's Reef Trust and the Great Barrier Reef Foundation, and the Australian Institute of Marine Science.

We acknowledge Aboriginal and Torres Strait Islander Peoples as the Traditional Owners of the places where AIMS works, both on land and in the Sea Country of tropical Australia. We pay our respects to the Elders; past, present, and future; and their continuing culture, beliefs, and spiritual relationships and connection to the land and Sea Country. We would also like to thank the Woppaburra TUMRA Steering Committee and the Darumbal People Aboriginal Corporation RNTBC for consent to access sites located in Woppaburra and Darumbal Sea Country. We would also like to acknowledge the ongoing relationship with the Darumbal TUMRA steering committee.

We are grateful to everyone involved in field and labwork this year including Ulysse Bove, Bruce Brady, Kathy Connellan, Daniel Moran, Christian O'Dea, Irena Zagorskis, the staff at Vision Environment, the AIMS Oceanographic Technician team, and the crew of the RV Cape Ferguson. Many thanks to the dedicated staff of the AIMS Analytical Technology Laboratory for analysis of water samples. Thanks also to Seanan Wild for project support.

D-2 Introduction and Background

The Fitzroy National Resource Management (NRM) Region extends from Carnarvon Gorge National Park to Rockhampton and out to the mouth of the Fitzroy River. Covering 15.7 million hectares, it has the largest catchment area draining into the Great Barrier Reef (the Reef) (Lewis *et al.,* 2021), equating to ~33% of all suspended sediment load from all the Great Barrier Reef Catchment Area (GBRCA) (Packett *et al.,* 2009). The region has a sub-tropical, semi-arid climate with high inter-annual variability in rainfall, high evaporation rates, and prolonged dry periods followed by infrequent major floods. The most consistent rain usually occurs during the wet season (November–March). Annual rainfall varies substantially across the region, from ~530 mm in the west to ~850 mm in the central and ~2,000 mm in the northeast coastal area (Packett *et al.,* 2009). The region's rainfall has been decreasing by ~30 mm annually for the past 30 years (Yu *et al.,* 2013).

From 2005 to 2014, water quality monitoring by the Australian Institute of Marine Science (AIMS) occurred three times per year at three sites in the Fitzroy region under the Marine Monitoring Program (MMP) and results were published annually (Thompson *et al.*, 2014, previous reports cited therein). A program re-design of the MMP occurred in 2015 to increase the number of sites and the sampling frequency across the focus regions being monitored at that time. Due to funding constraints, this new program design could not be extended to the Fitzroy region, so monitoring in this region by AIMS ceased at the end of 2014.

A partnership between the Great Barrier Reef Foundation and AIMS began in 2020 to re-establish marine water quality monitoring in the Fitzroy region. The program design for this monitoring follows the same design principles as the MMP in other NRM regions (see Appendix A) and is funded until 2024.

The primary land use in The Fitzroy Region is cattle grazing (75%), followed by nature conservation (8.7%) and forestry (6.6%). This extensive grazing area supports 55% of the cattle in the GBRCA (Lewis *et al.,* 2021). Mining is another prominent industry in the area, accounting for 102,389 hectares of the catchment. The region holds 75% of Queensland's active coal mines and 47% of its gas mines (QLUMP, 2019). This type of land-use requires clearing of vegetation, leaving sediment susceptible to erosion. Erosion of hillslope and streambank soil ends up in local waterways and is transported into the Great Barrier Reef lagoon (Marwick *et al.,* 2014). Much of this sediment is extremely fine and remains suspended in the water, travelling onto coral reefs, seagrass beds and other sensitive marine ecosystems and reducing light availability (Bainbridge *et al.,* 2018). Catchment-derived sediments contain fertilizer and pesticides from agricultural sources. This additional nutrient input generates an increase in macroalgae and can cause algal blooms and eutrophication (Brodie *et al.,* 2011). Additionally, river discharge can increase susceptibility of coral to disease (Bruno *et al.,* 2003; Haapkylä *et al.,* 2011; Kline *et al.,* 2006; Kuntz *et al.,* 2005; Weber *et al.,* 2012; Vega Thurber *et al.,* 2013) and exacerbate coral bleaching (Wooldridge, 2009). This discharge often contains pesticides. Pesticide exposure can inhibit photosynthesis (Gallen *et al.,* 2014) and affect corals, seagrass, fish, and other marine organisms.

Large-volume floods, which occur once every few decades, can deliver catchment sediment and pollution to the mid and outer reef (Devlin *et al.,* 2001). However, small-scale local flooding adversely affects the inshore reef zone at a much higher frequency. The coastal area of the Fitzroy region comprises many inshore reefs and islands. This includes the 19 islands making up the Keppel group. Long-term monitoring of inshore coral reef sites in the Fitzroy region consistently classed these sites as 'very poor' to 'poor' and from 2005 to 2022 (Thompson *et al.,* 2021). Reefs closest to rivers had the lowest coral cover and improved with distance from the coast. Macroalgae abundance was 'high' at almost all reefs in the region.

D-3 Methods

This Section provides a brief overview of the sampling methods and indicators that are monitored in the Fitzroy region. More details are presented in the main MMP report above and in a separate quality assurance/quality control (QA/QC) report (Great Barrier Reef Marine Park Authority, 2022).

Sampling design

This program is designed to measure the annual condition and long-term trends in coastal water quality rather than short-term episodic changes in water quality associated with periods of high river discharge. This type of monitoring is considered 'ambient', which refers to routine sampling during the wet and dry seasons outside of major flood events. This program design is analogous to ambient monitoring conducted since 2005 under the MMP.

Monitoring site locations were selected along water quality gradients related to exposure to land-based runoff, with sites located with increasing distance from the Fitzroy River mouth and from the coast (Álvarez-Romero *et al.*, 2013). In order to maintain some continuity with the existing 10-year monitoring dataset (2005–2014), the three original sites (FTZ1–3) were re-instated in the current design (Table D - 1, Figure D - 3).

Table D - 1: Description of the Fitzroy water quality sites monitored during 2022–23. Presence of data-logging instruments (turbidity/fluorescence or salinity loggers) is indicated by tick marks.

Site Name (Short Name)	Latitude	Longitude	Turbidity/fluorescence logger	Salinity logger	Number of times sampled (season)	Sampling
Barren Island (FTZ1)*	-23.152	151.069	√		10 times per year (7 wet season and 3 dry season)	Duplicate samples surface and bottom
Humpy Island (FTZ2)*	-23.217	150.960	√	√	10 times per year (7 wet season and 3 dry season)	Duplicate samples surface and bottom
Pelican Island (FTZ3)*	-23.233	150.873			10 times per year (7 wet season and 3 dry season)	Duplicate samples surface and bottom
North Keppel (FTZ4)	-23.092	150.913			10 times per year (7 wet season and 3 dry season)	Duplicate samples surface and bottom
Peak West (FTZ5)	-23.341	150.905			10 times per year (7 wet season and 3 dry season)	Duplicate samples surface and bottom
Fitzroy River Mouth (FTZ6)	-23.475	150.938	√	√	10 times per year (7 wet season and 3 dry season)	Duplicate samples surface and bottom

*Indicates sites that were monitored by AIMS from 2005–2014

From 2005 to 2014, monitoring occurred ~3 times per year at 3 sites in the various MMP monitoring regions including in the Fitzroy region (discontinued in 2015). These data are included in this report.

Water quality sampling

At each of the sampling locations (Figure D - 3, Table D - 1), vertical profiles of water salinity and temperature were measured with a Conductivity Temperature Depth (CTD) profiler (Sea-Bird Electronics SBE19plus). CTD profiles are used to characterise the water column and to identify its state of vertical mixing. See the QA/QC report for a detailed description of CTD data processing (Great Barrier Reef Marine Park Authority, 2022).

Immediately following the CTD cast, discrete water samples were collected with Niskin bottles. Samples collected at ambient sites were from the surface (~0.5 m below water surface) and bottom (~1 m above the seabed) of the water column, whereas for some event-based sampling only surface water samples were collected. Samples from the Niskin bottles were taken in duplicate and were analysed for a suite of water quality parameters (Table 2-1). Detailed descriptions of analytical chemistry techniques can be found in the QA/QC report (Great Barrier Reef Marine Park Authority, 2022). Values of water quality variables presented in this report are depth-weighted means calculated using surface and bottom samples.

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

- **Total Suspended Solids (TSS)** is a measure of the suspended particulate material in the water column. These solids include suspended sediments (sand, silt, and clay), living plankton, and detrital (non-living organic) material. TSS concentrations are affected by oceanographic processes including primary production and resuspension, as well as inputs from other sources such as dredging and land-based runoff.
- **Secchi depth** is a visual measure of water clarity and proxy for light penetration, which is measured using a high-contrast black and white patterned disc called a Secchi disc. The Secchi depth is the average of the vertical disappearance and reappearance depths of the disc, where clarity increases with increasing Secchi depth. Secchi depth is a simple method that has been used for over 150 years, so is excellent for assessing Long-term change and for cross-system comparisons.
- **Turbidity** is a measure of light scattering caused by fine suspended particles, such as sediment, detritus, and plankton. Turbidity is affected by a wide range of factors including oceanographic processes such as resuspension of bottom sediments by wind, waves and currents; river discharge; and anthropogenic factors such as dredging.
- **Chlorophyll *a* (Chl-*a*)** concentration is a measure of phytoplankton biomass in a water body. Phytoplankton grow quickly in response to nutrient availability, so elevated values of Chl-*a* can indicate increased nutrient loading.
- **Dissolved inorganic nutrients (NH_3, NO_X, PO_4 and Si)** measure the amount of readily available nutrients for plankton growth in water samples. Inorganic nitrogen (NH_3, NO_x) and phosphate (PO_4) represent around 1% of the nutrient pools in the Reef. The inorganic nutrient pools are affected by a complex range of biogeochemical processes including both natural (for example, plankton uptake, upwelling, nitrogen fixation, and remineralisation) and anthropogenic (for example, dredging and nutrient inputs from changed land use) processes.
- **Particulate nutrients (POC, PN and PP)** are a measure of the suspended material retained on a filter with a pore size of approximately 0.7 µm. This material consists of a minor fraction of living biomass (for example, bacteria, phytoplankton) and a major fraction of detritus (for example, dead cells, faecal pellets). Particulate nutrient concentrations are affected by oceanographic processes (primary production, bacterial production, resuspension, and remineralisation) as well as sources such as dredging and land-based runoff.
- **Dissolved organic carbon (DOC)** is a measure of organic carbon concentrations passing through a filter with a pore size of 0.45 µm. DOC has a complex chemical composition and is used by bacteria as a source of energy. The DOC pool is affected by a range of production and degradation pathways. The sources include primary production by phytoplankton, zooplankton grazing, resuspension events, river runoff, and abiotic breakdown of POC. DOC can by degraded by sunlight.

In situ loggers

Continuous *in situ* chlorophyll fluorescence and turbidity were measured using WET Labs ECO FLNTUSB Combination Fluorometer and Turbidity Sensors located at three sites (Table D - 1), which were deployed at 5 m below the surface and sampled at 10 min intervals. Water samples for analyses of Chl-*a* and TSS were collected three times per year to calibrate logger fluorescence and turbidity to *in situ* conditions. Diver-operated Niskin bottles were used to sample close to the moored loggers and samples were preserved and analysed in the same manner as ship-based water samples.

