Australian Government

Great Barrier Reef Marine Park Authority

Great Barrier Reef Marine Monitoring Program

Inshore water quality monitoring
Annual Report
2021–22

Australian Government | Australian Institute of Marine Science | Cape York Water Partnership | TropWATER | James Cook University Australia

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:

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.

Front cover image: The river mouth mooring at the combined mouth of the Russell and Mulgrave Rivers in the Wet Tropics region. Photo taken prior to recovery of the mooring and instruments for maintenance and retrieval of data. © Irena Zagorkis, Australian Institute of Marine Science.

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.

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

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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, particularly Dr Adele Pile and Stuart Alexander from Mission Beach Charters who have been involved in our long-term sampling of the Tully and Russell-Mulgrave marine waters, Andrew Mead from Barra Charters for the Burdekin region sampling. Thanks to the Australian Institute of Marine Science Oceanographic Technician team, Marine Operations team, Data Centre, and the crew of the RV Cape Ferguson, who have been a critical part of this program for many years. From the Cape York Water Partnership, we thank Eric Dick, Sarah Herkess, the Lama Lama Rangers (Yintinga Aboriginal Corporation), Yuku Baja Muliku rangers, Jason Carroll (South Cape York Catchments). 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 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 data over 17 years of monitoring.

This year the water quality program is reporting in a summary report format: all of the core analyses have been conducted, but some secondary analyses that would be included in a full report have been omitted (modelling and mapping of river-derived dissolved inorganic nitrogen, fine sediment, and particulate nitrogen loads; and weekly condition assessments based on remote sensing analysis). Instead of including a detailed Discussion section in this summary report, key discussion items have instead been included in the Conclusions. This summary report has been internally reviewed by the Reef Authority but unlike a full report, it has not been externally peer-reviewed. However, the included analysis follows the same methods as in previous years which have been subject to extensive external peer-review throughout the Program's 17-year history.

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 (insensitive to year-to-year variability) showed that long-term inshore water quality:

- **declined** gradually in the Wet Tropics region from 2008 to 2018 but has **improved** in recent years,
- **declined** gradually in the Burdekin region since 2010 and is showing early signs of **improvement** this year,
- **declined** steadily in the Mackay-Whitsunday region since 2008, but **stabilised** in recent years and shows signs of **improvement** over the last two years, and
- **improved** gradually in the Fitzroy region from 2008 to 2015 and shows stability over the last two years.

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 the annual condition for inshore water quality (sensitive to year-to-year variability) in 2021–22 was:

- **'good'** in Cape York, following some improvements in the focus regions relative to 2020–21,
- **'moderate'** in the Wet Tropics and Burdekin regions, similar to 2020–21,
- **'moderate'** in the Mackay-Whitsunday and improved on the annual condition score from 2020–21, and
- **'good'** in the Fitzroy region, similar to 2020–21.

Overall discharge for the Reef was slightly greater in 2021–22 than in 2020–21, and annual condition Index scores for the regions were generally similar to 2020–21.

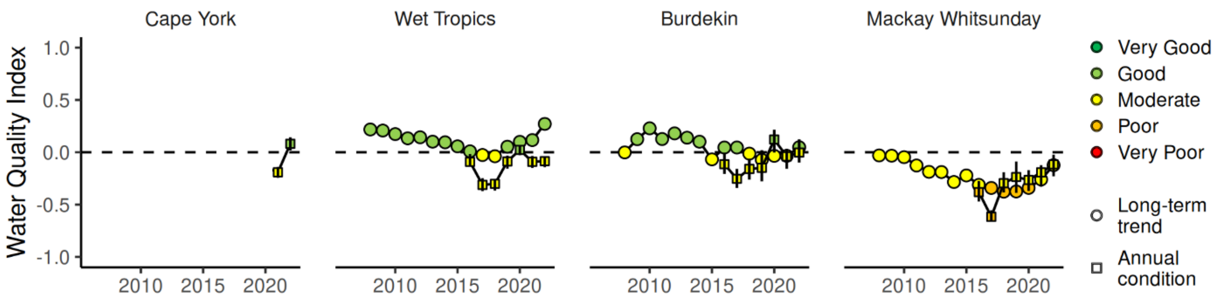


Figure i: Water Quality Index scores from 2008 to 2022 for the Cape York, Wet Tropics, Burdekin and Mackay-Whitsunday regions. The Index is calculated to show the long-term trend in water quality since the start of monitoring (circles), where seasonal and short-term variability signals are removed. An 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 variables: water clarity, concentrations of nitrate/nitrite, particulate nitrogen, particulate phosphorus, and chlorophyll *a*. Long-term data are not available for Cape York. Details of calculations are in Appendix B.

Individual water quality indicators were monitored for trends and compared against water quality guideline values (GVs). This water year (1 October to 30 September), concentrations of chlorophyll *a*, total suspended solids and phosphate (dissolved inorganic phosphorus) generally met the local GVs within most regions and have showed recent trends for improvement in condition. In the 2021–22 water year, particulate phosphorus and Secchi depth values generally improved or were stable across all regions. Particulate phosphorous met local GVs in some regions (Barron-Daintree, Johnstone Russell-Mulgrave and Burdekin) but exceeded GVs in others (Tully-Herbert and Mackay-Whitsunday regions). Nitrate/nitrite, particulate nitrogen and Secchi depth exceeded GVs in most or all regions during 2021–22, however all of these parameters are now showing trends of minor improvement or stability over the last five years, in contrast with trends of degradation in condition which had been seen from 2008 to 2015 in many regions.

In Cape York, chlorophyll *a* and particulate phosphorus met water quality GVs at most sites for all focus regions while nitrate/nitrite and Secchi depth did not meet the GVs at most sites and focus regions. Total suspended solids, phosphorus, and particulate nitrogen comparisons against GVs were mixed.

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). The spatial and temporal variability in the *in situ* water quality discussed in this report highlights the combination of complex factors including river discharge, biogeochemical processes, and physical forcing that drive water quality.

Drivers and pressures

Environmental conditions over the 2021–22 wet season included rainfall and river discharge just above the long-term median for the total Reef discharge. On a regional basis, discharge relative to the long-term median was variable. The northern Natural Resource Management (NRM) regions had discharge around the long-term median including the Cape York (1.2 times higher than long term median), Wet Tropics (just below the median) and Burdekin (1.2 times higher). In comparison, the Mackay Whitsunday region had discharge around half of the long-term median while the Fitzroy region was 1.5 times above the long-term median. The Burnett Mary region had very high discharge which extended beyond the wet season and was 8.8 times above the long-term median.

There was limited cyclone activity for the Reef with only one cyclone, TC Tiffany that crossed the Cape York coast in early January 2022. However, the season was characterised by some relatively late rainfall events in April and May 2022.

End-of-catchment sediment and nutrient load estimates showed distinct variations between the focus areas which were consistent with the typical patterns that are expected. In 2021–22 the highest estimated dissolved inorganic nitrogen exports were from the Tully-Murray-Herbert (1,789 t), followed by the Russell Mulgrave-Johnstone (1,389 t), Burdekin-Haughton (1,160 t), Fitzroy (730 t), Daintree-Mossman-Barron (472 t) and then the Mackay Whitsunday basins (391 t). This finding was largely due to the near-median discharges from all focus areas (compared to the long-term) but higher discharges from the Wet Tropics catchments. Estimated loads of total suspended solids and particulate nitrogen were dominated by the Burdekin-Haughton basins.

For the second time Sentinel-3 satellite images were used to map Reef optical water types (WT). 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, this water type is often the result of marine processes such as upwelling rather than direct influence of catchment discharge. The area exposed to any water quality potential risk in 2021–22 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 10,000km^2. Eighty-seven percent of the total Reef area was exposed to no or very low potential risk.

It is important to note that the revised Reef water type terminology (Reef WT1, WT2, WT3) may be adjusted again next year as part of the reprocessing of the long-term remote sensing composites and mean water quality concentrations. Importantly, while names of the water types may change, the definition of the water types will essentially remain the same.

Conclusion

This report presents some positive results for inshore water quality in the Reef for the 2021–22 sampling period. Long-term trends of stability or improvement in water quality were observed in all focus regions. The relationship between runoff and water quality is complex and is confounded by large inter-annual rainfall variability in tropical coastal waters. Progress of changed land 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 these trends cautiously; further monitoring is needed to determine if trends of stability and improvement are broad-reaching and sustained.

1 Introduction

1.1 The Great Barrier Reef

The Great Barrier Reef (the Reef) is the most extensive reef system in the world, comprising over 2900 km^2 of coral reefs. 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) 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 run-off on water quality, the *Reef 2050 Water Quality Improvement Plan* (Reef 2050 WQIP; Australian and Queensland governments, 2003; 2018a) was updated by the Australian and Queensland governments in 2017 and integrated as a major component of the Reef 2050 Long-Term Sustainability Plan (Commonwealth of Australia, 2018)[1], which provides a framework for the integrated management of the *Great Barrier Reef World Heritage Area*.

A key deliverable of the Reef 2050 WQIP is the *Paddock to Reef Integrated Monitoring, Modelling and Reporting Program* (Australian and Queensland governments, 2018b) which is used to evaluate the efficiency and effectiveness of the implementation of the Reef 2050 WQIP and report 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 the following 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.*, 2022; Thompson *et al.*, 2022). 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 (for example, Moran *et al.*, 2022). Loads of sediments, nutrients, and pesticides within rivers are monitored by the Catchment Loads Monitoring Program (Water Quality Investigations, 2021).

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 summary report

This year's annual report is presented in a shorter, summary report format. It provides a comprehensive summary of the 2021–22 monitoring efforts and is in a format that focuses more briefly on the observations this year and the emerging trends in water quality conditions over the

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

long-term. It is anticipated that this year's report will be followed in 2022-23 by the traditional reporting format that will include more in-depth discussion of the conditions and trends, and further discussion on implications for the Reef generally and specifically to inshore ecosystems. For this summary report, wherever possible consistency of formatting and content has been retained with the traditional full reporting layout.

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 are presented in Section 4 at Reef and regional scales. Detailed results from focus areas are presented in Section 5, including monitoring results, indices, and catchment loading. A brief Discussion and Conclusions are given in Section 6. Detailed tables and figures are included in Appendix C. The following context has been excluded from this report for brevity but will be retained in future reporting:

- detailed modelling and mapping of river-derived DIN, fine sediment and PN using eReefs model output
- weekly panels showing wet-season water quality and environmental conditions for the regions based on remote sensing products
- detailed discussion section. Instead, summary information is provided with the Conclusions.

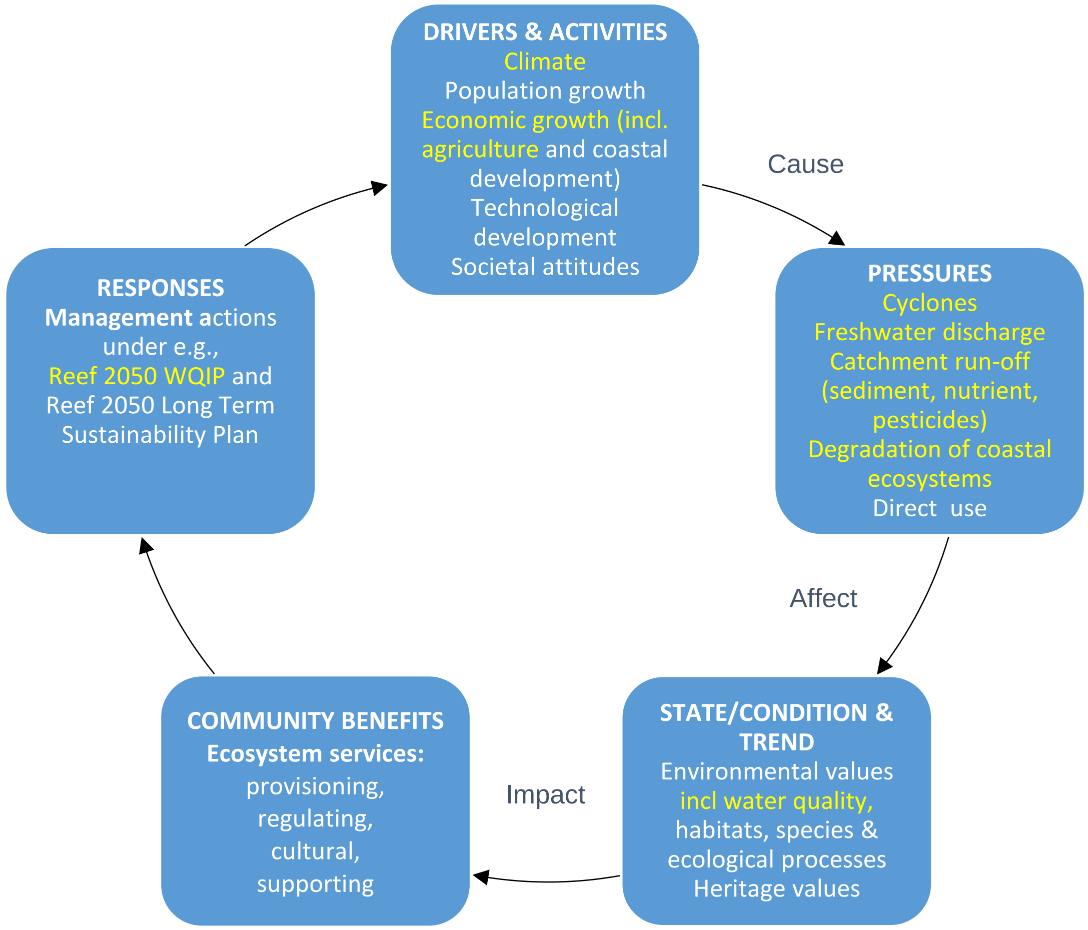


Figure 1-1: DPSIR framework used to guide the structure of the MMP derived from the Great Barrier Reef Strategic Assessment (Great Barrier Reef Marine Park Authority, 2014). The aspects highlighted in yellow are included in this report.

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 Appendix A, B and C and in a separate quality assurance/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 both ambient conditions and 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 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 and Burdekin regions).

The program currently covers four NRM regions including Cape York, the Wet Tropics, Burdekin, and Mackay-Whitsunday, chosen based on previous 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 3 sites in the regions listed above 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 areas, each with 5 to 6 sites measured routinely: Pascoe, Normanby-Kennedy, Annan-Endeavour and Stewart Rivers (in the Cape York NRM, all added in 2017); Barron-Daintree, Russell Mulgrave and Tully Rivers (in the Wet Tropics NRM); Burdekin and Mackay-Whitsunday. The frequency of ambient water quality monitoring was increased in 2015, and sites are now visited 3–10 times annually, depending on the focus region.

This report also presents results from water quality monitoring along the Cairns Transect in the Barron-Daintree focus region of the Wet Tropics. AIMS has been monitoring the 6 Cairns Transect sites 3 times annually since 1989, making this dataset one of the world's longest tropical water quality datasets. In 2005, monitoring at the Cairns Transect sites became part of the MMP.

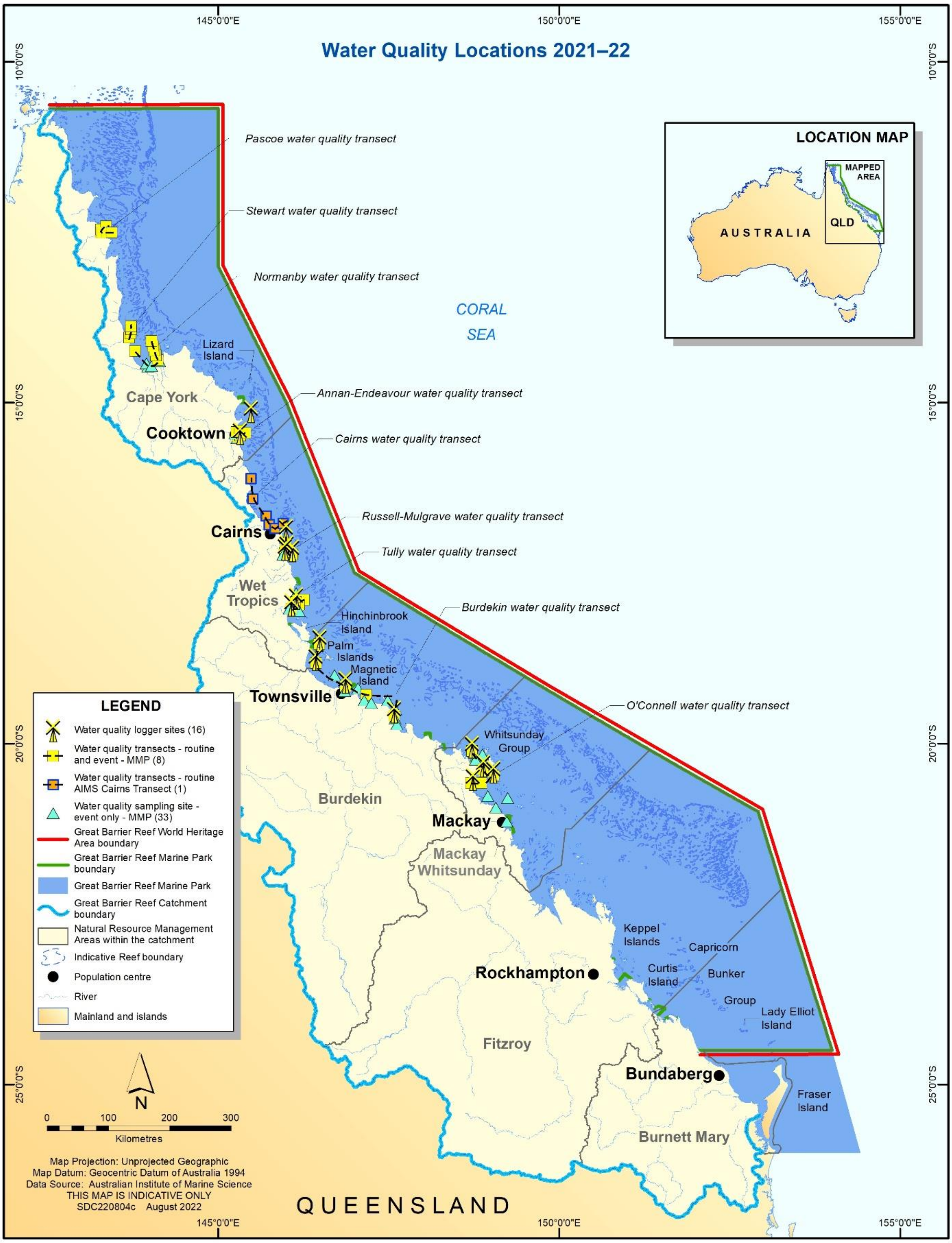


Figure 2-1: Sampling locations of the water quality monitoring sampled from 2015 onwards. Note that the Cape York transects were added in 2017.

The list of parameters sampled in 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 the 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 of the sampling locations (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 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 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. 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 wind and tide-driven resuspension, as well as inputs from other sources such as dredging and run-off 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, 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 run-off.
- **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.

Pesticides have also been measured in the past but were not included in the 2021–22 monitoring efforts.

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) and compared with the guideline value (GV) (Appendix C Table C-3).

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 represented as 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-8), 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 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).

In order to provide a more quantitative assessment of trend, linear change in values of GAMMs was measured from the present sampling year to five years prior (a five-year period). This period was chosen as it incorporates the MMP re-design, which began in 2015; using earlier data would unbalance this analysis as the amount of sampling greatly changed in 2015. As GAMMs are de-trended to remove the effects of seasons, tides, and wind, this analysis aims to quantify 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
- 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 compared to GVs, scored based on performance relative to guidelines, 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 condition that ecosystems are exposed to, which both affect the response of those ecosystems but in different ways. Changes in the MMP design that occurred in 2015 also needed to be accommodated. The changes in design included increased number of sites, increased sampling frequency and a higher sampling frequency during December to April to better represent wet season variability. Thus, statistical comparisons between MMP data from 2005–15 to 2015–onwards must account for these changes. The two versions of the WQ Index have different purposes:

1. **Long-term trend**: This version is based on the pre-2015 MMP sampling design and uses only the original sites (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 (Appendix B 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
    - the Index is an average of scores for five indicators: 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 for scoring monitoring data (i.e., wet season data are compared to a wet season GV and dry season data are compared to a dry season GV) (Appendix C Table C-8)
- both AIMS and JCU monitoring data are used
- a running mean is not applied
- 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) are weighted equally.

A Water Quality Index (annual condition version) was produced for Cape York focus regions for the first time in 2020–21. The methods for this are the same as those detailed above, although results are not presented in a time-series format like other regions. Details of Index calculation are in Appendix B.

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 the water quality variables measured. Using 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 three distinct water types: the primary (corresponding to colour classes 1 to 4), secondary (colour class 5) and tertiary (colour class 6) wet season water types (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 run-off in sediment-laden river discharge appears in satellite images as brownish flood plumes, while productive waters appear with a greenish colour, and ambient (clear) marine waters are a bluish 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 the Reef rivers discharge) in optical satellite images. Therefore, the term "wet season waters" referred collectively to flood river plumes, associated resuspension and marine processes occurring in the Reef during the wet season.

For the second year in a row, Sentinel-3 Ocean Land Colour Instrument (OLCI) satellite imagery of the Reef and the Forel-Ule (FU) colour scale (Wernand *et al.,* 2012, 2013; Van der Woerd *et al.,* 2016; Van der Woerd and Wernand, 2018) were used to produce Reef water type maps instead of the MODIS imagery and the wet season colour scale (Petus *et al.,* 2019, Moran *et al.,* 2022). Equivalent FU water types were defined by grouping the 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≥10 (equivalent to the primary water type), as defined in Petus *et al*. (2019) (Table 2-2). For this report, the water type terminology was modified to: Reef water type (WT) 1, WT2, WT3 and WT4 instead of primary, secondary, tertiary and marine 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 the shallower part of the GBR, and the Reef WT3 (tertiary waters) may represent marine processes such as upwelling or the fine sediment resuspension around reefs and islands (Table 2-2). It is important to note that this revised terminology may be adjusted again next year as part of the reprocessing of the long-term remote sensing composites and mean water quality concentrations. Importantly, while names of the water types may change, the definition of the water types in Table 2-2 will essentially remain the same.

Several monitoring products have been 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 TSS, Chl-a, CDOM, DIN, DIP, PP and PN concentrations and 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).
- Assess the exposure of coral reefs and seagrass ecosystems to potential risk from land-sourced 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 large 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). 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 part of the GBR.
- **The greenish Reef WT2 *(FU6–9)*** represents the less turbid part 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 marine processes such as upwelling or the fine sediment resuspension around reefs and islands.
- **The blueish Reef WT4 *(FU1–3)*** represents ambient waters with high light penetration and negligible concentrations of optically active and water quality constituents.

Match up of *in situ* water quality concentrations and the four Reef water types are regularly performed to validate this concept and quantify the range and average of water quality concentrations found in each Reef water type. The last update was in 2019 (Gruber *et al.,* 2020), 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 weekly colour class maps (see method in Appendix B). Weekly composites (see Section 2.6.3) were used rather than daily colour class/water type data in order to minimise data loss to due to the periodic dense cloud cover in the Reef. This allowed a maximum of water quality parameters measured during each wet season since 2003–04 to 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 water quality concentrations 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 water quality concentrations were calculated using all surface data (<0.2 m) collected between December and April by JCU since 2003-04, and included data collected by AIMS and the CYWP since 2016-17. Reef water type (and colour class) categories for all these sites and sampling weeks were extracted from the archive of weekly wet season water type composites (MODIS, 2002–03 to 2018–19). 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. Note that PN/PP definitions changed in 2018–19 to be direct measurements as defined in the QA/QC report (GBRMPA, 2022). Long-term water quality values will be reviewed in 2023 using all field data available to ensure that the water type characterisation remains appropriate, and to improve its accuracy building on the additional field data that is collected every wet season.

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 (Section 4). Reef-wide wet season GVs are 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 tabled. Details are in Appendix B. For this annual report which is more of a summary of the data, the weekly panel maps were not produced.

Reef water type maps 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 (URL: https://www.eumetsat.int/eumetsat-data-centre). Sentinel-3 are atmospherically corrected and were processed with the FU Satellite Toolbox implemented in the Sentinel Application Platform (SNAP, URL: URL: 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 (including, for example, 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).

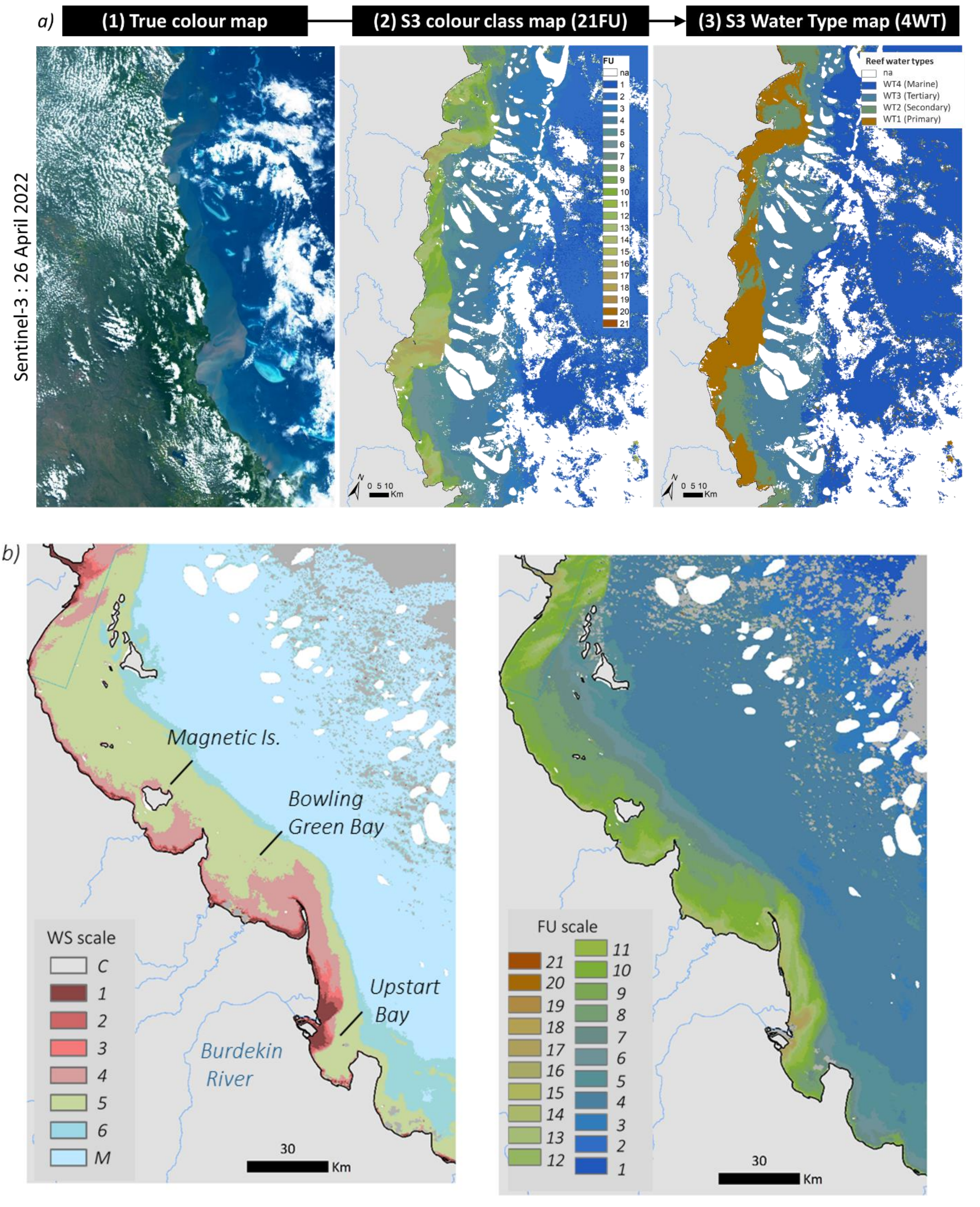


Figure 2-2: Methods for Reef water type, frequency and exposure maps a) Summary of the process to produce the Reef water type maps (1) downloading of the Sentinel-3-OLCI true colour imagery, (2) processing of Sentinel-3 Forel Ule colour class map using the Forel-Ule (FU) colour scale Toolbox implemented in the Sentinel Application Platform (SNAP), and (3) reclassification into Reef water type map. Sentinel-3 images are from the Eumetsat data centre and were captured the 26 April 2022 (source: Sentinel Hub EO browser). b) Burdekin River plume (14 March 2018). This panels 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).

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). Long-term water quality concentrations across the Reef water types 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*	*Water types*
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 waters, this water bodies typically contain high sediment and dissolved organic matter concentrations resulting in reduced light levels. It is also enriched in CDOM and phytoplankton concentrations and has elevated nutrient levels.*	*SDD: 1.8 ± 1.7 m* *TSS: 18.3 ± 45.7 mg L^{-1}* *Chl-a: 1.6 ± 2.4 µg L^{-1}*
WT2 (previously secondary)	*FU6-9 (WS5)*	*Greenish to greenish-blue turbid water typical of coastal waters with colour dominated by algae (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-water plumes where relatively high nutrient availability and increased light levels due to sedimentation favour coastal productivity (Bainbridge et al., 2012).*	*SDD: 4.0 ± 2.3 m* *TSS: 5.9 ± 8.0 mg L^{-1}* *Chl-a: 0.8 ± 0.8 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 sea. This water type includes the outer areas of river flood plumes, fine sediment resuspension around reefs and islands and marine processes such as upwelling. Reef WT3 waters are associated with low land-sourced contaminant concentrations and the ecological relevance of these conditions is likely to be minimal although not well researched. The Type III areas have a low magnitude score in the Reef exposure assessment.*	*SDD: 7.0 ± 3.8 m* *TSS: 3.9 ± 5.1 mg L^{-1}* *Chl-a: 0.5 ± 0.5 µg L^{-1}*
WT4 (previously marine)	*No number*	*Bluish marine waters with high light penetration.*	*SDD*: 11.1 ± 5.1 m* *TSS*: 2.2 ± 3.9 mg L^{-1}* *Chl-a*: 0.7 ± 1.0 µg L^{-1}*

*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 (Table B-4 in supplementary material). Long-term water quality concentrations in the Reef WT4 are thus just given as an indication and are not used in the monitoring products presented in this report". A current pilot study - funded by Reef Trust Partnership – aims to collect more water quality data mid-shelf and offshore and will help progressing the characterisation of the Reef WT4 *(Waterhouse et al, in review).*

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) for this reporting wet season (2021–22),
(ii) over the long-term (2002–03 to 2017–18: 16 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. This is explained further in Appendix B. The composites frequency maps will be reviewed next year (20 years: 2002–03 – 2021–22) to ensure they remain appropriate and to improve their accuracy as more satellite data are available. The last 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 hydrodynamic 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 teams and the AIMS coral monitoring team) and modified from Petus *et al*. (2016). The last update was in the 2018–19 reporting (Gruber *et al*., 2020). Long-term exposure composites will also be reviewed in 2023 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-sourced pollutants during the wet season and focuses on TSS, Chl-*a*, PP and PN concentrations. The *'magnitude of the exposure'* corresponds to the mean 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 (section 2.6.2). 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 water quality concentrations 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 presently 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[2] (Appendix B-3). The exposure classes were defined by applying the Jenks classification to the mean long-term (2003–2018) exposure map, because this map presented the highest number of observations (16 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 per se. have no 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 16 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 used to calculate constituent loads) are located well upstream of the river mouth and only capture a certain proportion of the catchment/basin area. Such disparities mean that river gauge data should not be directly compared across basins and NRM regions. For example, the Daintree and Barron Basins within the Wet Tropics region contain a similar area (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 gauge captures 89% of the Barron Basin. If gauge data are used to compare discharge between these basins, the gauge on the Barron Basin is covering 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.

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], 2022). 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—marked with an asterisk), 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.

[2] 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).

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

NRM Region	Basin	AWRC No.	Basin area (km^2)	Relevant gauges	Percentage of Basin covered by key gauges	Correction factor
Cape York	Jacky Jacky Creek	101	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 Battle Camp + Hann River gauges with factor of 4.7	53	1.8
	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	52	1.9

				Creek with factor of 1.6x + 75,000		
	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
	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
	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 are indicated with a *						

Current annual and pre-development TSS, DIN and PN load estimates were calculated for all basins using a systematic approach. The DIN loads for the basins of the Wet Tropics and 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. If 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 were coupled with the annual discharge to calculate 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 measured/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.

3 Drivers and pressures influencing water quality in 2021–22

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 has an area of 2,088 km^2 with a high proportion (84%) of nature/conservation land use with some (15%) closed grazing (QLUMP, 2015). However, there is no longer any active grazing within the Pascoe catchment (Polglase pers. comm., February 2022). 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 approximately 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 2186 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 run-off 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). Extensive wildfires burnt large portions of the Annan catchment late in the 2021 dry season, likely impacting water quality and sediment loads in the Annan River.
- 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 2021–22 wet season was an inactive cyclone season with only Tropical Cyclone Tiffany impacting the Princess Charlotte Bay coastline as a category 1 system in January 2022. Some rainfall was received in the Wet Tropics and Burdekin regions from the passage of ex-Tropical Cyclone Seth, which crossed over the Gulf of Carpentaria through the north Queensland region in early January 2022 before entering the Coral Sea and recurving and causing major flooding in the Burnett Mary region as a tropical depression (Figure 3-1).

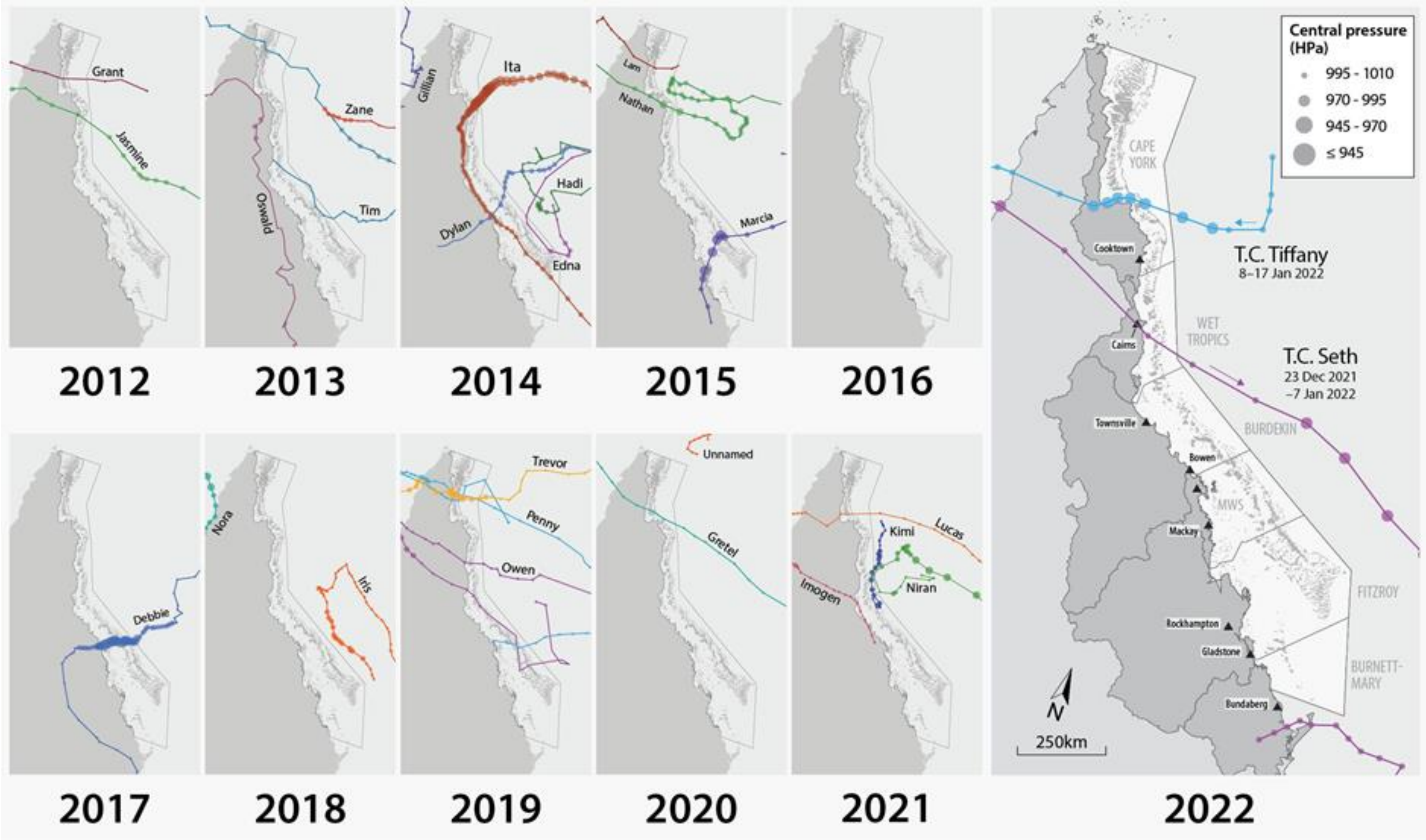


Figure 3-1: Trajectories of tropical cyclones affecting the Reef in 2021–22 and in previous years (2012 to 2021).

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 2021–22 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 predominately concentrated in the Burnett-Mary region in the 2021–22 season with particularly elevated rainfall in the Mary River Basin (Figure 3-2 and Figure 3-3). We note that some Reef basins received elevated rainfall in May 2022, which was outside of the defined wet season period accounting for some discrepancies between the rainfall patterns and the basin discharge. This particularly applies to the Wet Tropics and Upper Burdekin regions where the wet season rainfall map suggests a drier than average year; in fact, the largest rain event occurred in May in these areas and if this was incorporated into the maps then it would be considered an average wet season.

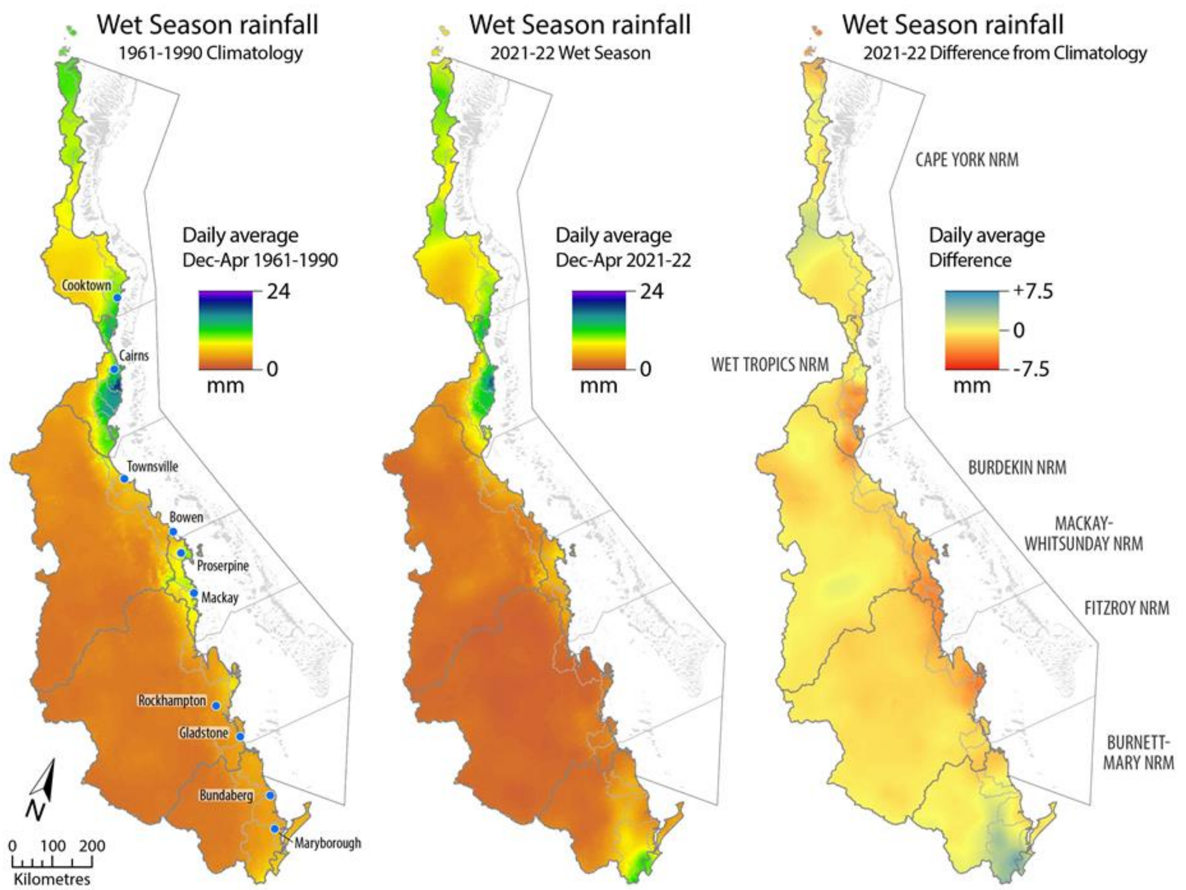


Figure 3-2: Average daily wet season rainfall (mm d^{-1}) in the Reef catchment (left) long-term daily average (1961–1990 time period produced by BoM), (centre) 2021–22 and (right) the difference between the long-term average and 2021–22 rainfall. Source data: Bureau of Meteorology (2022).

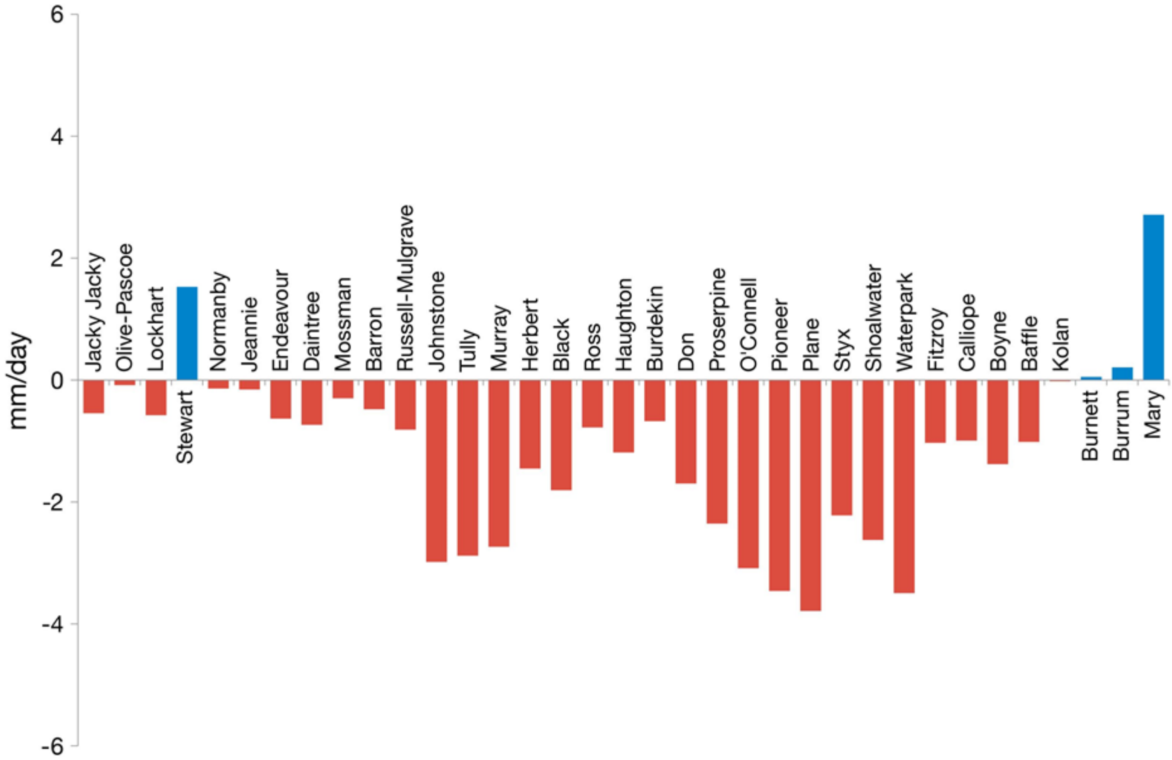


Figure 3-3: Difference between daily average wet season rainfall (December 2021–April 2022) and the long-term wet season rainfall average (from 1961–1990). Red and blue bars denote basins with rainfall below and above the long-term average, respectively. Note that the basins are ordered from north to south (left to right). Source data: Bureau of Meteorology (2022).

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 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 at the regional level is shown in Figure 3-5.

In 2021–22, the overall Reef catchment area had river discharge just above the long-term average (1.2 times the long-term median). On a regional basis, the most northern three NRM regions had discharge around the long-term median including the Cape York (1.2 times higher than long term median), Wet Tropics (just below the median) and Burdekin (1.2 times higher) NRM regions. In comparison, the Mackay Whitsunday region had discharge around half of the long-term median while the Fitzroy NRM region was 1.5 times above the long-term median. The Burnett-Mary NRM region had very high discharge in the 2021–22 water year at 8.8 times above the long-term median.

Annual discharge for each of the 35 Reef basins in 2021–22 is shown in Table 3-1 and compared to long-term median annual flows. Of these basins, the Olive-Pascoe and Lockhart (Cape York NRM), and Styx, Shoalwater and Fitzroy (Fitzroy NRM) had values 1.5 times above their long-term median while Waterpark Creek (Fitzroy NRM) and Baffle Creek (Burnett Mary NRM) basins were between 2 and 3 times higher than the long-term median discharge. The Kolan, Burnett, Burrum and Mary basins (Burnett Mary NRM) had discharge exceeding 3 times the long- term median discharge.

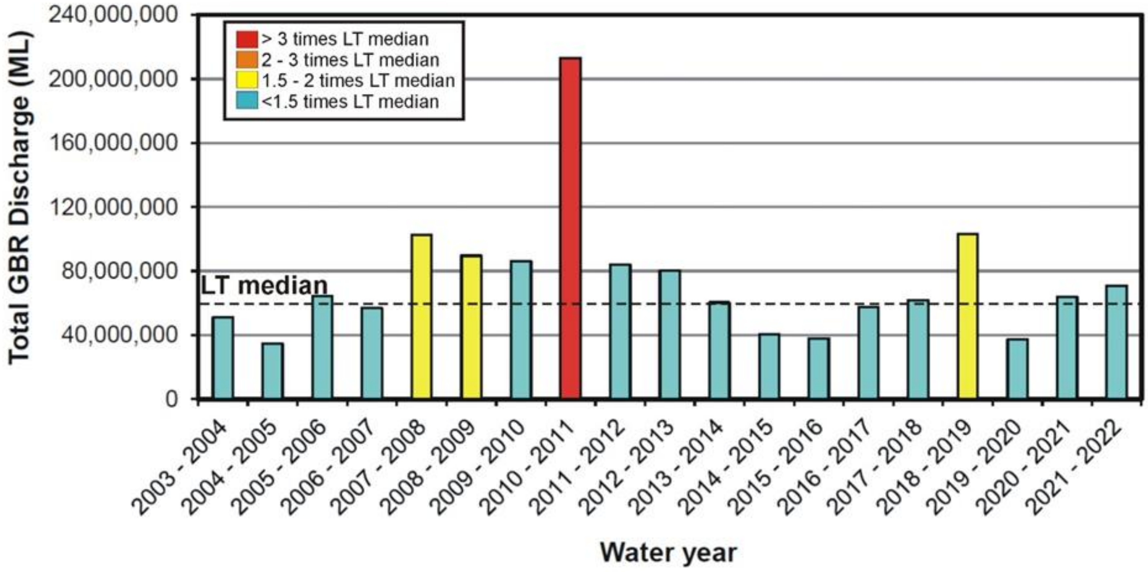


Figure 3-4: Long-term total discharge in ML (water year: 1 October to 30 September) for the 35 main Reef basins. Source: DRMW, https://water-monitoring.information.qld.gov.au/.

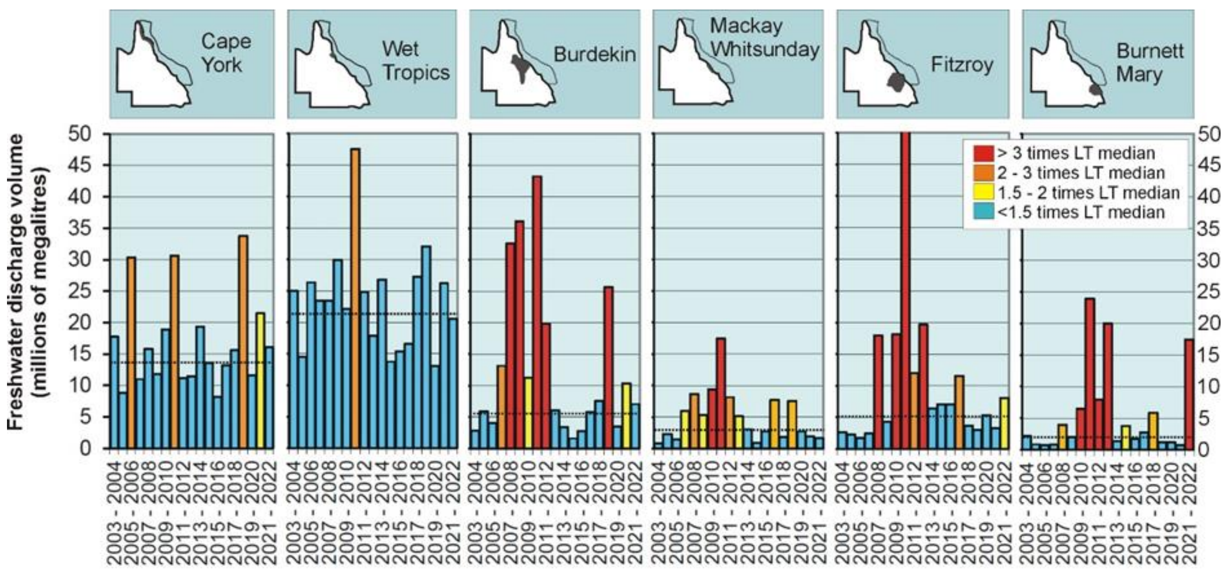


Figure 3-5: Corrected annual water year (1 October to 30 September) discharge from each NRM region (using the correction factors in Table 2-3) for 2003–04 to 2021–22 in ML per year. Data derived from DRMW (2022).

Table 3-1: Annual water year discharge (ML) of the 35 main Reef basins (1 October 2018 to 30 September 2022, inclusive) 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	2018 - 2019	2019 - 2020	2020 - 2021	2021 - 2022
Jacky Jacky Creek	2,471,267	3,423,675	2,320,007	3,607,722	2,365,731
Olive Pascoe River	3,180,267	7,225,892	3,295,502	5,540,683	4,879,388
Lockhart River	1,538,839	3,496,399	1,594,598	2,680,976	2,360,994
Stewart River	758,172	3,001,843	564,816	1,419,942	569,738
Normanby River	3,864,344	11,851,554	2,752,573	6,149,878	3,562,637
Jeannie River	523,852	1,072,218	298,336	570,538	577,219
Endeavour River	1,583,881	3,660,507	752,514	1,489,348	1,734,492
Daintree River	1,918,174	5,849,018	1,109,229	1,834,774	2,519,318
Mossman River	604,711	1,355,506	399,108	654,566	800,754
Barron River	622,447	1,663,883	346,727	667,265	692,908
Mulgrave-Russell River	4,222,711	5,521,561	2,870,672	4,771,460	4,091,750
Johnstone River	4,797,163	5,633,064	3,466,725	5,324,040	4,712,174
Tully River	3,393,025	4,020,452	2,200,744	4,123,338	3,175,489
Murray River	1,484,246	1,781,225	1,053,705	1,947,050	1,269,280
Herbert River	3,879,683	6,226,046	1,606,187	6,842,168	3,283,590
Black River	293,525	1,360,539	144,144	429,282	273,677
Ross River	279,376	2,531,556	293,165	232,975	202,811
Haughton River	558,735	3,150,945	335,094	595,709	735,754
Burdekin River	4,406,780	17,451,417	2,203,056	8,560,072	5,442,976
Don River	496,485	1,134,548	481,577	510,906	383,927
Proserpine River	859,348	2,590,512	592,063	537,613	446,839
O'Connell River	835,478	2,518,553	575,617	522,680	434,427
Pioneer River	616,216	1,158,768	383,506	235,359	277,610
Plane Creek	1,058,985	1,304,733	1,141,784	600,958	489,222
Styx River	629,037	519,769	796,233	927,219	1,080,829

Basin	LT median	2018 - 2019	2019 - 2020	2020 - 2021	2021 - 2022
Shoalwater Creek	727,306	600,785	920,902	1,072,570	1,250,433
Water Park Creek	392,614	289,097	551,010	675,102	820,627
Fitzroy River	2,875,792	1,473,960	2,786,994	436,730	4,505,289
Calliope River	257,050	97,998	184,697	123,050	250,551
Boyne River	179,108	3,313	99,139	31,002	171,925
Baffle Creek	347,271	96,312	161,554	112,323	1,000,587
Kolan River	115,841	28,153	28,792	19,211	818,716
Burnett River	264,307	202,436	332,366	118,241	3,894,616
Burrum River	130,835	103,766	112,113	44,691	1,612,683
Mary River	908,873	767,683	551,344	420,909	10,139,380
Sum of basins	59,819,075	103,167,687	37,306,591	63,830,350	70,828,340

4 Modelling and mapping marine water quality

This section presents results from satellite remote sensing of wet season water quality.

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 2021 to April 2022 (the 2021–22 wet season).

It is important to note that the revised terminology (Reef WT1, WT2, WT3) may be adjusted again next year as part of the reprocessing of the long-term remote sensing composites and mean water quality concentrations. Importantly, while names of the water types may change, the definition of the water types in Table 2-2 will essentially remain the same.

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 Wet Tropics, Burdekin and the Mackay-Whitsunday regions (Figure 4-1a,e,f), indicating drier conditions. The frequencies of occurrence measured across the Tully transect were similar to the typical dry-year composite in 2021–22 (Figure 4-1g), while in the Burdekin and Pioneer transects, the frequencies of occurrence were slightly above the representative dry-year composite and under the long-term average. In the Cape York region, the frequencies of occurrence of the combined Reef WT1-2 were similar to higher (in the Northern Cape York) long-term frequencies (Figure 4-1f). In the southern Reef, both the Fitzroy and Burnett-Mary regions had frequencies higher than the mean long-term frequencies, indicating wetter conditions (Figure 4-1f).

Reef area exposed: In 2021–22 only 3% of the Reef was exposed to the Reef WT1, 17% of the Reef was exposed to the Reef WT2 and 61% of the Reef was exposed to the Reef WT3 (Figure 4-3b and Table B-3 in supplementary material). 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: 72% and 14% of the total enclosed coastal and open coastal waterbody areas, respectively). The area exposed to the Reef WT2 was similar (+1%) to both the long-term and coral recovery period percentages (16% of the Reef) and 91% of the total open coastal, 58% of the total enclosed coastal and 21% of the total mid-shelf waterbody areas were exposed.

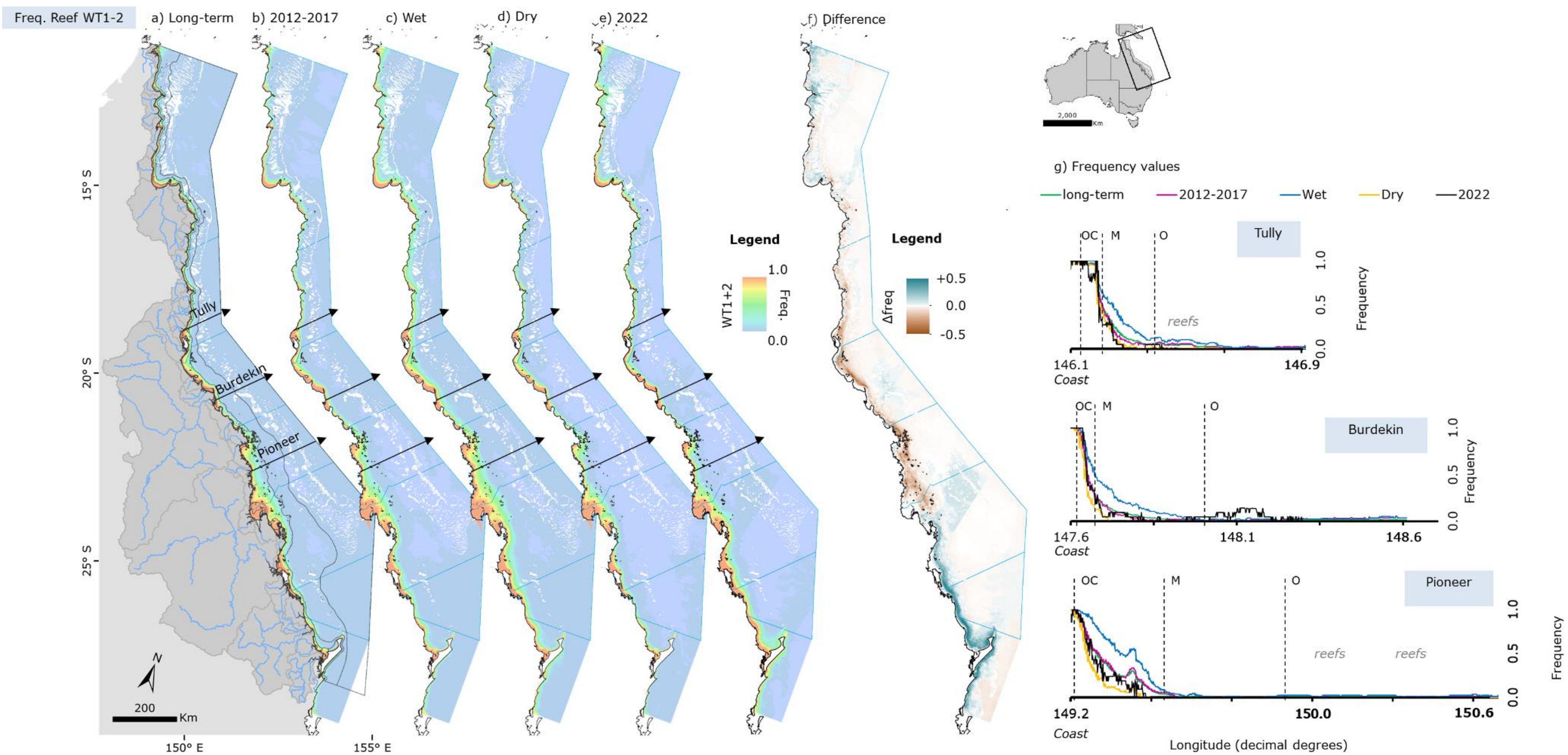


Figure 4-1: Map showing the frequency of the Reef WT1-2 combined in the a) long-term (16 wet seasons since 2002–03) b) representative coral recovery period (2011–12 to 2016–17, 6 wet seasons or 132 weeks), c) typical wet-year composite, d) typical dry-year wet season composites and e) 2021–22 wet season (22 weeks. The 2021–22 frequency maps were produced using Sentinel-3 images and the FU colour scale. Previous wet seasons and reference period composites have been produced using MODIS satellite imagery and the wet season colour scale (Waterhouse *et al.*, 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 2021–22 against long-term trends (calculated as (e) 2022 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.

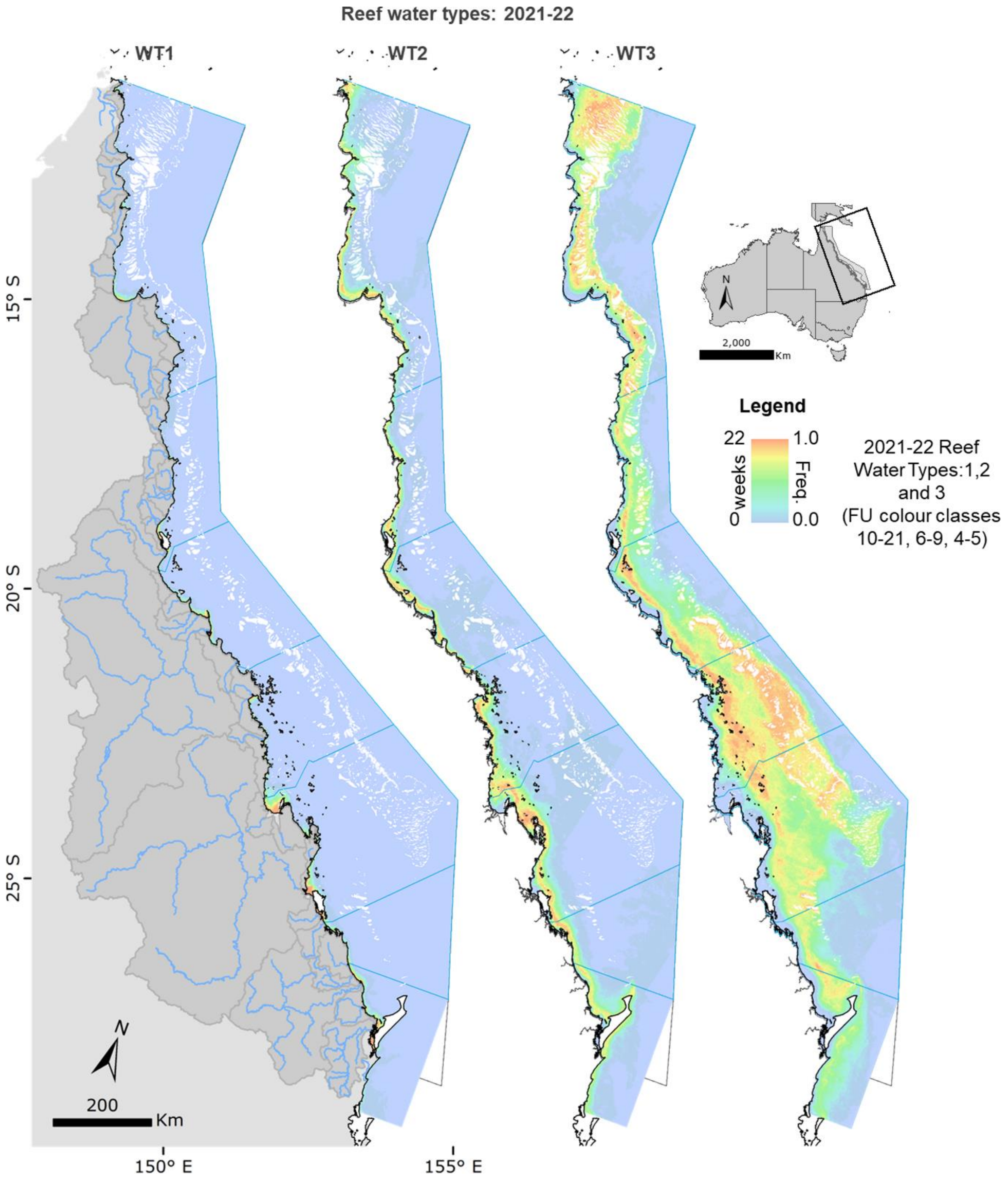


Figure 4-2: Map showing the frequency of the Reef WT1, WT2 and WT3 in the 2021–22 wet season (22 weeks). The highest frequency is shown in orange and the lowest frequency is shown in blue. These maps are used in the exposure assessment to represent the spatial likelihood of exposure of each of the wet season water types in 2021–22.

Figure 4-3: Areas (km²) (and percentages, %) of the Reef lagoon (total 348,839 km²) and division by waterbodies (WB: enclosed coastal, OC: Open coastal, Mid = mid-shelf and Off = 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 (22: 2021–22 wet season, LT: long-term, CR: Coral Recovery, W: Wet years and D: Dry years composites). The data are presented in detail in Table B-3 (supplementary material).

As in the two previous years, the Reef area exposed to Reef WT3 was greater than the long-term average (61% of the Reef, 70% in 2019–20) and the 'wet' year's area (56% 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 47% of the total mid-shelf and offshore waterbody areas, respectively). This result is not fully understood but is likely an indication of offshore 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 processes not influenced by catchment discharges. 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-sourced contaminant concentrations or the influence of marine processes and have 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 99% of the offshore areas were classified as no/very low potential risk in the 2021–22 exposure assessment (Figure 4-6 and Figure 4-7).

4.1.2 Composition of Reef water types

Boxplots of long-term water quality parameters in the Reef water types are shown in Figure 4-4 and are fully described in Moran *et al.* (2022). The last update was in the 2018–19 reporting year (Gruber *et al.*, 2020) using field data collected from 2004 to 2019 and the archive of weekly MODIS water types. The long-term values will be reviewed next year to ensure the water type characterisation remains appropriate, and to improve its accuracy building on the additional field data that is collected every wet season. Detailed summaries of water quality parameters for the long-term period (16 wet seasons) and reporting year are provided in Appendix B.

Mean long-term concentrations of water quality parameters showed similar patterns between focus regions, with maximum concentrations measured in Reef WT1 (previously primary water type) and minimum concentrations in Reef WT3 (previously tertiary water type) (Figure B-2 in Appendix B). However, there were distinct differences in the concentrations of individual pollutants 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 water quality concentrations 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 were above the Reef-wide wet season GVs in the Reef WT1 and WT2 (PP and PN just slightly above in Reef WT2) and only the long-term mean TSS concentration was above the wet season GV in the Reef WT3 (Figure 4-5).

Using this 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 *per se*. have no 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).

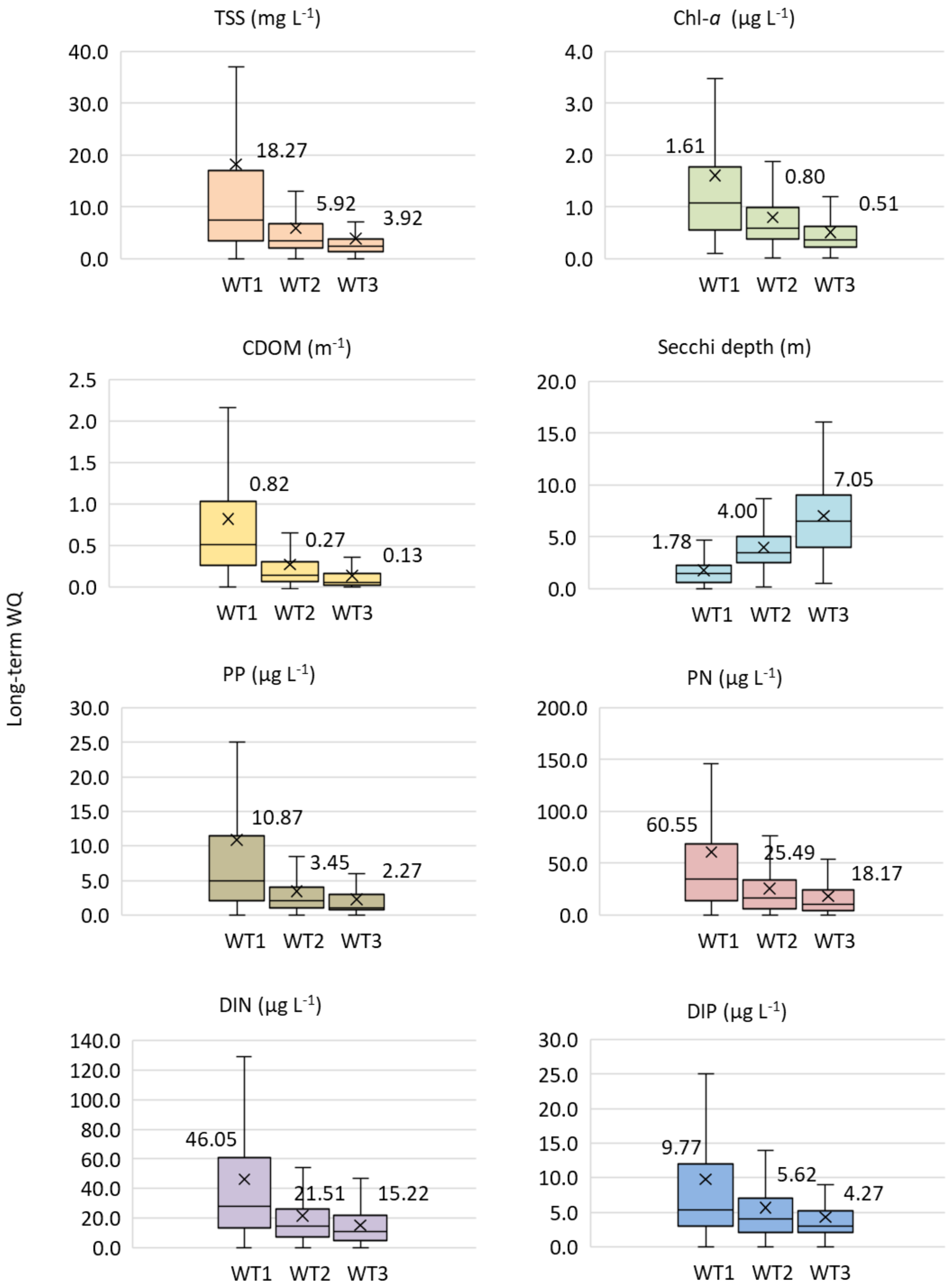


Figure 4-4: Long-term water quality (WQ) concentration and Secchi disk depth boxplots for each Reef water type (WT1, WT2 and WT3, previously primary, secondary and tertiary water types). The mean is plotted as a cross and its numerical value is indicated The interquartile range is delimited by the box 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 WQ values will be reviewed by JCU in 2023 (Last update was in 2019).

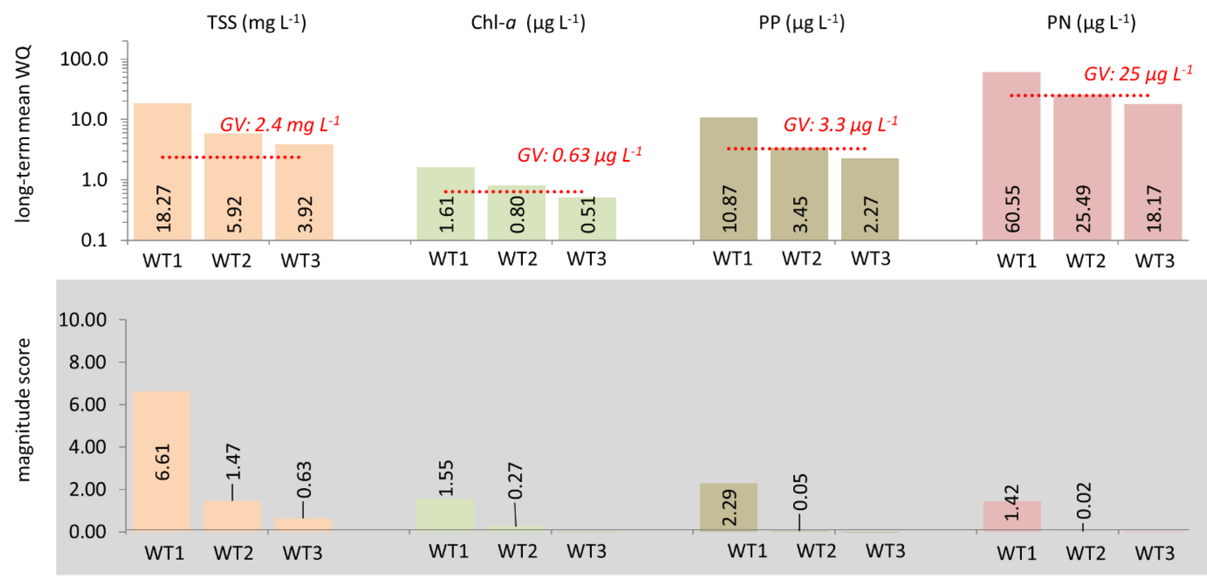


Figure 4-5: Mean long-term water quality concentrations (top) and magnitude score across the three Reef water types (bottom). Red lines show the Reef-wide wet season GVs (Appendix B Table B-4). Magnitude scores are calculated as the proportional exceedance of the guideline: $magnitude_{water\ type} = ([Poll.]_{water\ type} - GV)/GV$ and Poll. = TSS, Chl-*a*, PP or PN. Negative Magnitude score are scored as zero. Mean long-term water quality concentrations and Magnitude score will be reviewed in 2023 (last update was in 2019). Mean long-term water quality concentrations include samples collected from the enclosed coastal water type where high concentrations are likely to contribute to exceedances of the Reef-wide GVs, particularly for primary waters.

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 2021–22 was spatially limited relative to the scale of the Reef with 87% exposed to no or very low potential risk (Table 4-1 and Figure 4-6e). This result is similar to the long-term patterns (87% of the Reef). Approximately 12% of the Reef was exposed to combined potential risk categories II–IV, which is still a relatively large area at approximately 43,600 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 9,711km^2. These patterns were very similar to the long-term patterns (Table 4-1). Patterns were also similar across marine regions, with more than 85% of each regions 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.

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 2021–22 wet season and the long-term (2003–2018). The last three rows show the differences between % affected in 2021–22 and the long-term average (red: increase, blue: decrease, and green: 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	2021	305,256	33,872	5,531	4,180	43,583
			LT	304,664	35,767	4,853	3,555	44,175
	%	*100%*	2021	87%	10%	2%	1%	12%
			LT	87%	10%	1%	1%	13%
Coral reefs	area	24,914	2021	21,194	2,608	235	111	2,954
			LT	23,147	861	98	43	1,002
	%	*100%*	2021	88%	11%	1%	<1%	12%
			LT	96%	4%	<1%	<1%	4%
Surveyed seagrass	area	4,660	2021	858	2,411	783	588	3,782
			LT	875	2,387	691	687	3,765
	%	*100%*	2021	18%	52%	17%	13%	82%
			LT	19%	51%	15%	15%	81%
Difference (2021 – Long Term average)	*Surface area*			<1%	<-1%	<1%	<1%	<-1%
	Coral Reef			-8%	7%	<1%	<1%	8%
	Surveyed seagrass			-1%	1%	2%	-2%	1%

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 (II: 67%) and only 9% and 2% 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 51% of the combined inshore waters exposed to risk category IV. Approximately 77% (<3,600 km^2) of the Reef seagrass occur in the inshore waters, but only 4% (< 900 km^2) of the coral reefs (Appendix C-6). The mid-shelf and offshore waterbodies were largely classified as no / very low potential risk (88% of the mid-shelf and 99% of the offshore waters) (Figure 4-7a).

Similar cross-shore patterns were observed across Reef marine regions and all mid-shelf and offshore waterbodies were largely classified as no or very low potential risk (Figure 4-7c). Mid-shelf waterbodies in the Cape York and Wet Tropics regions had the greatest exposure to potential risk category II (32% and 22% of the Cape York and the Wet Tropics mid-shelf waterbodies), followed by the Burnett-Mary and Fitzroy regions (11% and 5% of the Burnett-Mary and the Fitzroy mid-shelf waterbodies). The Burnett-Mary and Fitzroy region open coastal waterbodies had the greatest exposure to risk categories III (27% and 14% of the Burnett-Mary and Fitzroy open coastal waterbodies), followed by the Burdekin (10%). In the other Reef regions, less than 10% of the open coastal waterbodies were exposed to risk categories III. Differences across regions are further described in the Regional Reporting (Section 4.3 to 4.8).

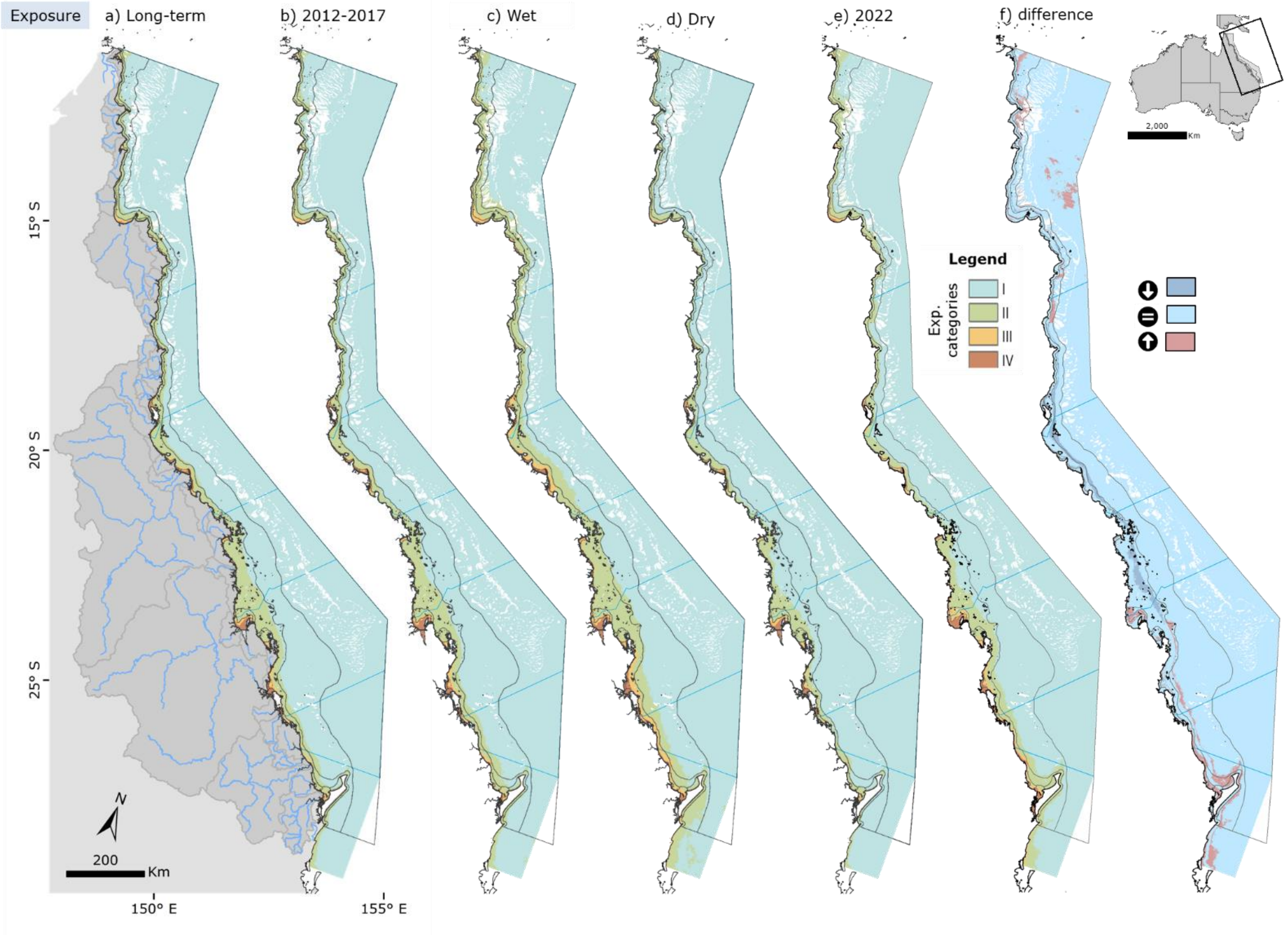
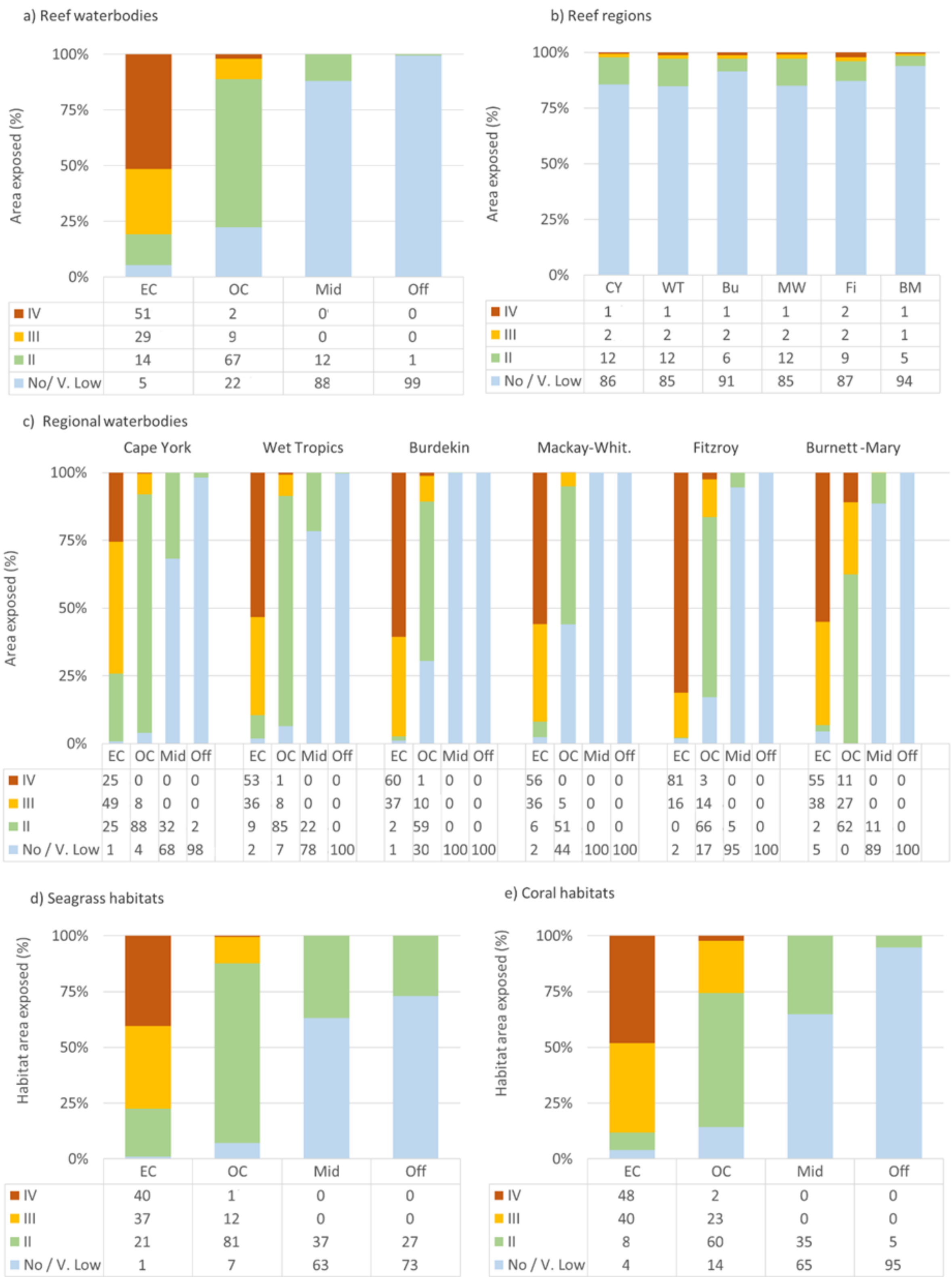


Figure 4-6: Map showing the reclassified surface exposure in the a) long-term (16 wet seasons since 2002–03), b) representative coral recovery period (2012–2017, 132 weeks), c) typical wet-year and d) typical dry-year wet season composites and e) 2021–22 wet seasons (22 weeks). Relative potential risk categories range from I: no to low risk to IV: highest relative risk. f) Difference map showing areas with an increase (in red, ➊) and decrease (in purple, ➋) in risk category in 2021–22 against long-term trends (calculated as (e) 2022 minus (a) long-term).



a) Reef waterbodies

	EC	OC	Mid	Off
IV	51	2	0	0
III	29	9	0	0
II	14	67	12	1
No/ V. Low	5	22	88	99

b) Reef regions

	CY	WT	Bu	MW	Fi	BM
IV	1	1	1	1	2	1
III	2	2	2	2	2	1
II	12	12	6	12	9	5
No / V. Low	86	85	91	85	87	94

c) Regional waterbodies

	Cape York EC	OC	Mid	Off	Wet Tropics EC	OC	Mid	Off	Burdekin EC	OC	Mid	Off
IV	25	0	0	0	53	1	0	0	60	1	0	0
III	49	8	0	0	36	8	0	0	37	10	0	0
II	25	88	32	2	9	85	22	0	2	59	0	0
No / V. Low	1	4	68	98	2	7	78	100	1	30	100	100

	Mackay-Whit. EC	OC	Mid	Off	Fitzroy EC	OC	Mid	Off	Burnett-Mary EC	OC	Mid	Off
IV	56	0	0	0	81	3	0	0	55	11	0	0
III	36	5	0	0	16	14	0	0	38	27	0	0
II	6	51	0	0	0	66	5	0	2	62	11	0
No / V. Low	2	44	100	100	2	17	95	100	5	0	89	100

d) Seagrass habitats

	EC	OC	Mid	Off
IV	40	1	0	0
III	37	12	0	0
II	21	81	37	27
No / V. Low	1	7	63	73

e) Coral habitats

	EC	OC	Mid	Off
IV	48	2	0	0
III	40	23	0	0
II	8	60	35	5
No / V. Low	4	14	65	95

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 2021–22 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 2021–22, it was estimated that:

- Approximately 12% of coral reefs (or almost 3,000 km^2) were exposed to combined potential risk categories II–IV (Table 4-1). However, less than 2% were in the highest exposure categories IV and III and only *the* enclosed coastal and open coastal coral reef habitats were exposed, equating to 347 km^2. The total enclosed coastal coral reef area affected by the highest exposure categories was 88% (48% to cat. IV and 40% to cat. III, Figure 4-7e). Only 2% of the open coastal reefs were exposed to cat. IV and 23% 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 were similar to the long-term patterns (< 2% of the coral reefs, Table 4-1). There was however an increase in area exposed to the lowest potential risk category (II: + 7%).
- Approximately 82% of seagrasses (or almost 3,800 km^2) were exposed to combined potential risk categories II–IV. Approximately 13% (588 km^2) were in the highest exposure category (IV) and 17% were in category III (783 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 77% (40% to cat. IV and 37% to cat. III). Only 12% of the open coastal seagrasses were exposed to cat. III and 1% only was 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 2021–22 were similar to the long-term (+ 1%).

4.2 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.

4.2.1 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 Figure 4-8, 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 2021–22 wet season; and a difference map showing areas exposed to an increased risk in 2022.

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.