Daily averages of the chlorophyll and turbidity time-series are presented in section D-7. Annual means and medians of turbidity were also calculated for each site based on the 'water year' (1 October to 30 September) and compared with the water quality guideline value (GV) (Table D-4).

Salinity and temperature loggers (Sea-Bird Electronics SBE37) were deployed at two locations, with one of these being placed on a fixed mooring near the Fitzroy River mouth (Figure D - 3, Table D - 1). See the QA/QC report (Great Barrier Reef Marine Park Authority, 2022) for detailed descriptions of logger pre- and post-deployment procedures. Site-specific time-series of salinity and temperature can be found in Figure C - 2.

Data analyses – Summary statistics and trends

Concentrations of water quality parameters at each sampling occasion were calculated as depth-weighted means by trapezoidal integration of the data from all sampling depths. At most sites, only two vertical points are sampled (i.e., surface and bottom samples), and this method averages these values to derive the depth-weighted mean. Measurements falling below the instrumental detection limit were represented as half the detection limit. Summary statistics for all water quality variables are presented for all monitoring sites in Table C - 1. Concentrations were compared to site-specific GVs (Table C - 9), which are defined for Chl-*a*, PN, PP, TSS, Secchi depth, NO_x, and PO_4. Concentrations of water quality parameters are presented along the sampling transects for each focus region with distance from river mouths. Trends in water quality are represented with generalised additive models, fitted with a maximum of five knots and modelled with a gamma-distributed response and log-link function.

Temporal trends in key water quality variables (Chl-*a*, TSS, Secchi depth, turbidity, NO_x, PN, PP, DOC, and POC) since 2005 are reported using only open coastal and mid-shelf sites, as GVs for enclosed coastal waters are derived differently and are not available for all variables, creating statistical imbalance.

Generalised additive mixed effects models (GAMMs) were used to decompose each irregularly spaced time-series into its trend cycles (long-term) and periodic (seasonal) components (Wood, 2006). GAMMs are an extension of additive models (which allow flexible modelling of non-linear relationships by incorporating penalised regression spline types of smoothing functions into the estimation process), where the degree of smoothing of each smooth term (and by extension, the estimated degrees of freedom of each smoother) is treated as a random effect and thus estimable via its variance as with other effects in a mixed modelling structure (Wood, 2006).

For each water quality variable within each focus region, the variable was modelled against a thin-plate smoother for date and a cyclical cubic regression spline (maximum of 5 knots) over months within 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). All GAMMs were fitted using the mgcv (Wood, 2006, 2011) package in R 4.2.2 (R Core Team, 2022).

No monitoring occurred in the Fitzroy region from 2015–2020. GAMMs are therefore presented with no data through this period and should be interpreted with caution, until more data become available.

Data analyses – Water Quality Index

The Water Quality Index (WQ Index) is an interpretation tool developed by AIMS to visualise trends in the suite of water quality variables measured, and to compare monitored water quality to existing Water Quality Guidelines (Department of Environment and Resource Management, 2009; Great Barrier Reef Marine Park Authority, 2010). The WQ Index uses a set of five key indicators:

- Water clarity
- Chl-*a* concentrations
- PN concentrations
- PP concentrations
- NO_x concentrations.

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

Details of WQ Index calculation are given in Appendix B.

D-4 Drivers and pressures influencing water quality in 2022–23

Coastal development including agriculture

The Fitzroy Region is home to ~235,000 people, just 5% of Queensland's population (FBA, 2018). By area, cattle grazing is the primary land use in the catchment (Brodie *et al.,* 2003) and the initial clearing of vegetation for this purpose marked a significant change in the source and quantity of sediment exported by the Fitzroy River (Hughes *et al.,* 2009). Intensive cultivation of food crops and livestock feed production also contributes to the sediment load in the Fitzroy River (Hughes *et al.,* 2009). The region has over 472,000 ha of grain crops, largely for feeding livestock, and 25,000 ha of cotton (Thorburn and Wilkinson, 2013). Fluctuations in climate, cattle numbers and farming can greatly affect the state and nature of vegetation cover, and therefore, the susceptibility of soils to erosion, which leads to greater runoff of suspended sediments and nutrients. As Australia's cattle production has stayed relatively consistent since 2000 (MLA, 2021), the erosion of soil on cleared grazing and crop land will continue without the adoption of best management practice.

Annual TSS export from the Fitzroy Basin into the Reef lagoon is between 3 and 4.5 million tonnes per year, accounting for ~33% of all annual TSS reaching the Reef lagoon (Dougall *et al.,* 2005). The current best estimate of anthropogenically-derived TSS from the Fitzroy Region is 2.9 million tonnes per year (Kroon *et al.* 2012), which is 3.4 times greater than pre-European levels. The Fitzroy region has the second highest anthropogenically-derived TSS load in the Reef lagoon. TSS samples taken from the Fitzroy River during flood events were highest in areas with substantial intensive agriculture but were highly variable (Packet *et al.,* 2009). Inshore TSS and Chl-*a* annual mean values in the sector regularly exceed the water quality guideline values (Tracey *et al.,* 2017).

Fertilisers are lost from cropping systems and transported to nearby waterways, contributing to dissolved inorganic nitrogen (DIN) and phosphorus (DIP) concentrations in runoff (Brodie *et al.,* 2019). Pristine forested catchments export mostly organic forms of nitrogen, which are largely unavailable to phytoplankton (Harris, 2001). Runoff enriched with anthropogenically-derived inorganic nutrients is linked to increased primary production and Chl-*a* concentrations in Reef inner-shelf waters (Wooldridge *et al.,* 2006). Estimated anthropogenic derived total nitrogen (TN) and total phosphorus (TP) in the Fitzroy Region is the highest in the Reef lagoon (TN = 14,000 tonnes y^{-1}, TP = 4,100 tonnes y^{-1}) (Kroon *et al.,* 2012). This nutrient-enriched runoff means the Fitzroy produces 44% of the anthropogenic plume-based Chl-*a* content in coastal waters (Baird *et al.,* 2021).

The Fitzroy Region has 20% of the mapped seagrass beds in the Reef lagoon and many inshore reefs associated with the Keppel Islands. The main threats to seagrass are reduced light availability and smothering from suspended sediment and increased growth of epiphytic algae from excess nutrients. Seagrass monitoring in the region has rated seagrass sites as 'poor' (McKenzie *et al.,* 2022). Long-term monitoring of inshore coral reefs in the region show distinct differences in benthic composition in relation to the water quality gradients (Thompson *et al.,* 2022). Coral cover in the Fitzroy has declined overall since 2005 but has seen some improvements following combined acute and chronic disturbances that influenced the region between 2006 and 2015 (Thompson *et al.,* 2022).

Given that benthic communities of the inshore reefs respond to gradients in water quality, especially sedimentation and nutrient availability (Thompson *et al.,* 2011, 2016), improved land management practices can decrease the stress caused by poor water quality on coastal marine ecosystems. Concerns about the water quality in the Reef lagoon led to the formulation of the Reef Plan for catchments adjacent to the Great Barrier Reef World Heritage Area by the Australian and Queensland governments in 2003 (The State of Queensland and Commonwealth of Australia 2003). The Reef Plan was revised and updated in 2009 and 2013 (The State of Queensland and Commonwealth of Australia, 2009; The State of Queensland, 2013), and further developed into The Reef 2050 Water Quality Improvement Plan (WQIP) (The State of Queensland, 2018). This plan set out ambitious targets to improve catchment and coastal water quality and has the aim of building resilience, improve ecosystem health and benefit communities. One of the main proposed actions is the establishment of the Paddock to Reef program, which aims to reduce threats to the health and resilience of the Great Barrier Reef by promoting the adoption of best management practices (Waterhouse *et al.,* 2018).

Best management practice has currently been implemented on 4% of grazing land, 14% of sugarcane land and 73% of banana production land (Great Barrier Reef Marine Park Authority, 2019); however, previous water quality targets were not met. The WQIP estimates the full adoption of class-B best management practice will reduce DIN load by 19%, and by 30% if class-A practices (innovative/aspirational practice) are fully adopted (Waltham *et al.* 2021). Complete adoption of best grazing practices could reduce TSS export from the Great Barrier Reef catchments by ~20% (Thorburn *et al*., 2013; Thorburn and Wilkinson, 2013). However, there is limited data available on the direct efficacy of best practice strategies on water quality (Carrol *et al.,* 2012), and modelled values are used for improvement estimations (Baird *et al.,* 2021, Dougall *et al.,* 2014). Site surveys showed that practicing zero tillage on cropping land (wheat, sorghum and sunflower) in the Fitzroy basin reduced erosion rates by 75% compared to traditional cropping practices and that at a catchment level, using no tillage can reduce sediment yield by ~50% (Carroll *et al.*, 1997). Reducing nitrogen fertilizer application by 47% by increasing nitrogen use efficiency (Thorburn *et al.,* 2011) reduced nitrogen surplus (excess nitrogen left in the soil) by 60% and reduced DIN in runoff and deep drainage water (Webster *et al.,* 2012).

Several types of erosion occur due to heavy rainfall and poor land management. Hillslope erosion, the erosion of topsoil on hillslopes by water runoff, is primarily affected by cattle stocking rates. Increasing grazing pressure removes vegetation cover from the land, leaving the fertile topsoil vulnerable to erosion. Gully erosion is the incision of flowing surface water, creating deep, unstable channels, often leaving the land unsuitable for agriculture. Gully erosion is often the main source of sediment in floodwater (Wasson *et al.,* 2002; de Vente *et al.,* 2005; Huon *et al.,* 2005). Streambank erosion arises when grazing occurs too close to vulnerable streambanks and riparian cover is not managed. These erosional processes cause fertile land to lose productive sediments, reducing vegetation, further destabilizing the area. Prolonged dry periods followed by intense rainfall cause massive gully erosion.

Sediment erosion can be managed by reducing stocking rates in the more vulnerable areas and slope stabilisation and sediment reinforcement by increasing root bonding (Shen *et al.,* 2017). Various types of restoration have been effective at reducing erosion rates. For example, Hillslope runoff in the Fitzroy Region was 50–90% less in sites with 40–50% ground cover when compared with sites with 10% cover (Owens *et al.,* 2003; Bartley *et al.,* 2006; Hawdon *et al.,* 2008; Silburn *et al.,* 2011). Streambank erosion is greatly reduced by increasing riparian forest buffers. This can reduce erosion rates by 59–91% (Zaimes *et al.,* 2008). This re-introduced vegetation stabilises existing sediments and reduces erosion, but also creates a sediment sink (Askey-Doran *et al.,* 1996; Furnas, 2003). This helps remove excess nutrients from groundwater and overland flooding (Apan *et al.,* 2002) and can capture up to 89% of nitrogen in runoff water (Thibault 1997). Sites along the Fitzroy River with higher riparian condition had better water quality (i.e., lower DOC, TN and dissolved metals), indicating the effectiveness of riparian restoration and management at improving water quality (Chua *et al.,* 2019). Fine sediments contribute 79% of the total nitrogen (TN) reaching the Great Barrier Reef, while DIN accounts for 17% (Kroon *et al.,* 2012). Decreasing erosion rates of agricultural land and the movement of both fine sediment and DIN to local waterways by riparian buffer restoration considerably decreases the TN load of river water (Thorburn and Wilkinson, 2013). However, the Fitzroy Region has only 1.3 million hectares of forested riparian areas, the lowest proportion within the GBRCA. From 2004 to 2008, 12,702 hectares of forested riparian areas were cleared. Sixty three percent of vegetation had been cleared in the region by 1999 and 0.5–0.75% of vegetation in the Fitzroy is currently cleared annually (CRC, 2003).

Climate and cyclone activity

Climate is a major driver of the condition of water quality and ecosystems and can vary substantially between years. It is heavily driven by the El Niño Southern Oscillation (ENSO) cycle. Climate models predict continued warming (IPCC, 2021); increasing intensity of extreme rainfall events and acute disturbances; fewer but more intense tropical cyclones; and more frequent and extreme La Niña and El Niño events (Schaffelke *et al.,* 2017).

Cyclones create waves which resuspend sediment. Several cyclones have impacted the Reef lagoon in the past two decades, most notable are the intense category 4 and 5 systems; cyclone Larry (2006) and cyclone Yasi (2011) in the Wet Tropics and Burdekin Regions, and cyclone Debbie (2017) in the Mackay-Whitsunday Region. The Fitzroy Region was impacted by cyclone Tasha in 2010 and cyclone Marcia in 2015, a category 5 severe tropical cyclone. In recent years, there has been very limited cyclone activity in the Reef and none in the Fitzroy Region. The 2022–23 year also showed no cyclone activity directly impacting the Fitzroy region.

Freshwater discharge volumes into the Reef lagoon are closely related to rainfall during the wet season and have a significant influence on coastal water quality. The total annual freshwater discharge for all of the Reef basins relative to long-term medians (based on water year, calculated using the methods described in Section 2.7) is shown in Figure 3-4. Discharge at the regional level is shown in Figure 3-5. In 2022–23 the overall Reef catchment area had discharge just above the long-term median while discharge in the Fitzroy region was equivalent to the long-term median.

Due to its large catchment area, the Fitzroy Region is prone to flooding. Acute disturbances, such as heavy rainfall and storms, cause increased sediment load entering coastal waters and resuspension of particles already in the environment. In the Fitzroy flood associated with cyclone Joy (1991), extensive mortality of corals in shallow reefs of the Keppel Islands occurred (van Woesik and Done, 1996). This was primarily attributed to an extended period of low salinity at these sites (Brodie and Mitchell, 1992; O'Neill *et al.,* 1992). A period of compounding large flooding events and storms in the Fitzroy Region between 2006 and 2014 instigated a further decline in coral cover on the inshore reefs and the Keppel Islands (Thompson *et al.,* 2014a). Low salinity in the 2011 flooding triggered widespread mortality of coral at 2 m on Peak, Pelican and Keppels South sites (Thompson *et al.,* 2013). Some sites experienced 100% mortality down to a depth of 8 m (Jones and Berkelmans, 2014). This coincided with high incidences of coral disease, supporting evidence that the confounding effects of low salinity (Haapkylä *et al.,* 2011) and increased organic matter and nutrients, most notably DOC (Brandt *et al.,* 2013; Kline *et al.,* 2006), can initiate coral disease outbreaks. The cumulative stress of high turbidity (low light) and an increase in algal growth from nutrients hinders coral recovery (Diaz-Pulido, 2009; Rogers and Miller, 2006; Roth *et al.,* 2018). Between 2005 and 2014, coral cover declined. Since 2014, coral cover and coral juvenile density have slightly improved but are still classified as 'poor' (Thompson *et al.,* 2016, 2021, 2022).

Flood plumes in the Reef lagoon rarely reach the mid and outer shelf, however, plumes from large flood events from cyclones can affect these reefs over short time periods. In the Wet Tropics region, the mid shelf reefs are closer to the coast (<30 km), and are more easily reached by flood plumes, for example cyclone Sadie (1994). However, the mid and outer shelf reefs of the Fitzroy Region are further from the coast (90 km to the Capricorn and Bunkers, 210 km to the Swains Reefs from Fitzroy River mouth). Physical conditions, such as wind are key factors in the spread of flood plumes. The prevailing winds in the Fitzroy Region are usually south-easterly, keeping flood plumes close to shore. However, the wind during cyclone Joy (1991) turned to blow offshore, moving the large plume out to the Capricorn and Bunker group, stretching 200 km offshore, lowering salinity on the Capricorn reefs to 27 ppt (Devlin *et al.,* 2001, Preker *et al.* 1992). Events such as this are seen on a scale of multiple decades, while the reefs associated with the Keppel Islands see extreme impacts from river plumes every 4–6 years, and Barren Island, Hummocky Island and Masthead Island every 10 years (Devlin *et al.,* 2001). Vertical distribution of flood plumes largely affects the salinity, turbidity and nutrient content of the top 3 to 4 m (Devlin *et al.,* 2001), but physical conditions, such as high winds can lead to deeper mixing during these extreme events.

Current patterns in the Reef lagoon are seasonal. South-easterly trade winds dominate most of the year, creating a strong north-westward alongshore current movement (Orpin *et al.,* 2010), especially from January to August. Some periods of southerly movement can be seen from August to December depending on prevailing oceanographic conditions (Luick *et al.,* 2007). This transport tends to move small, easily suspended particles discharged from the Fitzroy River northward. Water quality in the Whitsundays region has deteriorated since 2007 and it is speculated that this could be partly due to inputs of flood discharge from the Fitzroy River (Baird *et al.,* 2019, Cantin *et al.,* 2019). In more recent years, there has been a stabilisation and subsequent improvement in conditions observed in the Whitsundays region between 2017 to 2022 (Moran *et al.,* 2023). Analysis of coral cores in the Whitsunday Islands show that Barium/Calcium (Ba/Ca) ratios (which correlate well with flood events) of some sites increased significantly after large flood events in the Fitzroy Region. The Fitzroy River is thought to have the largest and longest-lasting influence of any river on the water quality of the Whitsunday region. However, the Ba/Ca ratios have not increased significantly from flood events before the period of poorer water quality in the Whitsunday region (2007–2017). Anomalous high Ba/Ca ratios at Scawfell do not seem to relate to Fitzroy River discharge. Hence, declining water quality in the area is more likely due to marine resuspension than flood plume inputs (Cantin *et al.* 2019). A high percentage of sediment in various sites around the Whitsunday Islands had a grain size of <63 µm (Thompson *et al.,* 2014b), which is easily resuspended during disturbance events.

The natural occurrence of the ENSO is closely linked to wet and dry periods on the east coast of Australia. Moderate La Niña conditions were observed in 2020–21 and continued through 2021–2023 and there has been minimal direct impact from acute disturbance associated with tropical cyclones. During La Niña, tropical cyclones are typically more common compared to intermediate years, and the first occurrences of cyclones is earlier in the season. This means these years have an increased likelihood of extensive flooding from rain and damage from high winds. Between 2010 and 2012, there was a strong La Niña event, increasing rainfall and causing extensive flooding (NOAA, 2017). Discharge from the Fitzroy River was considerably higher than the long-term median discharge (2.8 million litres) in 2008 (Devlin, 2008) and 2010–2013 (Jones and Berkelmans, 2014). In 2010–11, it was nearly 38 million litres, reaching a peak mean daily discharge of 1.16 million mega-litres per day over a period of 18 days (Jones and Berkelmans, 2014).

Future changes to the ENSO due to anthropogenic warming are projected, but are difficult to quantify (Collins *et al.,* 2010). Strong ENSO events are predicted to become more common, especially extreme El Niño followed by La Niña events (Cai *et al.,* 2021). Tropical cyclones in the South Pacific are expected to become less frequent in future oceans (Murakami and Sugi, 2010; Sugi *et al.,* 2009; Zhao *et al.,* 2009; Gualdi *et al.,* 2008; Emanuel *et al.,* 2008), although by how much is disputed (Walsh *et al.,* 2012). Cyclone intensity, however, is predicted to increase marginally (Windlansky *et al.,* 2019). El Niño years bring drier weather to the Fitzroy Region, and with it, less vegetation growth to stabilise sediment in the catchment. La Niña years are wetter than normal years. If the frequency of intermediate years decreases, more extended dry years followed by major flood events may lead to an increase in erosion as vegetation will not have the time to recover between extreme dry and wet conditions, leaving more bare sediment that is vulnerable to erosion.

D-5 Focus region water quality and Water Quality Index

Fringing reefs are formed around continental islands in Keppel Bay, many of which are used extensively for recreational and tourism activities. Six monitoring sites are sampled in this focus region ten times per year during ambient conditions in the dry and wet seasons. The monitoring sites are located in a transect from the river mouth in a north-easterly direction, representing a gradient in water quality. Four sites are located in the open coastal water body, one site is located in the mid-shelf water body, and one site is in enclosed coastal waters (Figure D - 1).

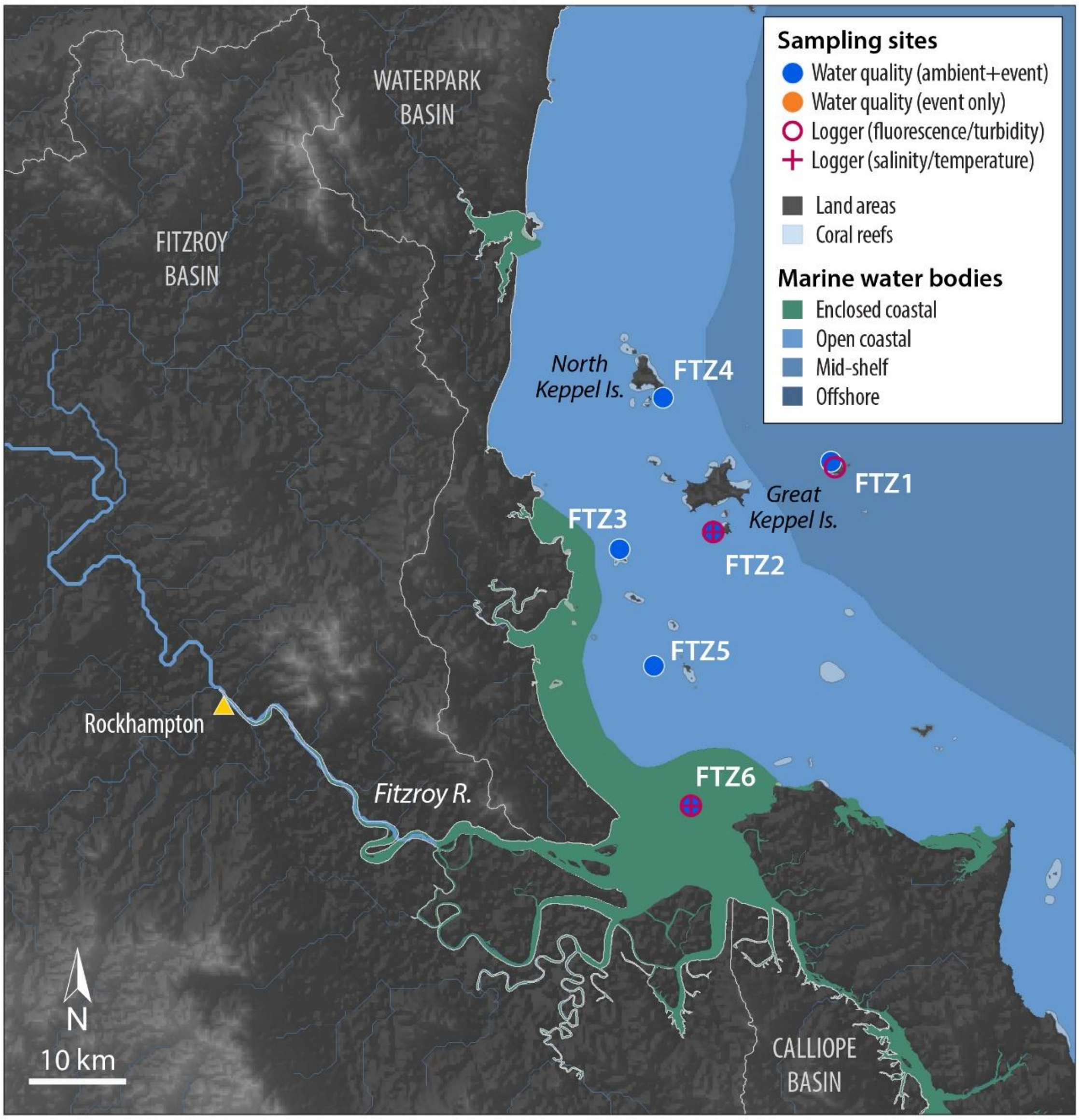


Figure D - 1: Sampling sites in the Fitzroy focus region, shown with the water body boundaries. Sites FTZ1–FTZ3 were monitored from 2005–2014 under the Marine Monitoring Program.