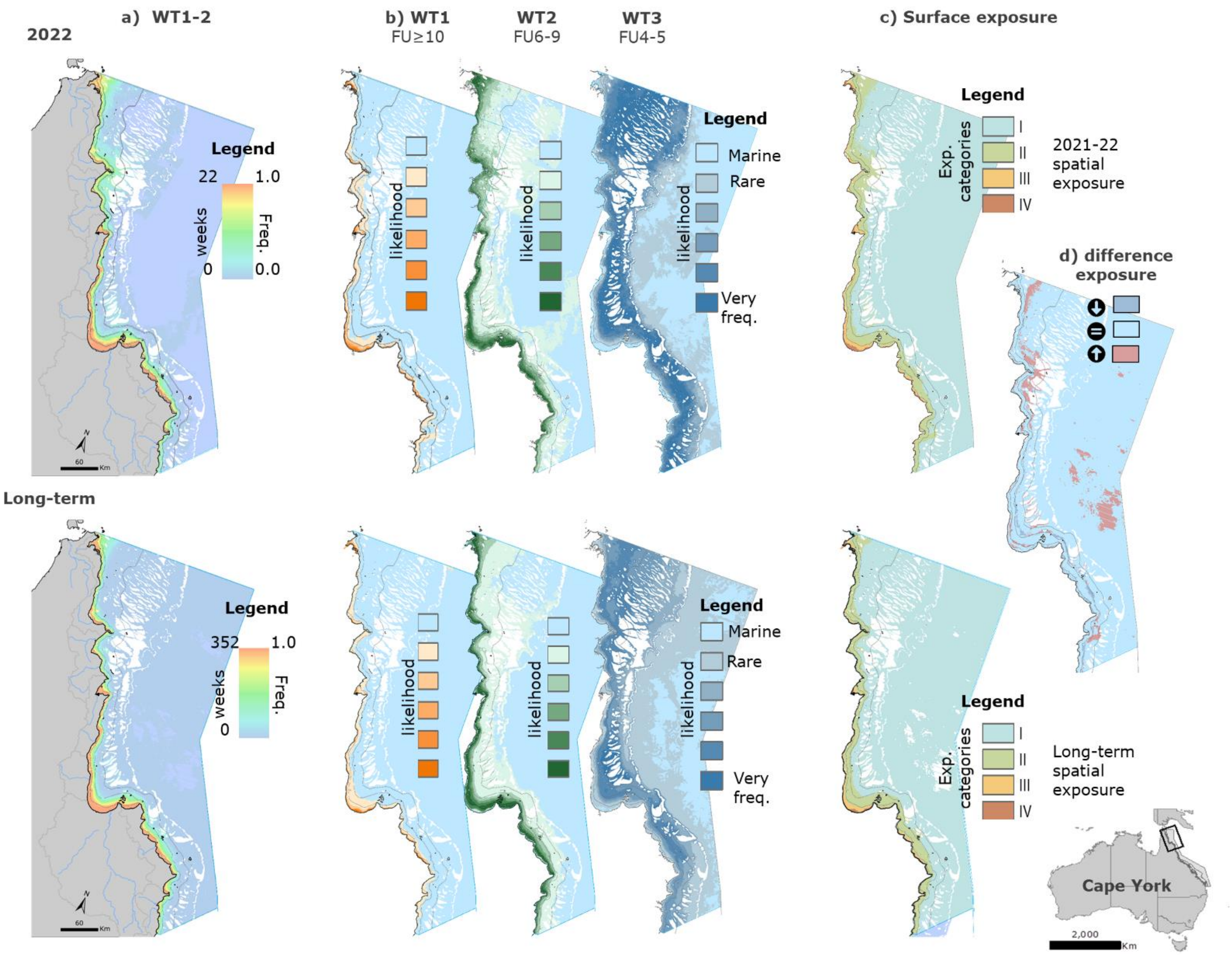


Figure 4-8: Long-term and current year remote sensing results for the Cape York region showing the a) frequency of combined Reef WT1–2; b) the frequency of Reef WT1, WT2 and WT3 individually regrouped into five likelihood categories [<0.2 (Rare), 0.2–0.4, 0.4–0.6, 0.6–0.8 and 0.8–1 (very frequent)]; c) exposure to potential risk - each in the long-term (bottom) and 2021–22 wet season (top). d) Difference map showing any areas with an increase (in red, ➊) or decrease (in purple, ➋) in risk category in 2021–22 against long-term trends [calculated as (c, top) exposure in 2022 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 coastal and marine 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 or Very low risk) represents waters with ambient or detectable but low water quality concentrations 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.

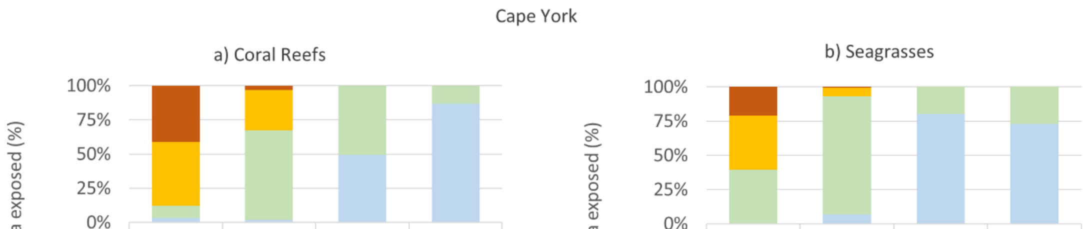
In 2021–22, it was estimated that:

- Cape York region: Approximately 86% of Cape York was not exposed to a potential risk, similar to long-term patterns (89%, Table 4-2). Approximately 14% (or about 14,000 km^2) of the Cape York region was exposed to combined potential risk categories II–IV. However, only 1% (562 km^2) of the Cape York region was in the highest exposure category (IV) and 2% (1,466 km^2) was in category III.
- Cape York waterbodies: The mid-shelf and offshore Cape York waterbodies were largely exposed to no / very low risk (68% and 98% 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 49% (cat. III) and 25% (cat. IV) of the total Cape York enclosed coastal area (Figure 4-7c) and 8% (cat. III) of the open coastal areas. Less than 0.01% of the open coastal areas was exposed to the highest category of risk (IV).
- Cape York habitats:
  - **Coral reefs**: Approximately 76% 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 161 km^2) and they were all inshore - and more particularly enclosed coastal - reefs (Figure 4-9a). 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 47% (cat. III) and 41% (cat. IV) of the total enclosed coastal coral reef area in Cape York, and to 30% (cat. III) and only 3% (cat. IV) of the total open coastal coral reef area. Mid-shelf reefs were exposed to the lower risk category II or to no / very low risk (51% and 49% of the total mid-shelf coral reef area in Cape York). 87% of the Cape York offshore reefs were classified as no / very low risk.
  - **Seagrasses**: Approximately 71% (or 1,898 km^2) of seagrasses in the Cape York region were exposed to combined potential risk categories II–IV (Table 4-2). 6% (156 km^2) of seagrasses were in the highest exposure category (IV) and 13% were in category III (356 km^2), and they were all inshore - and more particularly enclosed coastal - seagrasses (Figure 4-9b). A total of 27% and 40% (~ 1800 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 40% (cat. III) and 21% (cat. IV) of the total enclosed coastal seagrass area in Cape York and to only 7% (cat. III) of the total open coastal seagrass area. Mid-shelf and Offshore seagrasses were largely classified as no / very low risk (80% and 73% 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 (<2% of the coral reefs). There was however an increase in the coral area exposed to the lowest

potential risk category (II: +17%). The seagrass areas exposed to potential risk categories II–IV were similar to the long-term patterns (± 1%).

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 2021–22 wet season and the long-term (2003–2018). The last three rows show the differences between % affected in 2021–22 and the long-term average (red: increase, blue: decrease, green: no change, difference <5%).

Cape York		**Total**		**Potential Risk category**				**Total area exposed II–IV**
				No / Very low	**Lowest**		**Highest**	
				I	**II**	**III**	**IV**	
Surface area	area	96,316	2021–22	82,390	11,898	1,466	562	13,926
			LT	86,044	8,649	1,125	498	10,272
	%	*100%*	2021–22	86%	12%	2%	1%	14%
			LT	89%	9%	1%	1%	11%
Coral reefs	area	10,375	2021–22	7,936	2,278	107	53	2,439
			LT	9,837	496	34	8	538
	%	*100%*	2021–22	76%	22%	1%	1%	24%
			LT	95%	5%	<1%	<1%	5%
Surveyed seagrass	area	2,655	2021–22	757	1,386	356	156	1,898
			LT	777	1,371	319	189	1,878
	%	*100%*	2021–22	29%	52%	13%	6%	71%
			LT	29%	52%	12%	7%	71%
Difference (2021–22 – Long Term average)	*Surface area*			-3%	3%	<1%	<-1%	3%
	Coral Reef			-19%	17%	<1%	<1%	19%
	Surveyed seagrass			<-1%	<1%	1%	-1%	<1%



a) Coral Reefs

	EC	OC	Mid	Off
IV	41%	3%	0%	0%
III	47%	30%	0%	0%
II	9%	65%	51%	13%
No/V. Low	3%	2%	49%	87%

b) Seagrasses

	EC	OC	Mid	Off
IV	21%	0%	0%	0%
III	40%	7%	0%	0%
II	39%	86%	20%	27%
No/V. Low	0%	7%	80%	73%

Figure 4-9: Percentage of the Cape York region a) coral reef and b) surveyed seagrass habitats affected by different risk categories of exposure during the 2021–22 wet season. Water body classifications are shown along the x-axes: enclosed coastal (EC), open coastal (OC), mid-shelf (Mid), and offshore (Off).

4.2.2 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 Figure 4-10, 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 2021–22 wet season; and a difference map showing areas exposed to an increased risk in 2022.

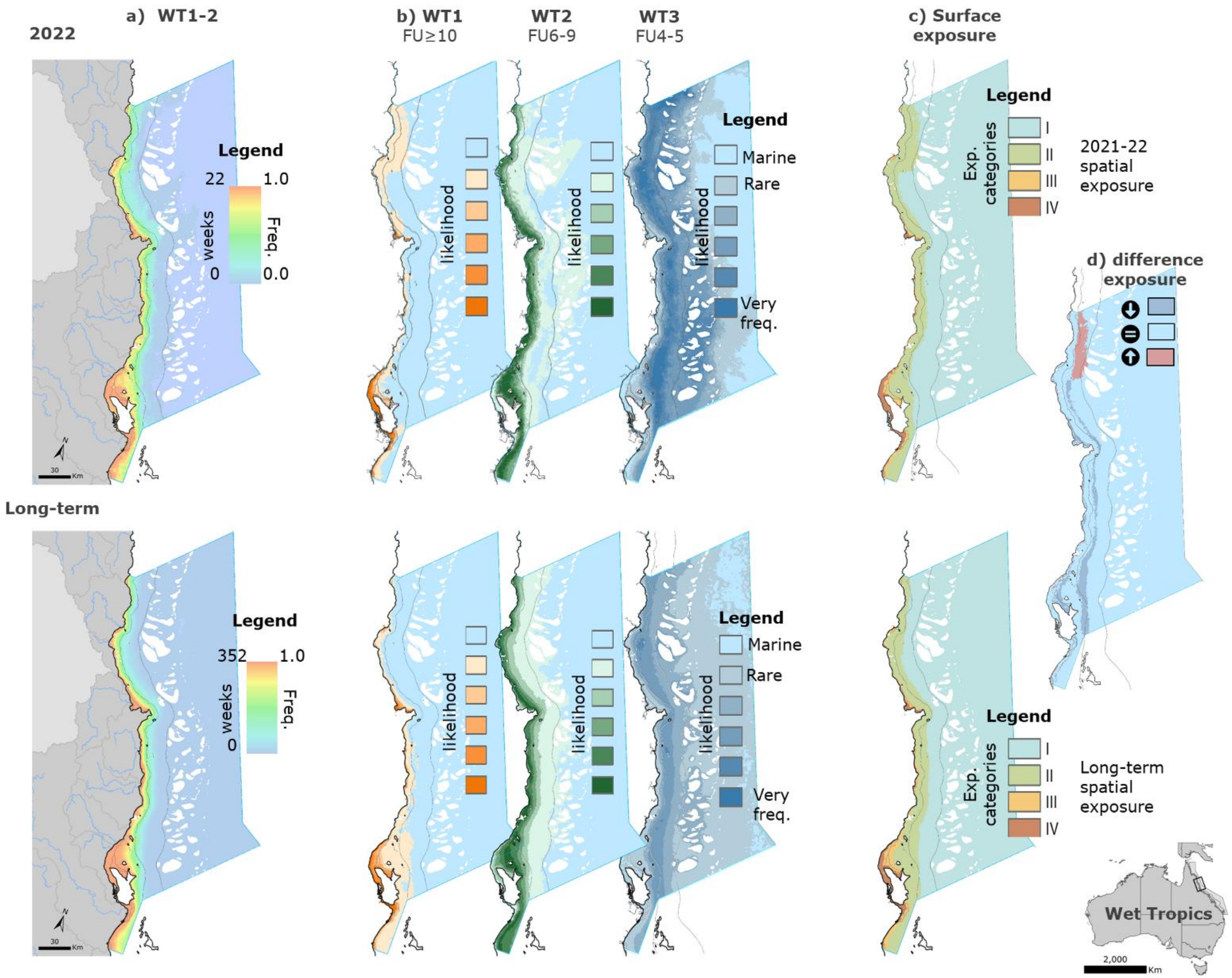


Figure 4-10: Long-term and current year remote sensing results for the Wet Tropics region showing the a) frequency of combined Reef WT1–2 II; b) the frequency of Reef WT1, WT2 and WT3 individually regrouped into five likelihood categories [<0.2 (Rare), 0.2–0.4, 0.4–0.6, 0.6–0.8 and 0.8–1 (very frequent)]; c) exposure to potential risk - each in the long-term (bottom) and 2021–22 wet season (top). d) Difference map showing any areas with an increase (in red, ➊) or decrease (in purple, ➋) in risk category in 2021–22 against long-term trends [calculated as (c, top) exposure in 2022 minus (c, bottom) long-term]. Note that optical water types – especially Reef WT3– do not always correspond to direct catchment discharge influence, and can also be due to coastal and marine 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 or Very low risk) represents waters with ambient or detectable but low water quality concentrations 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 2021–22, it was estimated that:

- Wet-Tropics wide: 85% of the Wet Tropics region was not exposed to a potential risk, similar to long-term patterns (84%, Table 4-3). 15% (or about 4900 km^2) of the Wet Tropics region was exposed to combined potential risk categories II–IV. However, only 1% (405 km^2) of the region was in the highest exposure category (IV) and only 2% was in category III (505 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 8% (cat. III) and 1% (cat. IV) of the total Wet Tropics inshore area (Figure 4-7c). A total of 36% and 53% 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 (78% and 100% of the Wet Tropics mid-shelf and offshore waterbodies).
- Wet Tropics habitats:
    - **Coral reefs:** 4% of coral reefs in the Wet Tropics region were exposed to a potential risk (combined potential risk categories II–IV, Table 4-3). However, 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 4-11a). 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 35% (cat. III) and 3% (cat. IV) of the total open coastal reef area in the Wet Tropics. A total of 61% and 33% 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 229 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 29% (67 km^2) of seagrasses were in the highest exposure category (IV) and 30% (71 km^2) were in category III, and they were all inshore seagrasses (Figure 4-11b). 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 17% (cat. III) and 1% (cat. IV) of the total inshore coastal seagrass in the Wet Tropics. A total of 41% and 49% of the total enclosed coastal seagrass were exposed to categories III and IV, respectively. Mid-shelf seagrasses were largely classified as no / very low risk (73% of the Wet Tropics mid-shelf seagrasses) or the lowest category of potential risk (II: 27% 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 2021–22 were similar to the

average long-term areas (changes = 2%). 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 category (IV: -14%) and an increase in the seagrass area exposed to the lowest potential risk category (II: +22%)

Table 4-3: Areas (km^2) and percentages (%) of the Wet Tropics region, coral reefs, and surveyed seagrass affected by different risk categories of exposure during the 2021–22 wet season and the long-term (2003–2018). The last three rows show the differences between % affected in 2021–22 and the long-term average (red: increase, blue: decrease, green: no change, difference <5%).

Wet Tropics		**Total**		**Potential Risk category**				**Total area exposed II–IV**
				No / Very low	**Lowest**		**Highest**	
				I	**II**	**III**	**IV**	
Surface area	area	31,976	2021–22	27,088	3,978	505	405	4,888
			LT	26,928	3,919	710	419	5,048
	%	*100%*	2021–22	85%	12%	2%	1%	15%
			LT	84%	12%	2%	1%	16%
Coral reefs	area	2,425	2021–22	2,334	54	31	6	91
			LT	2,380	34	10	2	46
	%	*100%*	2021–22	96%	2%	1%	<1%	4%
			LT	98%	1%	<1%	<1%	2%
Surveyed seagrass	area	232	2021–22	4	90	71	67	229
			LT	14	40	79	99	219
	%	*100%*	2021–22	2%	39%	30%	29%	98%
			LT	6%	17%	34%	43%	94%
Difference (2021–22 – Long-term average)	*Surface area*			<1%	<1%	<-1%	<1%	<-1%
	Coral Reef			-2%	1%	<1%	<1%	2%
	Surveyed seagrass			-4%	22%	-3.5%	-14%	4%

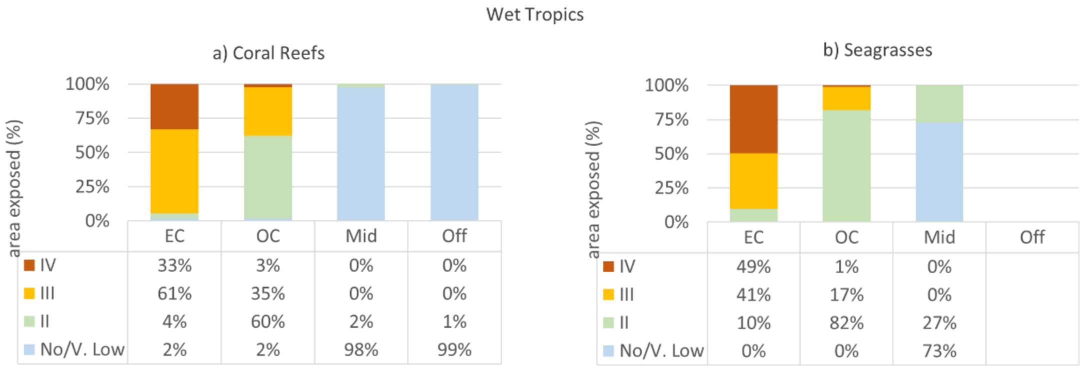


Figure 4-11: Percentage of the Wet Tropics region a) coral reef and b) surveyed seagrass habitats affected by different risk categories of exposure during the 2021–22 wet season. Water body classifications are shown along the x-axes: enclosed coastal (EC), open coastal (OC), mid-shelf (Mid), and offshore (Off).

4.2.3 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 Figure 4-12, 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 2021–22 wet season; and a difference map showing areas exposed to an increased risk in 2022.

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 or Very low risk) represents waters with ambient or detectable but low water quality concentrations 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 2021–22, it was estimated that:

- Burdekin-wide: 91% of Burdekin region was not exposed to a potential risk, slightly over (+5%) long-term patterns (86%, Table 4-4). 9% (or about 4000 km^2) of the Burdekin region was exposed to combined potential risk categories II–IV. However, only 1% (599 km^2) of the region was in the highest exposure category (IV) and 2% (752km^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 10% (cat. III) and 1% (cat. IV) of the total Burdekin open coastal area (Figure 4-7c). 37% and 60% 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 (100% 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 18 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 40% (cat. III) and 3% (cat. IV) of the total open coastal reefs area in the Burdekin region (Figure 4-13a). A total of 30% and 70% of the enclosed coastal areas were exposed to categories III and IV respectively. Mid-shelf and offshore coral reefs were exposed to no risk (100% of both waterbodies).

- **Seagrasses:** 90% (or 637 km^2) of seagrasses in the Burdekin region were exposed to combined potential risk categories II–IV. 18% (125 km^2, Table 4-4) of seagrasses were in the highest exposure category (IV) and 29% (202 km^2) were in category III, and they were all inshore seagrasses (Figure 4-13b). 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 24% (cat. III) and 1% (cat. IV) of the total inshore seagrass area in the Burdekin region (Figure 4-13b). A total of 40% and 59% 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 (99% of the Burdekin mid-shelf seagrasses).

- **Comparison to long-term trends:** The coral areas in the Burdekin region exposed to combined potential risk categories II–IV in 2021–22 was similar to the average long-term areas (± 1% change), while the seagrass areas were slightly under to the average long-term areas (-5%).

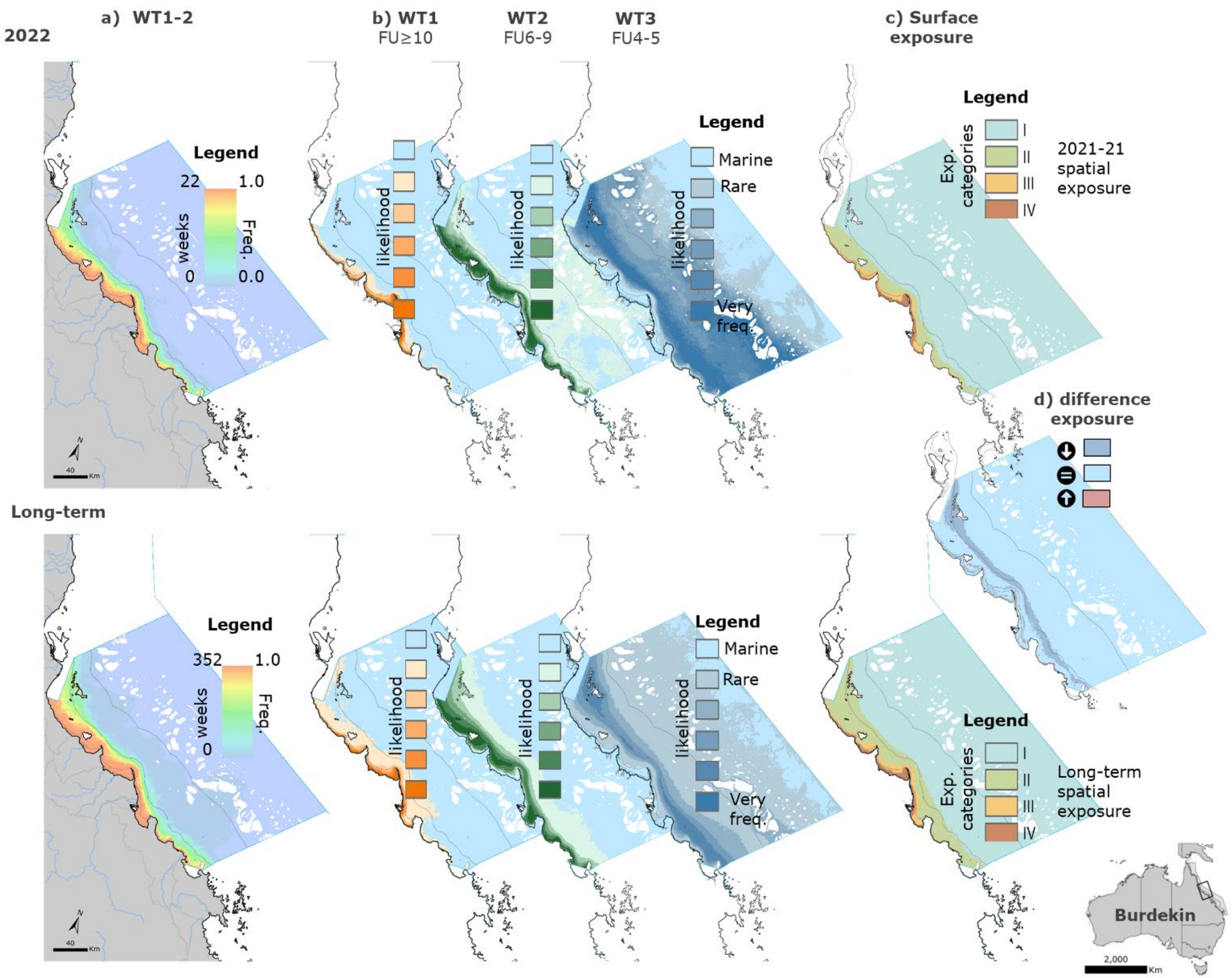


Figure 4-12: Long-term and current year remote sensing results for the Burdekin region showing the a) frequency of combined Reef WT1-2; b) the frequency of Reef WT1, WT2 and WT3 individually regrouped into five likelihood categories [<0.2 (Rare), 0.2–0.4, 0.4–0.6, 0.6–0.8 and 0.8–1 (very frequent)]; c) exposure to potential risk - each in the long-term (bottom) and 2021–22 wet season (top).d) Difference map showing any areas with an increase (in red, 🡅) or decrease (in purple, 🡇) in risk category in 2021–22 against long-term trends [calculated as (c, top) exposure in 2022 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 coastal and marine processes (see definitions in Table 2-2).

Table 4-4: Areas (km²) and percentages (%) of the Burdekin region, coral reefs, and surveyed seagrass affected by different risk categories of exposure during the 2021–22 wet season and the long-term (2003–2018). The last three rows show the differences between % affected in 2021–22 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	2021–22	42,976	2,682	752	599	4,033
			LT	40,627	4,867	914	602	6,382
	%	*100%*	2021–22	91%	6%	2%	1%	9%
			LT	86%	10%	2%	1%	14%
Coral reefs	area	2,966	2021–22	2,934	15	13	5	32
			LT	2,916	36	13	1	50
	%	*100%*	2021–22	99%	<1%	<1%	<1%	1%
			LT	98%	1%	<1%	<1%	2%
Surveyed seagrass	area	708	2021–22	71	310	202	125	637
			LT	32	346	184	146	676
	%	*100%*	2021–22	10%	44%	29%	18%	90%
			LT	5%	49%	26%	21%	95%
Difference (2021–22 – Long Term average)	*Surface area*			5%	-4%	<-1%	<1%	-5%
	Coral Reef			<1%	<1%	<1%	<1%	<-1%
	Surveyed seagrass			5%	-5%	3%	-3%	-5%

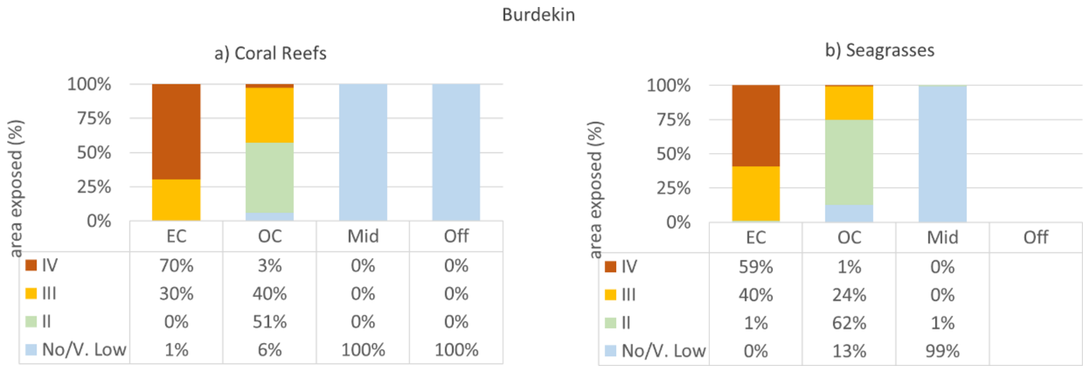


Figure 4-13: Percentage of the Burdekin region a) coral reef and b) surveyed seagrass habitats affected by different risk categories of exposure during the 2021–22 wet season. Water body classifications are shown along the x-axes: enclosed coastal (EC), open coastal (OC), mid-shelf (Mid), and offshore (Off).

4.2.4 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 Figure 4-14, 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 2021–22 wet season; and a difference map showing areas exposed to an increased risk in 2022.

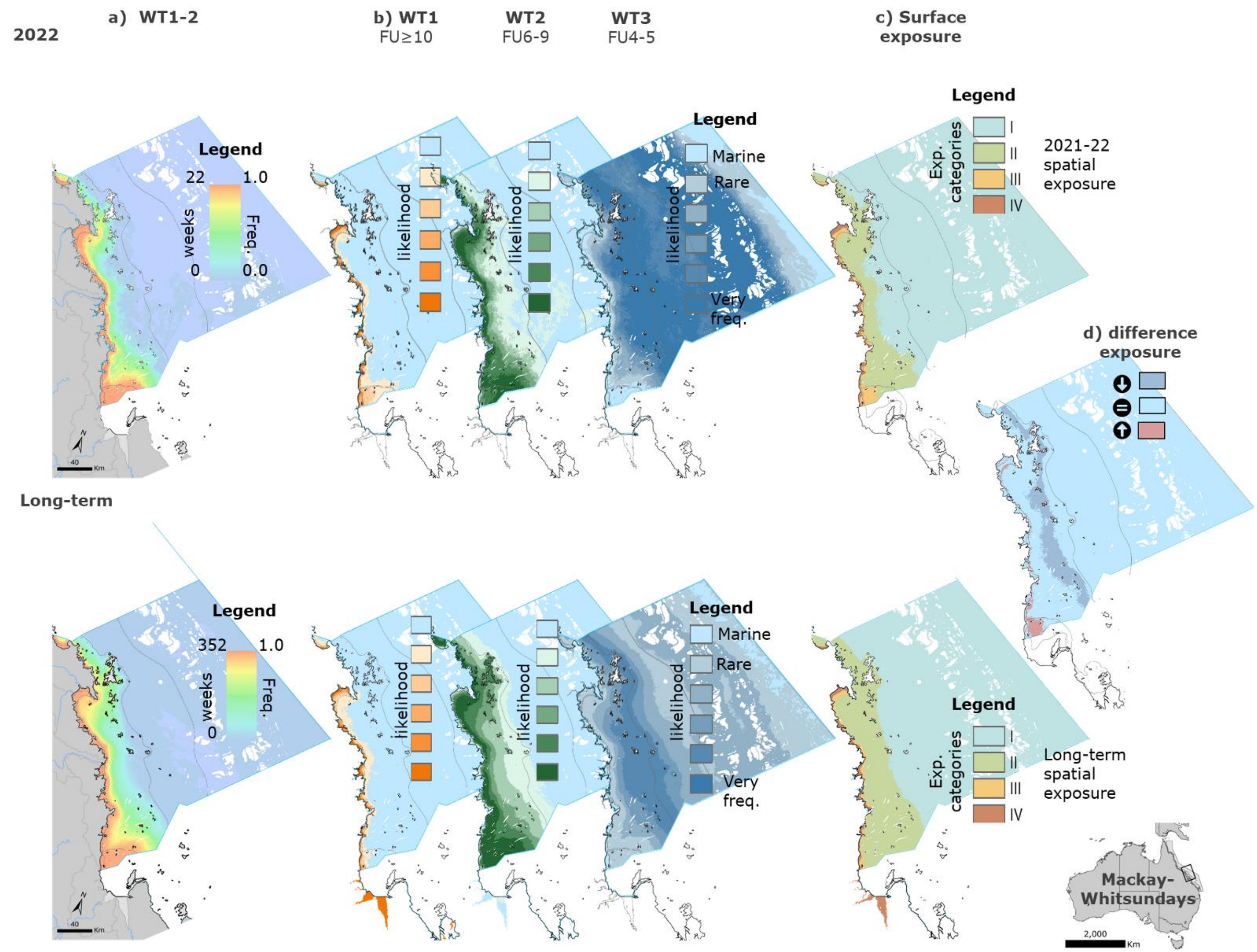


Figure 4-14: Long-term and current year remote sensing results for the Mackay-Whitsunday region showing the a) frequency of Reef WT1–2; b) the frequency of Reef WT1, WT2 and WT3 individually regrouped into five likelihood categories [<0.2 (Rare), 0.2–0.4, 0.4–0.6, 0.6–0.8 and 0.8–1 (very frequent)]; c) exposure to potential risk - each in the long-term (bottom) and 2021–22 wet season (top).d) Difference map showing areas with an increase (in red, ➊) or decrease (in purple, ➋) in risk category in 2021–22 against long-term trends [calculated as (c, top) exposure in 2022 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 coastal and marine 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 or Very low risk) represents waters with ambient or detectable but low water quality concentrations 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 2021–22 wet season and the long-term (2003–2018). The last three rows show the differences between % affected in 2021–22 and the long-term average (red: increase, blue: decrease, green: no change, difference ≤5%).

Mackay-Whitsunday		Total		Potential Risk category: No / very low I	Lowest II	III	Highest IV	Total area exposed II–IV
Surface area	area	48,957	2021–22	41,610	5,997	863	487	7,346
			LT	38,701	9,320	515	419	10,255
	%	*100%*	2021–22	85%	12%	2%	1%	15%
			LT	79%	19%	1%	1%	21%
Coral reefs	area	3,216	2021–22	3,017	150	37	12	199
			LT	3,004	194	16	2	212
	%	*100%*	2021–22	94%	5%	1%	<1%	6%
			LT	93%	6%	<1%	<1%	7%
Surveyed seagrass	area	307	2021–22	18	174	46	69	290
			LT	19	169	42	77	288
	%	*100%*	2021–22	6%	57%	15%	23%	94%
			LT	6%	55%	14%	25%	94%
Difference (2021–22– Long-term average)	*Surface area*			6%	-7%	<1%	<1%	-6%
	Coral Reef			<1%	-1%	<1%	<1%	<-1%
	Surveyed seagrass			<-1%	2%	1%	-2%	<1%

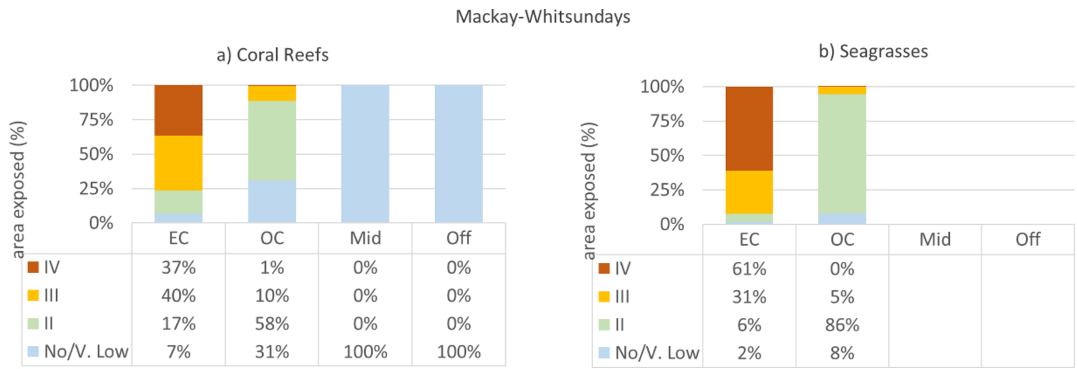


Figure 4-15: Percentage of the Mackay-Whitsunday region a) coral reef and b) surveyed seagrass habitats affected by different risk categories of exposure during the 2021–22 wet season. Water body classifications are shown along the x-axes: enclosed coastal (EC), open coastal (OC), mid-shelf (Mid), and offshore (Off).

In 2021–22, it was estimated that:

- Mackay-Whitsunday wide: 85% of the Mackay-Whitsunday region was not exposed to a potential risk, over long-term patterns (79%, Table 4-5). A total of 15% of the Mackay-Whitsunday region was exposed to combined potential risk categories II–IV (or about 7,346 km^2). However, only 1% (487 km^2) of the region was in the highest exposure category (IV) and 2% (863 km^2) in category III.
- Mackay-Whitsunday waterbodies: only the enclosed coastal and open coastal Mackay-Whitsunday 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 5% (cat. III) and less than 0.01% (cat. IV) of the total Mackay-Whitsunday inshore area. A total of 36% and 56% 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 6% (or 199 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 49 km^2), and they were all enclosed coastal or open coastal reefs (Figure 4-15a). 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 10% (cat. III) and 1% (cat. IV) of the total open coastal reef area in the Mackay-Whitsunday region. A total of 40% and 37% 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 94% of seagrasses in the Mackay-Whitsunday region were exposed to combined potential risk categories II–IV (290 km^2, Table 4-5). A total of 23% (69 km^2) of seagrasses were in the highest exposure category (IV) and 15% (46 km^2) were in category III.

    The open coastal seagrass area exposed to higher potential risk was spatially limited and corresponded to 5% (cat. III) of the total open coastal seagrass area in the Mackay-Whitsunday region Figure 4-15b. Approximately 31% and 61% of the enclosed coastal areas were exposed to categories III and IV respectively.

- **Comparison with long-term trends:** The coral and seagrass areas in the Mackay-Whitsunday region exposed to combined potential risk categories II–IV in 2021–22 were very similar to the long-term areas (±1% change).

4.2.5 Fitzroy and Burnett-Mary regions

As no water quality monitoring is currently conducted under the MMP in the Fitzroy and Burnett-Mary regions, the remote sensing results for these regions are typically not reported. However, the results of the assessment of potential risk are presented below as it was a wet year for both regions, and more particularly the Burnett-Mary region (Figure 3-5). The remote sensing results are relevant context for the coral reef and seagrass data in these regions. This year, water quality monitoring in the Fitzroy region has been monitored in accordance with the MMP water quality monitoring design via a separately funded project, and the results of this are included as Appendix D. 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 of water quality conditions from *in situ* monitoring.

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 or Very low risk) represents waters with ambient or detectable but low water quality concentrations 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

The river discharge from the Fitzroy region in 2021–22 was just above the long-term median (<1.5 times the long-term median).

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 2021–22, it was estimated that:

- Fitzroy-wide: 87% of the Fitzroy region was not exposed to a potential risk, similar to long-term patterns (88%, Table 4-6). 13% (or about 11,000 km^2) of the Fitzroy region was exposed to combined potential risk categories II–IV. However, only 2% (1,868 km^2) of the region was in the highest exposure category (IV) and 2% (1,599 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 14% (cat. III) and 3% (cat. IV) of the total Fitzroy inshore area (Figure 4-7c). 16% and 81% of the enclosed coastal areas were exposed to categories III and IV respectively. The offshore Fitzroy waterbody was not exposed to a potential risk, and only 5% of the mid-shelf Fitzroy waterbody was exposed to the lowest category of risk (II).
- Fitzroy habitats:
  - **Coral reefs:** Approximately 4% of coral reefs in the Fitzroy region were exposed to combined potential risk categories II–IV (Table 4-6). However, only 2% of coral were in both the highest exposure category (IV) and category III (combined 76 km^2), and they were all enclosed coastal or mid-shelf reefs (Figure 4-16a). 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 28% (cat. III) and 3% (cat. IV) of the total open coastal coral reef area in the Fitzroy. Approximately 9% and 90% of the enclosed coastal areas were exposed to categories III and IV respectively. Nearly all of the mid-shelf and offshore reefs were classified as no / very low risk.

- **Seagrasses:** Approximately 99% (or about 480 km^2) of seagrasses in the Fitzroy region were exposed to combined potential risk categories II–IV (Table 4-6). 26% (122 km) 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 4-16b). 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 10% (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). 23% 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 however an increase in the seagrass area exposed to the risk cat. III (+6%).

Table 4-6: Areas (km²) and percentages (%) of the Fitzroy region, coral reefs, and surveyed seagrass affected by different risk categories of exposure during the 2021–22 wet season and the long-term (2003–2018). The last three rows show the differences between % affected in 2021–22 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**				**Total area exposed II–IV**
				No / Very low	**Lowest**		**Highest**	
				I	**II**	**III**	**IV**	
Surface area	area	86,869	2021–22	75,810	7,592	1,599	1,868	11,059
			LT	76,616	7,457	1,322	1,475	10,253
	%	*100%*	2021–22	87%	9%	2%	2%	13%
			LT	88%	9%	2%	2%	12%
Coral reefs	area	4,881	2021–22	4,696	109	42	34	185
			LT	4,729	100	22	30	152
	%	*100%*	2021–22	96%	2%	1%	1%	4%
			LT	97%	2%	<1%	<1%	3%
Surveyed seagrass	area	478	2021–22	5	289	61	122	473
			LT	20	286	34	137	457
	%	*100%*	2021–22	1%	61%	13%	26%	99%
			LT	4%	60%	7%	29%	96%
Difference (2021–22 – Long-term average)	*Surface area*			<-1%	<-1%	<-1%	<1%	<1%
	Coral Reef			<-1%	<1%	<1%	<1%	<1%
	Surveyed seagrass			-3%	<1%	6%	-3%	3%

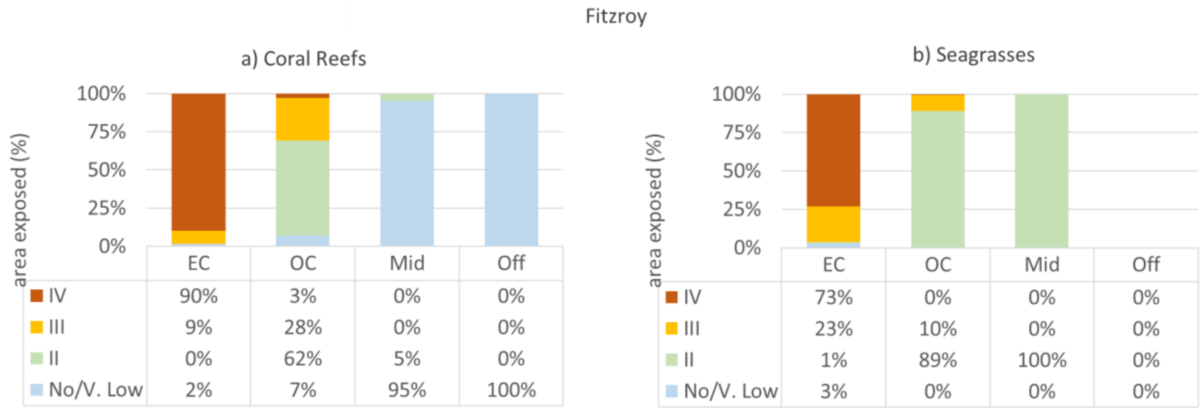


Figure 4-16: Percentage of the Fitzroy region a) coral reef and b) surveyed seagrass habitats affected by different risk categories of exposure during the 2021–22 wet season. Water body classifications are shown along the x-axes: enclosed coastal (EC), open coastal (OC), mid-shelf (Mid), and offshore (Off).

Burnett-Mary

The river discharge from the Burnett-Mary region in 2021–22 was 8.8 times the long-term median, and there were large flood plumes captured in satellite imagery in the Burnett-Mary region during the wet season.

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 2021–22, it was estimated that:

- Burnett-Mary wide: Approximately 94% of the Burnett-Mary region was not exposed to a potential risk, which was similar long-term patterns (95%, Table 4-7). 6% of the Burnett-Mary region (or about 2300 km^2) was exposed to combined potential risk categories II–IV, with 1% in both the highest exposure category (IV) and category III (combined 605 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 27% (cat. III) and 11% (cat. IV) of the total Burnett-Mary inshore area (Figure 4-7c). A total of 38% and 55% of the enclosed coastal areas were exposed to categories III and IV respectively. 89% and100% of the mid-shelf and offshore Burnett-Mary waterbodies were exposed to no / very low risk, respectively.
- Burnett-Mary habitats:
    - **Coral reefs:** Approximately 3% of coral reefs in the Burnett-Mary region were exposed to combined potential risk categories II–IV (Table 4-8). 2% of coral were exposed to the highest risk categories III and IV (about 6 km^2) and there were all enclosed coastal or open coastal reefs (Figure 4-17a). 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 52% and 47% of the total enclosed coastal and open coastal coral reef area in the Burnett-Mary region, largely over last year areas (9 and 1%). The enclosed coastal area exposed to potential risk category III and IV corresponded to 83% and 17% 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 99% (or 256 km^2) of seagrasses in the Burnett-Mary region were exposed to combined potential risk categories II–IV (Table 4-7). 19%

(48 km^2) of seagrasses were in the highest exposure category (IV) and 18% (47 km^2) were in category III and they were all enclosed coastal or open coastal seagrasses (Figure 4-17b). 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 12% (cat. III) and 1% (cat IV) of the total inshore seagrass area in the Burnett-Mary region. A total of 39% and 52% 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 2021–22 were similar to long-term areas. However, there was a large increase in the seagrass areas exposed to combined potential risk categories II–IV (+46% over the average long-term areas), with a +10% increase in the seagrass area exposed to the highest risk category IV.

Table 4-7: Areas (km²) and percentages (%) of the Burnett-Mary region, coral reefs, and surveyed seagrass affected by different risk categories of exposure during the 2021–22 wet season and the long-term (2003–2018). The last three rows show the differences between % affected in 2021–22 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.