From 2008–2013, the Fitzroy NRM region experienced several years of intense flooding with annual discharge from the Fitzroy River exceeding the long-term median in 2008, 2010, 2011, 2012, and 2013 (Figure D - 2, Figure 3-5). In four of these years, the freshwater discharge was greater than three times the long-term median, with the 2011 flood event being the largest on record (Figure D - 3). Annual discharge of the Fitzroy River from 2014–2022 was generally close to or less than the long-term median (Figure D - 2).

Annual discharge for the Fitzroy Basin in the 2022–23 water year was around the long-term median (Figure 3-5; Table 3-1). The combined discharge and loads calculated for the 2022–23 water year were also around the long-term average (Figure D - 2). Over the 17-year period from 2006–07:

- discharge ranged from 437 GL (2020–21) to 41,736 GL (2010–11);
- TSS loads ranged from 16 kt (2013–14) to 7,000 kt (2010–11);
- DIN loads ranged from 74 t (2020–21) to 3,900 t (2010–11); and
- PN loads ranged from 100 t (2020–21) to 17,000 t (2010–11).

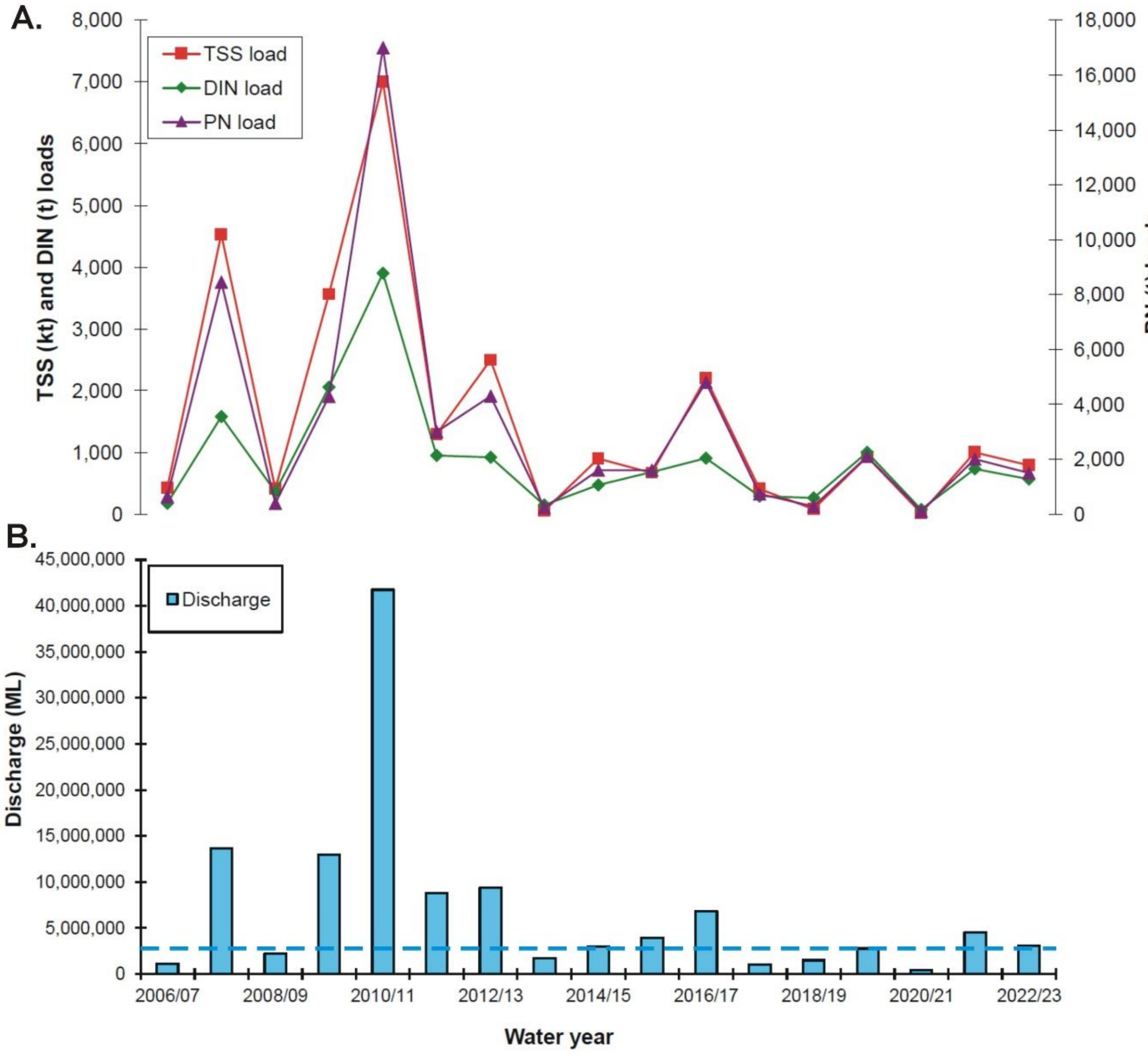


Figure D - 2: Loads of (A) TSS, DIN and PN and (B) discharge for the Fitzroy Basin. The loads reported here are based on the monitoring data from the Fitzroy River as reported in the Great Barrier Reef Catchment Loads Monitoring Program with a long-term annual mean concentration of the existing data calculated to produce a load for the 2021–22 and 2022–23 water years (where monitored load data have not yet been reported). Dotted line represents the long-term median for basin discharge. Note the different scales on the two y-axes.

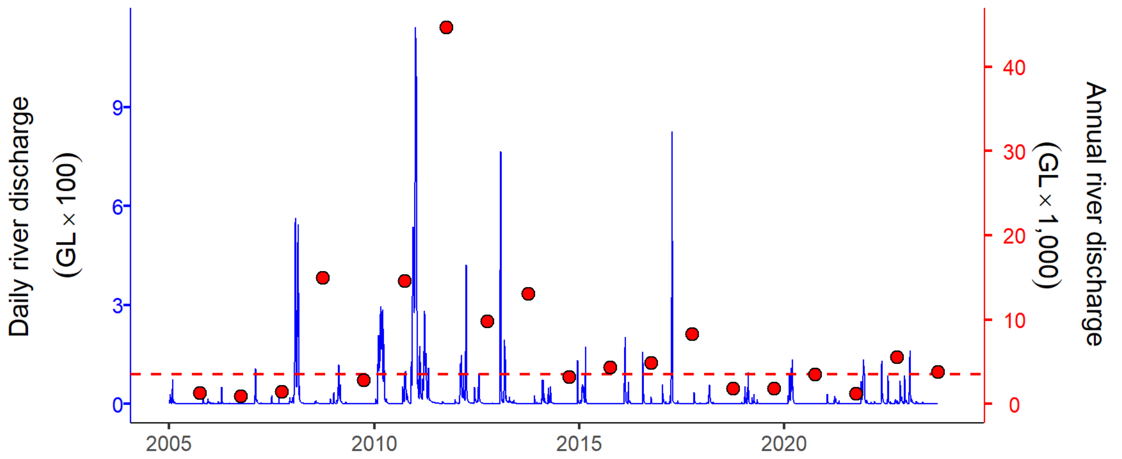


Figure D - 3: Total discharge for the Fitzroy region (Table 2-3). Daily (blue) and water year (1 October to 30 September, red) discharge is shown. Red dashed line represents the long-term median annual discharge.

Ambient water quality and the in situ *Water Quality Index*

Water quality showed trends along the sampling transect (cross-shelf gradient in northerly direction). Sites located nearest to the river mouth (distance from river mouth = 0 km) had high concentrations of Chl-*a*, NO_x, TSS, and particulate nutrients (PN and PP), which declined with distance away from the river mouth, reaching low levels in mid-shelf waters (Figure D - 4). Secchi depths were low at sites near the river mouth (water clarity was poor) and increased (water clarity improved) with distance from the river mouth. These spatial patterns are generally consistent with those that are typically observed in the region.

This year, seasonal differences in Chl-*a*, TSS, PN, and PP were observed, where concentrations were higher during the dry than the wet season. These seasonal differences tended to become less pronounced further offshore (e.g., concentrations of PN during wet and dry seasons were similar in mid-shelf waters). Secchi depth and NO_x were generally similar along the transect between wet and dry seasons. (Figure D - 4). These seasonal differences may be driven by strong physical forcing rather than by river discharge events given this was a year of near-median discharge.

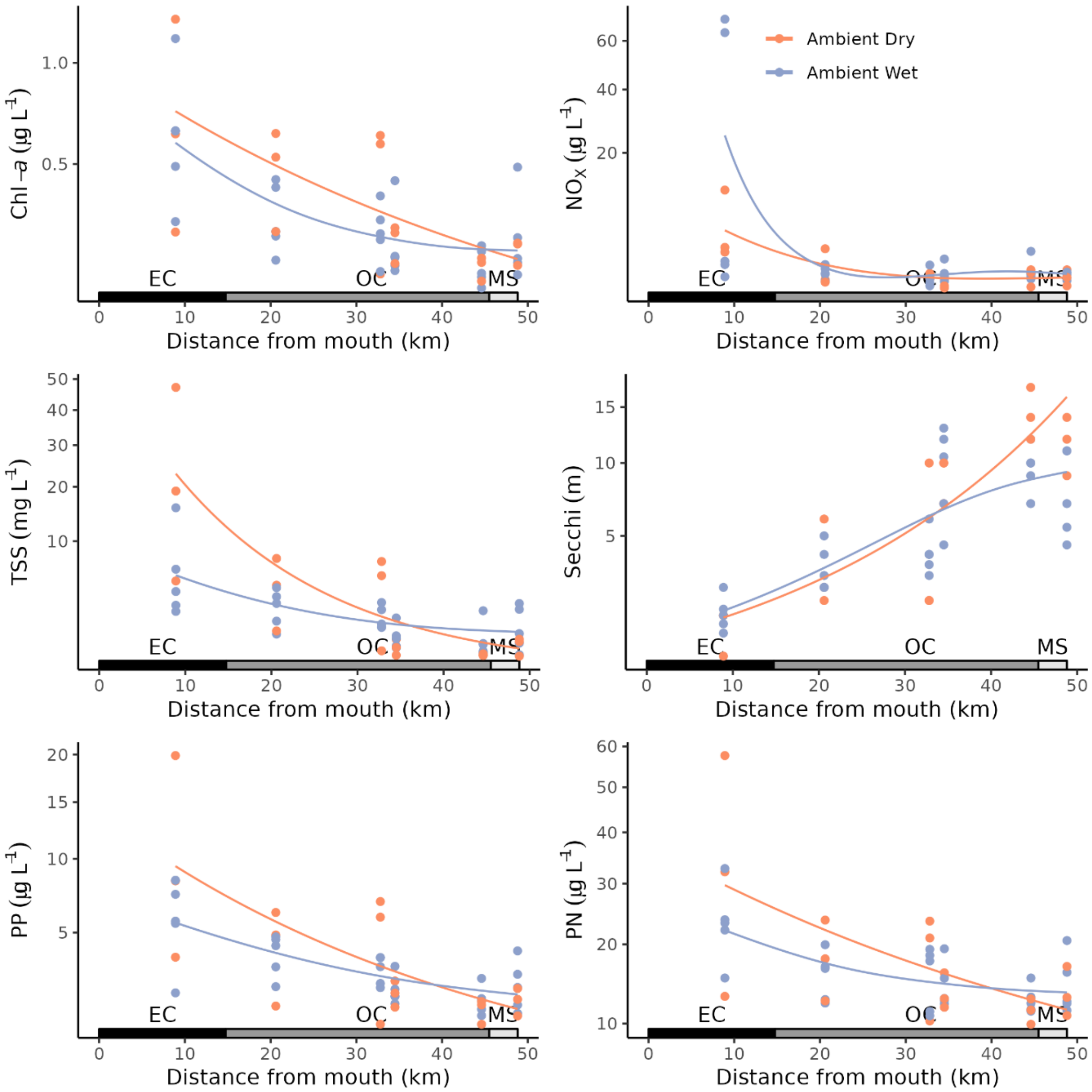


Figure D - 4: Water quality variables measured during ambient sampling in 2022–23 along the Fitzroy focus region transect. Chlorophyll a (Chl-a), nitrate/nitrite (NOx), total suspended solids (TSS), Secchi depth, particulate nitrogen (PN), and particulate phosphorus (PP) are shown with distance from the Fitzroy River mouth. Water body classifications are shown along the x-axes: Enclosed coastal (EC), open coastal (OC) and mid-shelf (MS). Note the y-axes are logarithmic scales. Fitted lines are generalised additive models.

Site-specific water quality results are presented in Table C - 1. During the 2022–23 water year, concentrations of Chl-*a* were generally below (meeting) the GVs at most sites except Peak West FTZ5. Concentrations of PO_4 met GVs at three of the six sites and concentrations of TSS met GVs at two of five sites. All other variables showed a mixed response of meeting GVs at each site. Concentrations of NO_x exceeded (did not meet) the GVs at most sites in the Fitzroy region (except Fitzroy River Mouth FTZ6). Secchi depth did not meet GVs at most sites in the region (except North Keppel Island FTZ4). Concentrations of PN and PP exceeded (did not meet) GVs at Pelican (FTZ3) and Peak West (FTZ5) but met GVs at all other sites.

The gap in observational data between 2015 and 2020 limits the utility of the GAMMs in detecting long-term trends over this interval. The apparent sharp gradients in some water quality variables since the reinstatement of monitoring (2020–23) (Figure D - 5) are almost certainly a statistical artefact of the limited recent data available and are likely to show smoother trends when a few more years of monitoring data become available. Despite this, trend analysis over the last several years suggests that NO_x, PO_4, PP, PN, Secchi depth, and Chl-*a* are relatively consistent with concentrations seen around the time MMP monitoring ended in the region (2015).

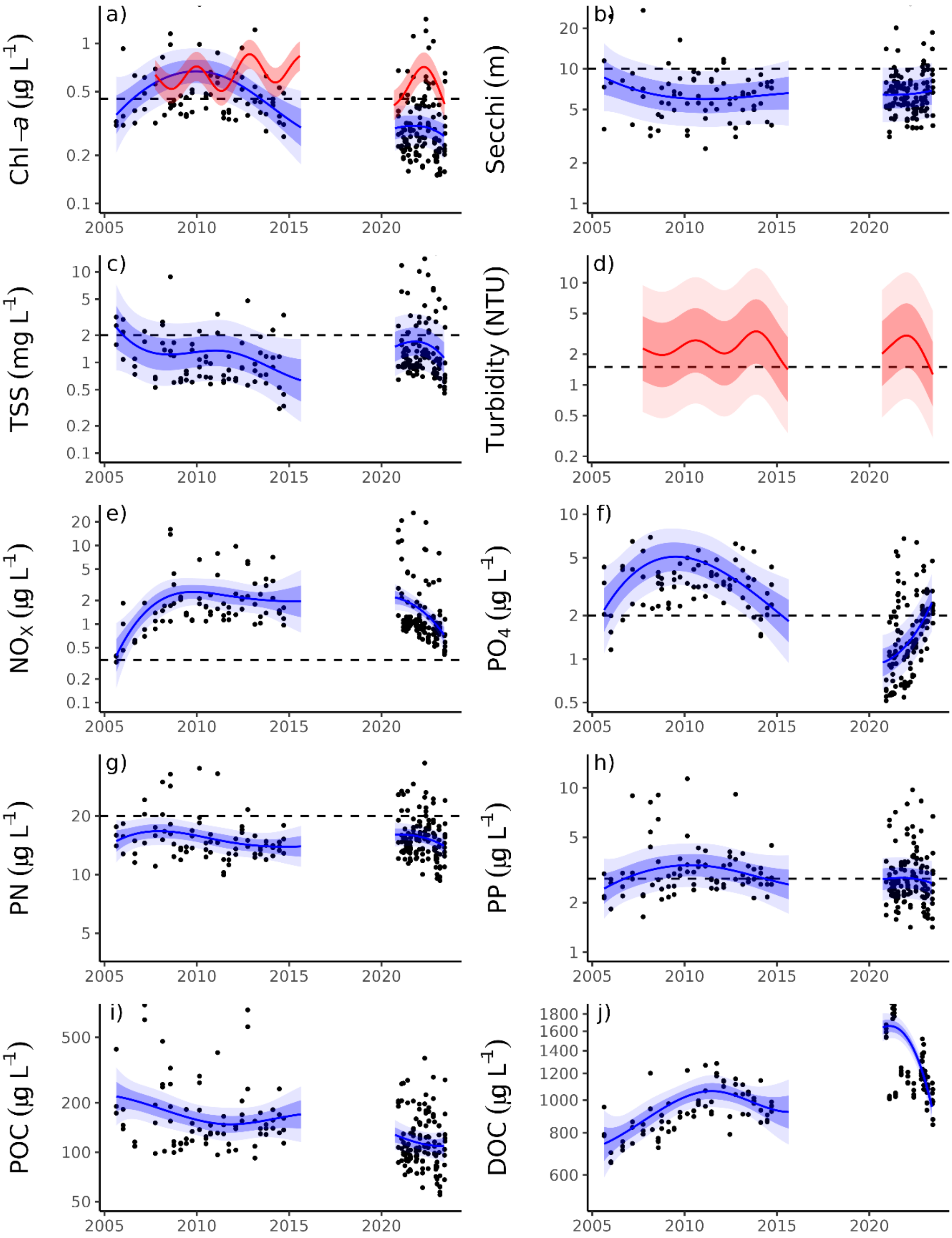


Figure D - 5: Temporal trends in water quality variables for the Fitzroy focus region: a) chlorophyll *a* (Chl-*a*), b) Secchi depth, c) total suspended solids (TSS), d) turbidity, e) nitrate/nitrite (NO_x), f) phosphate (PO_4), g) particulate nitrogen (PN), h) particulate phosphorus (PP), i) particulate organic carbon (POC) and j) dissolved organic carbon (DOC). Generalised additive mixed effect models (trends) are represented by blue lines with shaded areas defining 95% confidence intervals of those trends accounting for the effects of wind, waves, tides, and seasons after applying x-z detrending. Trends of records from ECO FLNTUSB instruments are represented in red, and individual records can be found in Figure C - 1. Dashed horizontal reference lines indicate annual guidelines. The apparent steep gradients in some variables during 2020–2023 are likely statistical artefacts of the lack of data from 2015–2020 and will improve as more monitoring data are collected.

Trend analysis suggests that TSS has potentially increased (water clarity has worsened) since MMP monitoring ended in 2015 (Figure D - 5), although this is a very preliminary finding; long-term trends will become clearer as additional data are collected. There are also some signs that DOC has increased in recent years (as it has in other focus regions monitored under the MMP).

The WQ Index is calculated using two different formulations to communicate the a) long-term trend in water quality (based on the pre-2015 sampling design) and b) annual condition of water quality (based on the post-2015 sampling design, which increased the power to detect change). Section 2.5 and Appendix B contain details of the calculations for both Index formulations.

The long-term WQ Index has shown a small (i.e., changing by a single grade) overall improvement in water quality from the period 2007–2015, driven by Chl-*a*, PN, and PP indicators (Figure D - 6a). A trend of improvement in water quality has also been observed since monitoring resumed in 2020, although this finding is preliminary until further data are available (Figure D - 6a). This improving trend is driven primarily by improvements in water clarity, PN, and PP indicators.

The annual condition WQ Index has scored water quality as ‘good’ since its inception (2020–present), with the 2022–23 year receiving a ‘good score (Figure D - 6b). This version of the Index scores water quality parameters against GVs relevant to the season when samples are collected (wet versus dry GVs).