Burnett-Mary		**Total**		**Potential Risk category** No / Very low	Lowest		Highest	**Total area exposed II–IV**
				I	**II**	**III**	**IV**	
Surface area	area	37,713	2021–22	35,382	1,726	346	259	2,331
			LT	35,748	1,556	267	142	1,965
	%	*100%*	2021–22	94%	5%	1%	1%	6%
			LT	95%	4%	<1%	<1%	5%
Coral reefs	area	285	2021–22	277	2	4	2	8
			LT	281	0	3	0	4
	%	*100%*	2021–22	97%	1%	1%	1%	3%
			LT	99%	0%	<1%	<1%	<1%
Surveyed seagrass	area	259	2021–22	3	161	47	48	256
			LT	9	170	39	42	251
	%	*100%*	2021–22	1%	62%	18%	19%	99%
			LT	3%	36%	8%	9%	53%
Difference (2021–22 – Long term average)	*Surface area*			-1%	<1%	<1%	<1%	1%
	Coral Reef			-2%	<1%	<1%	<1%	2%
	Surveyed seagrass			-2%	26%	10%	10%	46%

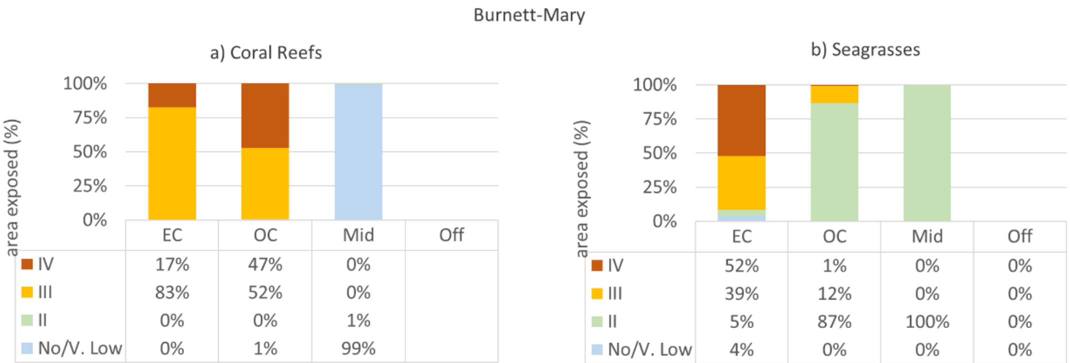


Figure 4-17: Percentage of the Burnett-Mary region a) coral reef and b) surveyed seagrass habitats affected by different risk categories of exposure during the 2021–22 wet season. Water body classifications are shown along the x-axes: enclosed coastal (EC), open coastal (OC), mid-shelf (Mid), and offshore (Off).

4.3 Modelling and mapping summary and discussion

Water type frequency maps (Sentinel-3 data)

For the second year, Sentinel-3 satellite images of the reef and the Forel-Ule colour scale (FU, 21 colour classes) were used to produce map Reef water types instead of the MODIS imagery and the wet season colour scale (wet season, 6 colour classes). 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).

Results are very encouraging 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. 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-sourced contaminant concentrations, a low risk of any detrimental ecological effect and often mixed with the influence of marine processes).

A 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., *in prep*.) has 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 retrieving 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 water quality concentrations and the four Reef water types and can help improving 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.

Only 3% of the Reef (inshore waters only) was exposed to Reef WT1 waters during the 2021–22 wet season, and 17% was exposed to Reef WT2, which is similar to the pattern for the long-term and representative coral recovery periods. However, for the fourth year in a row, the Reef area exposed to Reef WT3 was unexpectedly large (61% of the Reef) and covered a larger area than all reference periods, including the ‘wet’ years (56% of the Reef). This result is related to anomalously large Reef WT3 areas measured in the mid-shelf and offshore region of the Reef, which is almost certainly due to oceanic 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-sourced contaminant concentrations) and a low magnitude score in the Reef exposure assessment. While Reef WT3 areas in 2021–22 were much larger than usual, this did not result in increasing the Reef-wide potential risk. The total Reef area exposed to a potential risk in 2021–22 was spatially limited and similar to the long-term patterns. Eighty seven percent of the Reef was exposed to no or very low potential risk and only 3% (but almost 10,000 km^2) of the Reef was in the highest exposure categories III and IV.

Cross-shore, the offshore and mid-shelf and waterbodies were largely classified as no or very low potential risk (88% and 99% respectively), in all Reef regions. Open coastal waters were largely exposed to the lowest category of risk (II, 67% 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 29% and 51% 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). Across Reef regions, the Burnett-Mary and Fitzroy region open coastal waterbody had the greatest exposure to risk categories III (27% and 14% of the Burnett-Mary and Fitzroy open coastal waterbodies), followed by the Burdekin (10%).

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 and were not exposed to the highest exposure categories III and IV. Open coastal seagrasses and coral reefs were largely exposed to the lowest category of risk (II, 81% and 60% of the total Reef seagrass and coral areas, respectively). Enclosed coastal habitats were the most at risk, with 88% (less than 1% of the total coral reef area of the Reef) and 77% (~6% 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 sediment resuspension (some of which may have been originally derived from the Reef river discharge) or bottom influence may influence the TSS concentrations and resulting exposure results in this very coastal region.

Habitat areas exposed to a potential risk (combined risk categories II, III and IV) were largely similar to the long-term patterns in all regions (≤ 5% change). There was, however, an increase in coral areas exposed to the lowest risk category (II) in the Cape York region, and an increase in seagrass areas exposed to the risk category III in the Fitzroy region which was logical with the relatively high discharge measured in both regions in 2021–22. The river discharge from the Burnett-Mary region in 2021–22 was 8.8 times above the long-term median and there was a large increase in the seagrass areas exposed to combined potential risk categories II–IV (+46% over the average long-term areas, including +10% exposed to cat. IV) in this region

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

- This assessment does not take into account the current condition of Reef ecosystems and long-term impacts on these communities. For example, it is recognised that inshore communities may be adapted to 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 current 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 oceanic processes in some 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 in the Reef. 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 across Reef waterbodies, in both wet and dry seasons, and from the inshore to offshore Reef. Multi-variate 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 separate or 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 will be progressed for the next report as long-term mean water quality concentrations will be recalculated.

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 identification and interpretation of year-to-year 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 area
- regional trends in key water quality parameters from 2005 to 2022
- presentation of the long-term trend and annual condition of ambient water quality relative to GVs using the WQ Index.

Site-specific data and additional information tables are presented in Appendix 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 2021 to September 2022
- Appendix C-3 Table C-2: Annual summaries of moored FLNTUSB turbidity measurements for each monitoring location, including percentage exceedances of GVs
- Table C-3 to Table C-7: 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: Pascoe River, Stewart River, Normanby Basin and Endeavour Basin. 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 six 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. Ambient sampling primarily occurs between October to April (wet season) due to strong trade winds (>25 km h^{-1}) preventing access during the winter months.

The 2021–22 water year is the sixth year of sampling for the Cape York region. In consultation between CYWP, AIMS and the Reef Authority, both the analytical laboratory and the number of sites sampled in Cape York changed in 2020 (see Appendix A).

Because of this change, long-term trends are difficult to assess. 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 guidelines, 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 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 (this is the second) that the annual Index score has been generated for Cape York, a "coaster" format has been used to present the scores, rather than the timeseries format used in other regions.

The Cape York region received a 'good' annual Water Quality Index score for the 2021–22 monitoring year (Figure 5-2). This 'good' score was an improvement from the 2020–21 monitoring year, when Cape York received a 'moderate' score. During the 2021–22 monitoring year there was generally average or slightly above average rainfall and less river discharge in most focus regions compared to the previous monitoring year. There were significant variations in both relative rainfall and water quality, with most focus regions receiving a 'moderate' annual Index score and the Annan-Endeavour receiving a 'very good' score. The focus region scores are also 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 in 2021–22.

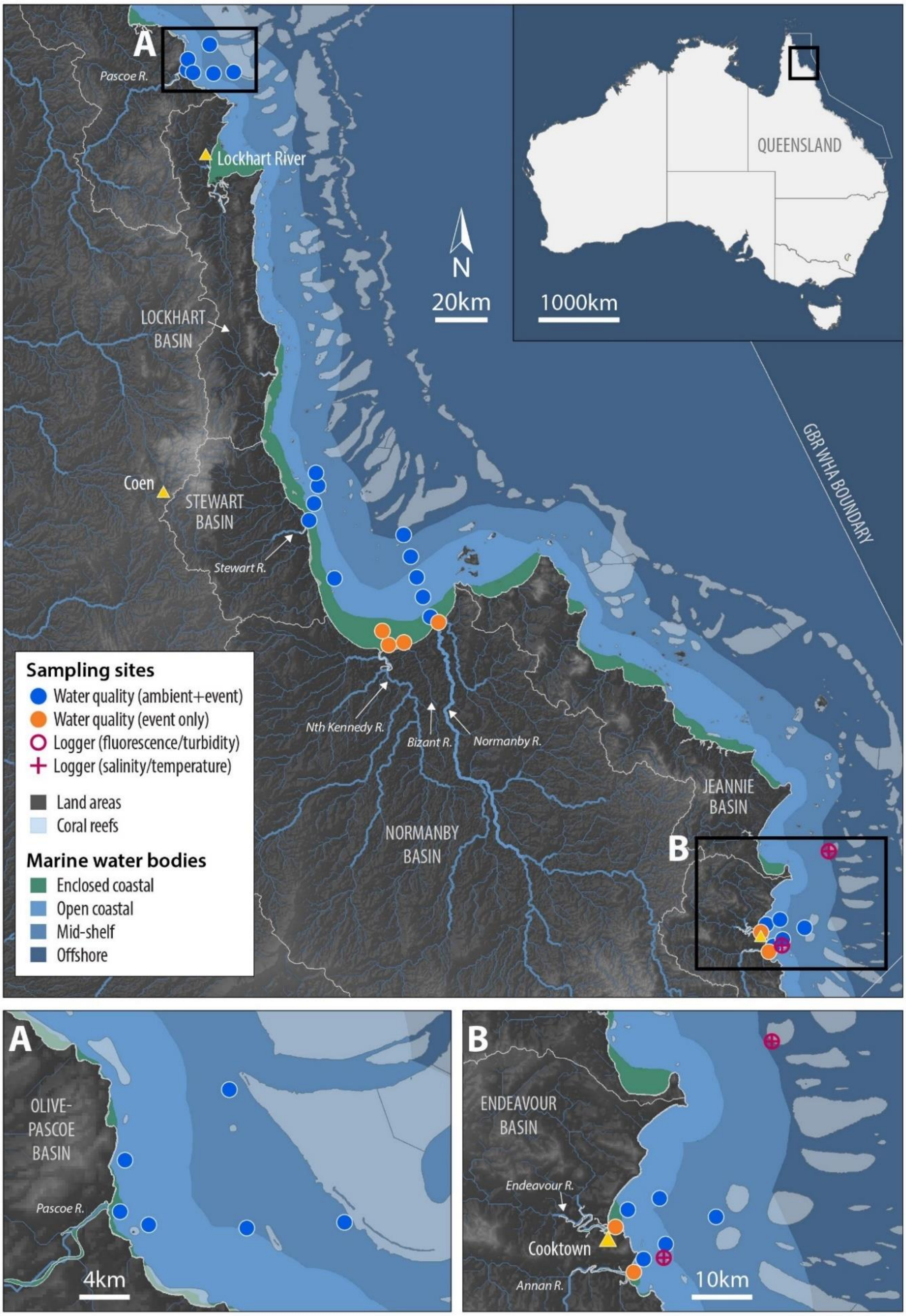


Figure 5-1: Water quality sampling sites in the Cape York region shown with water body boundaries. River datasets for map courtesy Grill *et al.* (2019).

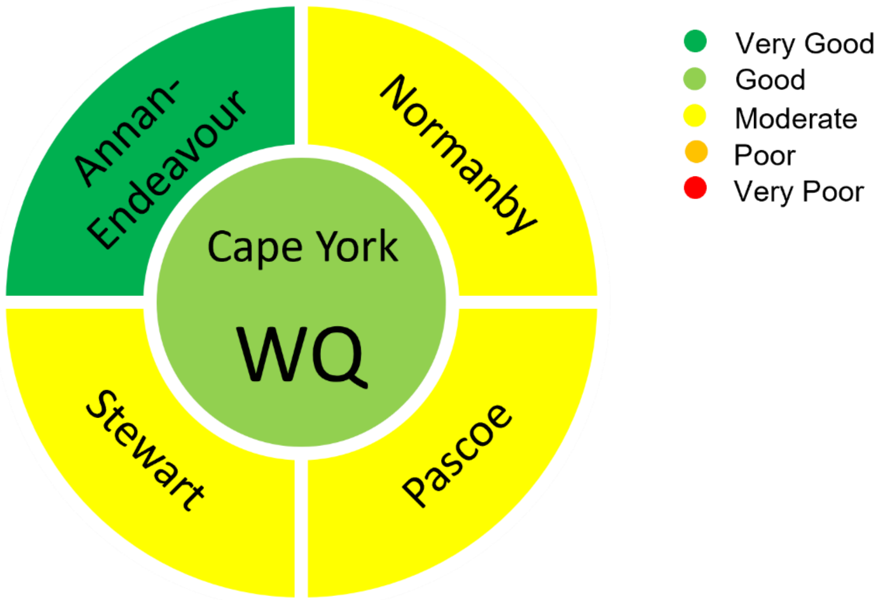


Figure 5-2: Cape York Annual WQ Index “coaster”. Calculations for Index formulations are described in Appendix B.

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 flushing and/or wind resuspension of shallow sediments.

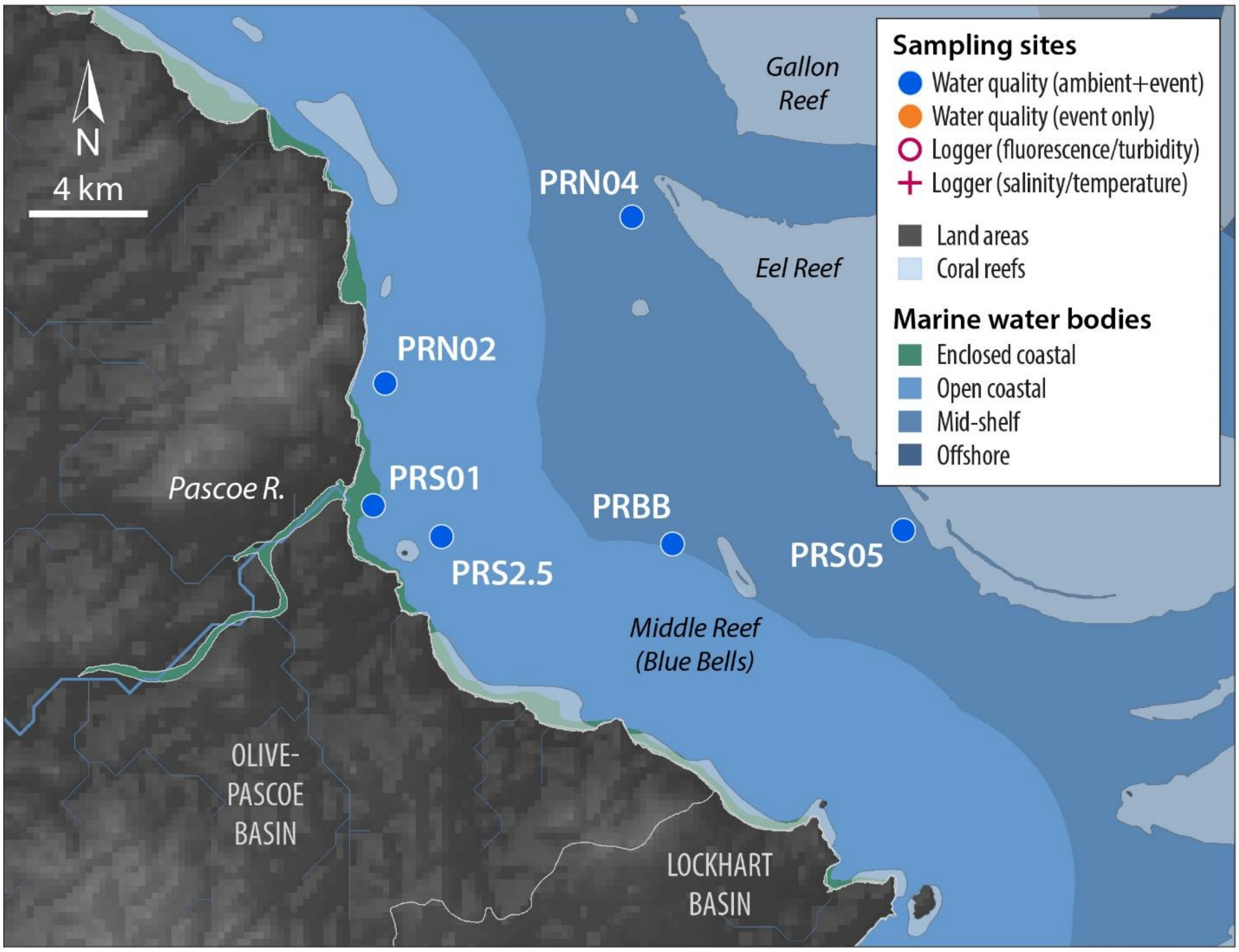


Figure 5-3: Water quality sampling sites in the Pascoe River transect with water body boundaries.

The Pascoe River transect was sampled four times under ambient wet season conditions and once under ambient dry season conditions from November 2021–May 2022 (Figure 5-4). A total of 48 surface and subsurface samples were collected. Total discharge for the year was above the annual median discharge (Figure 5-5), with most rainfall occurring during one major flood event from 15 to 26 April (Figure 5-4). No targeted flood monitoring was conducted during the April event due to access issues. Satellite images were cloudy during the event, however a turbid plume was seen to reach over 20 km to the north on the 29 April (Figure 5-9), and TSS concentrations in the open coastal water body were above GVs during sampling in mid-May (this could have been wind re-suspension). There was also significant freshwater influence in the enclosed coastal and open coastal water bodies during regular sampling conducted in mid-March 2022 (refer also Figure 5-4).

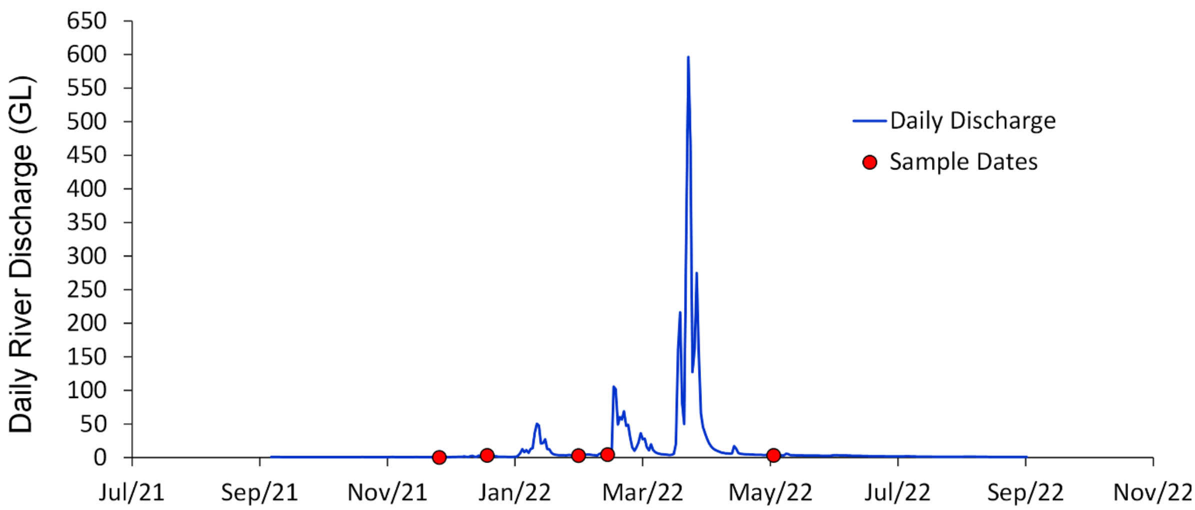


Figure 5-4: Daily discharge for the Pascoe River (gauge 102102A) for the 2021–22 water year. Red dots represent sampling dates.

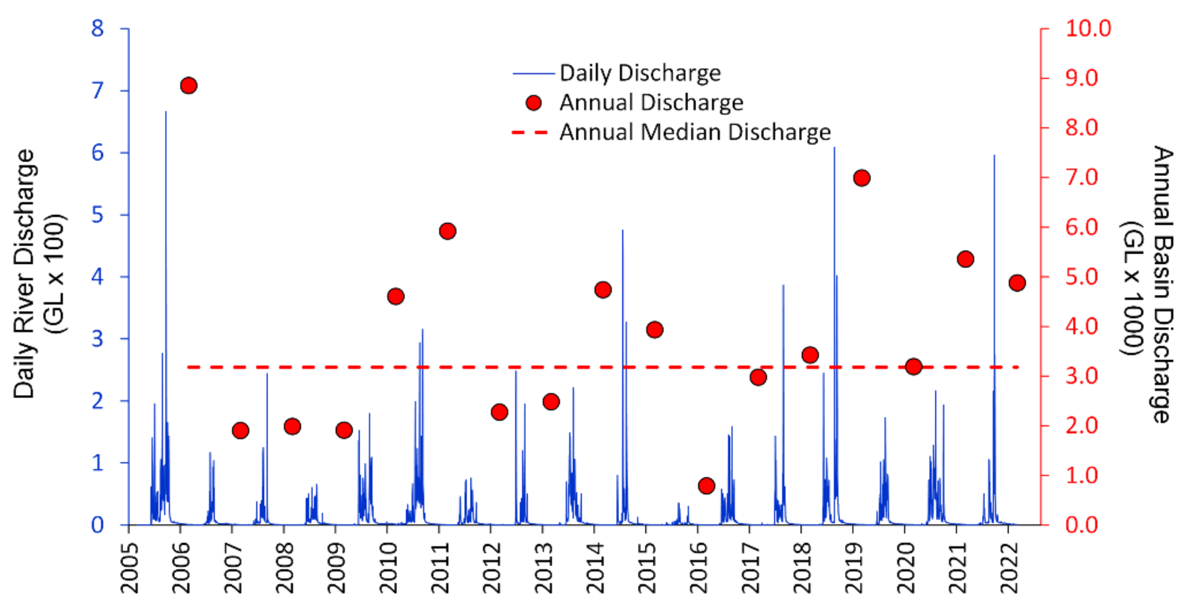


Figure 5-5: Long-term discharge for the Pascoe River (gauge 102102A). Daily (blue) and water year (October to September, red symbols) discharge volumes shown. Red dashed line represents long-term median of the combined annual discharge.

Estimated annual discharge for the Olive-Pascoe basin was 4,879 GL for the 2021–22 water year (Figure 5-5). The total discharge and modelled loads estimated for the 2021–22 water year from the Pascoe catchment (upscaled from the Garraway gauge) are shown in Figure 5-6. The discharge and loads calculated for the 2021–22 water year from the Pascoe catchment (not including the Olive catchment) were 1.8-fold above the long-term median. Over the 16-year period from 2006–07:

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

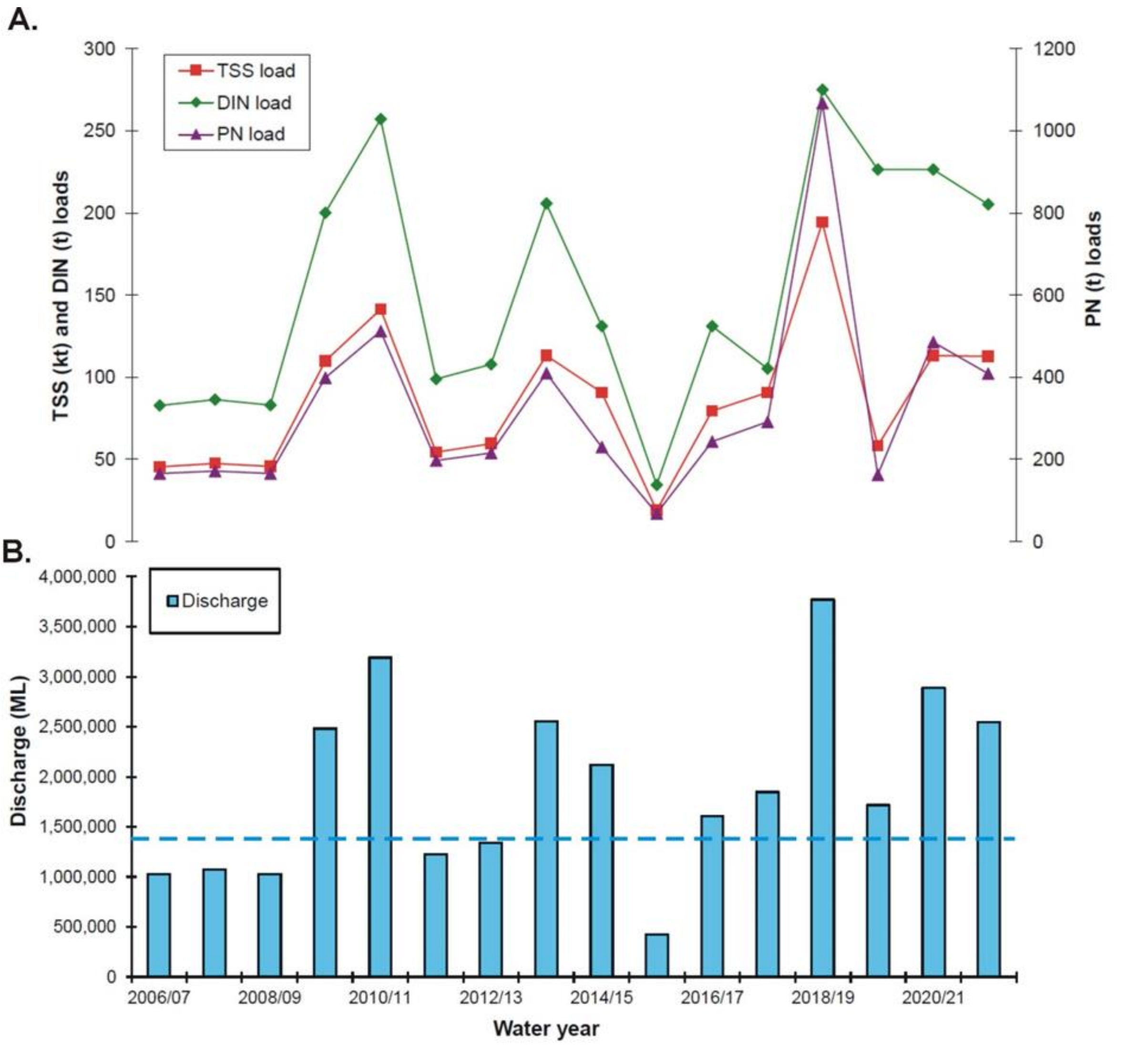


Figure 5-6: Modelled loads of (A) TSS, DIN and PN and (B) discharge for the Pascoe catchment (note Pascoe catchment only, does not include the Olive catchment) from 2006 to 2022. The loads reported here are a combination of 'best estimates' based on 'up-scaled' discharge data from gauging stations and 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

Median and mean TSS concentrations at Pascoe transect sites remained below annual, wet season and dry season GVs (Table C-8). Secchi depth was below the annual GV for the open coastal and enclosed coastal zone, however median depths increased compared to the previous monitoring year. Chl-*a* concentrations were below GVs at all sites except for PRS04, where elevated concentrations in sub-surface samples (0.6 to 0.8 µg L^{-1}) caused the median (0.4 µg L^{-1}) to exceed the annual GV (0.27 µg L^{-1}). There were no other Chl-*a* GV exceedances, and the median concentrations at all sites declined compared to previous years (Moran et al. 2022). There were some exceedances of GVs for particulate and dissolved inorganic nutrients in the open coastal and mid-shelf water bodies (Appendix C Table C-1) contributing to a 'moderate' annual Water Quality Index score (Figure 5-8). However, median concentrations of these parameters also declined compared to previous year. The improved water quality conditions may be due to the relatively low discharge up until mid-April (Figure 5-4).

There was some freshwater influence in the enclosed and open coastal water bodies (salinity ranging from 18 to 26) during the 15 March 2021 regular sampling event, associated with slightly elevated TSS (7.6 mg L^{-1}) and a doubling of nutrient (NO_x, DOC, POC, PN, PP, Si) concentrations compared to the rest of the ambient samples. Low salinity and higher concentrations close to the river mouth are common along the Pascoe transect in the wet season, and the concentrations measured were below the GVs for the enclosed coastal water body.

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

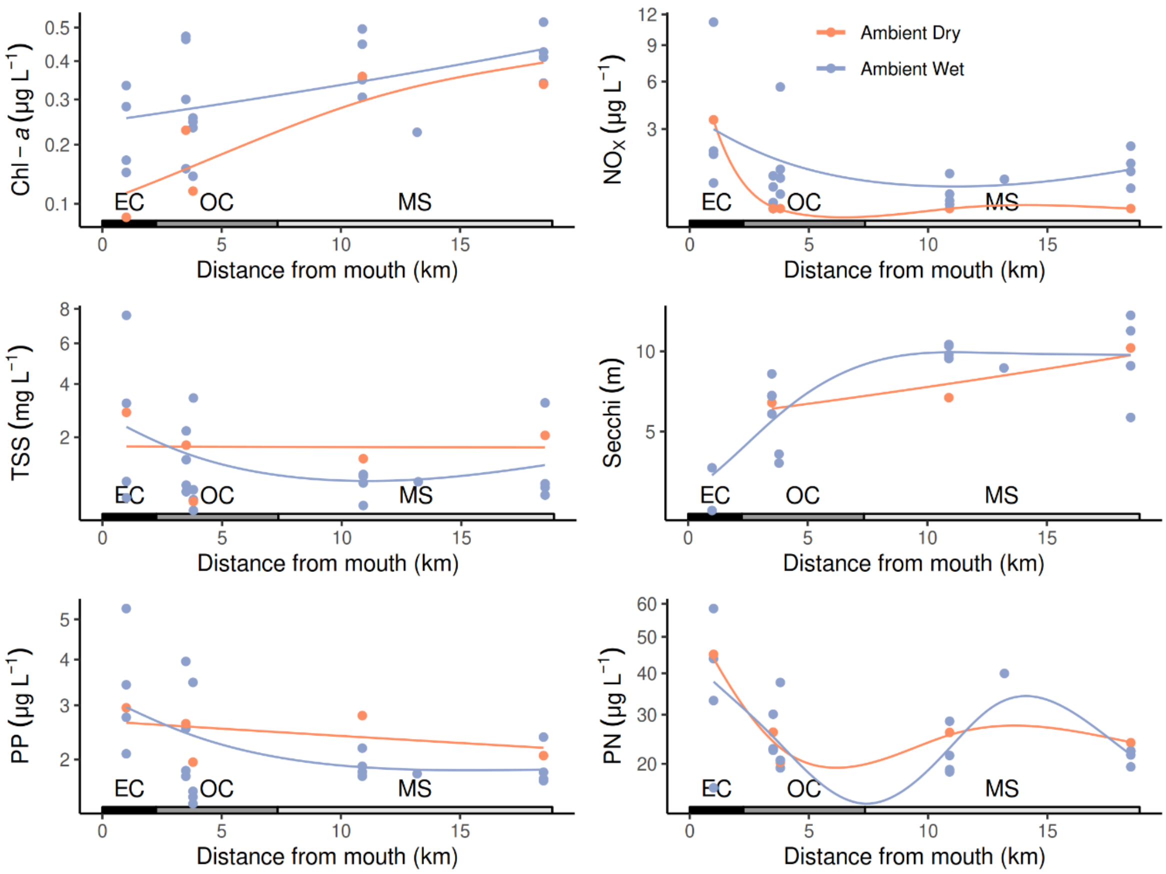


Figure 5-7: Water quality concentrations (surface and subsurface samples) and Secchi depth over distance (km) from river mouth for the Pascoe River focus region (all 2021–22 samples). Water body classifications are shown along the x-axes: enclosed coastal (EC), open coastal (OC) and mid-shelf (MS). Note the y-axes are logarithmic scales. Fitted lines are generalised additive models.

Comparison of the 2021–22 ambient results with previous years and the GVs (Table C-1) highlights that:

- Overall, the Pascoe annual Water Quality Index score was ‘moderate’, which was the same as the previous year (Figure 5-8).
- The productivity sub-indicator improved, from ‘poor’ in 2020–21 to ‘moderate’ in 2021–22, reflecting reduced NO_x and Chl-*a* concentrations.

- Median and mean TSS concentrations met the annual wet season GVs at all sites. This is reflected in the ‘good’ annual Water Quality Index score shown for clarity.
- Mean Secchi depths were less than the annual GV (≥10 m), except site PRS05 (mid-shelf water body). However, most samples were collected during the wet season, therefore may not be representative of annual means.
- NO_x concentrations exceeded the GVs at all Pascoe transect sites and across water bodies. This is consistent with previous years.

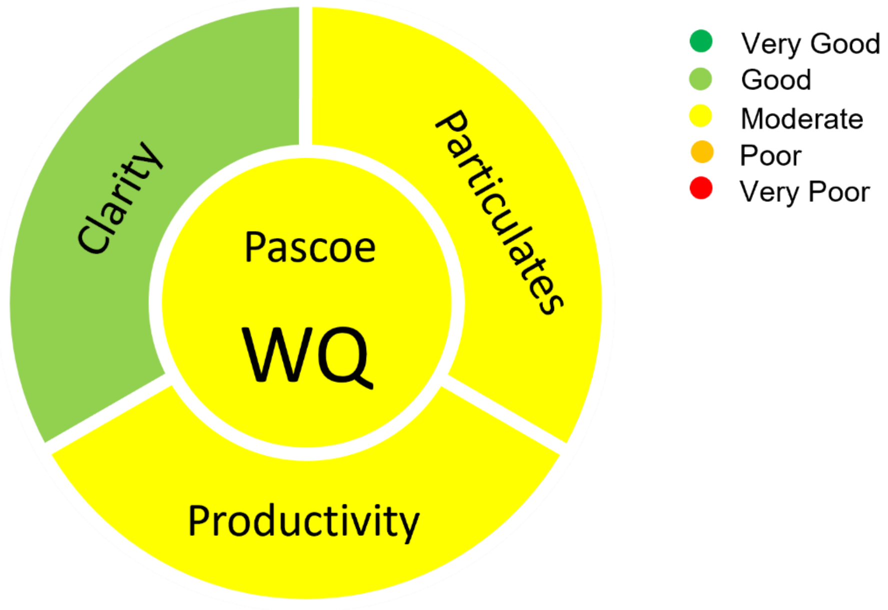


Figure 5-8: Pascoe Annual WQ Index “coaster”. Calculations for Index formulations are described in Appendix B.

Event water quality

Most rainfall for the Pascoe region in 2021–22 occurred during one major flood event from 15 to 26 April (Figure 5-4). No targeted flood monitoring was conducted during this event due to access issues. Satellite images were cloudy during the event; however, a turbid plume was seen to reach over 20 km to the north on 29 April (Figure 5-9)

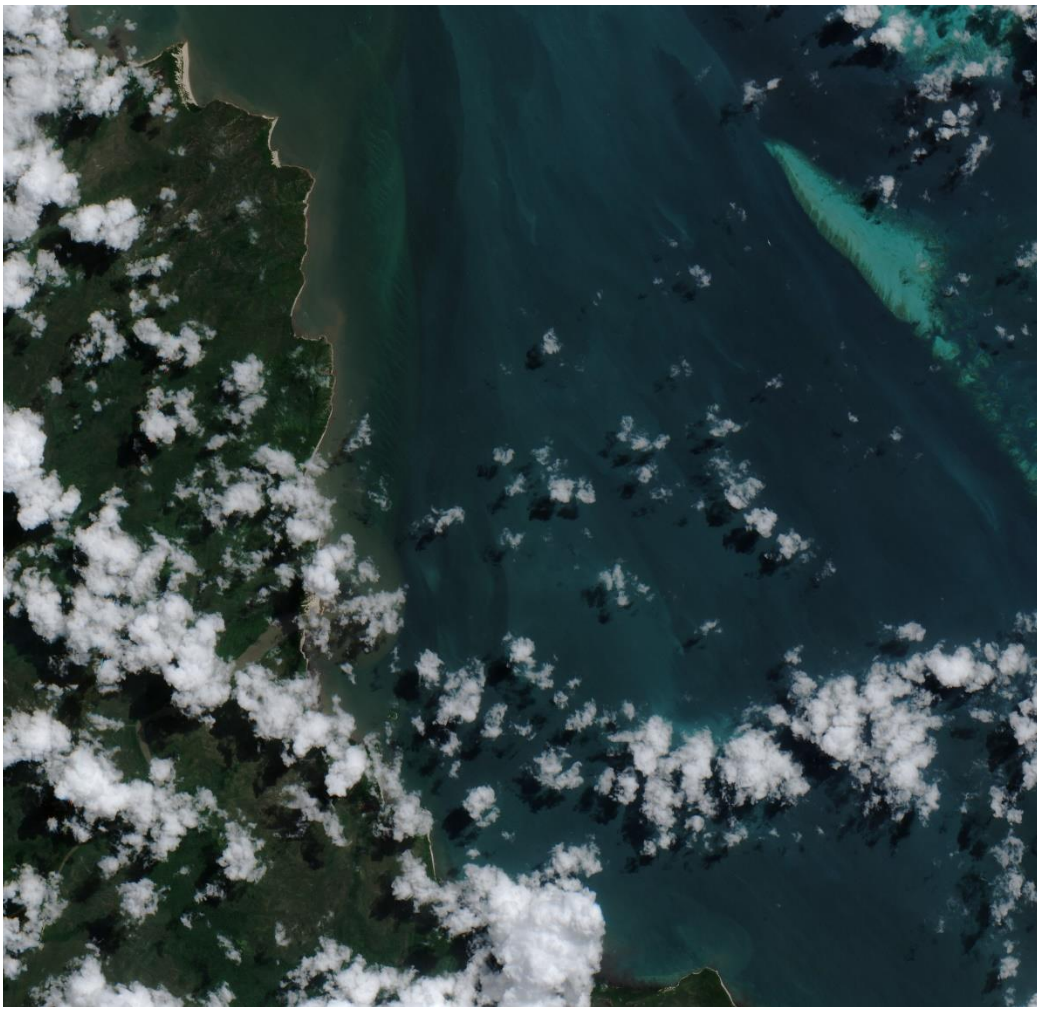


Figure 5-9: Sentinel-2 true colour image showing flooding from the Pascoe River on 29 April 2022. Source: Sentinel Hub EO Browser, extracted by Dr Caroline Petus, JCU TropWater.

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 run-off 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 (surface and subsurface) was sampled four times (three times during ambient wet conditions and once during ambient dry conditions) between December 2021 and May 2022 (Appendix A Table A-1). The fifth scheduled ambient sampling event for 2022 did not occur as the scheduled ambient samples from February 2022 were changed to event samples due to flood influences from the Normanby River. Supplementary samples were unable to be collected due to logistical constraints (weather and boat availability). Although there were no major flood events in the Stewart River over the 2021–22 wet season, there was significant freshwater influence identified from flooding in the nearby Normanby River system in February 2022 (also see event monitoring details in section 5.1.3).

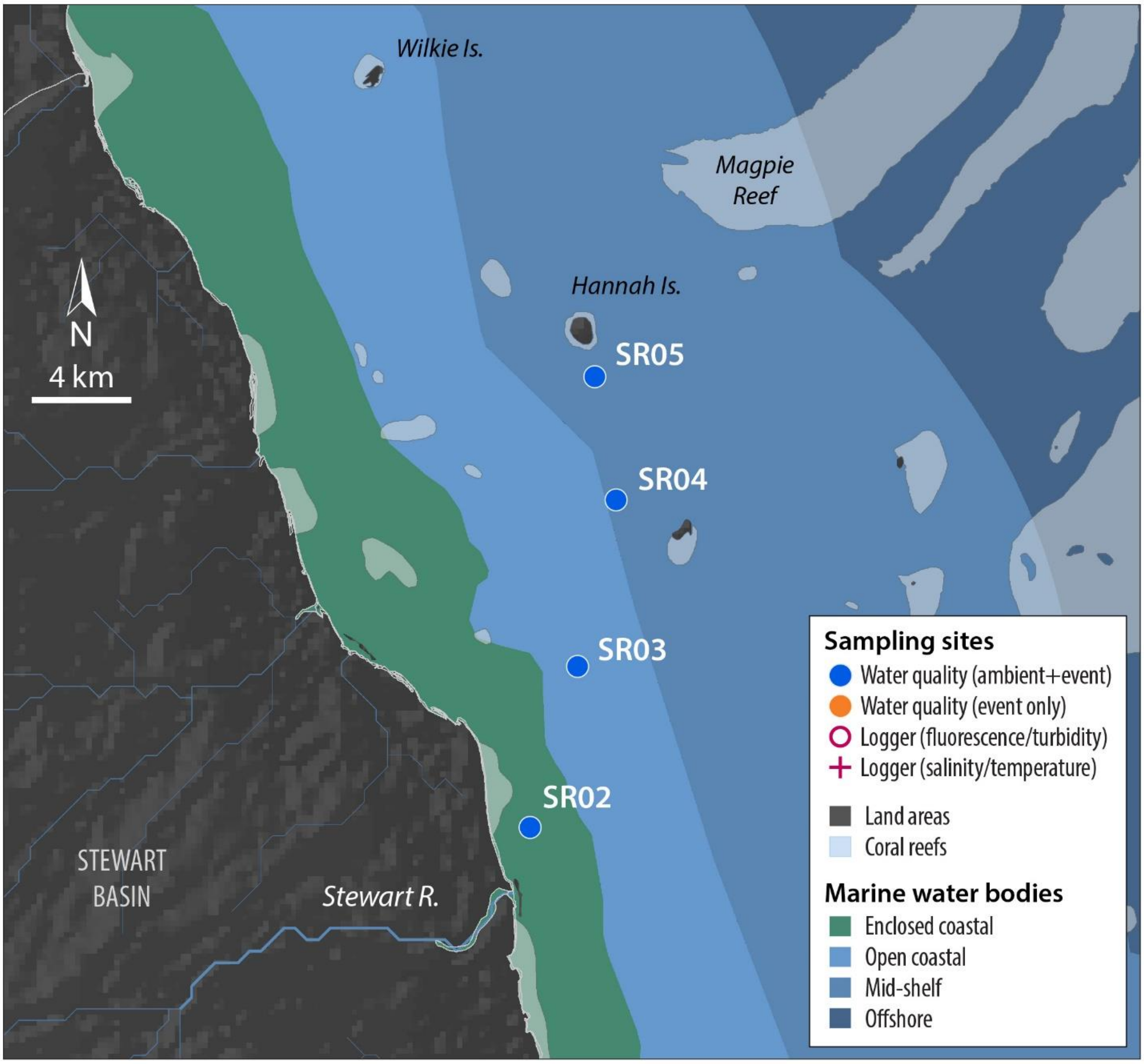


Figure 5-10: Water quality sampling sites in the Stewart River transect with water body boundaries.

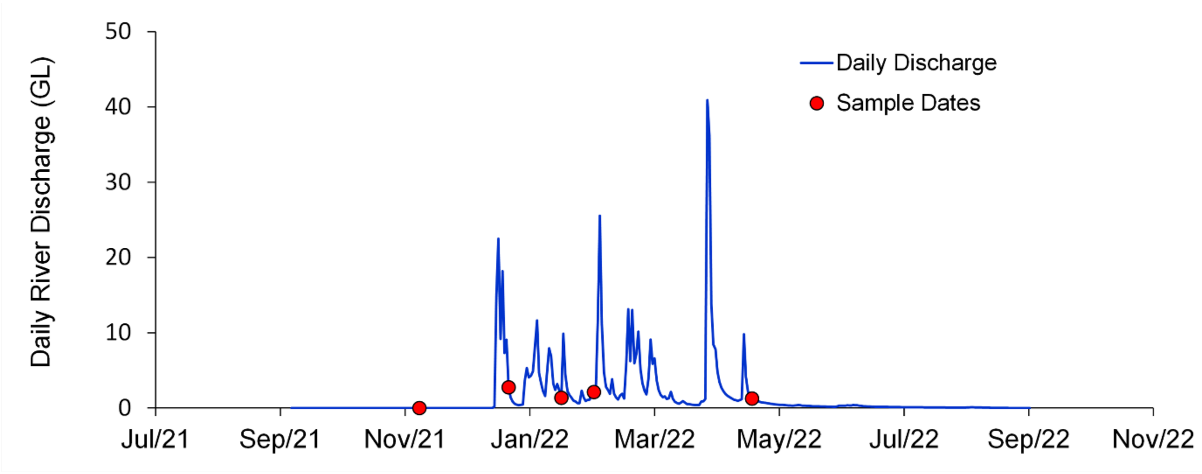


Figure 5-11: Daily discharge and sampling dates for the Stewart River (gauge 104001A) for the 2021–22 wet season.