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

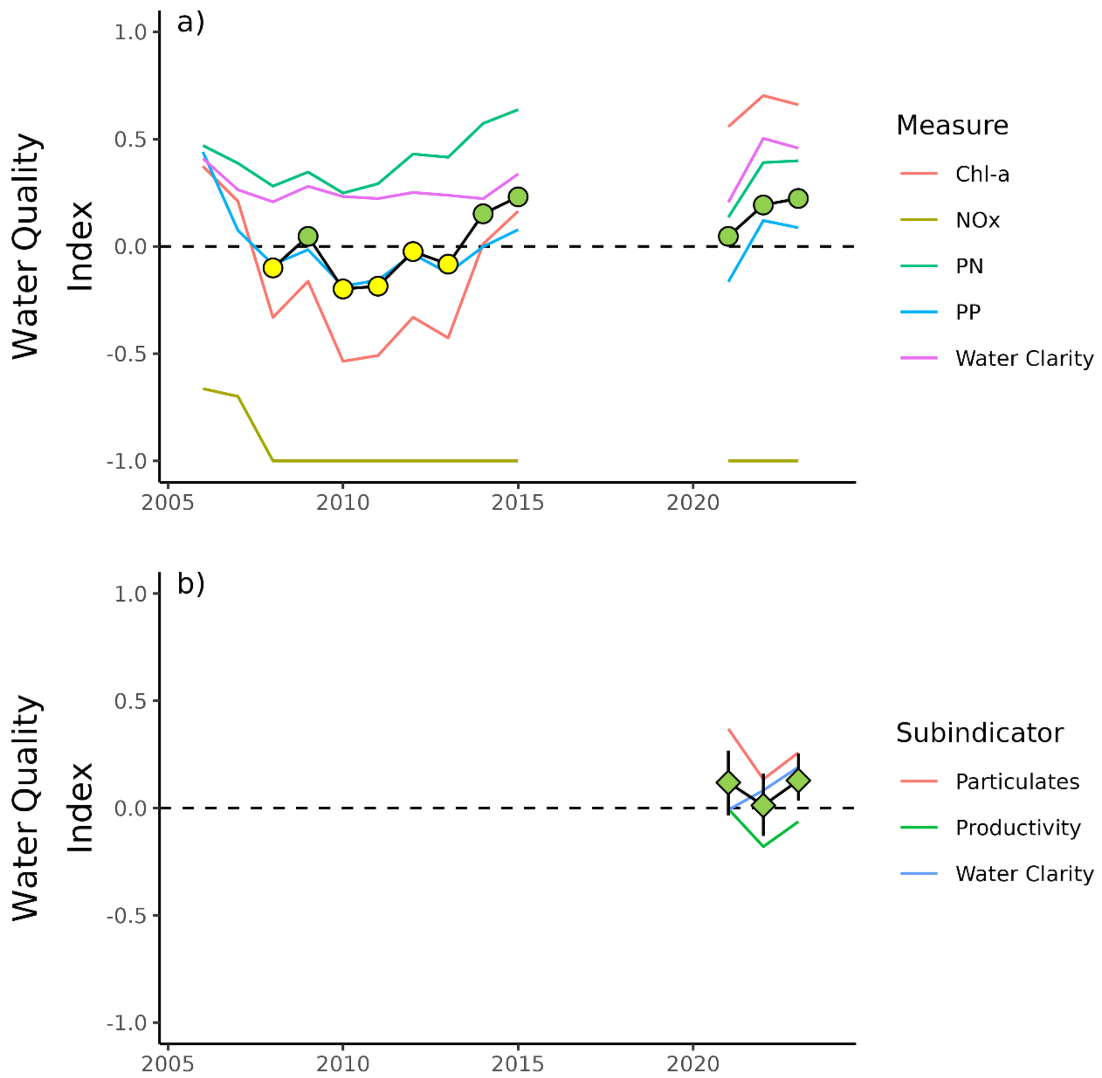


Figure D - 6: The Water Quality Index (WQ Index) for the Fitzroy focus region. The WQ Index uses two formulations to communicate: a) long-term trend (based on pre-2015 sampling design) and b) the annual condition (based on post-2015 sampling design). WQ Index colour coding: ■ / ◆– 'very good'; ■ / ◆ – 'good'; ■ / ◆ – 'moderate; ■ / ◆ – 'poor'; ■ / ◆ – 'very poor'. Indicators or sub-indicators that are used to calculate the WQ Index are shown as coloured lines. Error bars (vertical black lines) on the WQ Index represent the 95% quantile intervals. Calculations for both formulations are described in Methods and Appendix B.

D-6 Discussion and Conclusions

The discharge and loads calculated for the 2022–23 water year from the Fitzroy River were very close to the long-term median (Figure 3-5; Figure D - 2; Table 3-1). The discharge has been near or below-median for the previous five years in this region, and in the 2020–21 water year the discharge and loads calculated were amongst the lowest recorded over the past decade.

Ambient water quality - Enclosed coastal, open coastal, and mid-shelf waters:

- Concentrations of NO_x and Secchi depth did not meet GVs at most monitoring sites.
- Concentrations of PO_4, PN, PP, and TSS did not meet GVs at half the monitoring sites in the region.

- Concentrations of Chl-*a* were below (meeting) GVs at most monitoring sites in the region (except Peak West).
- The trend analysis conducted for other MMP focus regions (trends over the last five years) is not appropriate for this dataset as monitoring re-commenced in 2020. Preliminary trend analysis was conducted although not enough data exist to draw definitive conclusions; as future monitoring occurs, trends will become clearer. Trend analysis based on GAMMs suggests that over the last several years:
  - TSS has increased (water clarity has worsened) since monitoring under the MMP ended in 2015.
  - Chl-*a* may have decreased (an improvement in water quality) since monitoring under the MMP ended in 2015.
  - Other variables (NO_x, PO_4, PP, PN, and Secchi depth) show signs of stability since MMP monitoring ended in 2015 although more data are needed to confirm this conclusion.
- The long-term WQ Index showed a small (i.e., changing by a single grade) improvement in water quality over the period 2008 to 2015, which was driven by improvements in PN, PP, and Chl-*a* indicators. Over the period 2020–2023, a trend of improvement has been seen, although more data are needed to confirm this. For the 2022–23 water year, the annual condition WQ Index score was ‘good’.

Wet season and event water quality

- There were no major flood events in the Fitzroy region during the 2022–23 wet season.

D-7 References

Álvarez-Romero JG, Devlin M, Teixeira da Silva E, Petus C, Ban NC, Pressey RL, Kool J, Roberts JJ, Cerdeira-Estrada S, Wenger AS Brodie J (2013) A novel approach to model exposure of coastal-marine ecosystems to riverine flood plumes based on remote sensing techniques. Journal of Environmental Management 119: 194-207.

Apan AA, Raine SR, Paterson MS, (2002) Mapping and Analysis of Changes in the Riparian Landscape Structure of the Lockyer Valley Catchment, Queensland, Australia, 59(1): 43-57.

Askey-Doran M, Bunn S, Hairsine P, Price P, Prosser I, Rutherform I (1996) Riparian Management 3: Water Quality, Land and Water Resources Research and Development Corporation, Canberra.

Bainbridge Z, Lewis S, Bartley R, Fabricius K, Collier C, Waterhouse J, Garzon-Garcia A, Robson B, Burton J, Wenger A, Brodie J (2018) Fine sediment and particulate organic matter: A review and case study on ridge-to-reef transport, transformations, fates, and impacts on marine ecosystems. Marine pollution bulletin. 135:1205-20.

Baird M, Margvelashvili N, Cantin N (2019) Historical context and causes of water quality decline in the Whitsunday region. CSIRO Oceans and Atmosphere. https://www.environment.gov.au/ system/files/resources/995dd4ca-bd44-407d-87e8-a323e67fef6c/files/historical-context-causes-water-quality-decline-whitsundays.pdf, accessed 30 August 2021.

Baird ME, Mongin M, Skerratt J, Margvelashvili N, Tickell S, Steven AD, Robillot C, Ellis R, Waters D, Kaniewska P, Brodie J (2021) Impact of catchment-derived nutrients and sediments on marine water quality on the Great Barrier Reef: An application of the eReefs marine modelling system. Marine Pollution Bulletin. 167:112297.

Bartley R, Roth CH, Ludwig J, McJannet D, Liedloff A, Corfield J, Hawdon A, Abbott B (2006) Runoff and erosion from Australia's tropical semi-arid rangelands: Influence of ground cover for differing space and time scales. Hydrological Processes: An International Journal. 20(15):3317-33.

Berkelmans R, Jones AM, Schaffelke B (2012) Salinity thresholds of Acropora spp. on the Great Barrier Reef. Coral Reefs 31(4): 1103-1110.

BOM (Bureau of Meteorology) (2021) Fitzroy: Climate and water, accessed 11 October 2022.http://www.bom.gov.au/water/nwa/2021/fitzroy/index.shtml

Brandt ME, Smith TB, Correa AM, Vega-Thurber R (2013) Disturbance driven colony fragmentation as a driver of a coral disease outbreak. PLoS One. 8(2):e57164.

Brodie JE, Mitchell AW (1992) Nutrient composition of the January (1991) Fitzroy River flood plume, pp. 56–74 in Workshop on the Impacts of Flooding, ed. G.T. Byron, Workshop Series No. 17, Great Barrier Reef Marine Park Authority, Townsville.

Brodie JE, McKergow LA, Prosser IP, Furnas M, Hughes AO, Hunter H. (2003) Sources of sediment and nutrient exports to the Great Barrier Reef World Heritage Area.

Brodie J, Fabricius K, De'ath G, Okaji K (2005) Are increased nutrient inputs responsible for more outbreaks of crown-of-thorns starfish? An appraisal of the evidence. Marine pollution bulletin. 1;51(1-4):266-78.

Brodie JE, Devlin M, Haynes D, Waterhouse J (2011) Assessment of the eutrophication status of the Great Barrier Reef lagoon (Australia). Biogeochemistry. 106(2):281-302.

Brodie J, Grech A, Pressey B, Day J, Dale AP, Morrison T, Wenger A (2019) The future of the Great Barrier Reef: the water quality imperative. In Coasts and Estuaries (pp. 477-499). Elsevier.

Bruno JF, Petes LE, Drew Harvell C, Hettinger A (2003) Nutrient enrichment can increase the severity of coral diseases. Ecology letters. 6(12):1056-61.

Cai W, Santoso A, Collins M, Dewitte B, Karamperidou C, Kug JS, Lengaigne M, McPhaden MJ, Stuecker MF, Taschetto AS, Timmermann A (2021) Changing El Niño–Southern Oscillation in a warming climate. Nature Reviews Earth & Environment. 7:1-7.

Cantin N, Wu Y, Fallon S, Lough J (2019) Historical records of terrestrial sediment and flood plume inputs to the Whitsunday Island region from coral skeletons: 1861-2017. Australian Institute of Marine Science, Townsville, Qld. 30p.

Carroll C, Halpin M, Burger P, Bell K, Sallaway MM, Yule DF (1997) The effect of crop type, crop rotation, and tillage practice on runoff and soil loss on a Vertisol in central Queensland. Soil Research. 35(4):925-40.

Chua EM, Wilson SP, Vink S, Flint N (2019) The influence of riparian vegetation on water quality in a mixed land use river basin. River Research and Applications. 35(3):259-67.

Collins M, An SI, Cai W, Ganachaud A, Guilyardi E, Jin FF, Jochum M, Lengaigne M, Power S, Timmermann A, Vecchi G (2010) The impact of global warming on the tropical Pacific Ocean and El Niño. Nature Geoscience. 3(6):391-7.

CRC for Coastal Zone, Estuary & Waterway Management (CRC) (2003) Central Queensland information paper. Volume 6: Fitzroy Catchment, Queensland.

Department of Regional Development, Manufacturing and Water (DRMW) (2023). River discharge data. https://water-monitoring.information.qld.gov.au/ Accessed October 2023.

De Vente J, Poesen J, Verstraeten G (2005) The application of semi-quantitative methods and reservoir sedimentation rates for the prediction of basin sediment yield in Spain. Journal of Hydrology. 305(1-4):63-86.

Devlin M, Waterhouse J, Taylor J, Brodie J (2001) Flood plumes in the Great Barrier Reef: spatial and temporal patterns in composition and distribution. GBRMPA research publication. 68.