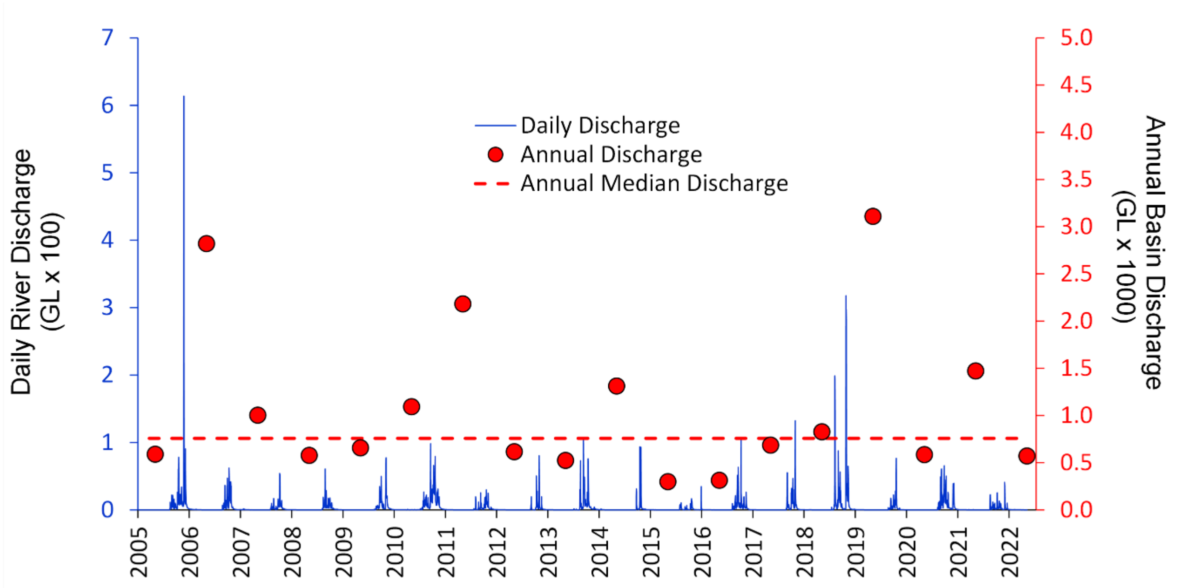


Figure 5-12: Long-term discharge for the Stewart River (gauge 104001A). Daily (blue) and water year (October to September, red circles) discharge volumes shown. Red dashed line represents long-term median annual discharge.

The total annual discharge for 2021–22 water year is estimated at 570 GL based on the measurements from the Upper Stewart River gauge 104001A (Figure 5-12) corrected for catchment area. The combined discharge and modelled loads estimated for the 2021–22 water year from the Stewart Basin are shown in Figure 5-13. The discharge and loads calculated for the 2021–22 water year from the Stewart Basin were just below (0.8 times) the long-term median. Over the 16-year period from 2006–07:

- Discharge has varied 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)
- PN loads ranged from 40 t (2014–15) to 420 t (2018–19).

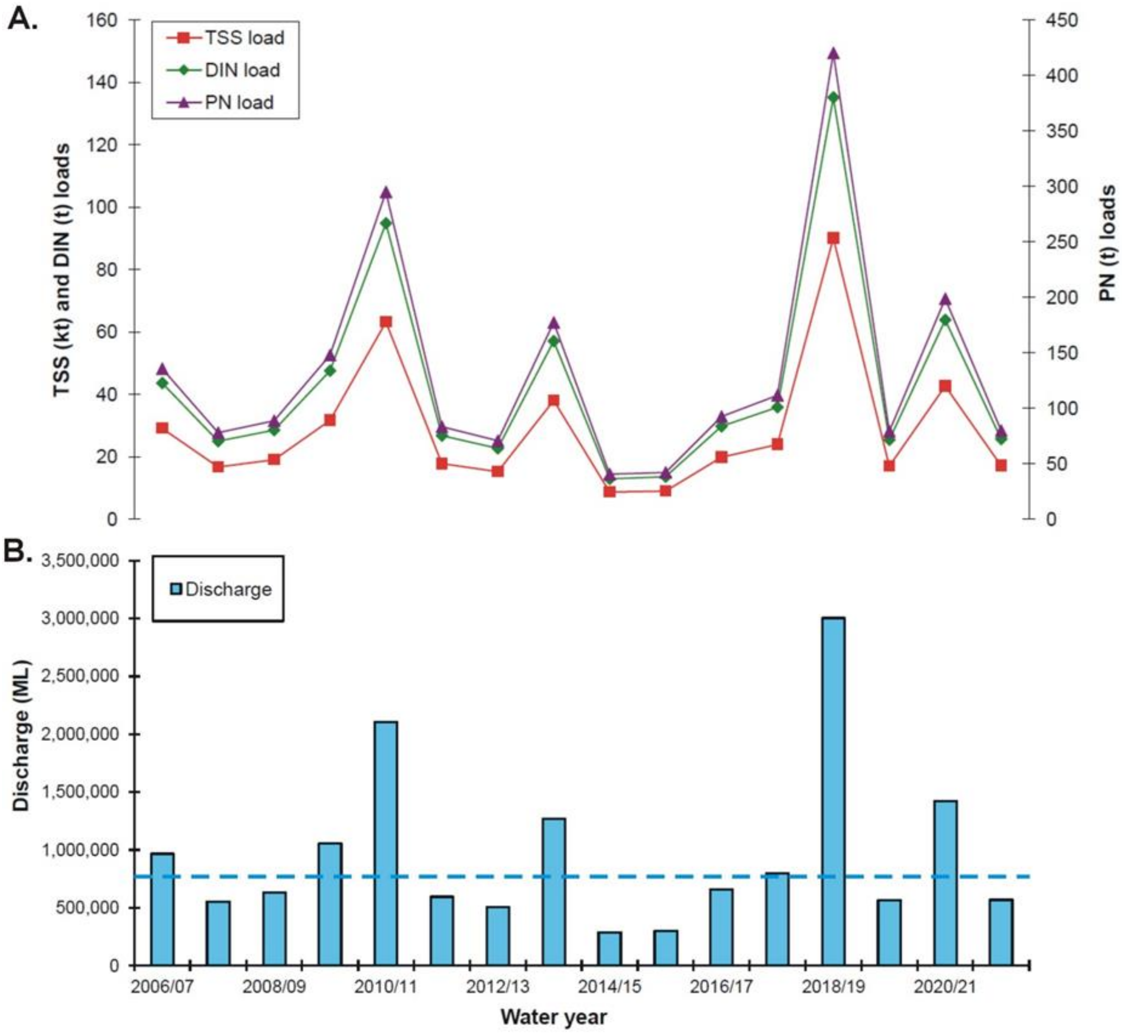


Figure 5-13. Loads of (A) TSS, DIN and PN, and (B) discharge for the Stewart Basin from 2006 to 2022. The loads reported here are based on the best estimates of annual mean concentration informed by nearest neighbour monitoring and by the Source Catchments modelling data and applied to each water year. 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 in Table C-8.

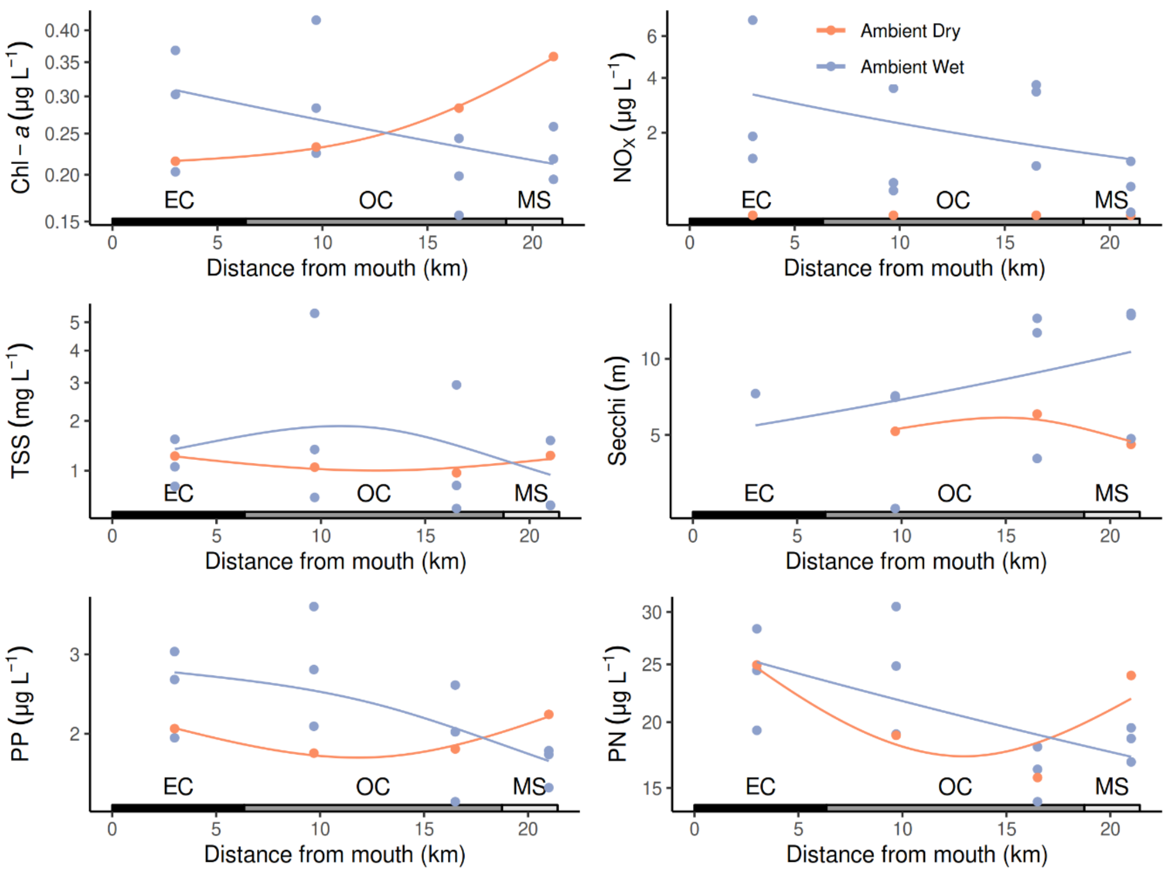


Figure 5-14 Water quality concentrations (all surface and subsurface samples for the 2021–22 season) and Secchi depth over distance (km) from river mouth for the Stewart River focus region, during ambient conditions in the wet season (red circles) and dry season (blue circles). Water body classifications 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 2021–22 ambient results with previous years and the water quality GVs (noting that the 4 sampling trips may not be representative of annual conditions) (Table C-1) highlights that:

- The annual Water Quality Index for the Stewart region scored ‘moderate’ overall, with a ‘moderate’ score for the productivity sub-indicator and ‘good’ scores for clarity and particulate sub-indicators (Figure 5-15).
- Median TSS concentrations met both the annual and wet season GVs at all sites, contributing to the ‘good’ score for clarity.
- Mean Secchi depth was just below the annual GV (>10 m) at open coastal or mid-shelf sites; depths increased compared to the previous year, potentially due to significantly lower 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 at all sites, contributing to the ‘moderate’ score for productivity. This is similar to the previous year.
- Median PO_4 concentrations met both the annual and wet season GVs at all sites.
- Median PP concentrations were below the annual GVs at all sites.
- Median PN concentrations were generally at or below the annual GVs.
- At Hannah Reef (SR05), most concentrations were below or at the GVs, with the exception of NO_x. This improved over previous year when most were above GVs.

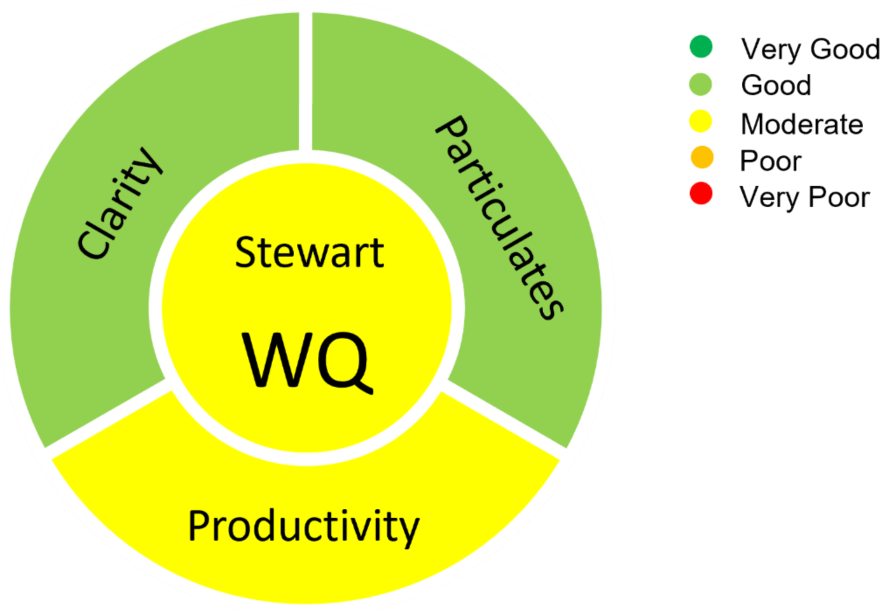


Figure 5-15: Stewart Annual WQ Index “coaster”. Calculations for Index formulations are described in Appendix B.

Event water quality

The 2021–22 wet season was characterised by low river discharge compared with the previous year, and there were no major flood events. However, there was some freshwater influence in the enclosed coastal zone (salinity 23 to 30) during the February 2022 sampling period, when there was rising discharge in the Stewart River and a major flood in the Normanby Basin. Satellite images from the 10 and 12 February 2022 (Figure 5-22) show the flood plume from the Kennedy River flowing north to join flood water from coastal creeks and the Stewart River, influencing the Stewart transect samples collected on that date. These samples have not been included in the calculations for ambient water quality statistics and comparisons against GVs.

Despite the presence of turbid water across the Stewart transect area during the 11 February sampling event (Figure 5-22), samples collected that day showed that TSS remained low (<2 mg L^{-1}) across the transect. Elevated Chl-*a* concentrations (exceeding GVs) were measured only in the mid-shelf waterbody samples, while NO_x and PO_4 concentrations also remained relatively low. DOC concentrations were elevated above ambient concentrations in the enclosed coastal and open coastal zone due to flood plume influence.

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 open coastal waters and Corbett Reef (Figure 5-16). Site CI01 is located near the 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.

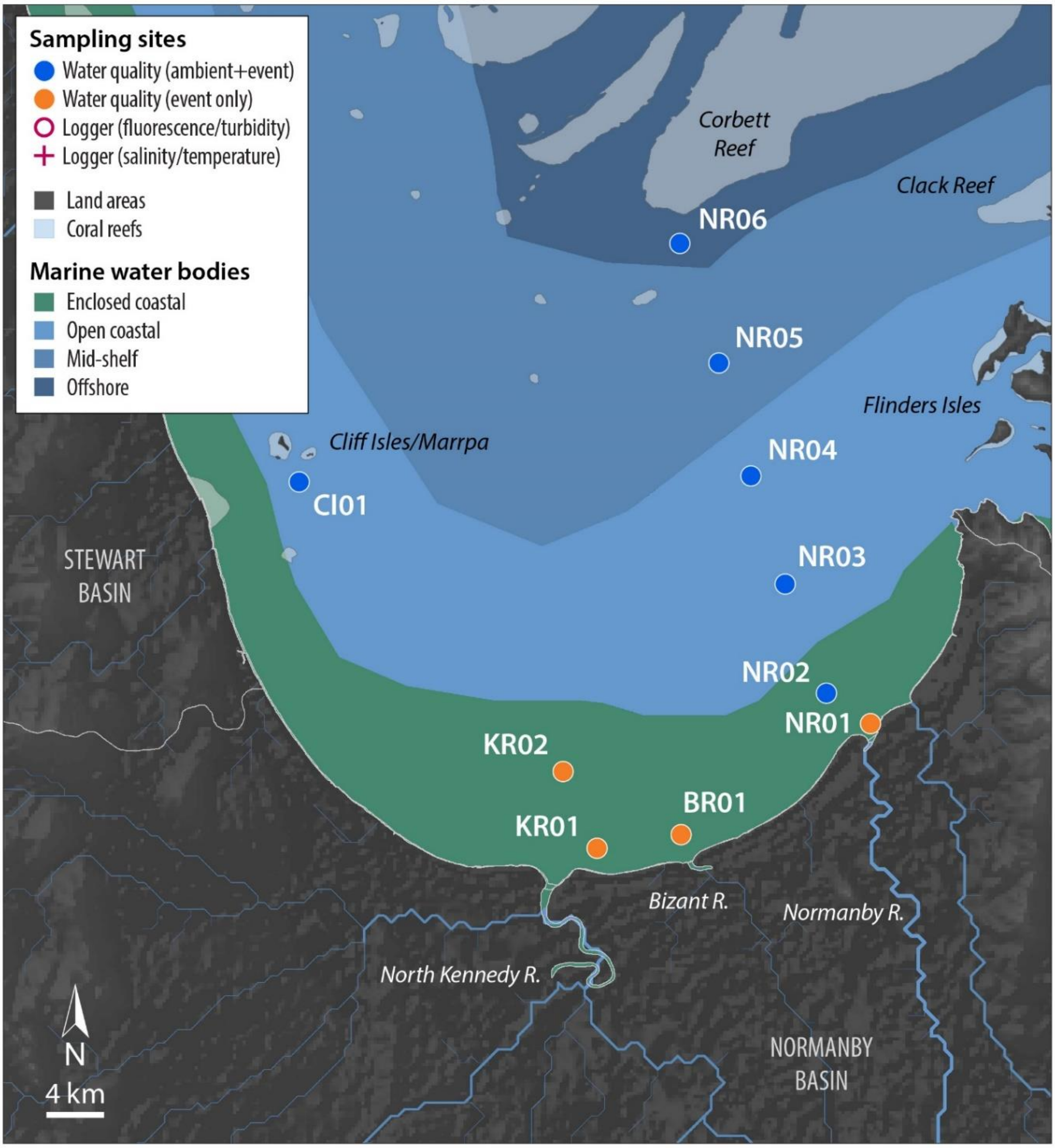


Figure 5-16: Water quality sampling sites in the Normanby Basin focus area with water body boundaries.

The Normanby transect was sampled four times (three times during ambient wet conditions and one time during ambient dry conditions) from December 2021 to May 2022 (Figure 5-17). Event samples were collected from throughout the Normanby transect in February 2022 and sites at the mouth of the Kennedy and Normanby Rivers in March 2022. Floodwaters from the February flooding event also influenced inshore samples within the Stewart transect. Ambient samples collected on the Stewart transect at this time were retrospectively classified as event monitoring (see Section 5.1.2). Long-term discharge is shown in Figure 5-18.

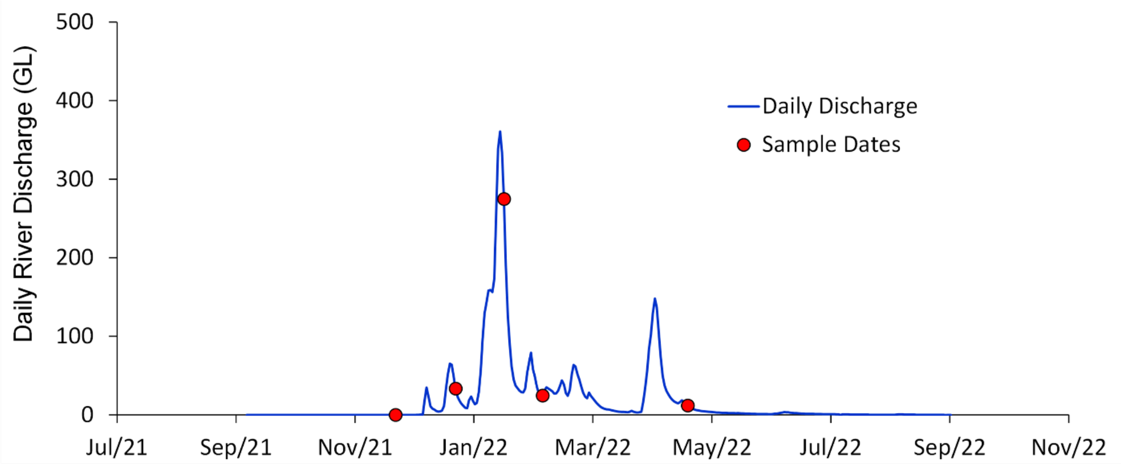


Figure 5-17: Daily discharge and sampling dates for the Normanby River (gauge 105107A) for the 2021–22 wet season. Note there is a 2 to 3-day travel time between the gauge and coastal waters, and thus the February event samples were collected earlier in the rising flood stage than shown on the hydrograph.

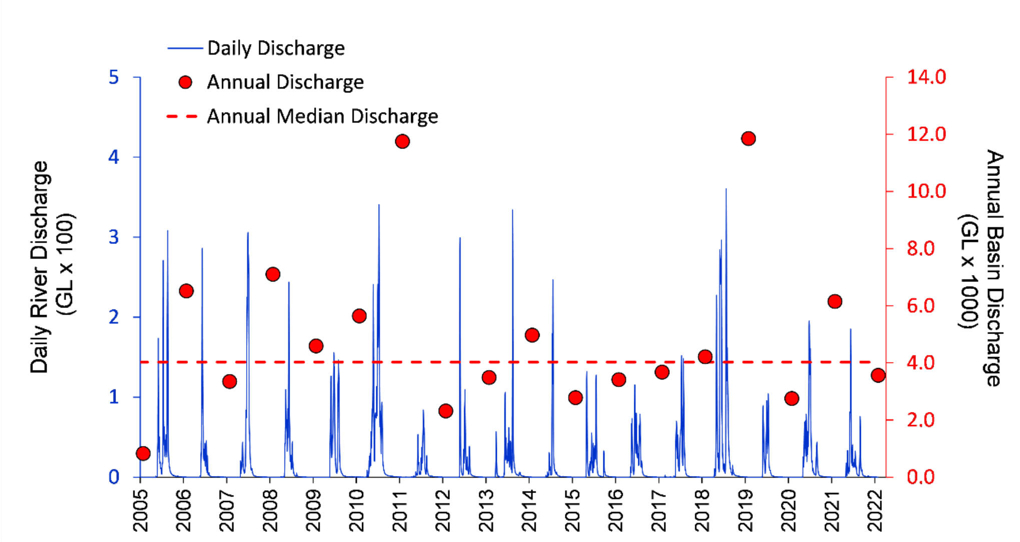


Figure 5-18: Long-term discharge for the Normanby River at gauge 105107A (Kalpowar Crossing). Daily (blue) and water year (October to September, red symbols) discharge volumes shown. Method for estimation is described in Table 2-3.

The discharge and modelled load estimates (Source Catchments) for the 2021–22 water year from the Normanby Basin were very close to the long-term median. Over the 16-year period from 2006–07:

- Discharge has varied from 2,314 GL (2011–12) to 11,852 GL (2018–19)
- TSS loads ranged from 55 kt (2014–15) to 401 kt (2007–08)
- DIN loads ranged from 42 t (2011–12) to 266 t (2010–11 and 2017–18)
- PN loads ranged from 124 t (2009–10) to 2,470 t (2018–19).

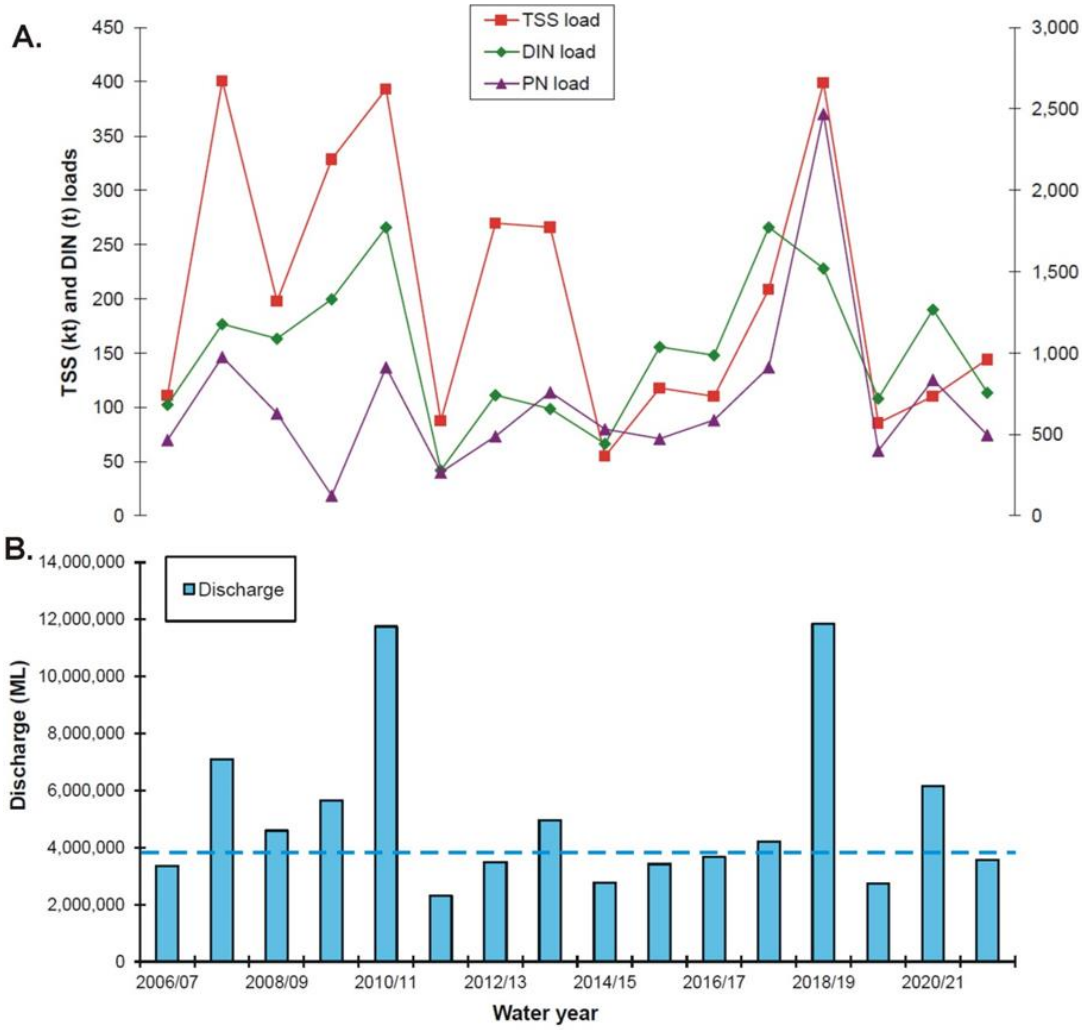


Figure 5-19: Modelled loads of (A) total suspended solids, dissolved inorganic (DIN) and particulate nitrogen (PN) and (B) discharge for the Normanby Basin. The loads reported here are a combination of 'best estimates' based on 'up-scaled' discharge and monitoring data from the Normanby River at Kalpowar 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

The Normanby results include three sampling events during the wet season and one during the dry season. Event sampling was also conducted in February and March (Figure 5-17). 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 GV for each water body in Table C-1.

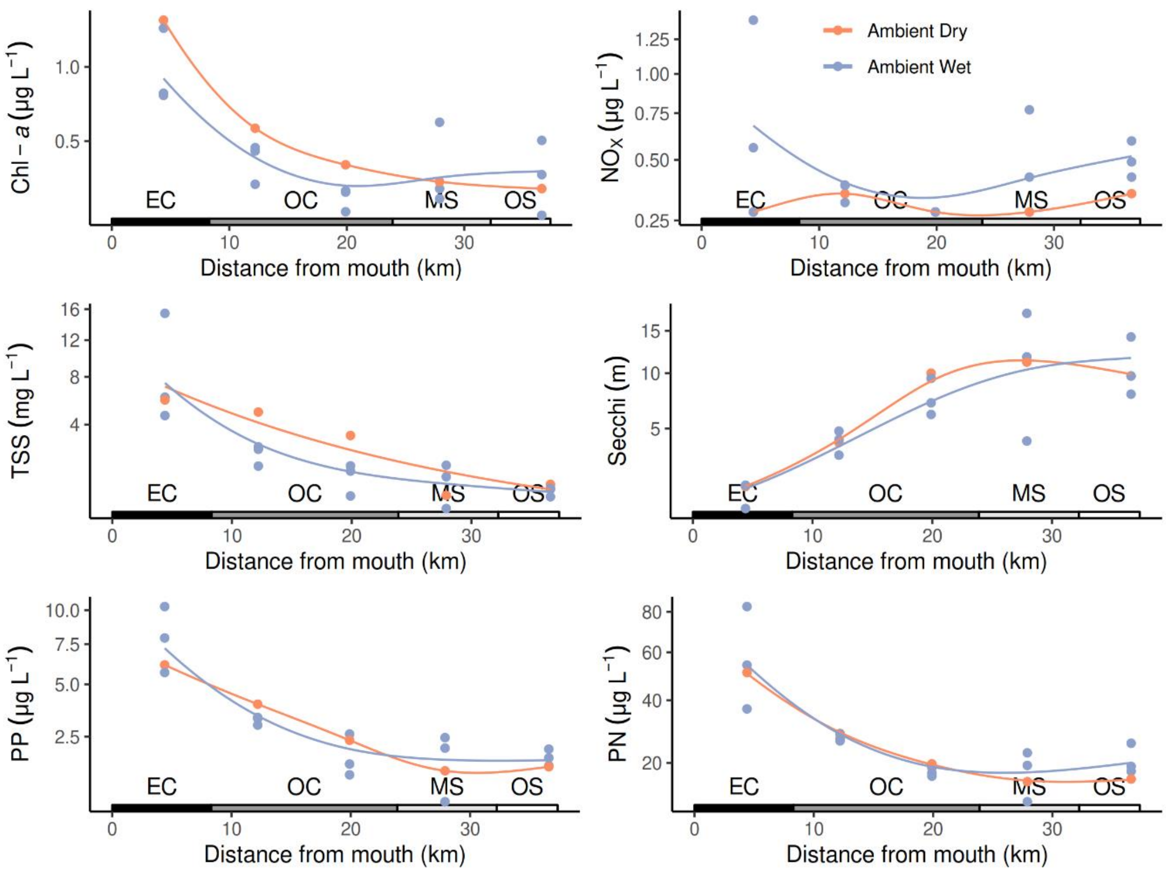


Figure 5-20: Water quality concentrations (surface and subsurface) and Secchi depth over distance (km) from river mouth for the Normanby focus region, all 2021–22 sampling dates. Water body classifications are shown along the x-axes: enclosed coastal (EC), open coastal (OC), and mid-shelf (MS). Note the y-axes are logarithmic scales. Fitted lines are generalised additive models.

Comparison of the 2021–22 ambient results with previous years and the GVs (Table C-8) highlights that:

- Overall, the annual Water Quality Index for the Normanby scored ‘moderate’, with a ‘poor’ score for the water clarity sub-indicator due to TSS and Secchi depth results and a ‘good’ result for productivity, associated with low NO_x and Chl-*a* concentrations (Figure 5-21).
- TSS met the GVs at most sites but exceeded the annual and wet season GVs at Corbett Reef (NR06) and NR03 respectively. This was an improvement from the previous year, when TSS exceeded the GVs at all sites except for NR02.
- Mean Secchi depths did not meet the minimum GVs for most sites, similar to the previous year. This contributed to the ‘poor’ score for clarity. Note that Secchi depth GVs are based on annual medians, while most Normanby samples are collected during the wet season.
- Median NO_x and PO_4 concentrations met the annual and wet season GVs at all enclosed coastal, open coastal and mid-shelf sites, but exceeded the annual GV at Corbett Reef (NR06) in the offshore waterbody. Median concentrations decreased compared to the previous wet season, with the lower concentrations contributing to the ‘good’ score for productivity.
- Median Chl-*a* concentrations met the wet season GVs in the open coastal waterbody, but slightly exceeded the annual GVs at the mid-shelf and offshore sites and exceeded the wet season GV at the enclosed coastal waterbody.

- Median PP concentrations were below the wet season and annual GVs at all sites except NR03. Median PN concentration exceeded the wet season and annual GVs at three sites. These mixed PN and PP results contributed to a 'moderate' score for the particulate sub-indicator.

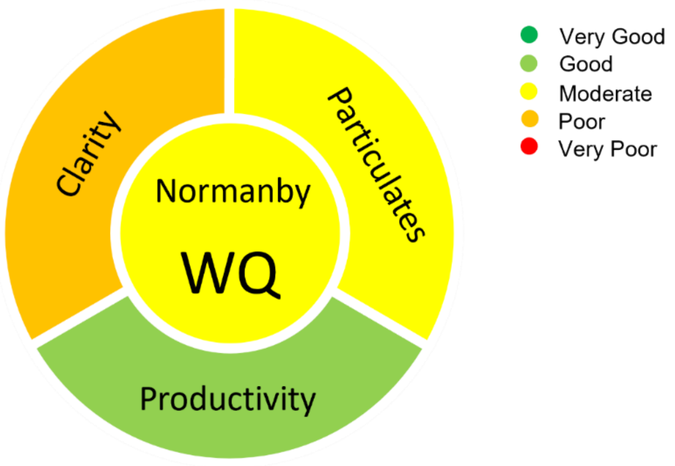


Figure 5-21: Normanby Annual WQ Index "coaster". Calculations for Index formulations are described in Appendix B.

Event water quality

Sampling conducted on 11 and 12 February 2022 coincided with the largest freshwater discharge event of the 2021–22 wet season. Total discharge was approximately 870 GL at Kalpowar Crossing gauge 105107A (Normanby distributary only), which is a below average event for the Normanby River. The Normanby Basin flood plume, combined with flood water from the Stewart River and other coastal inlets, is roughly estimated to have inundated over 3500 km^2 based on MODIS Terra and Aqua satellite images from 10 February to 12 February (Figure 5-22). The timing for sampling was approximately when peak discharge was likely to have reached Princess Charlotte Bay (PCB) from the Normanby and Kennedy Rivers (2 days after peak discharge at the upstream gauge).

TSS concentrations were surprisingly low (≤10 mg L^{-1}) at the mouth of the Normanby and Bizant river mouths, and across the Normanby transect. However TSS was 87 mg L^{-1} at the mouth of the Kennedy River, suggesting that the majority of the sediment load was transported to PCB via the Kennedy distributary (at the time of sampling). Secchi depth at the Normanby mouth was 1.1 m on 11 February, compared to 0.15 m near the Kennedy mouth. Secchi disc depth increased gradually across the Normanby transect, reaching a maximum depth of 16.6 m at NR05 in the mid-shelf waterbody. To the west, where satellite images showed darker flood waters travelling north up past the Stewart River, Secchi depth stayed relatively low, with a depth of 5.1 m at Cliff Isles (CL01) in the open coastal zone. Further north, Secchi disc depth was 3.6 to 5.7 m across the Stewart River transect, increasing to 9.6 m at the northern-most site of NR05 near Hannah Island.

Nutrient concentrations across the Normanby transect were also elevated above ambient concentrations during the February flood. NO_x ranged from 2.0 to 6.3 µg L^{-1} in the enclosed coastal waterbody and >1.0 µg L^{-1} across the open coastal and mid-shelf waterbody. In early March, NO_x concentrations across the transect (0.5 to 1.0 µg L^{-1}) remained elevated above ambient means and GVs, with sustained high discharge (but below flood levels; Figure 5-17). Correlating with lower TSS and elevated dissolved nutrients, Chl-*a* concentrations (0.74 to 1.54 µg L^{-1}) were also elevated above ambient means in the enclosed coastal and open coastal waterbodies on 11 and 12 February. In contrast, Chl-*a* concentrations remained below the wet season GVs across the rest of the Normanby transect sites, ranging from 0.10 to 0.26

µg L^{-1}. It is noted that this data only provides a quick snapshot of the plume conditions, which can change rapidly with shifting winds and currents. For example, the satellite image from 10 February showed Corbett Reef inundated by turbid plume water, while the Reef was relatively clear on 12 February (the date sampling occurred at that site), despite continued highly turbid plume water across much of the rest of PCB (Figure 5-22).

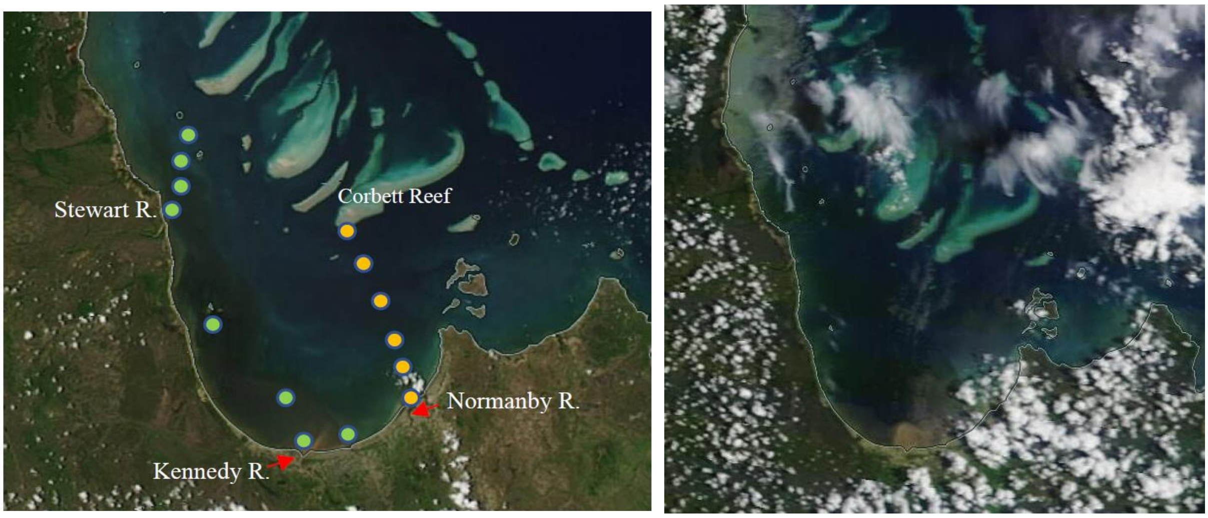


Figure 5-22: Satellite image of Kennedy and Normanby River during flooding on 10 February (left) and 12 February 2022 (right). River plumes are muddy or darker-coloured waters close to the coast. On 10 and 12 February, the flood plume can be observed as darker green-brown water along the coast from the Kennedy River past the Stewart River. Grey colouring over the reefs on 10 February indicates floodwater influence, compared to 12 February when that influence is less evident. Sampling occurred across the Stewart and Normanby transects on 11 (green dots) and 12 (orange dots) February. Red arrows denote the river mouth locations. Source: NASA MODIS Aqua & Terra.

5.1.4 Annan-Endeavour

The Annan-Endeavour focus area 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 ER02 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).

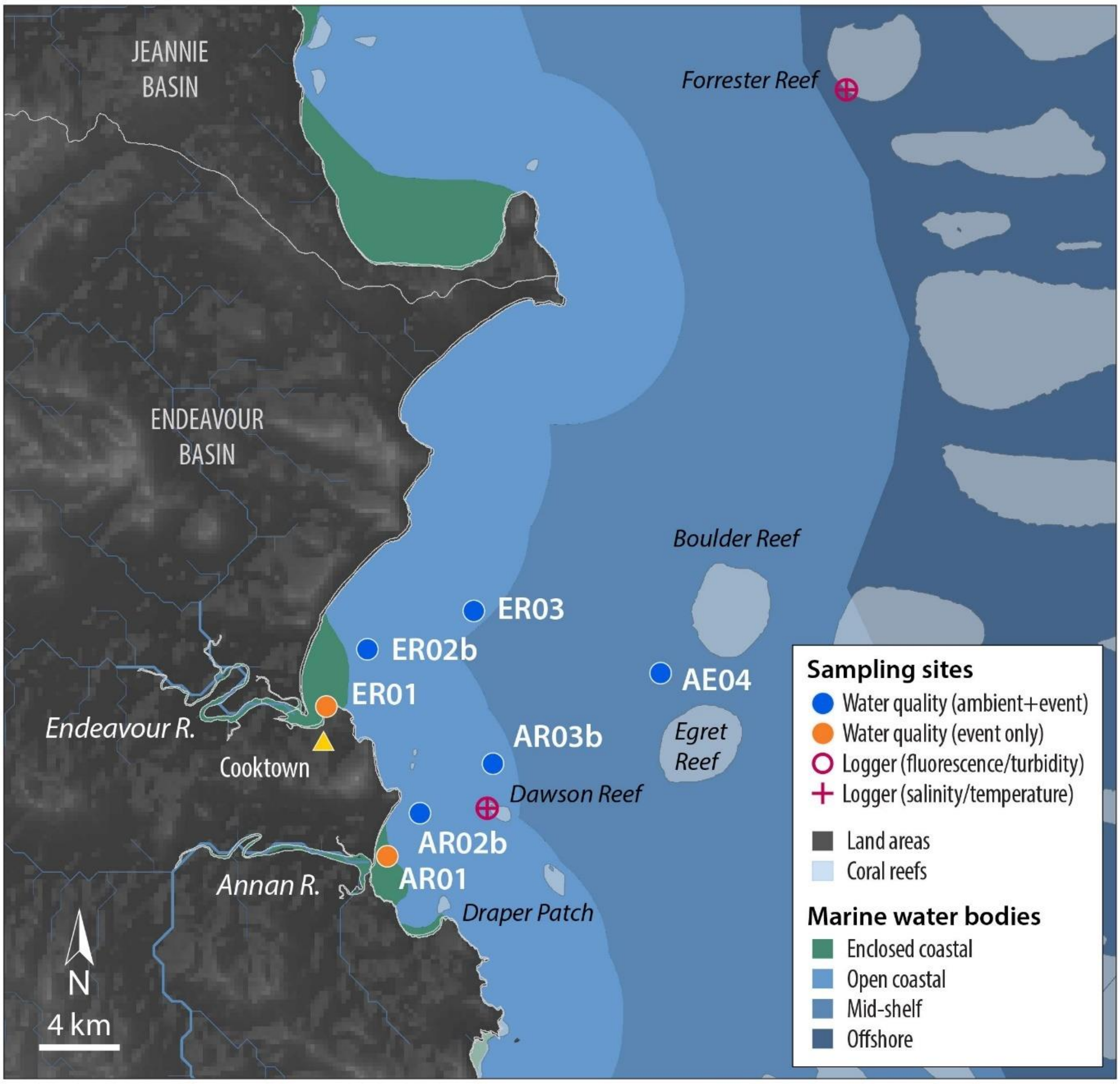


Figure 5-23: Water quality sampling sites in the Annan-Endeavour region shown with water body boundaries.

The Annan and Endeavour transect was sampled for ambient wet season conditions five times between November 2021–March 2022. Additional event samples were collected during relatively minor flood events in January and April 2022 (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 2021–22 water year was just above the long-term median (Table 3-1, Figure 5-20 and Figure 5-21). The combined discharge and modelled loads estimated for the 2021–22 water year from the Endeavour Basin are shown in Figure 5-21. Over the 16-year period from 2006–07:

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

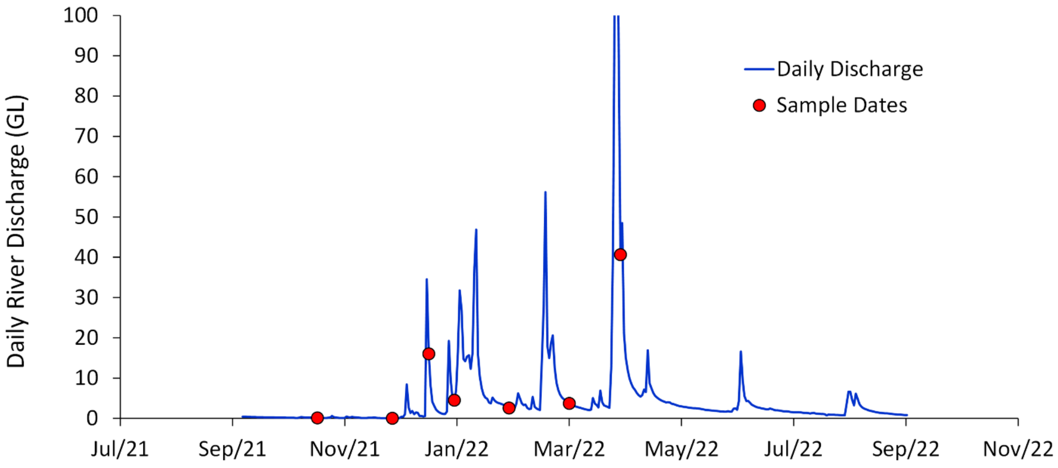


Figure 5-24: Daily discharge and sampling dates for the Endeavour Basin, combined (upscaled) values from the Annan River (gauge 107003A) and Endeavour River gauge (107001B) for the 2021–22 wet season.

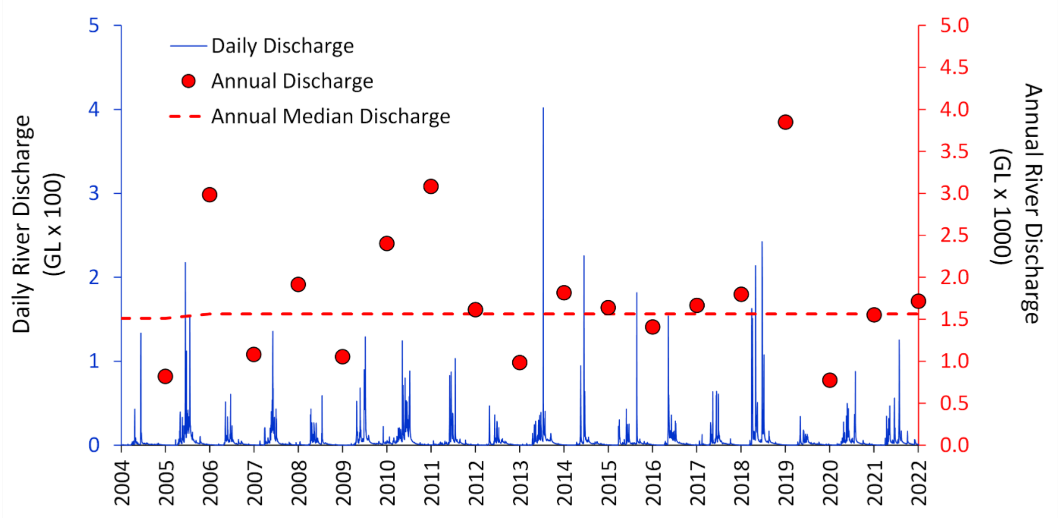


Figure 5-25: Long-term discharge for the Endeavour Basin, combined values from the Annan River (gauge 107003A) and Endeavour River (gauge 107001B). Daily (blue) and water year (October to September, red symbols) discharge volumes shown. Red dashed line represents long-term median of the combined annual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

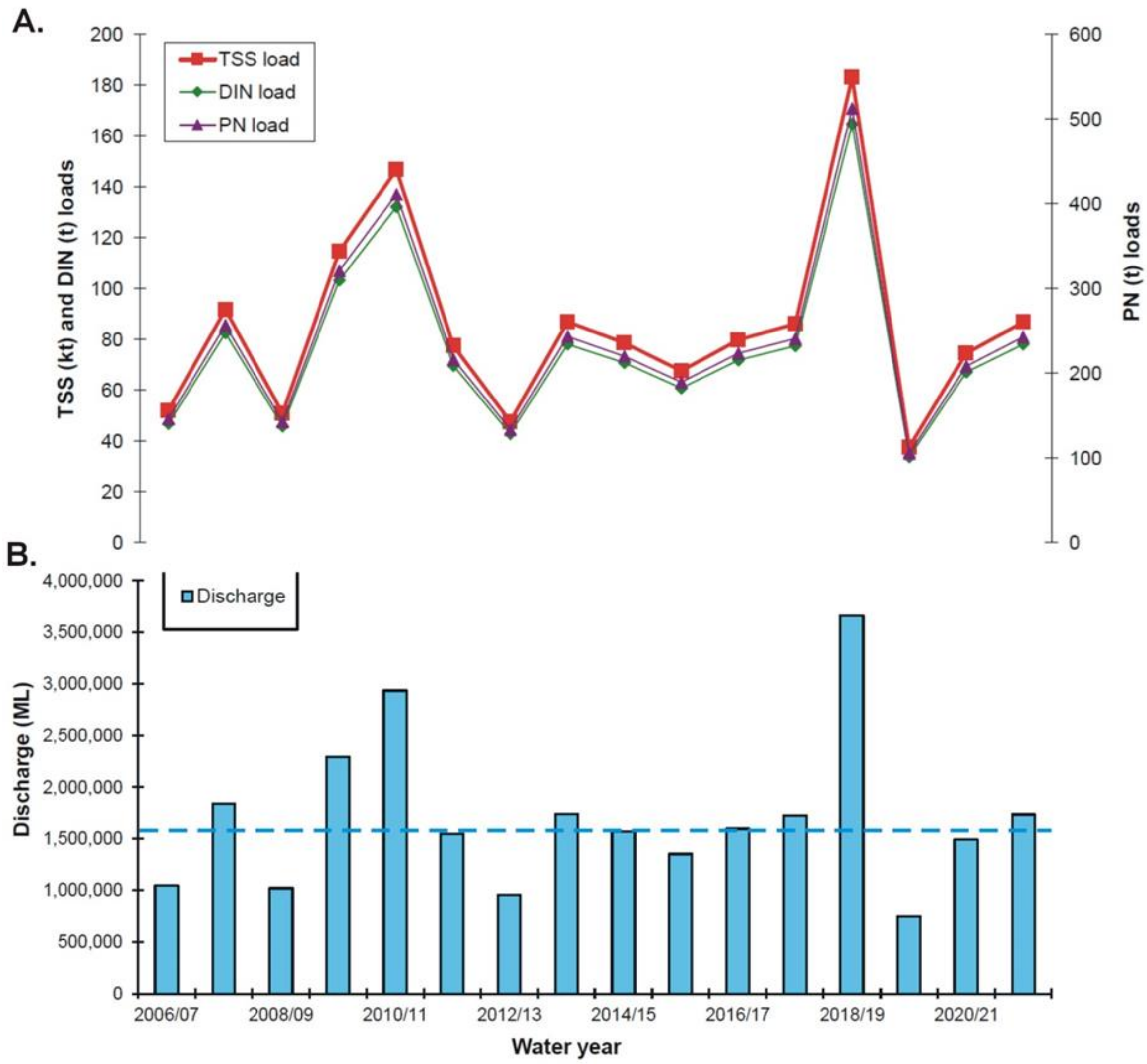


Figure 5-26. Loads of (A) total suspended solids, dissolved inorganic (DIN) and particulate nitrogen (PN) and (B) discharge for the Endeavour Basin from 2006 to 2022. The loads reported here the best estimates of annual mean concentration informed by nearest neighbour monitoring and by the Source Catchments 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

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 & Dawson Reef), mid-shelf (AE04) and offshore (Forrester Reef) water bodies in Appendix C Table C-1.

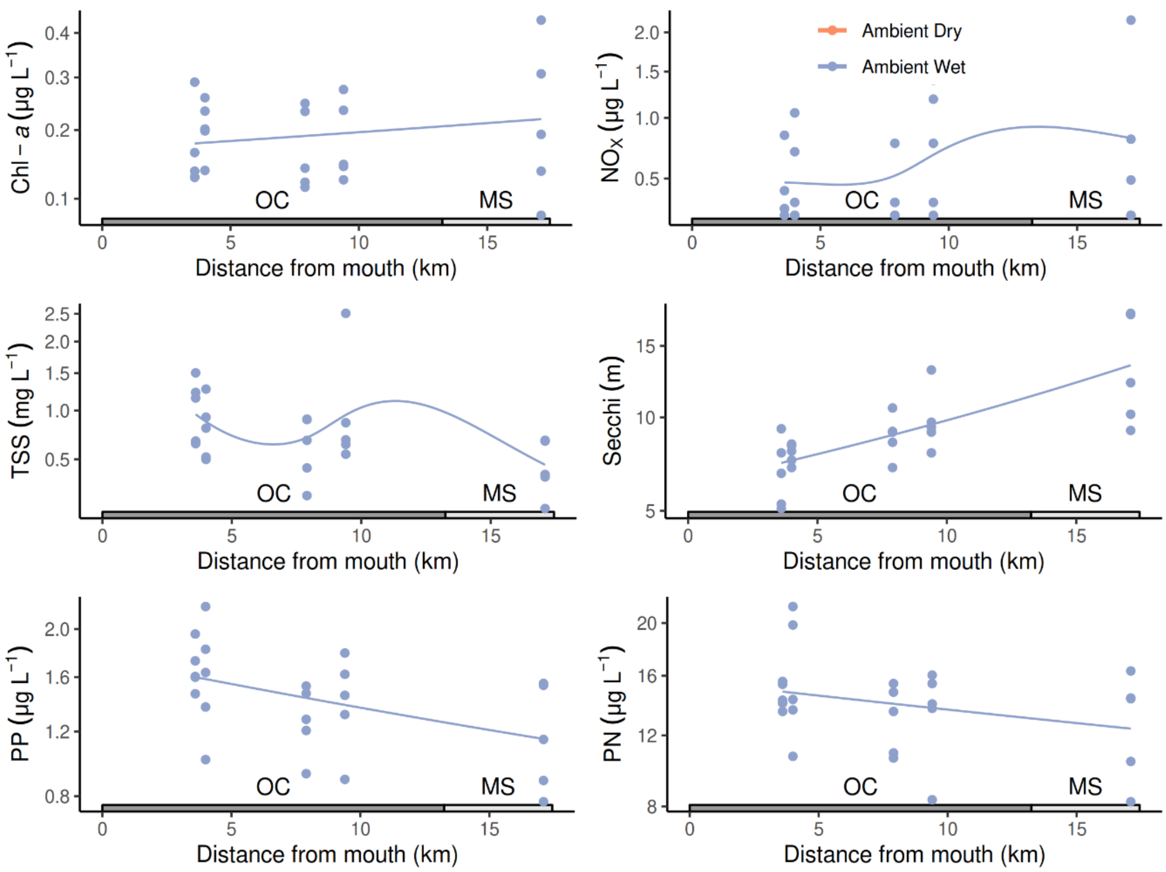


Figure 5-27: Water quality concentrations (surface and subsurface samples) and Secchi depth over distance from river mouth (km) for the Endeavour Basin focus region during ambient conditions (2021–22 water year). Note that data includes samples collected at varying distances from two river mouths (Annan 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 2021–22 ambient results with previous years and the water quality GVs (Table C-1) highlights that:

- Overall, the annual Water Quality Index scored 'very good' for the Annan-Endeavour focus region (Figure 5-28), which is an improvement from 'moderate' the previous wet season.
- The ambient monitoring for the 2021–22 water year was completed prior to the largest discharges for the water year, which occurred very late in the wet season.
- Chl-*a*, TSS, PN, PP, and PO_4 met the GVs at all sites and water bodies, contributing to the 'very good' score.
- Median NO_x concentrations were below the annual and wet season GVs at sites ER02, AR02, and AR03, but exceeded the GVs at sites ER03 (open coastal waterbody) and AE04 (mid-shelf waterbody).
- Mean Secchi depth was less than (did not meet) the annual GV at all sites, except site AE04 in the mid-shelf waterbody.
- The annual median wet season turbidity values calculated from continuous dataloggers at Dawson Reef (0.55 NTU) and Forrester Reef (0.29 NTU) were less than the respective GVs (0.8 and 0.5 NTU) for the open coastal and offshore waterbodies

(Figure 5-29). Median turbidity at both reefs remained similar to those measured over the 2019–20 wet season (Table C-2).

- Median Chl-*a* concentrations at Dawson & Forrester were also below the GVs.

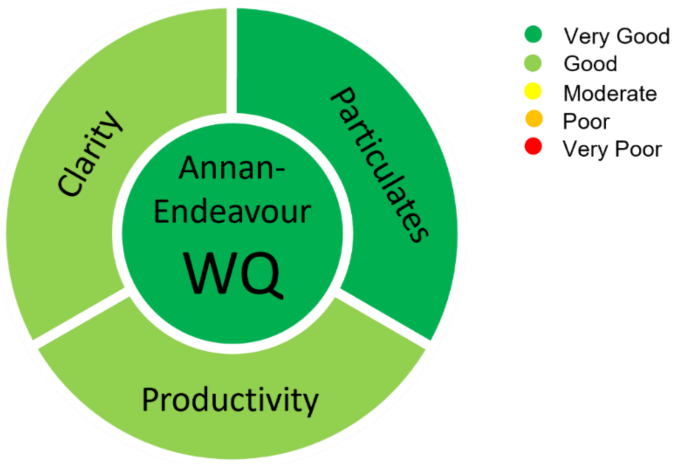


Figure 5-28: Annan-Endeavour Annual WQ Index “coaster”. Calculations for Index formulations are described in Appendix B.

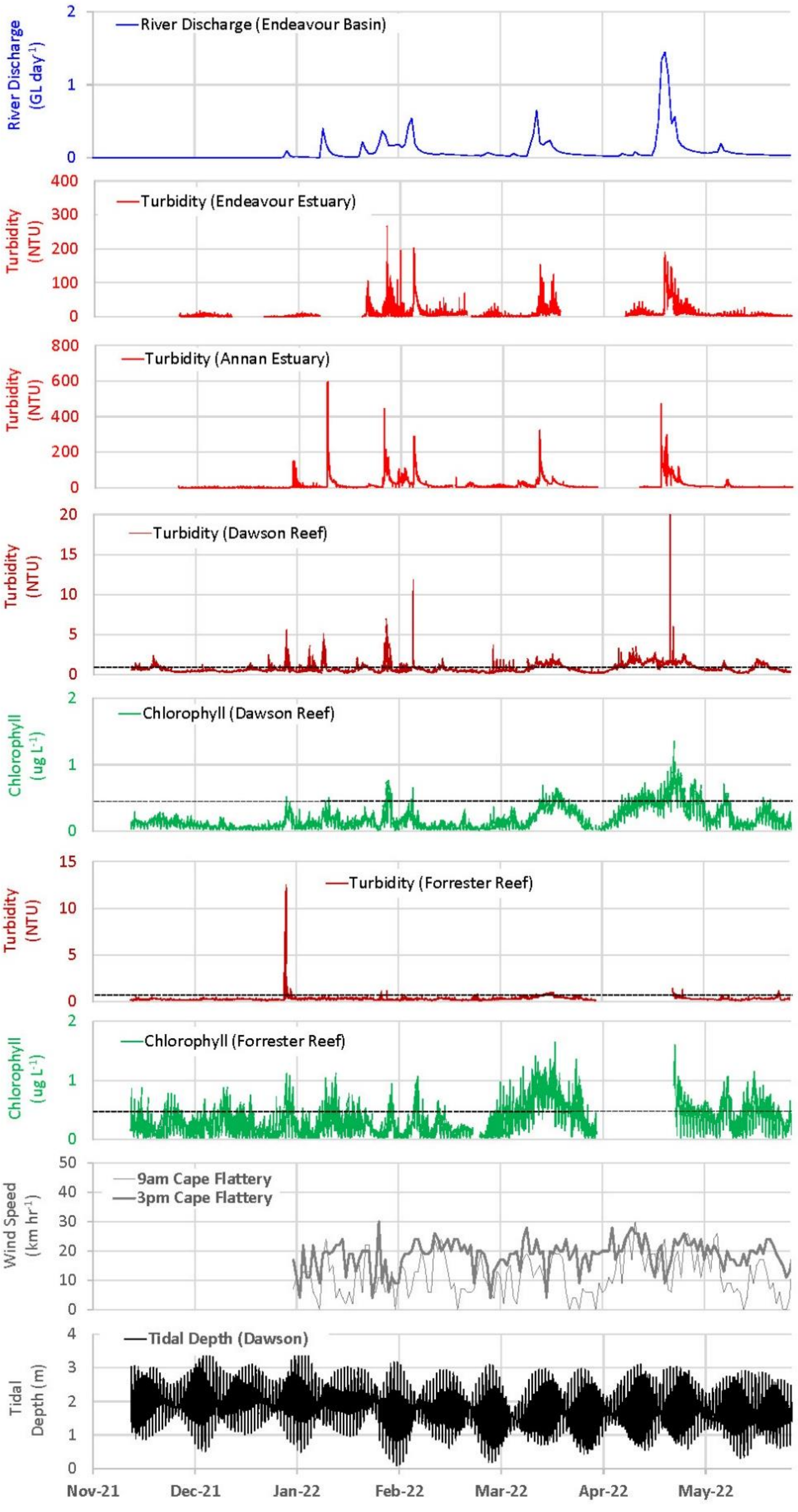


Figure 5-29: River discharge (combined Annan and Endeavour Rivers), turbidity measured on YSI EXO2s at the mouth of the Annan and Endeavour River, and turbidity and Chl-a fluorescence measured on the Wetlabs FLNTU at Dawson and Forrester Reefs over the 2021–22 wet season. Estuary turbidity (EXO2) data provided by CYWP and CSIRO. Wind speeds from the nearest BoM weather stations, daily tidal range from CYWP stage recorder. Dotted lines show wet season GVs.

Event water quality

The 2021–22 wet season saw slightly above average rainfall in the Endeavour Basin. There were several minor floods, however most rain and river discharge occurred during one event in April 2022 (Figure 5-24). Flood event monitoring occurred along the Annan & Endeavour transects during the first (relatively minor) event of the wet season (11 January 2022) and again during the largest event of the year on 26 April 2022.

Highlights from the relatively minor January 2022 event monitoring include:

- TSS ranged from 64 mg L^{-1} in the enclosed coastal waterbody near the mouth of the Annan River to <1 mg L^{-1} in the open coastal zone near Dawson reef.
- Secchi disc depths ranged from 0.5 m in the enclosed coastal waterbody to 5.0 m in the open coastal water body outside of the visible plume.
- Maximum NO_x concentration of 128.8 µg L^{-1} near the mouth of the Annan River.
- Maximum Chl-*a* was recorded along the Endeavour River transect, ranging from 1.04 µg L^{-1} at ER01 (enclosed coastal) to near ambient concentrations in the open coastal waterbody.

Satellite images from the April 2022 flood event showed that the flood plume flowed north, inundating reefs in the mid-shelf waterbody. This included Forrester Reef, approximately 30 km to the northeast of the Endeavour River mouth (Figure 5-30). Maximum TSS (74 mg L^{-1}) was measured in the enclosed coastal zone near the Endeavour River mouth, dropping to 2.6 mg L^{-1} at Forrester at the time of sampling. Continuous dataloggers at Forrester Reef showed that Chl-*a* remained elevated at concentrations ranging between 1.0 µg L^{-1} to 2.2 µg L^{-1} (compared to an ambient mean of 0.10 µg L^{-1}) for at least 5 days during the flood event.

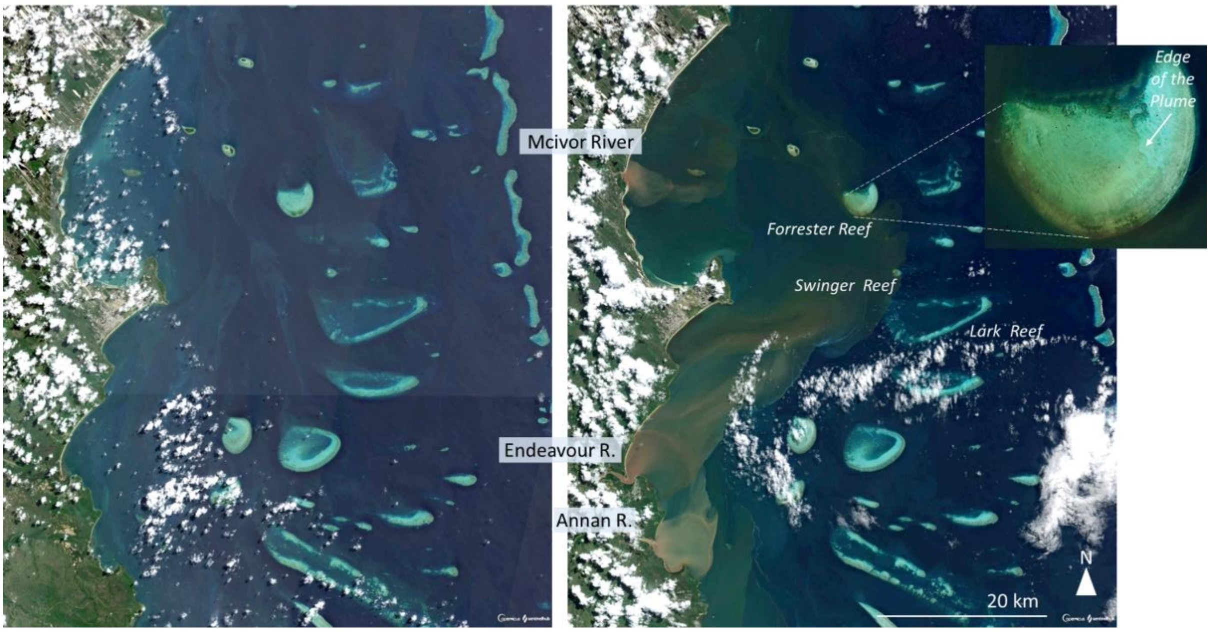


Figure 5-30: Sentinel satellite images showing ambient conditions before flooding (left, 6 April 2022) and flooding from the Annan and Endeavour Rivers on 26 April 2022 (right). Source: Caroline Petus, JCU TropWater

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).

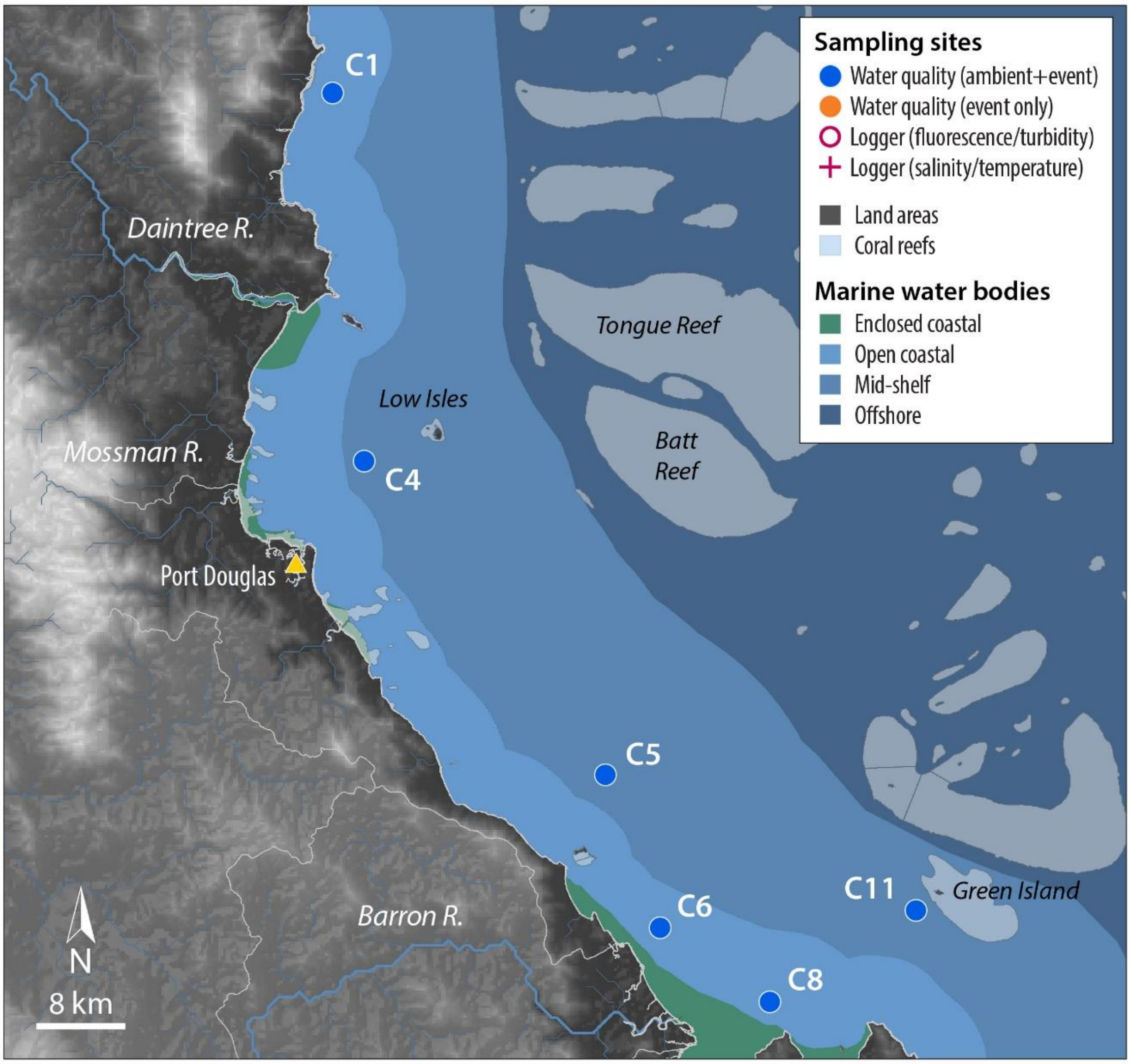


Figure 5-31: Sampling sites in the Barron Daintree focus region shown with water body boundaries.

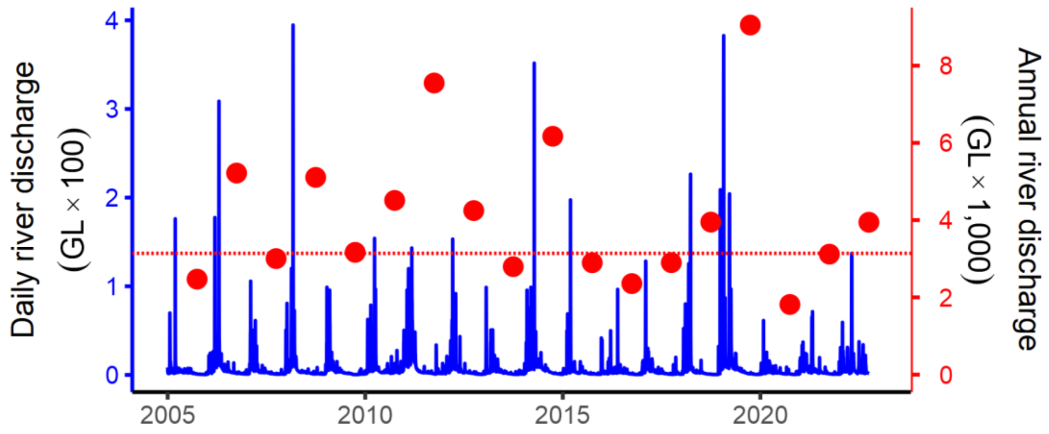


Figure 5-32: Combined discharge for the Barron (Myola gauge) and Daintree (Bairds gauge) Rivers. Daily (blue) and water year (October to September, red symbols) discharge volumes shown. Red dashed line represents long-term median of the combined annual discharge.

The combined discharge and loads calculated for the 2021–22 water year from the Barron, Daintree, and Mossman Basins were around 1.3 times higher than the long-term median values (Figure 5-26; Table 3-1). Over the 16-year period from 2006–07:

- Discharge has varied 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)
- 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).

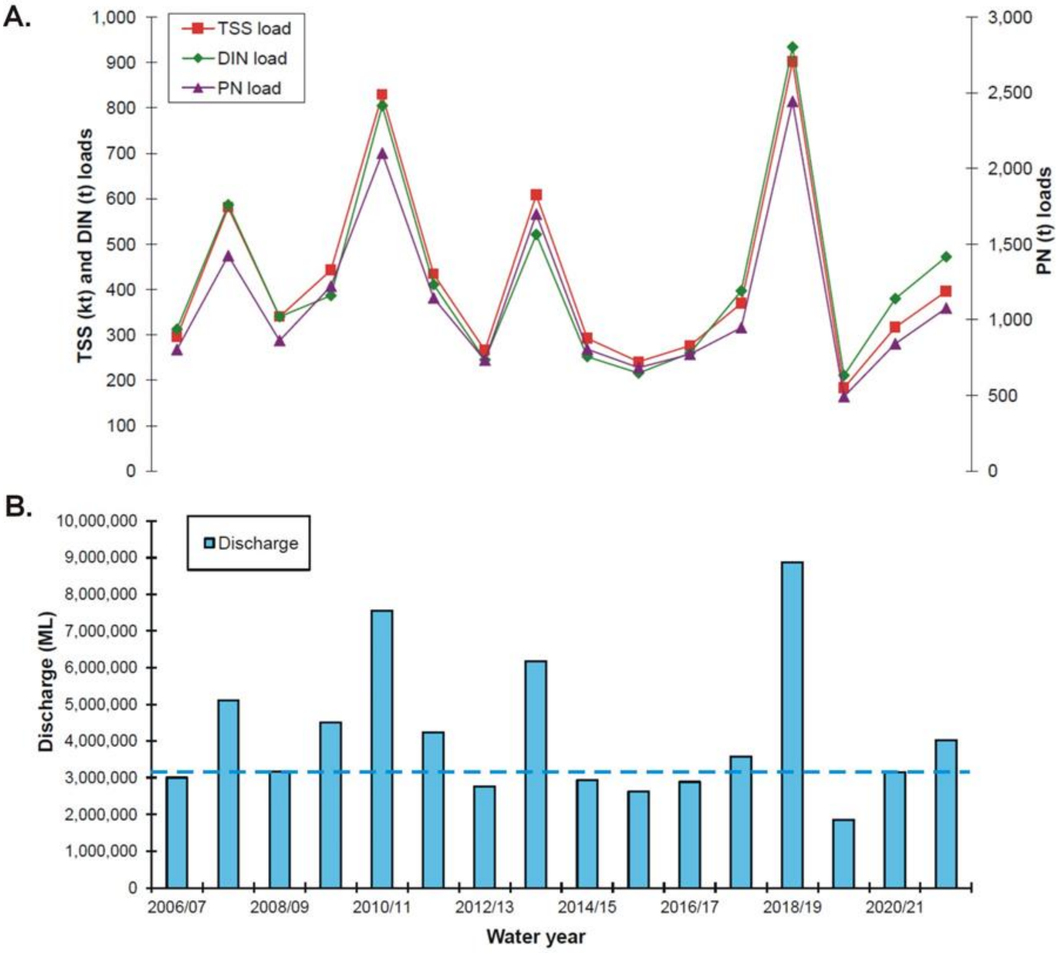


Figure 5-33: Loads of (A) TSS, DIN and PN and (B) discharge for the Barron, Daintree, and Mossman Basins from 2006–2022. The loads reported here are a combination of 'best estimates' for each basin based on 'up-scaled discharge data from gauging stations, monitoring data (Barron River), the DIN model 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*

Long-term trends in water quality variables measured during ambient periods (i.e., not peak flood events) of the dry and wet seasons are presented in Figure 5-34. It is important to note that this trend analysis removes variability associated with wind, tides, and seasons (see Methods). 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.

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 Appendix C Table C-1.

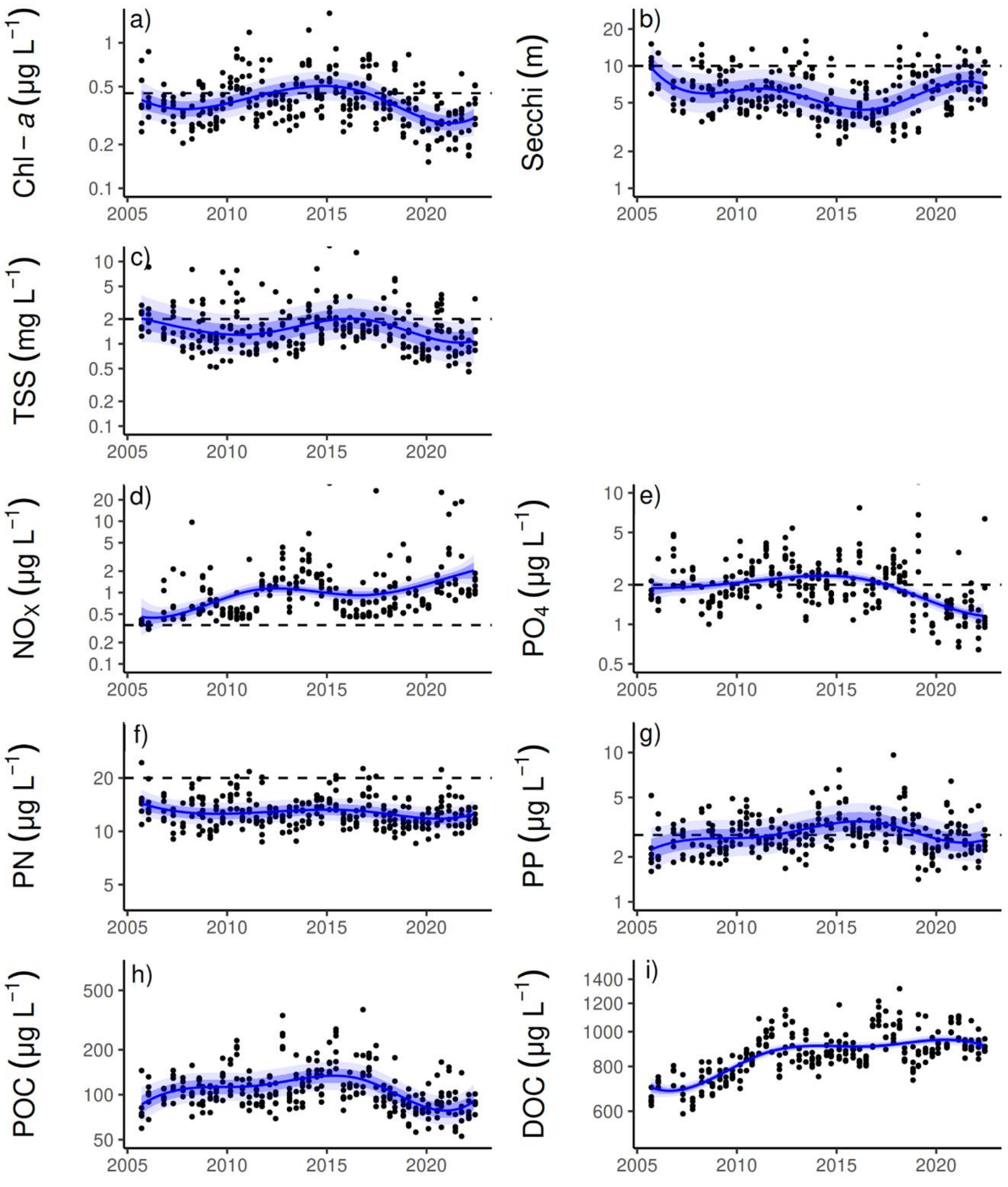


Figure 5-34: Temporal trends in water quality variables for the Barron Daintree focus region: a) chlorophyll *a* (Chl-*a*), b) Secchi depth, c) total suspended solids (TSS), d) nitrate/nitrite (NO_x), e) phosphate (PO_4), f) particulate nitrogen (PN), g) particulate phosphorus (PP), h) particulate organic 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.

Between 2005 and 2015, mean concentrations of TSS generally fluctuated around GVs (Great Barrier Reef Marine Park Authority, 2010). Analysis of trends shows from 2017–2022, mean concentration of TSS have decreased and in recent years have been below (meeting) the local water quality GVs.

Mean Secchi depth declined (i.e., water clarity worsened) from 2005 until 2016. Between 2017–2022, Secchi depth has increased (i.e., water clarity has improved), however, it is still not meeting the GVs.

Between 2005 and 2015, mean concentrations of Chl-*a* have also generally fluctuated around the GVs (Great Barrier Reef Marine Park Authority, 2010). Analysis of trends shows from 2017–2022, mean concentrations of Chl-*a* have decreased and are now generally below (meeting) local water quality GVs.

Mean concentrations of PO_4 were relatively stable between 2005 and 2017, remaining around the local GVs. Since 2017, concentrations have gradually declined and are now below (meeting) the GVs.

Concentrations of NO_x have generally increased since 2005 and remain well above (exceeding) GVs.

Mean concentrations of PN have remained relatively stable since the inception of the MMP, showing no significant change and remaining below (meeting) GVs.

Concentrations of PP slightly increased from 2005 until 2017. Since 2017, mean concentrations have shown signs of improvement and PP is now generally at or just below (meeting) the GVs.

Mean concentrations of POC have remained relatively stable, with only a slight increase between 2005 and 2017. Concentrations have been declining since 2017. Mean concentrations of DOC have increased substantially since 2005, although concentrations have remained stable from 2017–2022.

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 (the Cairns Transect sites), no additional sites were added in 2015, with sampling still conducted three times per year. The Methods section and Appendix B contain details of the calculations for both Index formulations.

The long-term WQ Index has generally scored water quality as 'good' since 2005 with two years of 'moderate' scores in 2016–17 and 2017–18 water years. The long-term trend has been for a small (i.e., changing by a single grade) but gradual decline in water quality from 2005–2018. Over the last four years, water quality appears to be trending towards improvement and was scored 'good' in 2021–22 (Figure 5-35a).

The annual condition WQ Index scored water quality as 'moderate' during the 2015–18 water years and 'good' during the past four water years, including 2021–22 (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). River discharge was slightly higher than the long-term median in this focus region this year. There have been no major discharge events, which likely contributed to the 'good' score.

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.

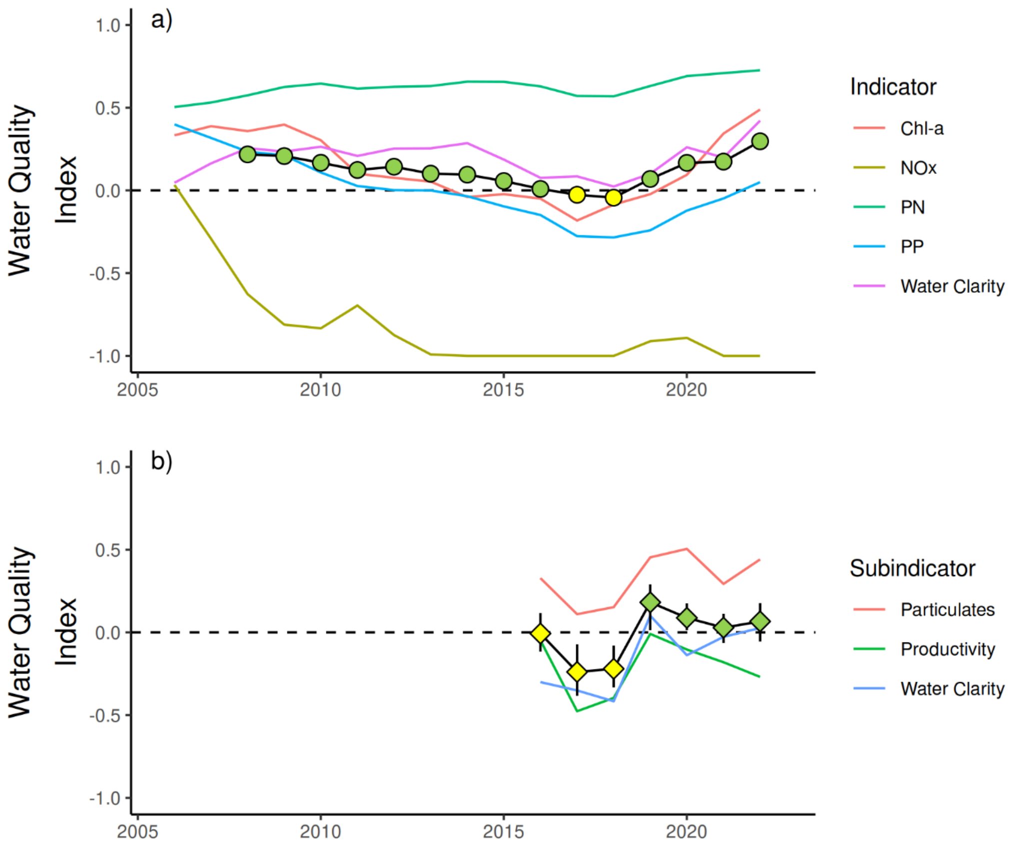


Figure 5-35: The Water Quality Index (WQ Index) for the Barron Daintree focus region. The WQ Index uses two formulations to communicate: a) long-term trend (based on pre-2015 sampling design) and b) the annual condition (based on post-2015 sampling design). WQ Index colour coding: ● / ◆– 'very good'; ● / ◆ – '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 area in 2021–22.

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).

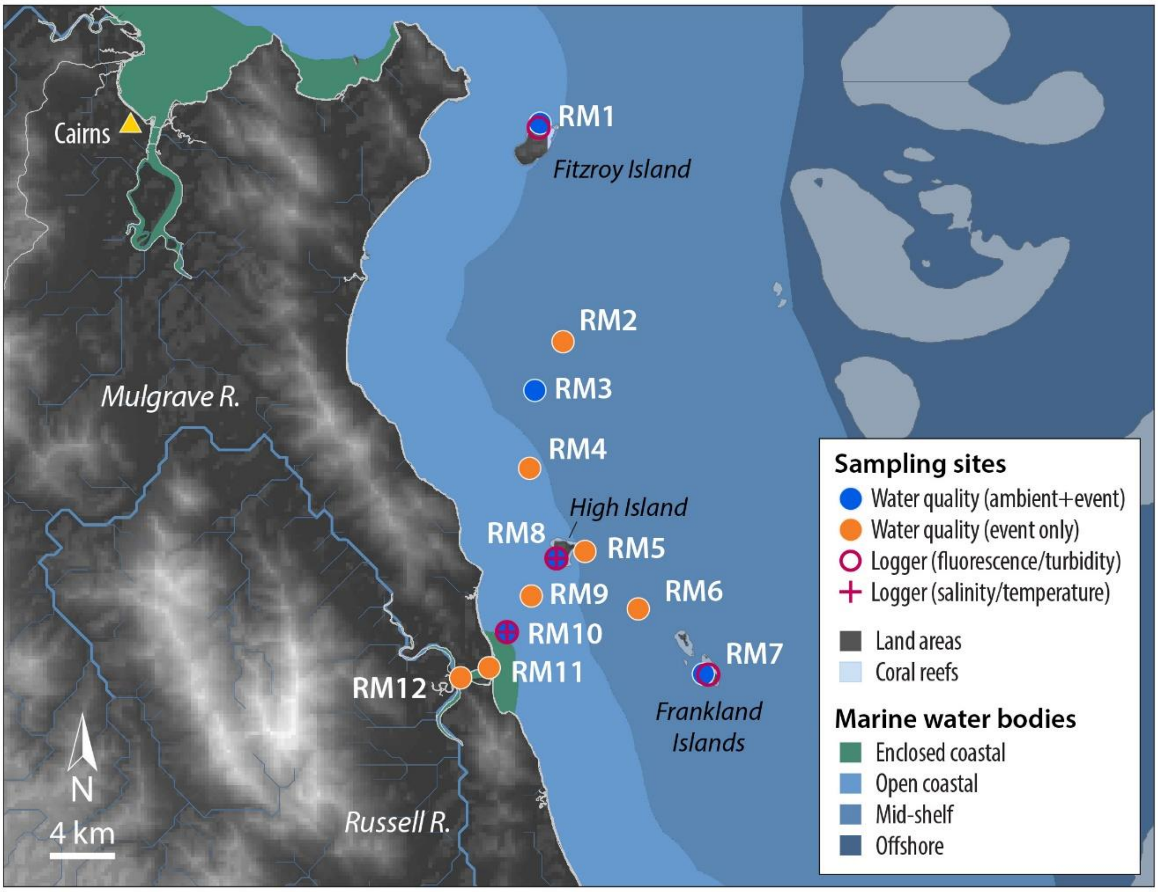


Figure 5-36: Sampling sites in the Russell-Mulgrave focus region, shown with the water body boundaries.