Devlin M (2008) The 2008 flood plume event on the Fitzroy River. Catchment to Reef Group, James Cook University. https://www.gbrmpa.gov.au/__data/assets/pdf_file/0010/7687/JCU_Fitzroy_v1_2009.pdf

Diaz-Pulido G, McCook LJ, Dove S, Berkelmans R, Roff G, Kline DI, Weeks S, Evans RD, Williamson DH, Hoegh-Guldberg O (2009) Doom and boom on a resilient reef: climate change, algal overgrowth and coral recovery. PloS one. 4(4):e5239.

Dougall C, Packett R, Carroll C (2005) Application of the SedNet model in partnership with the Fitzroy Basin community. In MODSIM 2005 International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand 2005 Dec (pp. 1119-1125).

Dougall C, McCloskey GL, Ellis R, Shaw M, Waters D, Carroll C (2014) Modelling reductions of pollutant loads due to improved management practices in the Great Barrier Reef catchments – Fitzroy NRM region, Technical Report, Volume 6, Queensland Department of Natural Resources and Mines, Rockhampton, Queensland (ISBN: 978-0-7345- 0444-9).

Emanuel K, Sundararajan R, Williams J (2008) Hurricanes and global warming: Results from downscaling IPCC AR4 simulations. Bulletin of the American Meteorological Society. 89(3):347-68.

Fabricius KE (2005) Effects of terrestrial runoff on the ecology of corals and coral reefs: review and synthesis. Marine pollution bulletin. 50(2):125-46.

FBA (Fitzroy Basin Association) (2018) Census of Population and Housing, 2016, accessed 30 August 2021, Population demographics | Fitzroy Basin Association (fba.org.au)

Furnas M, (2003) Catchments and Corals: Terrestrial Runoff to the Great Barrier Reef, Australian Institute of Marine Science and CRC Reef Research Centre, Townsville.

Gallen C, Devlin M, Thompson K, Paxman C, Mueller J (2014) Pesticide monitoring in inshore waters of the Great Barrier Reef using both time-integrated and event monitoring techniques (2013 - 2014). The University of Queensland, The National Research Centre for Environmental Toxicology (Entox). http://hdl.handle.net/11017/2930, accessed 30 August 2021.

Great Barrier Reef Marine Park Authority (2010). Water Quality Guidelines for the Great Barrier Reef Marine Park. Revised Edition 2010. Great Barrier Reef Marine Park Authority, Townsville. 100pp.

Great Barrier Reef Marine Park Authority (2019) Great Barrier Reef Outlook Report 2019. Great Barrier Reef Marine Park Authority, https://elibrary.gbrmpa.gov.au/jspui/bitstream/11017/3474/13/Outlook-Report-2019-Intro.pdf , accessed 30 August 2021.

Great Barrier Reef Marine Park Authority (2022) Great Barrier Reef Marine Monitoring Program quality assurance and quality control manual 2020–21, Great Barrier Reef Marine Park Authority, Townsville.

Gualdi S, Scoccimarro E, Navarra A (2008) Changes in tropical cyclone activity due to global warming: Results from a high-resolution coupled general circulation model. Journal of climate. 21(20):5204-28.

Haapkylä J, Unsworth RK, Flavell M, Bourne DG, Schaffelke B, Willis BL (2011) Seasonal rainfall and runoff promote coral disease on an inshore reef. PloS one. 10;6(2):e16893.

Harris GP (2001) Biogeochemistry of nitrogen and phosphorus in Australian catchments, rivers and estuaries: effects of land use and flow regulation and comparisons with global patterns. Marine and freshwater research. 52(1):139-49.

Hawdon AA, Keen RJ, Post DA, Wilkinson SN (2008) Hydrological recovery of rangeland following cattle exclusion. IAHS publication. 325:532.

Hughes AO, Olley JM, Croke JC, McKergow LA (2009) Sediment source changes over the last 250 years in a dry-tropical catchment, central Queensland, Australia. Geomorphology. 104(3-4):262-75.

Huon S, Bellanger B, Bonté P, Sogon S, Podwojewski P, Girardin C, Valentin C, de Rouw A, Velasquez F, Bricquet JP, Mariotti A (2005) Monitoring soil organic carbon erosion with isotopic tracers: two case studies on cultivated tropical catchments with steep slopes (Laos, Venezuela). Soil Erosion and Carbon Dynamics (pp. 301-328). CRC Press.

IPCC (2021) Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. In Press.

Jones AM, Berkelmans R (2014) Flood impacts in Keppel Bay, southern Great Barrier Reef in the aftermath of cyclonic rainfall. PloS one. 9(1):e84739.

Kline DI, Kuntz NM, Breitbart M, Knowlton N, Rohwer F (2006) Role of elevated organic carbon levels and microbial activity in coral mortality. Marine Ecology Progress Series. 314:119-25.

Kuntz NM, Kline DI, Sandin SA, Rohwer F (2005) Pathologies and mortality rates caused by organic carbon and nutrient stressors in three Caribbean coral species. Marine Ecology Progress Series. 294:173-80.

Kroon FJ, Kuhnert PM, Henderson BL, Wilkinson SN, Kinsey-Henderson A, Abbott B, Brodie JE, Turner RD (2012) River loads of suspended solids, nitrogen, phosphorus and herbicides delivered to the Great Barrier Reef lagoon. Marine pollution bulletin. 65(4-9):167-81.

Lewis SE, Bartley R, Wilkinson SN, Bainbridge ZT, Henderson AE, James CS, Irvine SA, Brodie JE (2021) Land use change in the river basins of the Great Barrier Reef, 1860 to 2019: A foundation for understanding environmental history across the catchment to reef continuum. Marine Pollution Bulletin. 166:112193.

Luick JL, Mason L, Hardy T, Furnas MJ (2007) Circulation in the Great Barrier Reef Lagoon using numerical tracers and *in situ* data. Continental Shelf Research. 27(6):757-78.

Marwick TR, Borges AV, Van Acker K, Darchambeau F, Bouillon S (2014) Disproportionate contribution of riparian inputs to organic carbon pools in freshwater systems. Ecosystems. 17(6):974-89.

McKenzie, L.J., Collier, C.J, Langlois, L.A., Yoshida, R.L. and Waycott, M. (2022). Marine Monitoring Program: Annual Report for Inshore Seagrass Monitoring 2020 21. Report for the Great Barrier Reef Marine Park Authority, Great Barrier Reef Marine Park Authority, Townsville, 177pp.

Meat and Livestock Australia (MLA) (2021) Industry Projections 2021 - Australian cattle - February, feb2021-mla-australian-cattle-industry-projections.pdf, accessed 30 August 2021.

Moran, D., Robson, B., Gruber, R., Waterhouse, J., Logan, M., Petus, C., Howley, C., Lewis, S., James, C., Tracey, D., Mellors, J., O'Callaghan, M., Bove, U., Davidson, J., Glasson, K., Jaworski, S., Lefevre, C., Nordborg, M., Vasile, R., Zagorskis, I., Shellberg, J., 2023. Marine Monitoring Program: Annual Report for Inshore Water Quality Monitoring 2021–22. Report for the Great Barrier Reef Marine Park Authority, Great Barrier Reef Marine Park Authority, Townsville.

Murakami H, Sugi M (2010) Effect of model resolution on tropical cyclone climate projections. Sola. 6:73-6.

NOAA (2017) National Weather Service: Climate Prediction Center. Climate Prediction Center - ONI (noaa.gov), accessed 30 August 2021.

O'Neill JP, Byron GT, Wright SC (1992) Some physical characteristics and movement of 1991 Fitzroy River flood plume. In Workshop Series (No. 17, pp. 36-51).

Orpin AR, Ridd PV, Stewart LK (1999) Assessment of the relative importance of major sediment-transport mechanisms in the central Great Barrier Reef lagoon. Australian Journal of Earth Sciences. 46(6):883-96.

Packett R, Dougall C, Rohde K, Noble R (2009) Agricultural lands are hot-spots for annual runoff polluting the southern Great Barrier Reef lagoon. Marine pollution bulletin. 58(7):976-86.

Preker M, Byron GT (1992) The effects of the 1991 central Queensland floodwaters around Heron Island, Great Barrier Reef. In Workshop series. Great Barrier Reef Marine Park Authority.

QLUMP (Queensland Land Use Mapping Program) (2019) Fitzroy and Burnett Mary natural resource management regions, https://www.qld.gov.au/environment/land/management/mapping/statewide-monitoring/qlump/qlump-datasets accessed 30 August, 2021.

R Core Team (2022) R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing. Vienna, Austria. URL: https://www.R-project.org/

Rogers CS, Miller J (2006) Permanent 'phase shifts' or reversible declines in coral cover? Lack of recovery of two coral reefs in St. John, US Virgin Islands. Marine Ecology Progress Series. 306:103-14.

Roth F, Saalmann F, Thomson T, Coker DJ, Villalobos R, Jones BH, Wild C, Carvalho S (2018) Coral reef degradation affects the potential for reef recovery after disturbance. Marine Environmental Research. 142:48-58.

Shen P, Zhang LM, Chen HX, Gao L (2017) Role of vegetation restoration in mitigating hillslope erosion and debris flows. Engineering Geology. 216:122-33.

Silburn DM, Carroll C, Ciesiolka CA, DeVoil RC, Burger P (2011) Hillslope runoff and erosion on duplex soils in grazing Lands in semi-arid central Queensland. I. Influences of cover, slope, and soil. Soil Research. 49(2):105-17.

Sugi M, Murakami H, Yoshimura J (2009) A reduction in global tropical cyclone frequency due to global warming. Sola. 5:164-7.

The State of Queensland and Commonwealth of Australia (2003) Reef water quality protection plan 2003: for the Great Barrier Reef World Heritage Area and adjacent catchments, new reefplan.indd (gbrmpa.gov.au), accessed 30 August 2021.

The State of Queensland and Commonwealth of Australia (2009) Reef water quality protection plan 2009: for the Great Barrier Reef World Heritage Area and adjacent catchments, http://hdl.handle.net/11017/1125

The State of Queensland (2013) Securing the health and resilience of the Great Barrier Reef World Heritage Area and adjacent catchment, reef-plan-2013.pdf (reefplan.qld.gov.au), accessed 30 August 2021.

The State of Queensland (2018) Reef 2050 Water Quality Improvement Plan: 2017-2022. Reef 2050 Water Quality Improvement Plan 2017-2022 (reefplan.qld.gov.au), accessed 30 August 2021.

Thibault PA. Ground cover patterns near streams for urban land use categories (1997) Landscape and urban planning. 39(1):37-45.

Thompson A, Costello P, Davidson J, Logan M, Schaffelke B, Uthicke S Takahashi M (2011) Reef Rescue Marine Monitoring Program. Report of AIMS Activities – Inshore coral reef monitoring 2011. Report for Great Barrier Reef Marine Park Authority. Australian Institute of Marine Science, Townsville. 128 pp.

Thompson A, Costello P, Davidson J, Schaffelke B, Uthicke S and Liddy M (2013) Reef Rescue Marine Monitoring Program. Report of AIMS Activities – Inshore coral reef monitoring 2012. Report for Great Barrier Reef Marine Park Authority. Australian Institute of Marine Science, Townsville. 120 p

Thompson A., C. Lønborg, P. Costello, J. Davidson, M. Logan, M. Furnas, K. Gunn, M. Liddy, M. Skuza, S. Uthicke, M. Wright I. Zagorskis, and B. Schaffelke (2014a). Marine Monitoring Program. Annual Report of AIMS Activities 2013 to 2014– Inshore water quality and coral reef monitoring. Report for the Great Barrier Reef Marine Park Authority. Australian Institute of Marine Science, Townsville.146 pp.