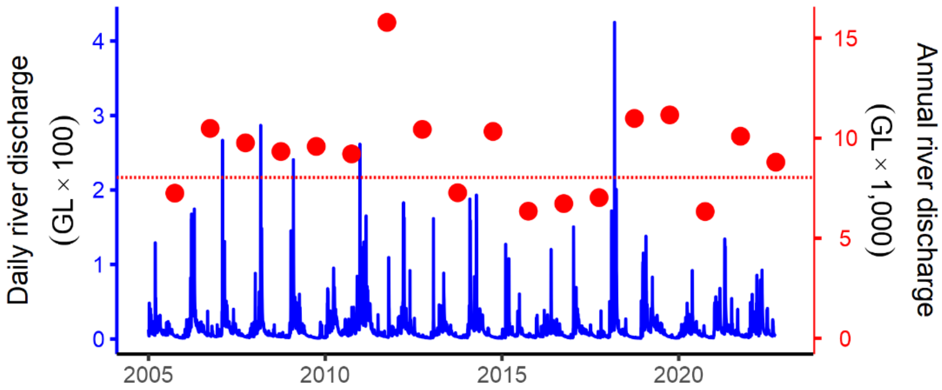


Figure 5-37: Combined discharge for the North and South Johnstone (Tung Oil and Central Mill gauges, respectively), Russell (Bucklands gauge) and Mulgrave (Peets Bridge gauge) Rivers. Daily (blue) and water year (October to September, red symbols) discharge is shown. Red dashed line represents the long-term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

The combined discharge volume of the Russell-Mulgrave and Johnstone Rivers for the 2021–22 water year was around the long-term median (Figure 5-37).

The combined discharge and loads calculated for the 2021–22 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 16-year period:

- Discharge has varied 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)
- 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 to 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.

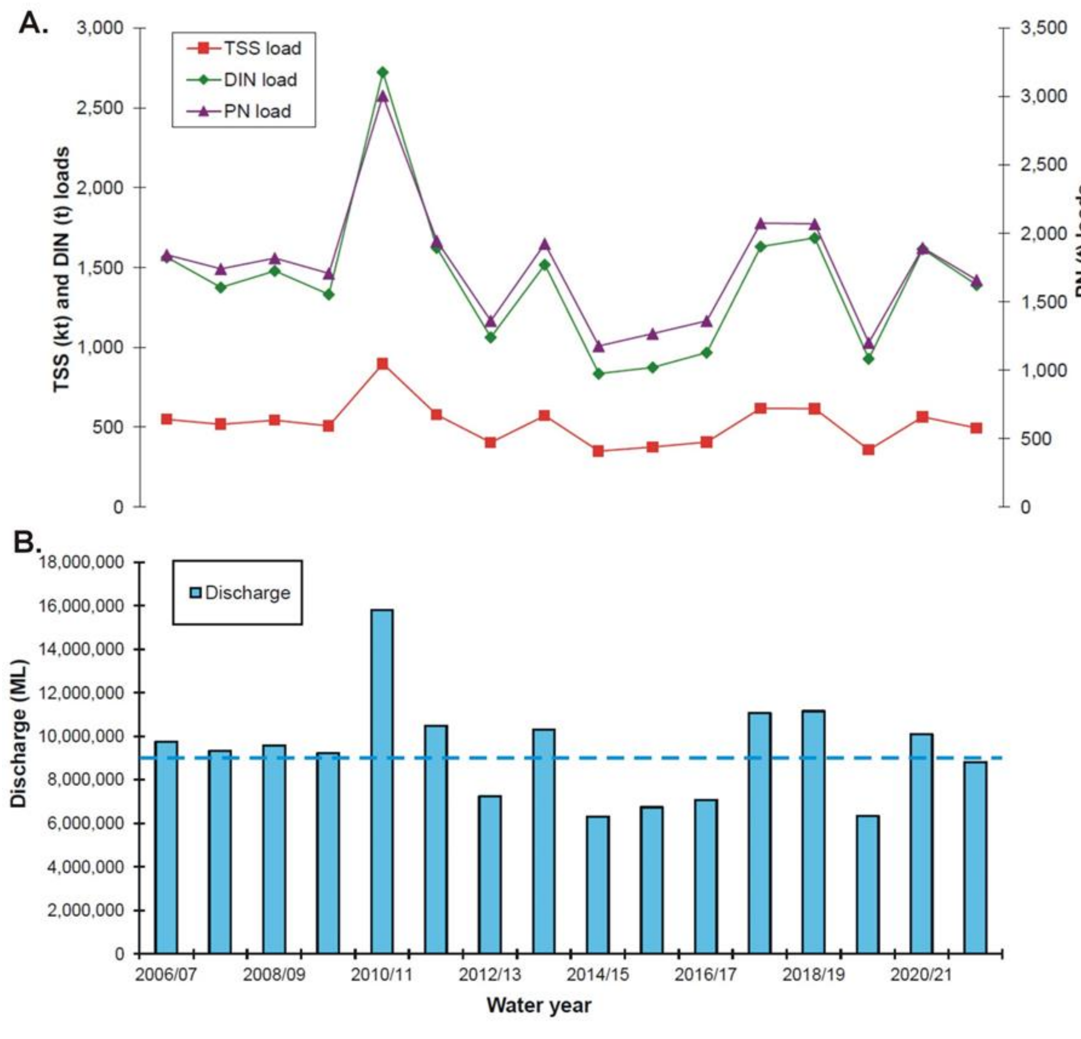


Figure 5-38: Loads of (A) TSS, DIN and PN and (B) discharge for the Russell, Mulgrave and Johnstone Basins from 2006 to 2022. The loads reported here are a combination of 'best estimates' for each basin based on 'up-scaled discharge data from gauging stations, monitoring data (Johnstone River), the DIN model developed in Lewis et al. (2014) and annual mean concentrations and discharge from monitoring data or Source Catchments modelling data. Dotted line represents the long-term median for basin discharge. 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, Appendix C 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 water quality were small for most variables. Typically, there are higher concentrations throughout the wet season. Rainfall and discharge patterns were atypical in the 2021–22 season, with several rain events in the early dry season (May and June). This likely resulted in the atypical variability in wet and dry season concentrations for some variables. For some variables including TSS, concentrations were higher in the dry season compared to the wet season. Concentrations of NO_x, Chl-*a*, PP and PN were similar between wet and dry seasons, though values were slightly higher in the dry season (Figure 5-39). Secchi depths were lower (water clarity was worse) during the dry season.

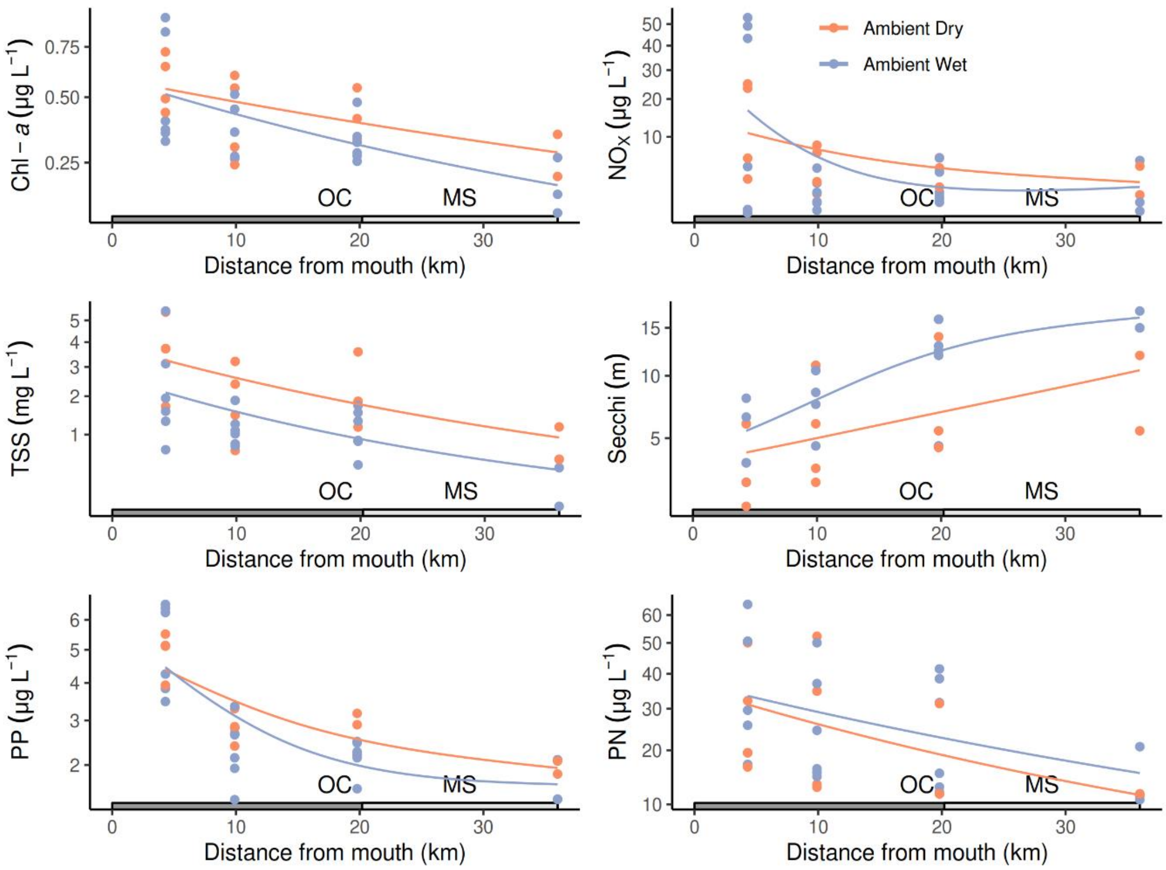


Figure 5-39: Water quality variables measured during ambient and event sampling in 2021–22 along the Russell-Mulgrave focus region transect. Chlorophyll *a* (Chl-*a*), nitrate/nitrite (NO_x), total suspended solids (TSS), Secchi depth, particulate nitrogen (PN), and particulate phosphorus (PP) are shown 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.

Long-term trends in water quality variables measured during ambient periods (for example, not during peak flood events) of the dry and wet seasons are presented in Figure 5-40. It is important to note that this trend analysis removes variability associated with wind, tides, and seasons (see Methods). Thus, individual data points will have different values compared to raw data. This analysis is designed to detect **long-term** and **regional-scale** trends in water quality, by removing the effect of short-term changes associated with weather and seasonal differences.

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 Appendix C Table C-1.

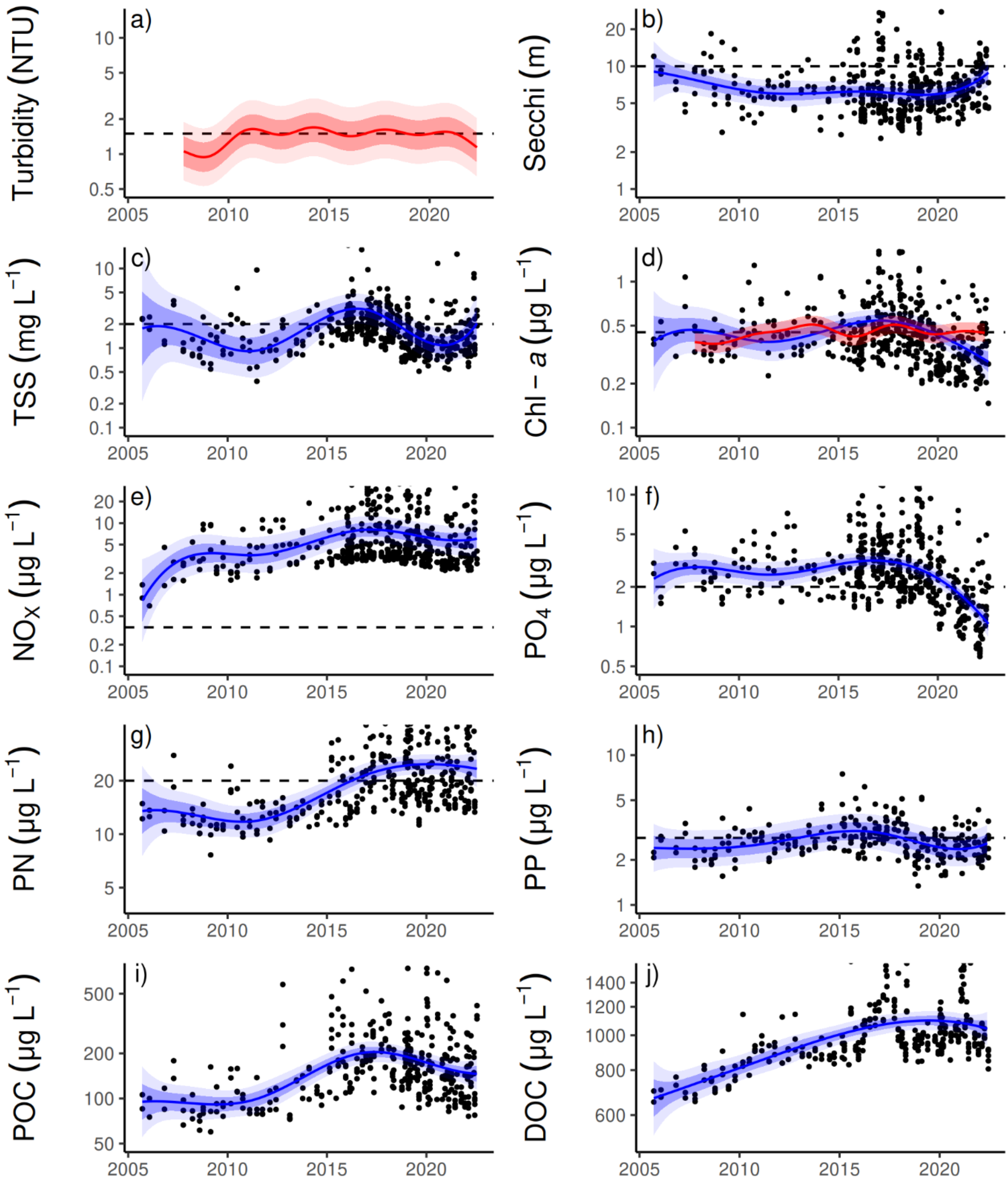


Figure 5-40: Temporal trends in water quality variables for the Russell-Mulgrave focus region: a) turbidity, b) Secchi depth, c) total suspended solids (TSS), d) chlorophyll *a* (Chl-*a*), e) nitrate/nitrite (NO_x), f) phosphate (PO_4), g) particulate nitrogen (PN), h) particulate phosphorus (PP), i) 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 Appendix C Figure C-1. Dashed horizontal reference lines indicate annual guidelines.

Concentrations of TSS have fluctuated above and below the GVs since monitoring began in 2005. The 5-year trends show that TSS values in 2022 are consistent with those seen in 2017, following an improvement and subsequent decline over that time (Figure 5-40c). FLNTU turbidity (Figure 5-40a) has also fluctuated above and below the GVs and has shown signs of improving within the last few years and is now below (meeting) GVs.

Mean Secchi depth declined (i.e., water clarity worsened) between 2005 and 2017. Since 2017, Secchi depth (water clarity) has improved, with results now similar to 2005 levels. However, results are still below (not meeting) the GVs.

Mean concentrations of Chl-*a* have generally fluctuated around GVs since the start of the MMP. Analysis of trends shows that from 2017–2022, mean concentrations of Chl-*a* have decreased and are currently below (meeting) water quality GVs at most sites. FLNTU chlorophyll fluorescence (Figure 5-40d) remains steady around the local GVs. The differences between FLNTU chlorophyll fluorescence and Chl-*a* concentration reflect differences in sampling location and technology.

Mean concentrations of PO_4 have been relatively stable between 2005 and 2017, with concentrations declining between 2017 and 2022. Concentrations are currently below (meeting) GVs at most sites.

Mean concentrations of NO_x have generally increased since 2005. Since 2017 concentrations have remained stable and are well above (not meeting) GVs.

Mean concentrations of PN, which were below GVs between 2005 and 2015, have increased between 2013 and 2017. Analysis of the recent trends shows that from 2017–2022, mean concentrations of PN have remained stable but continue to be above (not meeting) GVs at most sites.

Mean concentrations of PP have varied around the GVs since the inception of the MMP. Since 2017, mean concentrations of PP have marginally decreased (conditions have improved) and are currently below (meeting) GVs at most sites.

Mean concentrations of POC and DOC have substantially increased since monitoring began in 2005. Analysis of trends shows that from 2017–2022, POC has decreased slightly, while DOC has stabilised.

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). The Methods section and Appendix B contain details of the calculations for both index formulations.

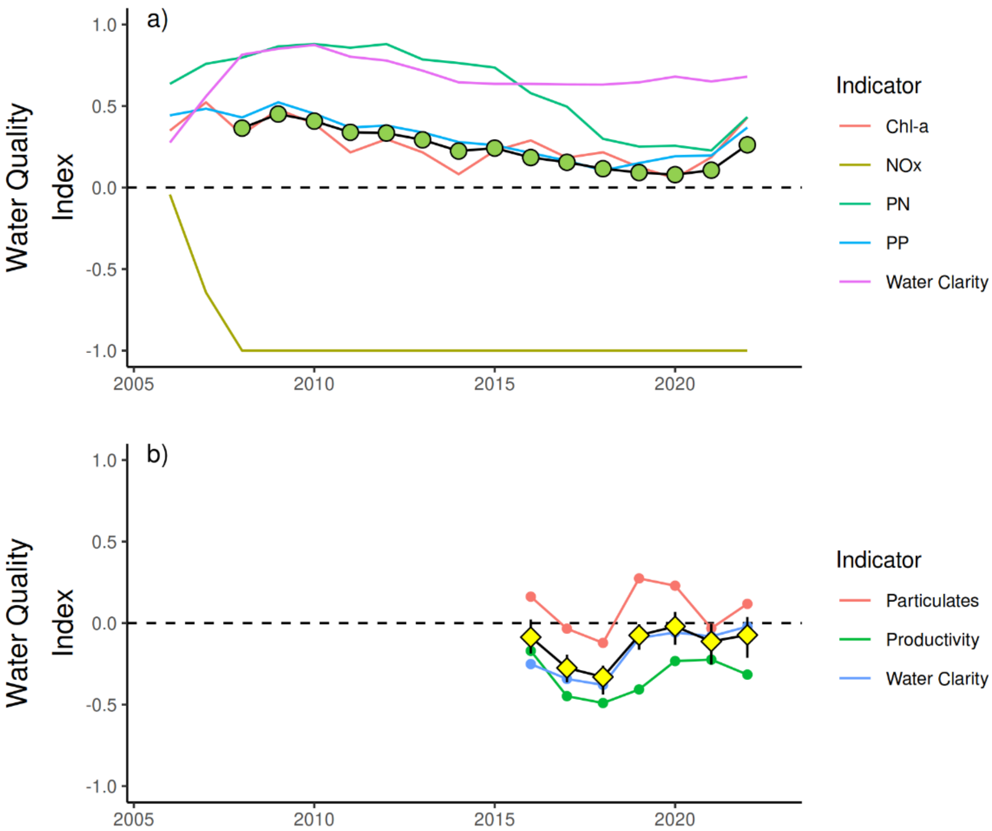


Figure 5-41: The Water Quality Index (WQ Index) for the Russell-Mulgrave focus region. The WQ Index uses two formulations to communicate the a) long-term trend (based on pre-2015 sampling design) and b) annual condition (based on post-2015 sampling design). WQ Index colour coding: ● / ◆– 'very good'; ● / ◆ – '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.

The long-term WQ Index has scored water quality as 'good' since 2008. However, this Index has shown a small (i.e., changing within a grade) but gradual decline in overall water quality condition since 2009 (Figure 5-41a). This downward trend has generally been driven by trends in PN, PP, and Chl-*a* indicators. This year the long-term Index showed signs of improvement. This improvement follows several years of around median discharge in the Johnstone and Russel-Mulgrave basins and no major discharge events.

The annual condition WQ Index scored water quality was scored as 'moderate' for the past seven years (Figure 5-41b). This version of the Index scores water quality parameters against GVs relevant to the season when samples were collected (wet versus dry GVs) and it includes additional sites in the open coastal water body to better characterise areas affected by river discharge.

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

Event water quality

No event sampling was conducted in the 2021–22 wet season in the Russell-Mulgrave focus area.

5.2.3 Tully

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

One site was sampled in this focus area 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).

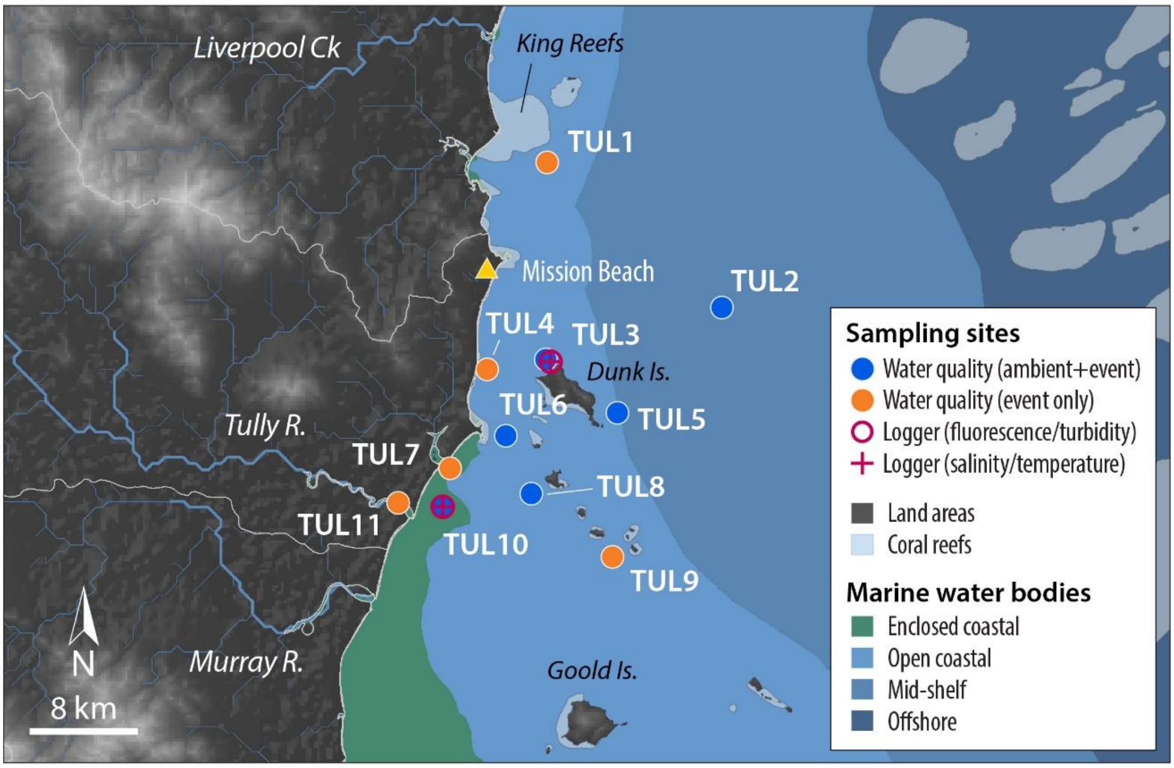


Figure 5-42: Sampling sites in the Tully focus area, shown with the water body boundaries.

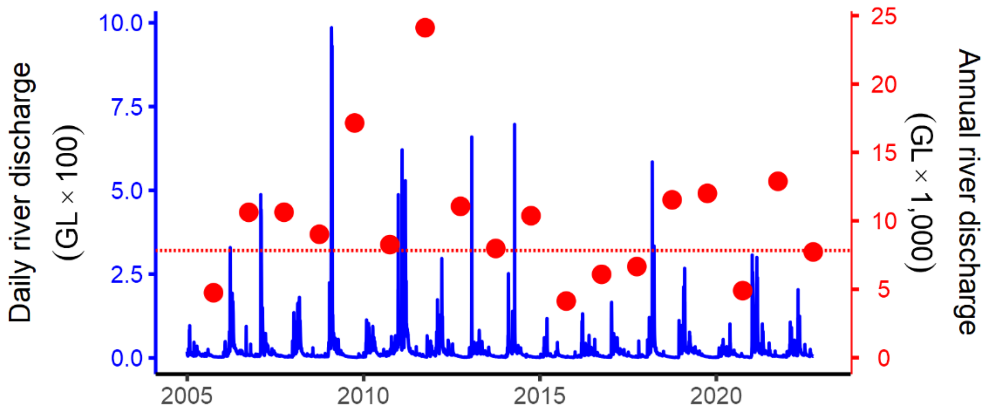


Figure 5-43: Combined discharge for Tully (Euramo gauge) and Herbert (Ingham gauge) Rivers. Daily (blue) and water year (October to September, red) discharge is shown. Red dashed line represents the long-term median of the combined annual discharge. Please note as this is the combined discharge, high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

The combined discharge volume of the Tully and Herbert Rivers for the 2021–22 water year was close to the long-term median (Figure 5-43).

The combined discharge and loads calculated for the 2021–22 water year from the Tully, Murray, and Herbert Basins were close to the long-term median (Figure 5-44). Over the 16-year period:

- Discharge has varied 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)
- 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.

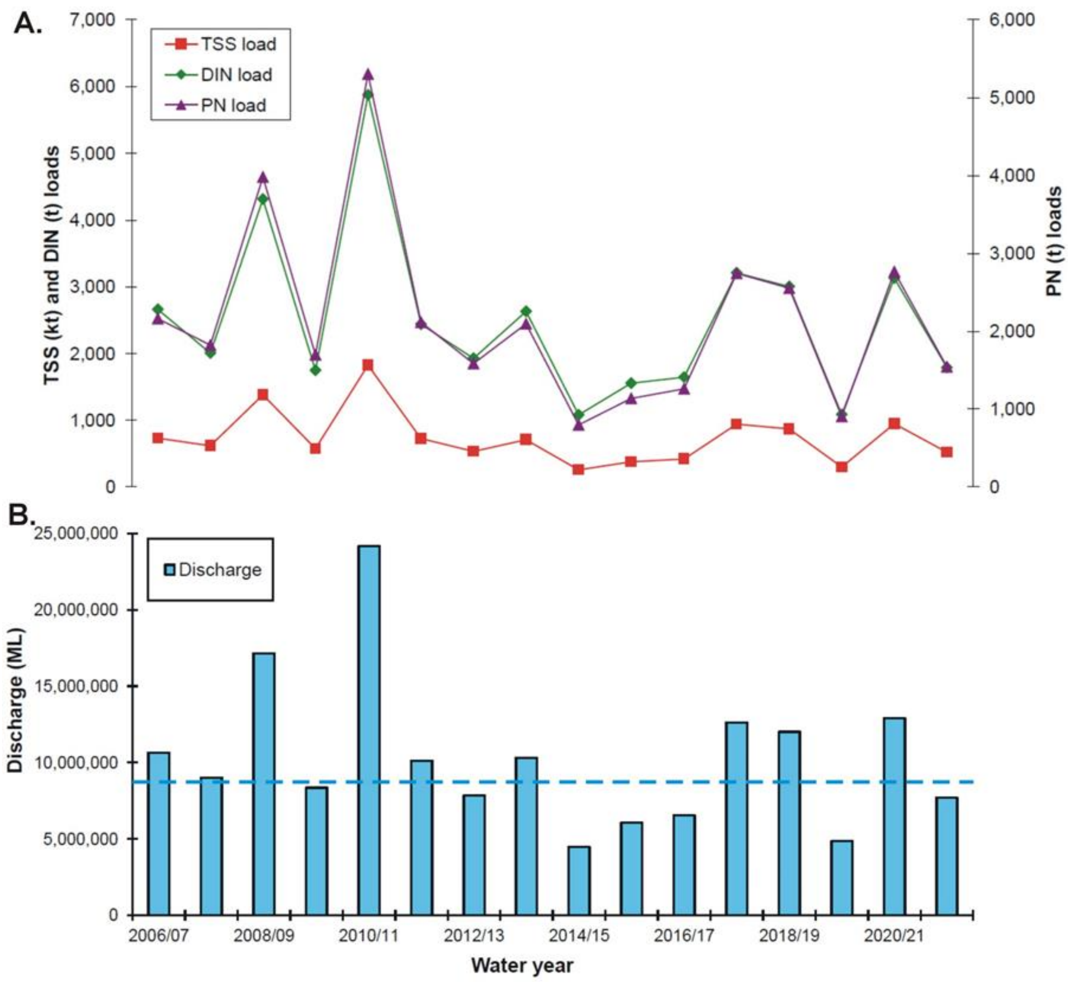


Figure 5-44: Loads of (A) TSS, DIN and PN and (B) discharge for the Tully, Murray, and Herbert Basins from 2006 to 2022. The loads reported here are a combination of 'best estimates' for each basin based on 'up-scaled discharge data from gauging stations, monitoring data (Tully and Herbert Rivers), the 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 particulate nutrients (PN and PP). Concentrations declined with distance away from the river mouth, reaching low levels in mid-shelf waters (Figure 5-45, Appendix C Table C-2). In previous years, this pattern has been more prominent in the wet season (Moran *et. al,* 2022). However similar concentrations were observed in the wet and dry season this year. This is most likely due to unseasonable rains throughout the 2022 dry season (May to September). Concentrations of Chl-*a* and TSS showed a similar pattern to particulate nutrient concentrations, declining with distance from the river mouth. Secchi depths were low (average of < 5 m) at sites near the river mouth (water clarity was poor) and increased (water clarity improved) with distance from the river mouth. Concentrations of NO_x declined strongly from the river mouth in both the wet and dry seasons. Seasonal differences were less prominent this year, compared with previous years, which is likely attributable to generally high dry season discharge (see Appendix C Figure C-1).

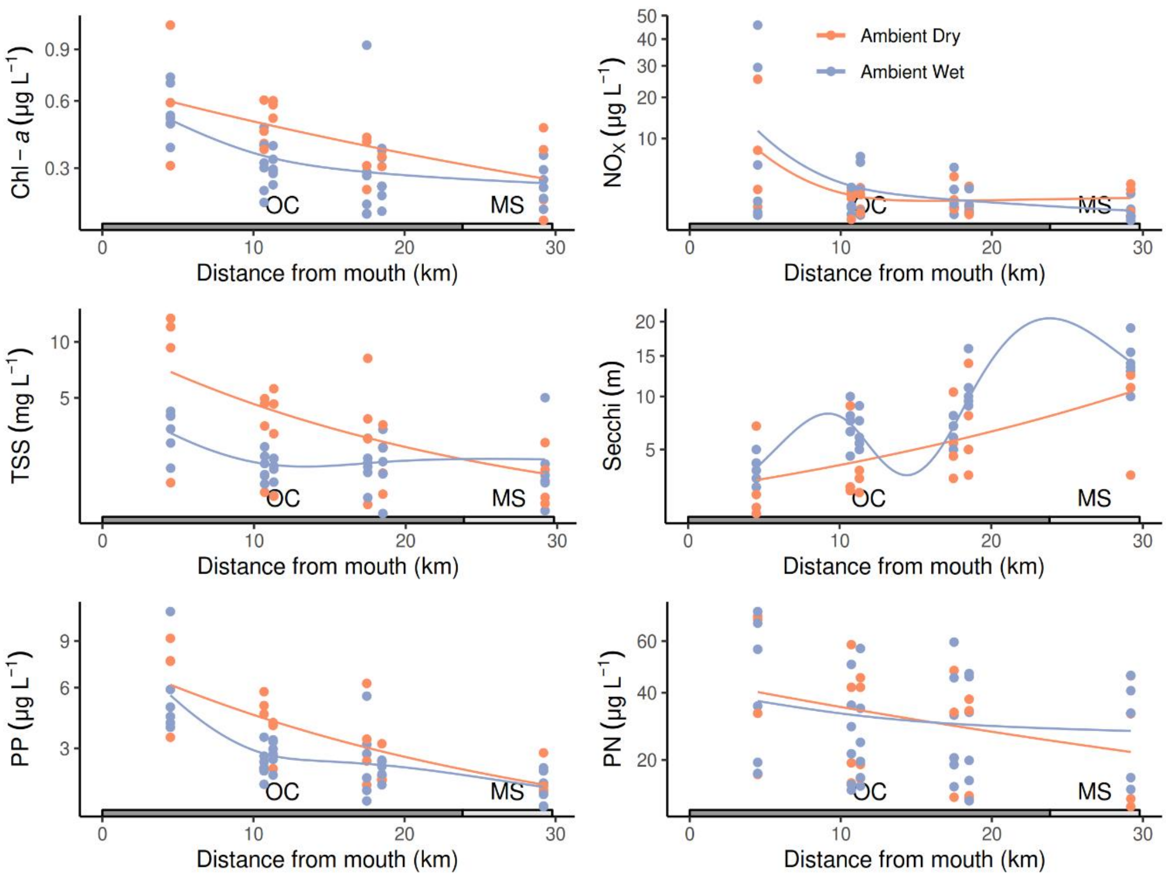


Figure 5-45: Water quality variables measured during ambient and event sampling in 2021–22 along the Tully focus region transect. Chlorophyll *a* (Chl-*a*), nitrate/nitrite (NO_x), total suspended solids (TSS), Secchi depth, particulate nitrogen (PN), and particulate phosphorus (PP) are shown with distance 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.

Long-term trends in water quality variables measured during ambient periods (for example, not during peak flood events) of the dry and wet seasons are presented in Figure 5-46. It is important to note that this trend analysis removes variability associated with wind, tides, and seasons (see Methods). Thus, individual data points will have different values compared to raw data. This analysis is designed to detect **long-term** and **regional-scale** trends in water quality by removing the effect of short-term changes associated with weather and seasonal differences.

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 Appendix C Table C-2.

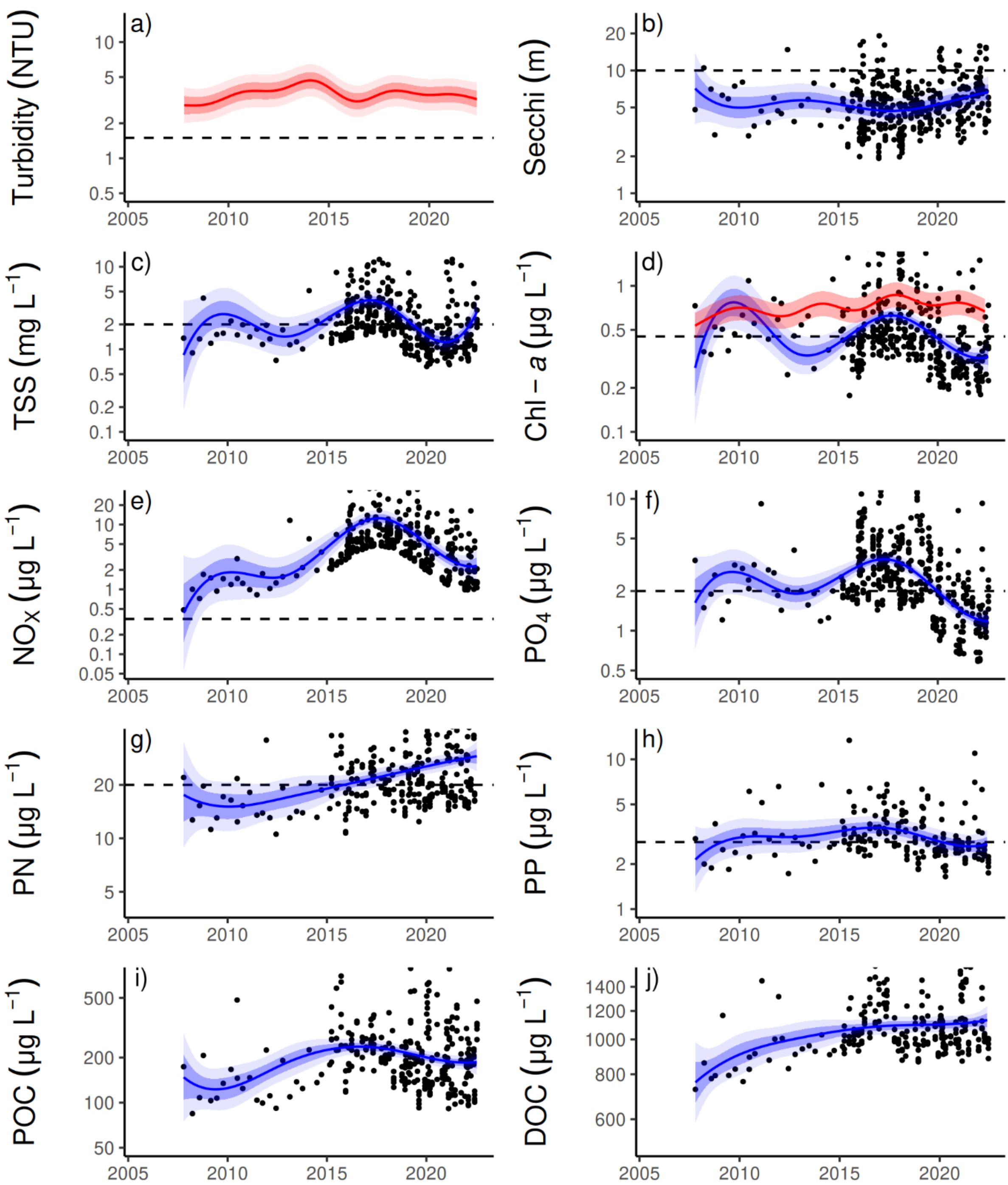


Figure 5-46: Temporal trends in water quality variables for the Tully focus region: a) turbidity, b) Secchi depth, c) total suspended solids (TSS), d) chlorophyll *a* (Chl-*a*), e) nitrate/nitrite (NO_x), f) phosphate (PO_4), g) particulate nitrogen (PN), h) particulate phosphorus (PP), i) particulate 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 Appendix C Figure C-1. Dashed horizontal reference lines indicate annual guidelines.

Mean concentrations of TSS have generally fluctuated around GVs since monitoring began in 2005 (Great Barrier Reef Marine Park Authority, 2010). Analysis of trends shows that current concentrations of TSS have decreased slightly from 2017; however, there was variability over the 5-year period and TSS appears to be trending upwards again (water clarity worsening) and is close to GVs.

Mean Secchi depth has been relatively stable since the inception of the MMP. Analysis of trends shows that from 2017–22 Secchi depth has slightly increased (water clarity has improved), although it currently remains below (not meeting) GVs.

Mean concentrations of Chl-*a* have also generally fluctuated around GVs since the inception of the MMP (Great Barrier Reef Marine Park Authority, 2010). Analysis of trends shows that from 2017–22, mean concentrations of Chl-*a* have decreased (improved) and are currently below (meeting) water quality GVs at most sites. FLNTU chlorophyll fluorescence (red line in Figure 5-46d) does not reflect this trend. The differences between FLNTU chlorophyll fluorescence and Chl-*a* concentration reflect differences in sampling location and technology.

Mean concentrations of PO_4 have been relatively stable since the inception of the MMP, but analysis of trends shows that from 2017–22 concentrations have declined and are currently below (meeting) GVs at all sites.

Mean concentrations of NO_x have increased since 2008, reaching a maximum around 2017. Analysis of trends shows that from 2017–22 concentrations have decreased but remain well above (exceeding) GVs.

Mean concentrations of PP have been relatively stable and close to GVs since the inception of the MMP. Mean concentrations of PP have declined slightly and are currently below (meeting) GVs at some sites and above (exceeding) GVs at others.

Mean concentrations of PN have steadily increased since 2005, and since 2017 have been above (exceeding) GVs.

Mean concentrations of POC and DOC have generally increased since 2008. However, analysis of trends shows that from 2017–22 POC has decreased while DOC has remained stable.

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

The long-term WQ Index has scored water quality as 'moderate' or 'poor' since 2010 (Figure 5-47a). The long-term trend has varied since the inception of the MMP but has shown a small (change by a single grade) decline over the time-series, perhaps stabilising in recent years. This trend has generally been driven by trends in water clarity, PN, PP, and Chl-*a*.

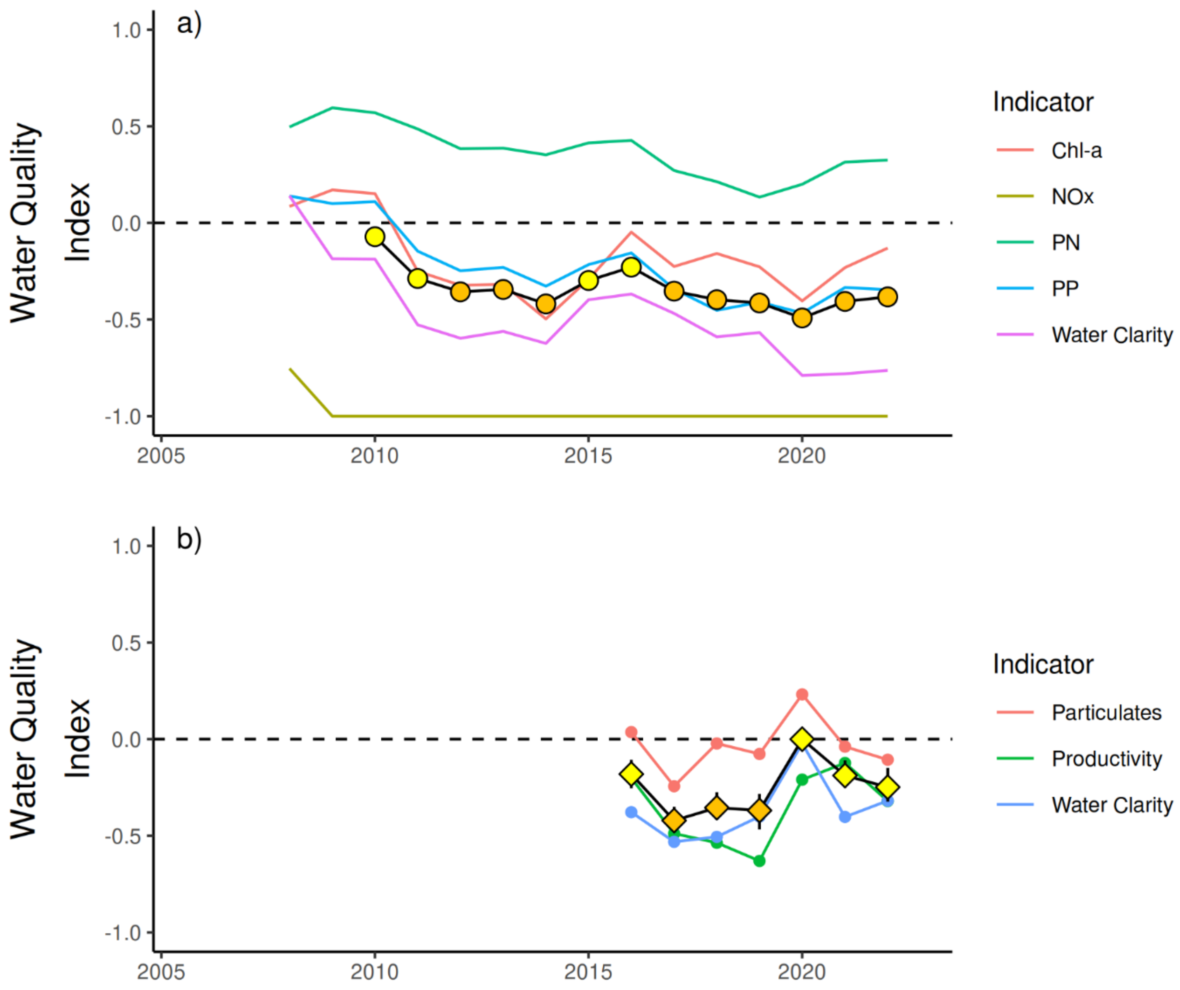


Figure 5-47: The Water Quality Index (WQ Index) for the Tully focus region. The WQ Index uses two formulations to communicate: a) long-term trend (based on pre-2015 sampling design) and b) the annual condition (based on post-2015 sampling design). WQ Index colour coding: ● / ◆– 'very good'; ● / ◆ – 'good'; ● / ◆ – '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.

The annual condition WQ Index scored water quality as 'poor' from 2016-2019 and 'moderate' for the 2019–20 and 2020–21 water years (Figure 5-47b). The score for the 2019–20 water year was much higher than previous years, probably due to low discharge that year. The score for 2021–22 is still 'moderate' but performed more poorly than the previous two years despite similar overall discharge figures. This might be due to the influence of generally high dry season discharge, which will have affected performance against the dry season GVs. This version of the Index scores water quality parameters against GVs relevant to the season when samples are collected (wet versus dry GVs). It also includes additional sites in the open coastal water body to better characterise areas affected by river discharge.