Thompson A, Schroeder T, Brando VE, Schaffelke B (2014b) Coral community responses to declining water quality: Whitsunday Islands, Great Barrier Reef, Australia. Coral Reefs. 33(4):923-38.

Thompson A, Costello P, Davidson J, Logan M, Gunn K, Schaffelke B (2016) Marine Monitoring Program. Annual Report for coral reef monitoring: 2014 to 2015. Report for the Great Barrier Reef Marine Park Authority. Australian Institute of Marine Science, Townsville.133 pp.

Thompson, A., Costello, P., Davidson, J., Logan, M., Coleman, G (2021) Marine Monitoring Program Annual Report for Inshore Coral Reef Monitoring: 2018–19. Report for the Great Barrier Reef Marine Park Authority, Great Barrier Reef Marine Park Authority, Townsville.142 pp.

Thompson, A., Davidson, J., Logan, M., Coleman, G. (2022) Marine Monitoring Program Annual Report for Inshore Coral Reef Monitoring: 2020 21. Report for the Great Barrier Reef Marine Park Authority, Great Barrier Reef Marine Park Authority, Townsville.151 pp

Thorburn PJ, Wilkinson S, Meier E (2010) Prioritising practice changes in Reef Rescue. CSIRO Water for a Health Country, ISSN: 1835-095X, 56 pp.

Thorburn PJ, Wilkinson SN (2013) Conceptual frameworks for estimating the water quality benefits of improved agricultural management practices in large catchments. Agriculture, ecosystems & environment. 180:192-209.

Thorburn PJ, Wilkinson SN, Silburn DM (2013) Water quality in agricultural lands draining to the Great Barrier Reef: a review of causes, management and priorities. Agriculture, ecosystems & environment. 180:4-20.

Tracey D, Waterhouse J, Da Silva E (2017) Preliminary investigation of alternative approaches for the Reef Plan Report Card Water Quality Metric report. Great Barrier Reef Marine Park Authority.

van Woesik R, Done TJ (1997) Coral communities and reef growth in the southern Great Barrier Reef. Coral Reefs. 16(2):103-15.

Vega-Thurber RL, Burkepile DE, Fuchs C, Shantz AA, McMinds R, Zaneveld JR (2014) Chronic nutrient enrichment increases prevalence and severity of coral disease and bleaching. Global change biology. 20(2):544-54.

Walsh KJ, McInnes KL, McBride JL (2012) Climate change impacts on tropical cyclones and extreme sea levels in the South Pacific—A regional assessment. Global and Planetary Change. 80:149-64.

Waltham NJ, Wegscheidl C, Volders A, Smart JC, Hasan S, Lédée E, Waterhouse J. Land use conversion to improve water quality in high DIN risk, low-lying sugarcane areas of the Great Barrier Reef catchments (2021) Marine Pollution Bulletin. 167:112373.

Wasson RJ, Caitcheon G, Murray AS, McCulloch MA, Quade JA (2002) Sourcing sediment using multiple tracers in the catchment of Lake Argyle, Northwestern Australia. Environmental Management. 29(5):634-46.

Waterhouse J, Henry N, Mitchell C, Smith R, Thomson B, Carruthers C, Bennett J, Brodie J, McCosker K, Northey A, Poggio M, Moravek T, Gordon B, Orr G, Silburn M, Shaw M, Bickle M, Ronan M, Turner R, Waters D, Tindall D, Trevithick R, Ryan T, VanderGragt M, Houlden B, Robillot C (2018) Paddock to Reef Integrated Monitoring, Modelling and Reporting Program: Program Design 2018-2022, Revised P2R draft for input (reefplan.qld.gov.au), accessed 30 August 2021.

Weber M, De Beer D, Lott C, Polerecky L, Kohls K, Abed RM, Ferdelman TG, Fabricius KE (2012) Mechanisms of damage to corals exposed to sedimentation. Proceedings of the National Academy of Sciences. 109(24):E1558-67.

Webster AJ, Bartley R, Armour JD, Brodie JE, Thorburn PJ (2012) Reducing dissolved inorganic nitrogen in surface runoff water from sugarcane production systems. Marine Pollution Bulletin. 65(4-9):128-35.

Wooldridge S, Brodie J, Furnas M (2006) Exposure of inner-shelf reefs to nutrient enriched runoff entering the Great Barrier Reef Lagoon: Post-European changes and the design of water quality targets. Marine pollution bulletin. 52(11):1467-79.

Wooldridge SA (2009) Water quality and coral bleaching thresholds: Formalising the linkage for the inshore reefs of the Great Barrier Reef, Australia. Marine Pollution Bulletin. 58(5):745-51.

Yu B, Joo M, Caroll C (2013) Land use and water quality trends of the Fitzroy River, Australia. Understanding Freshwater Quality Problems in a Changing World Proceedings of H. 4:1-8.

Zaimes GN, Schultz RC, Isenhart TM (2008) Streambank Soil and Phosphorus Losses Under Different Riparian Land-Uses in Iowa 1. JAWRA Journal of the American Water Resources Association. 44(4):935-47.

Zhao M, Held IM, Lin SJ, Vecchi GA (2009) Simulations of global hurricane climatology, interannual variability, and response to global warming using a 50-km resolution GCM. Journal of Climate. 22(24):6653-78.

Appendix E. Scientific publications and presentations associated with the program, 2022–23

E-1 Publications

Reports and scientific publications

Great Barrier Reef Marine Park Authority (2023). Great Barrier Reef Marine Monitoring Program Synthesis Report 2021–22. Great Barrier Reef Marine Park Authority, Townsville, pp.

Moran, D., Robson, B., Gruber, R., Waterhouse, J., Logan, M., Petus, C., Howley, C., Lewis, S., James, C., Tracey, D., Mellors, J., O'Callaghan, M., Bove, U., Davidson, J., Glasson, K., Jaworski, S., Lefevre, C., Nordborg, M., Vasile, R., Zagorskis, I., Shellberg, J. (2023). Marine Monitoring Program: Annual Report for Inshore Water Quality Monitoring 2021–22. Report for the Great Barrier Reef Marine Park Authority, Great Barrier Reef Marine Park Authority, Townsville.

Moran, D. (2023). GBR Marine Monitoring Program 2022-23 Progress Report. Report for the Great Barrier Reef Marine Park Authority, Townsville.

Data used for model validation and external investigations:

During the 2022–23 financial year, MMP WQ data has been used by several external groups, including:

- Validation of the eReefs marine models for the Great Barrier Reef, led by Jenny Skerratt at CSIRO. An extensive list of resulting publications is available from: https://research.csiro.au/ereefs/models/further-reading/
- Incorporation of data into the IMOS Bio-Optical Database for validation of satellite imagery, led by Thomas Schroeder at CSIRO.
- 2022–23 water quality data provided to NRM technical officers at the Mackay-Whitsunday-Isaac Healthy Rivers to Reef Partnership, the Dry Tropics Partnership for Healthy Waters, and the Wet Tropics Healthy Waterways Partnership to be used in preparation of the latest Regional Report Cards.
- Waterhouse J, Petus C, Lewis S, James C, O'Callaghan M, Tracey D, Doyle J, Patel F, Uthicke S (2023). Pilot study to investigate options for water quality sampling as part of the Reef Trust Partnership Crown of Thorns Starfish Control Program, Final Report July 2023. Report for the Reef Trust Partnership. TropWATER Report No. 23/50. 92 pp. James Cook University, Townsville.

Related papers – linking to MMP data/methods:

Ani, C. J., Baird, M., & Robson, B. (2024). Modelling buoyancy-driven vertical movement of *Trichodesmium* application in the Great Barrier Reef. Ecological Modelling, 487, 110567. doi:https://doi.org/10.1016/j.ecolmodel.2023.110567.

Burrows, R. M., Garzon-Garcia, A., Burton, J., Lewis, S. E., Gruber, R. K., Brodie, J. E., & Burford, M. A. (2023). Factors affecting broadscale variation in nearshore water-column organic carbon concentrations along the Great Barrier Reef. Regional Studies in Marine Science, 103032. doi:https://doi.org/10.1016/j.rsma.2023.103032

Lønborg, C., Carreira, C., Abril, G., Agustí, S., Amaral, V., Andersson, A., . . . Álvarez-Salgado, X. A. (2023). A global database of dissolved organic matter (DOM) measurements in coastal waters (CoastDOM v1). Earth Syst. Sci. Data Discuss., 2023, 1-30. doi:10.5194/essd-2023-348

E-2 Presentations

Bove U. Water Quality monitoring and research at AIMS. Presented to Indigenous students and teachers from the Indigenous Education Resource Centre (IERC) Winter School during AIMS site visit, Townsville, QLD. 28 July 2023.

Gruber R, et al. GBR Marine Monitoring Program Inshore water quality results: 2022-23. AIMS all-staff webinar, 15 November 2023.

Gruber R, et al. GBR Marine Monitoring Program Inshore water quality results: 2022-23. MMP Symposium, 16 November 2023.

MMP Synthesis Workshop October 2023 (team presentations by Gruber, Waterhouse, and Howley et al.)

Moran D. Great Barrier Reef Marine Monitoring Program - Routine Monitoring for Ambient Water Quality Conditions. Presented to 30+ GBRMPA managers and staff at GBRMPA science seminar - The importance of the inshore Reef: Latest results from the Marine Monitoring Program. At the Reef Authority's Townsville office and online. 21 September 2022.

Moran D. Water Quality Monitoring at AIMS. Girringin TUMRA Open Day, Cardwell, QLD, 03 June 2023.

Moran D, S. Garra, and CYWP team. MMP WQ Annual QA/Training Workshop. Workshop with AIMS and CYWP teams, at Christina's house, Cooktown, QLD, 06 Sept 2022.

Moran D. and JCU team. MMP WQ Annual QA/Training Workshop. Workshop with AIMS and JCU teams, JCU ATSIP Building, Townsville, QLD, 24 Nov 2022.

Robson B. The Marine Monitoring Program – Water Quality. Presented to the AIMS Council, AIMS Darwin, NT, 12 Oct 2022.

Howley et al. Marine Monitoring Program Inshore Water Quality: Cape York Program. MMP Symposium, 16 November 2023.

Howley C, Herkess S, Shellberg J. Reducing Land Use Impacts & Sediment Pollution to the Great Barrier Reef - SE Cape York Peninsula. Presented to GBRF Regional Sediment Program Coordinator Forum. Online 8 May 2023

Waterhouse J, Howley C, Petus C, Lewis S, Mellors J, James C, O'Callaghan M, Choukroun S. Marine Monitoring Program Inshore Water Quality: Event Monitoring. GBRMPA Science Seminar. October 2023.

Waterhouse J, Petus C, Lewis S, Howley C, Mellors J, James C, O'Callaghan M, Choukroun S. Marine Monitoring Program Inshore Water Quality: Wet season drivers, remote sensing and events. MMP Symposium, 16 November 2023.