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

Event water quality: Tully River

The Tully River had three flow events that exceeded the minor flood level over the 2021–22 water year (Figure 5-48). The largest event peaked at 7.4 m just below the moderate flood level (8.0 m) on 26 April 2022 and this flood plume was subject to event sampling two days after this peak.

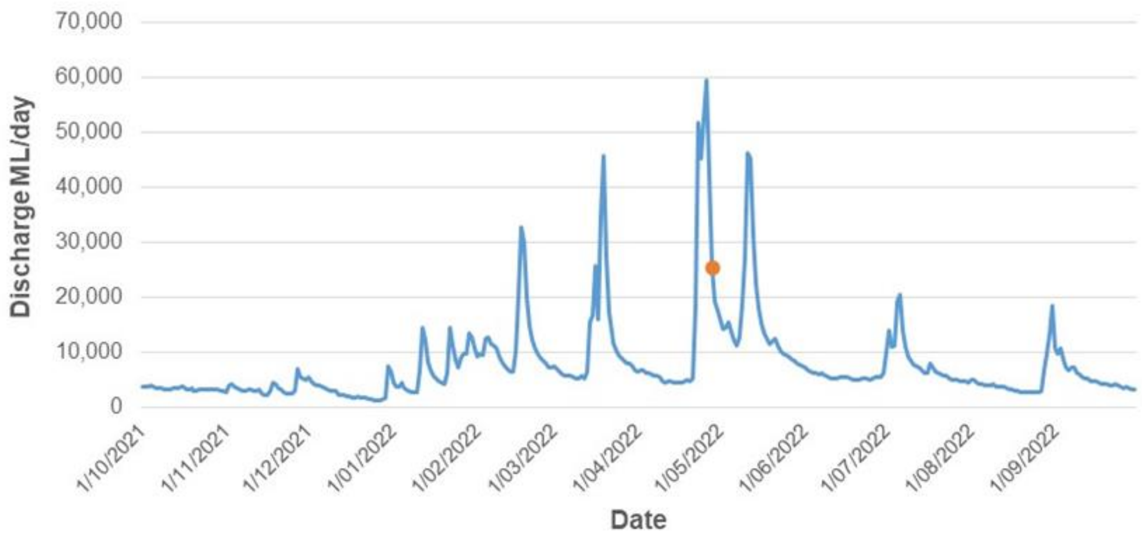


Figure 5-48: Tully River at Euramo flow gauge record for the 2021–22 water year. The date of offshore sampling by JCU is marked as a red dot.

The standard event monitoring sites off the Tully region were all sampled with selected results from the water column profiling shown in Figure 5-49. The profiles of salinity show the increasing influence of the river flood plume in the upper ~ 5 m of the water column at the sites closest to the river mouth. In contrast, the more distal sites from the river (e.g., TUL9 and TUL2) showed no apparent plume influence. The Tully flood plume at this time was observed to be restricted to the inshore waters and moving northwards along the coast. The light profiles show increasing PAR light available at greater water column depths from the river mouth to the more distal sites offshore. The Forel Ule images from the sites show a transition from brown turbid waters (i.e., Reef WT1) from the sites near or at the river mouth to greener waters (i.e., Reef WT2) in the sections that were further offshore but still under the influence of plume waters. Further offshore outside of the plume influence (qualified by the salinity profiles) the waters become bluer (i.e., Reef WT3) (Figure 5-49).

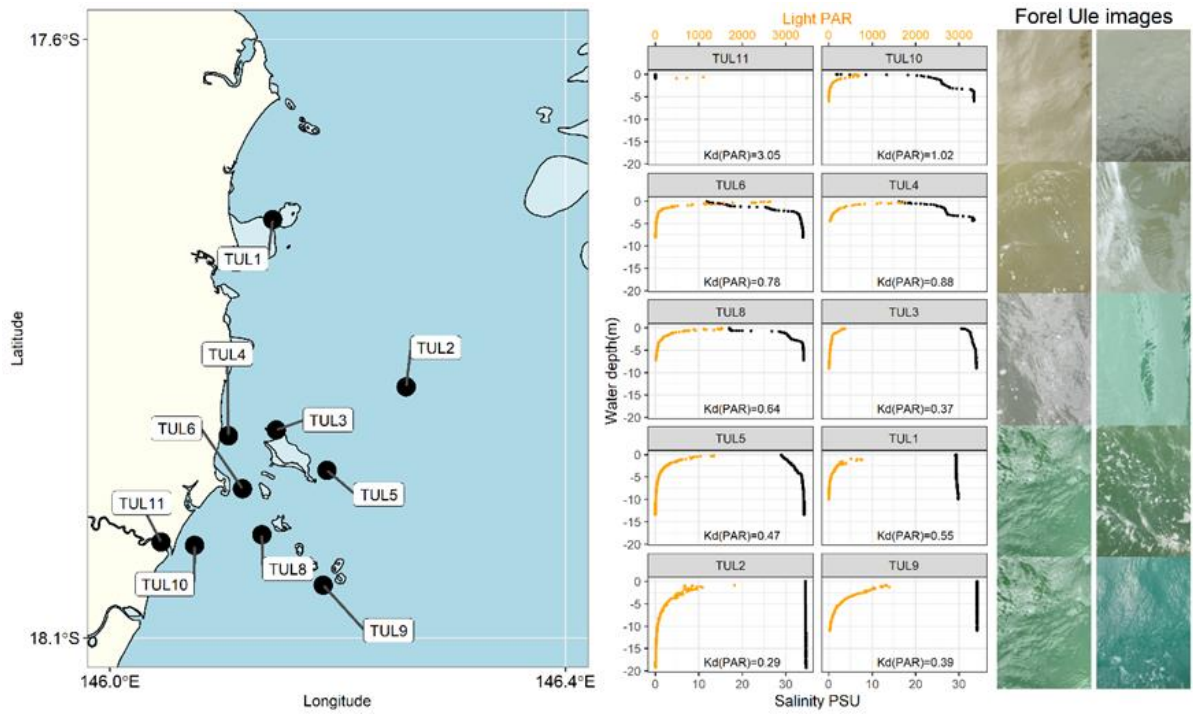


Figure 5-49: Event monitoring outputs for the Tully River. The map on the left shows the plume sampling sites offshore from the Tully River mouth (at the TUL11 site). The middle panel shows plots of the water column profiles of salinity (black lines) and light (orange lines) at the sites shown on the map. The right panel presents corresponding images of the water colour at each site.

The water quality data for the Tully focus area show clear trends in the flood plume samples collected over the inshore-offshore sites and over the salinity gradient (Figure 5-50 and Figure 5-51). The sampling also provides important insights on the difference between the surface and depth samples, which have been separated in the plots. In general, the TSS, nitrate (Figure 5-50), PN and PP (Figure 5-51) concentrations in the surface samples decline across the salinity gradient. The elevated concentrations of TSS, PN and PP are primarily related to the influence from the Tully River in areas with relatively low salinity (i.e., < 30 PSU). The elevated concentrations of TSS in the depth samples that had relatively high salinity (> 30 PSU) could be related to either sediment resuspension or from the flood plume. The nitrate concentrations generally follow a linear trend over the estuarine mixing zone from 0 to ~ 25 PSU before becoming rapidly depleted (Figure 5-50). The Chl-*a* concentrations were generally highest (> 0.5 µg L^{-1} and peaking at 1.2 µg L^{-1}) in the > 10 PSU salinity zone, which is generally consistent with previous monitoring data. No patterns were detected in the depth data for nitrate and chlorophyll.

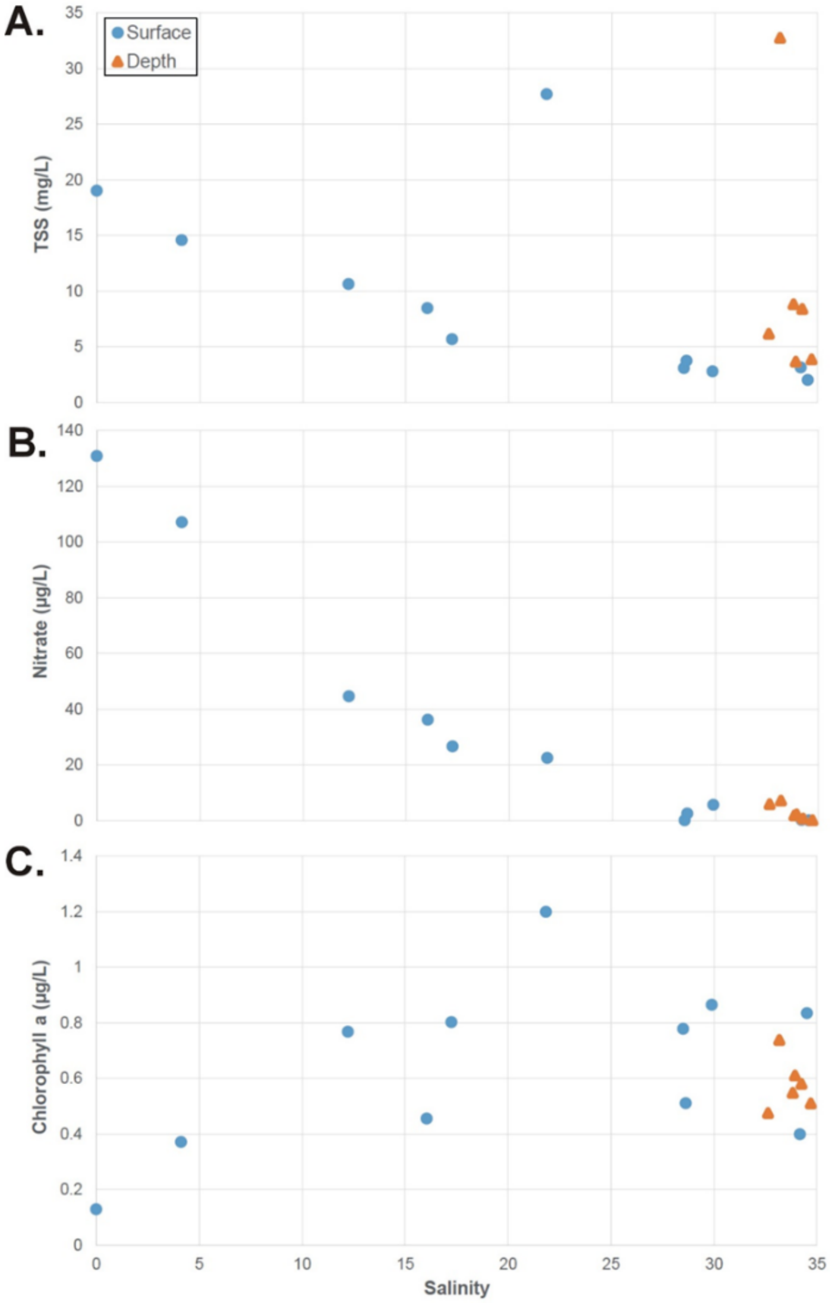


Figure 5-50: Water quality data from the Tully focus region under the influence of flood plumes over the 2021–22 wet season including TSS (A), nitrate (B) and chlorophyll *a* (C) plotted over the salinity gradient. Surface samples are plotted as circles and depth samples as triangles.

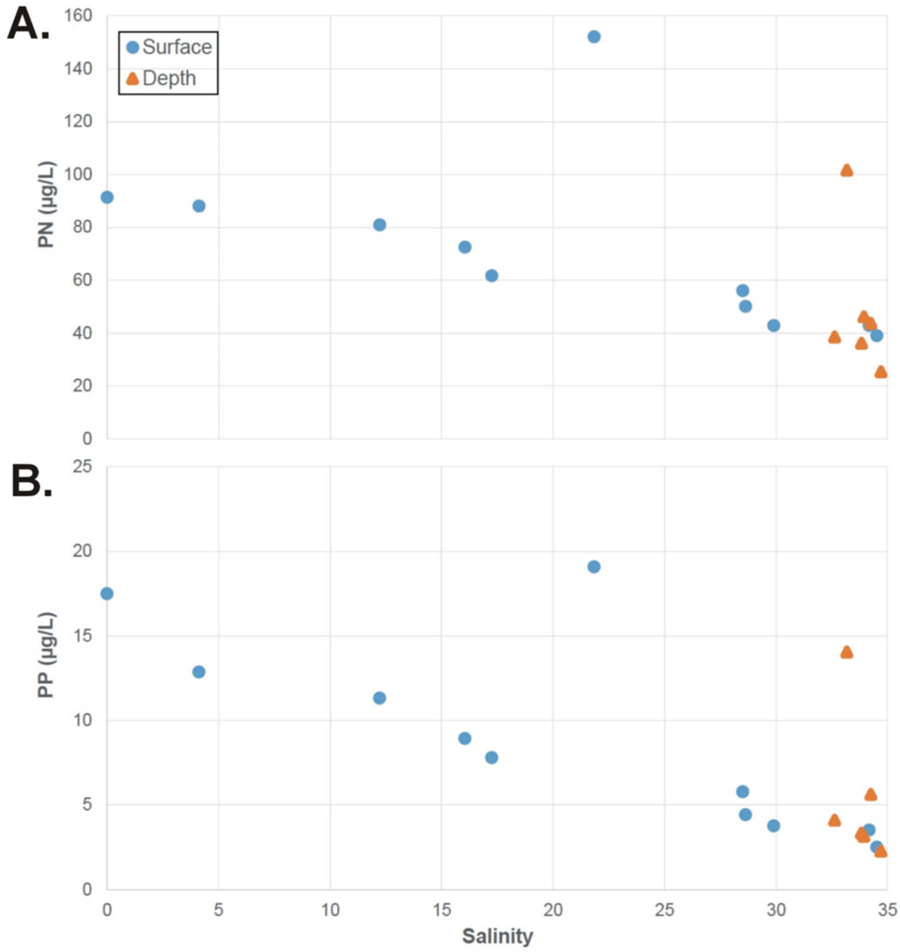


Figure 5-51: Water quality data from the Tully focus region under the influence of flood plumes over the 2021–22 wet season including PN (A) and PP (B) plotted over the salinity gradient. Surface samples are plotted as circles and depth samples as triangles.

5.3 Burdekin region

Three sites were sampled in this focus area 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 5-52).

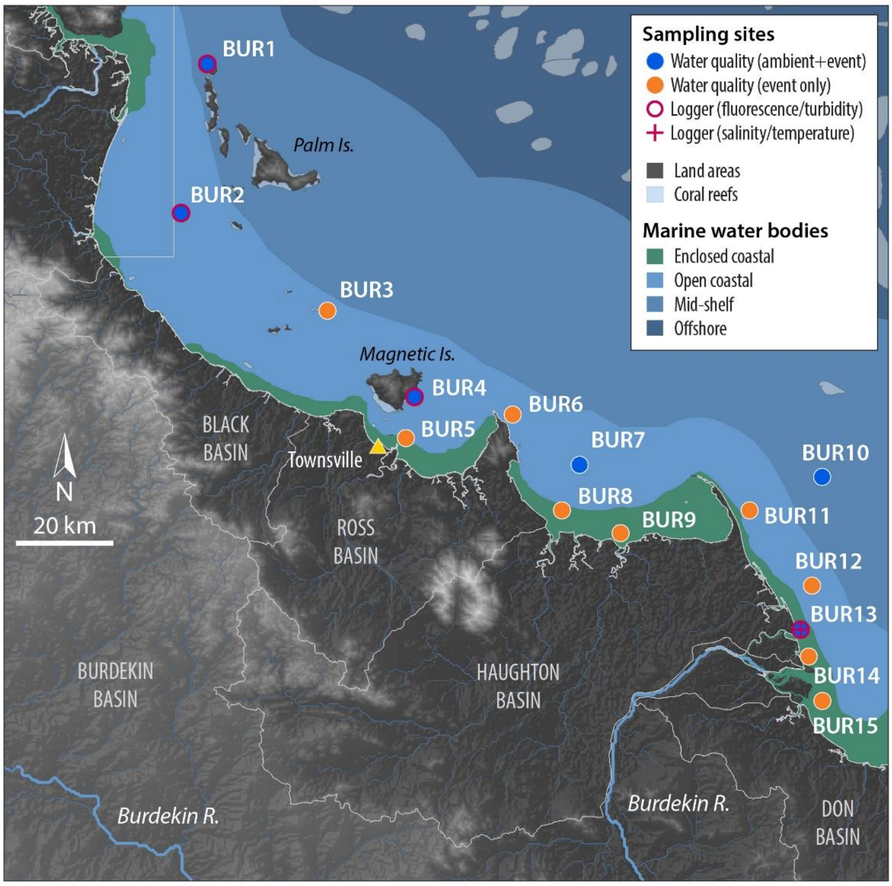


Figure 5-52: Sampling sites in the Burdekin focus area, shown with the water body boundaries.

The total discharge for the Burdekin region in 2021–22 was 1.2 times the long-term median (Figure 5-53; Table 3-1). The combined discharge and loads calculated for the 2021–22 water year from the Burdekin and Haughton Basins were in the lower range over the past decade (Figure 5-54). Over the 16-year period:

- Discharge has varied 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)
- 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.

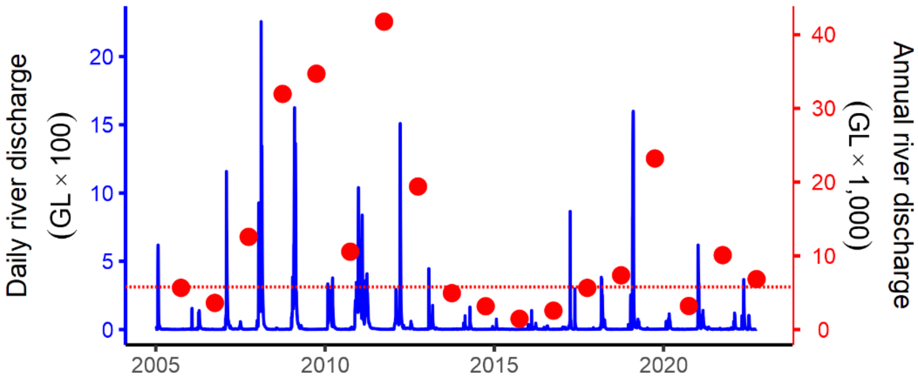


Figure 5-53: Total discharge for the Burdekin region (Table 2-3). Daily (blue) and water year (October to September, red) discharge is shown. Red dashed line represents the long-term median annual discharge.

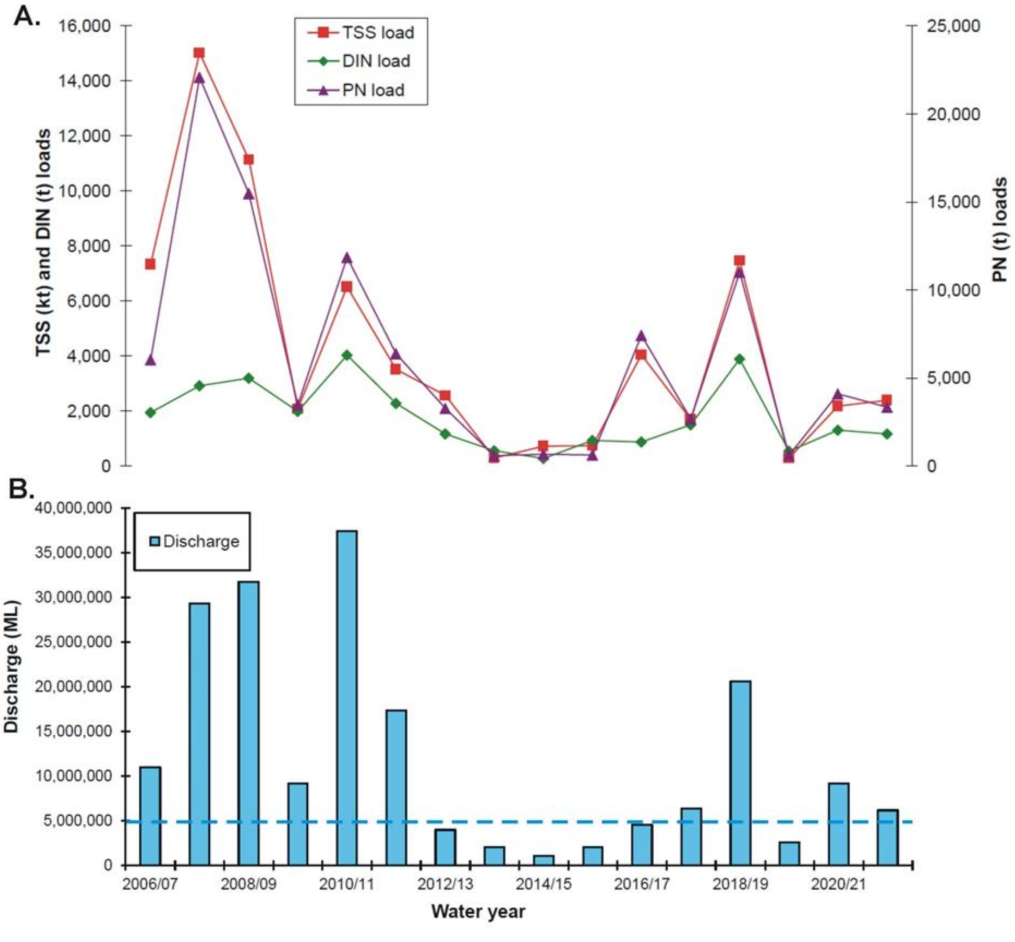


Figure 5-54: Loads of (A) TSS, DIN and PN and (B) discharge for the Burdekin and Haughton Basins from 2006 to 2022. The loads reported here are a combination of 'best estimates' for each basin based on 'up-scaled discharge data from gauging stations, monitoring data (Burdekin River), and annual mean 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 (Burdekin mouth to Palm Island group). Sites located nearest to the river mouth (distance from river mouth = 0 km) had high concentrations of TSS, Chl-*a*, PN, PP, and NO_x (Figure 5-55, Appendix C Table C-1). 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.

Seasonal differences in water quality are typically present for some variables. In previous years ambient monitoring during the wet season showed greater values of NO_x, PP, and PN than during the dry season (Moran *et al.* 2022). Concentrations of TSS, Chl-*a*, and Secchi depths are usually similar between wet and dry seasons. Dry season data was more variable and these seasonal differences were generally not present in the 2021–22 monitoring year (Figure 5-55), perhaps due to discharge events which occurred in the early dry season in 2022 (see below for further event monitoring details).

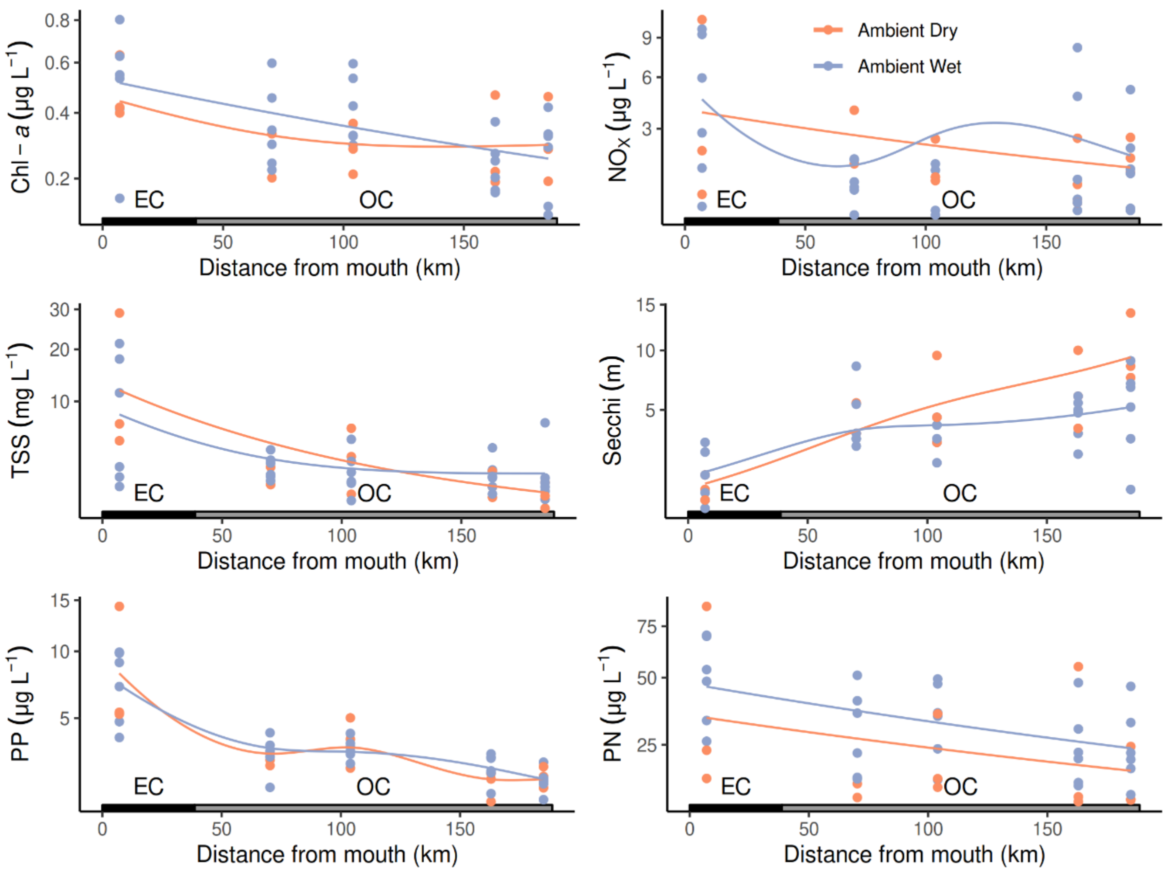


Figure 5-55: Water quality variables measured during ambient and event sampling in 2021–22 along the Burdekin focus region transect. Chlorophyll *a* (Chl-*a*), nitrate/nitrite (NO_x), total suspended solids (TSS), Secchi depth, particulate nitrogen (PN), and particulate phosphorus (PP) are shown with 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.

Long-term trends in water quality variables measured during ambient periods (i.e., not during peak flood events) of the dry and wet seasons are presented in Figure 5-56. It is important to note that this trend analysis removes variability associated with wind, tides, and seasons (see Methods). Thus, individual data points will have different values compared to raw data. This analysis is designed to detect **long-term** and **regional-scale** trends in water quality by removing the effect of short-term changes associated with weather and seasonal differences.

Distinct long-term trends (since 2005) were observed in some water quality variables, while others showed little change (Figure 5-56). Site-specific statistics and comparison to GVs for all variables are available in Appendix C Table C-1.

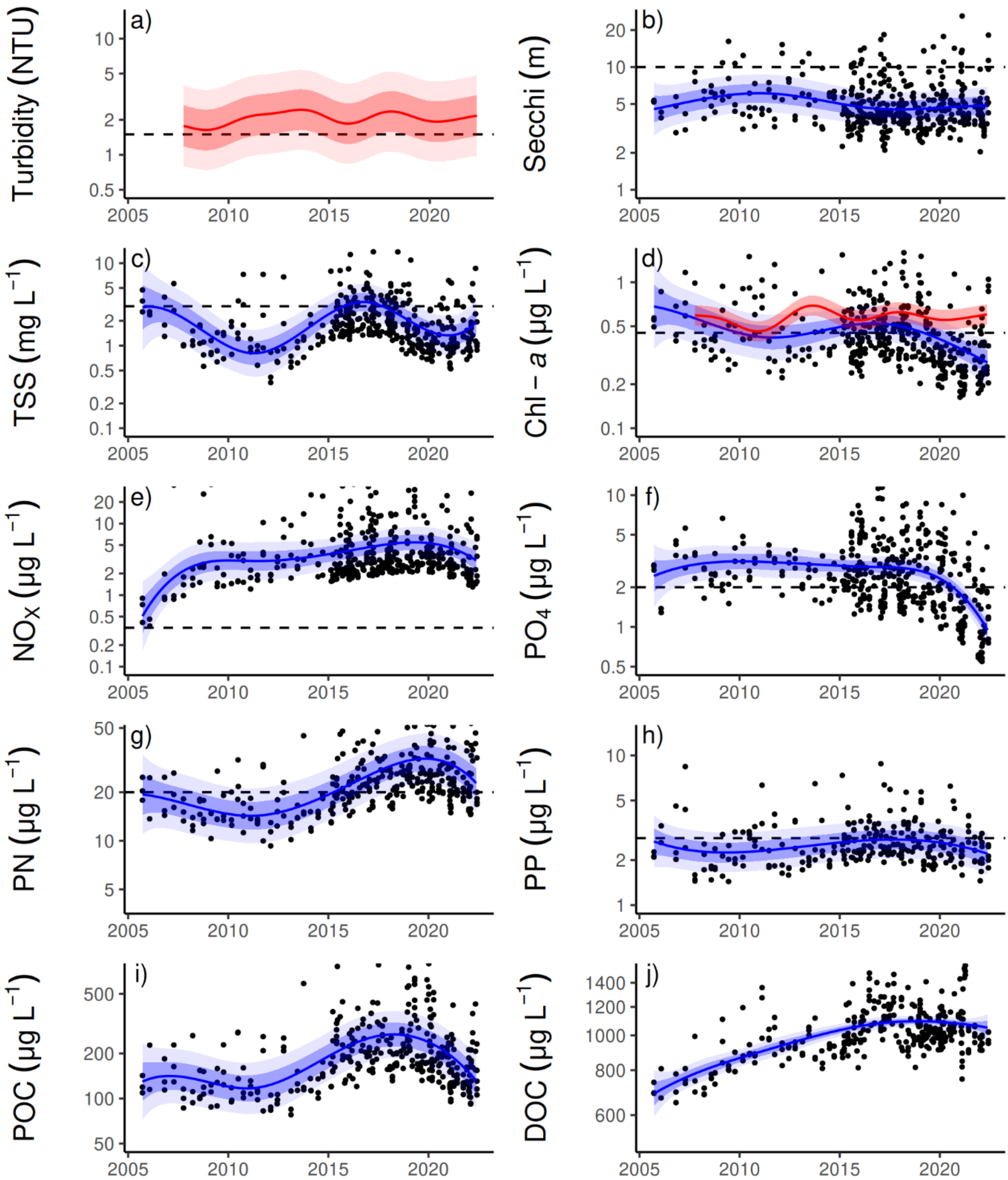


Figure 5-56: Temporal trends in water quality variables for the Burdekin focus region: a) turbidity, b) Secchi depth, c) total suspended solids (TSS), d) chlorophyll *a* (Chl-*a*), e) nitrate/nitrite (NO_x), f) phosphate (PO_4), g) particulate nitrogen (PN), h) particulate phosphorus (PP), i) particulate 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 Appendix C Figure C-1. Dashed horizontal reference lines indicate annual guidelines.

Concentrations of TSS have fluctuated since monitoring began in 2005. Analysis of trends shows that TSS has improved since 2017, but only marginally and is currently exceeding (not meeting) GVs at most sites in the Burdekin region.

Mean Secchi depth has been relatively stable since the inception of the MMP and is currently below (exceeding) the GVs.

Mean concentrations of Chl-*a* have varied around the GVs since 2005. There has been a general downward trend with concentrations currently below (meeting) water quality GVs at all sites.

Mean concentrations of PO_4 have remained relatively stable above GVs from 2005 until 2017. Since 2017, concentrations have declined and are currently below (meeting) the GVs at all sites, except at the river mouth where concentrations still exceed the GV.

Between 2008 and 2017, mean concentrations of NO_x gradually increased. Since 2017, concentrations have started to decline (improve) slightly, however they are still well above (exceeding) GVs.

Mean concentrations of PN have fluctuated above and below the GVs since 2010 and continue to be above (exceeding) the GVs.

Mean concentrations of PP have been relatively stable and close to GVs since the inception of the MMP. Since 2017, PP has decreased marginally and is currently below (meeting) the GVs at most sites.

Mean concentrations of POC generally increased between 2005 and 2017. Since 2017, concentrations have declined and are now back to around the 2005 levels. Mean concentrations of DOC have steadily increased from 2005 until 2020, with concentrations of DOC now stabilising.

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). The Methods section and Appendix B contain details of the calculations for both index formulations.

The long-term WQ Index has scored water quality as ‘good’ or ‘moderate’ since 2008 (Figure 5-57a). The long-term trend has shown a small (for example, change by a single grade) decline over the time-series since 2010. This downward trend has generally been driven by trends in PN and PP indicators. However, this year the long-term Index score has improved and is now ‘good’ for the first time since 2016–17. However, this ‘good’ score is on the boundary of the ‘moderate’-‘good’ scores.

The annual condition WQ Index scored water quality as ‘good’ for the 2019–20 water year (which was characterised by below-average river discharge) but returned to ‘moderate’ in 2020–21, as in each of the earlier four years (Figure 5-57b). In 2021–22 the annual Index score was once again scored as ‘moderate’. In this version of the Index, water quality parameters are scored against GVs relevant to the season when samples are collected (wet versus dry GVs). This index also includes additional sites in the open coastal water body to better characterise areas affected by river discharge.

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

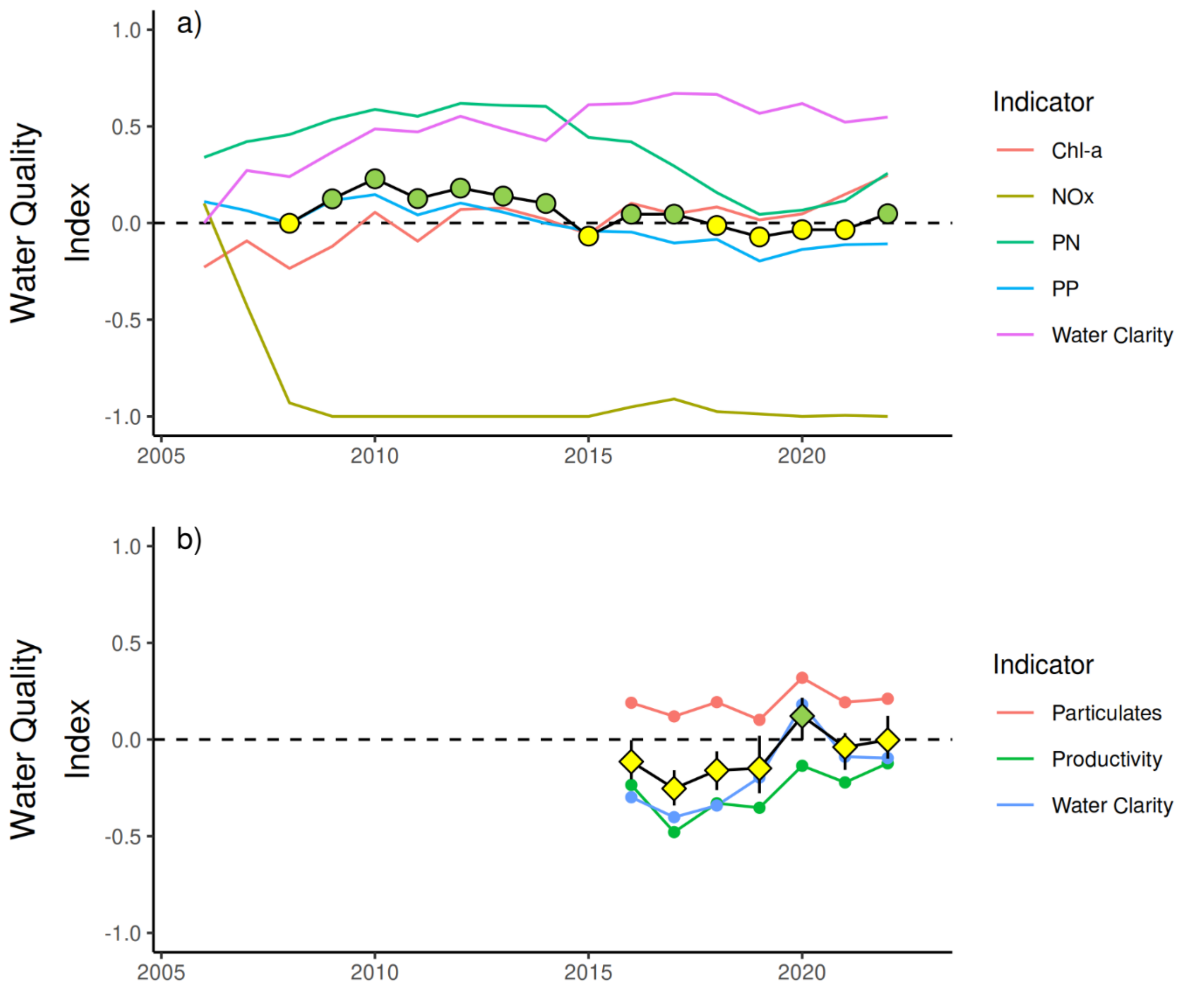


Figure 5-57: The Water Quality Index (WQ Index) for the Burdekin focus region. The WQ Index uses two formulations to communicate: a) long-term trend (based on pre-2015 sampling design) and b) the annual condition (based on post-2015 sampling design). WQ Index colour coding: ● / ◆– 'very good'; ● / ◆ – '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: Haughton River

The Haughton River had two flow events that exceeded the moderate flood level over the 2021–22 water year (Figure 5-58). The first event peaked at 6.77 m on 26 April 2022 and the second event peaked slightly higher at 6.84 m on 11 May 2022. Flood plume event sampling occurred two days after this peak.

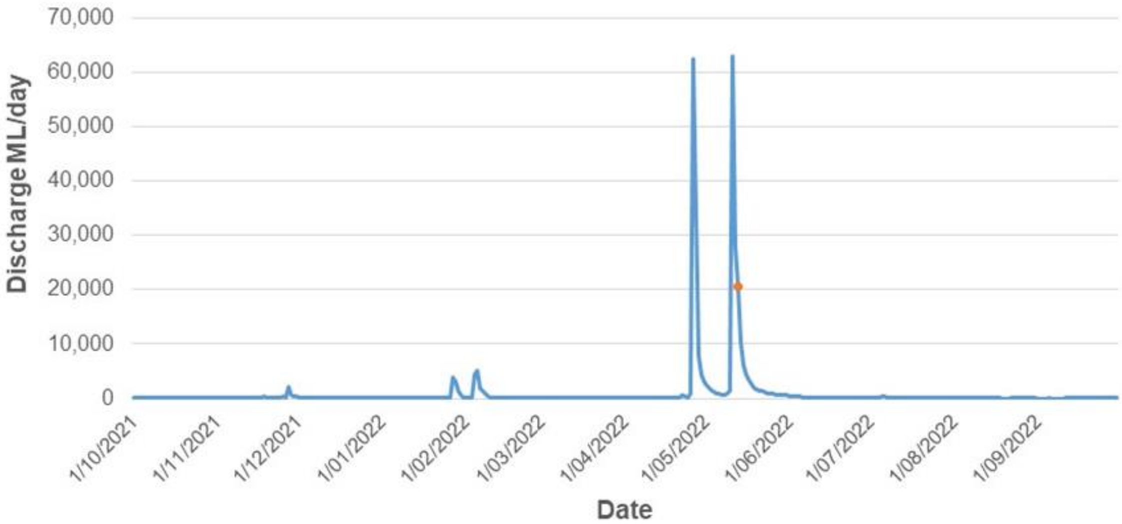


Figure 5-58: Haughton River at Powerline flow gauge record for the 2021–22 water year. The period of offshore sampling by JCU is marked as an orange dot.

The two standard event monitoring sites off the Burdekin region were sampled (BUR7 and BUR8) along with additional sites that comprise an offshore transect from the Haughton River mouth. Selected results from the water column profiling are shown in Figure 5-59. The profiles of salinity show the increasing influence of the river flood plume in the upper ~ 3 m of the water column towards the river mouth, while the most distal site from the river (i.e., HAU2) showed no apparent plume influence. Indeed, the Forel Ule colour map of the Haughton flood plume from the day of sampling showed that the HAU2 site was outside the main flood plume boundary and in the Reef WT3. The light profiles show increasing PAR light available at greater depths from the river mouth to the more offshore sites (Figure 5-59).

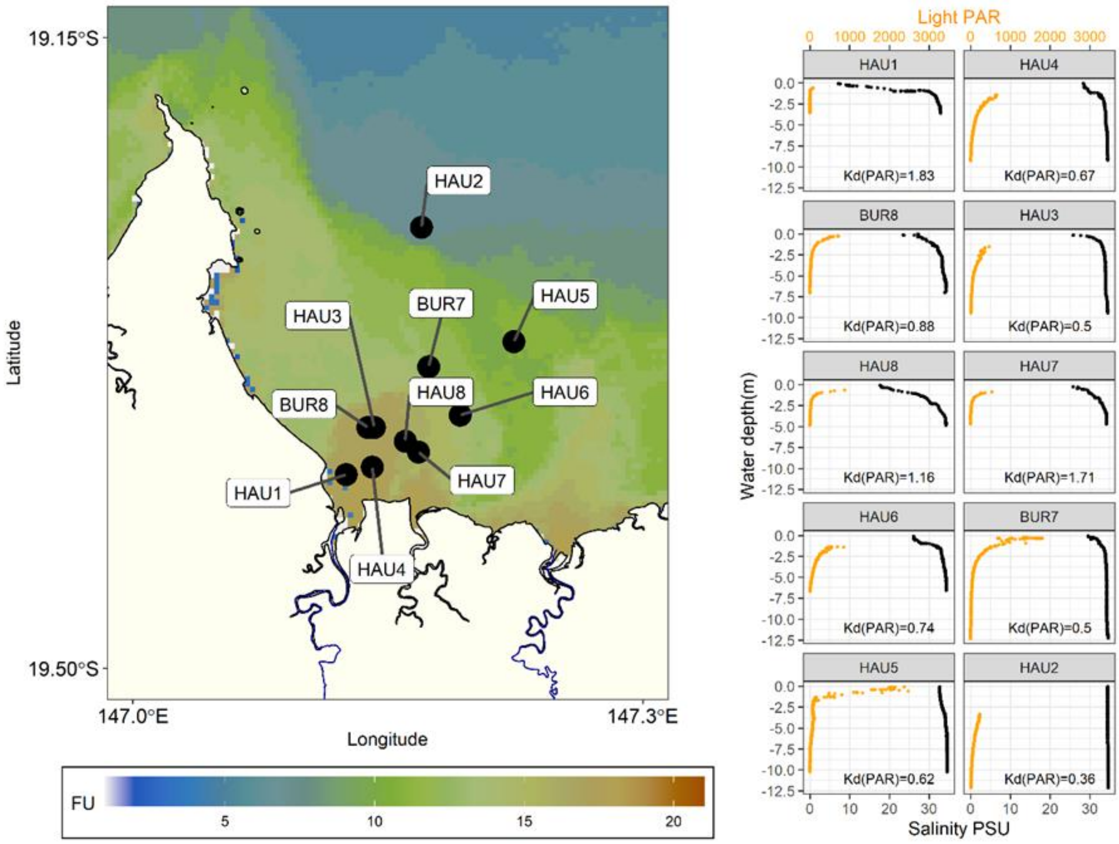


Figure 5-59: Event monitoring outputs for the Haughton River. Left panel: map of the offshore area off the Haughton River mouth (at the HAU1 site) overlaid on a Forel Ule (FU) colour map produced from the Sentinel 3 satellite image from the day of sampling; right panel: plots of the water column profiles of salinity (black lines) and PAR light (orange lines) at the sites shown on the map.

In contrast to the data from the Tully and Burdekin focus areas, the TSS, PN and PP data from the Haughton flood plume showed lower variability over the estuarine mixing gradient, with the exception of the 0 PSU salinity samples for PN and PP (Figure 5-60 and Figure 5-61). The nitrate concentrations in the plume generally declined over the whole estuarine gradient, while Chl-*a* concentrations show a general increasing trend over the salinity gradient (Figure 5-60). Given the relatively low initial nitrate concentrations (Figure 5-60) in the Haughton plume (i.e., ~ threefold lower than both the Tully and Burdekin plumes), it is likely the freshwater from this plume was sourced from the upper catchment area.

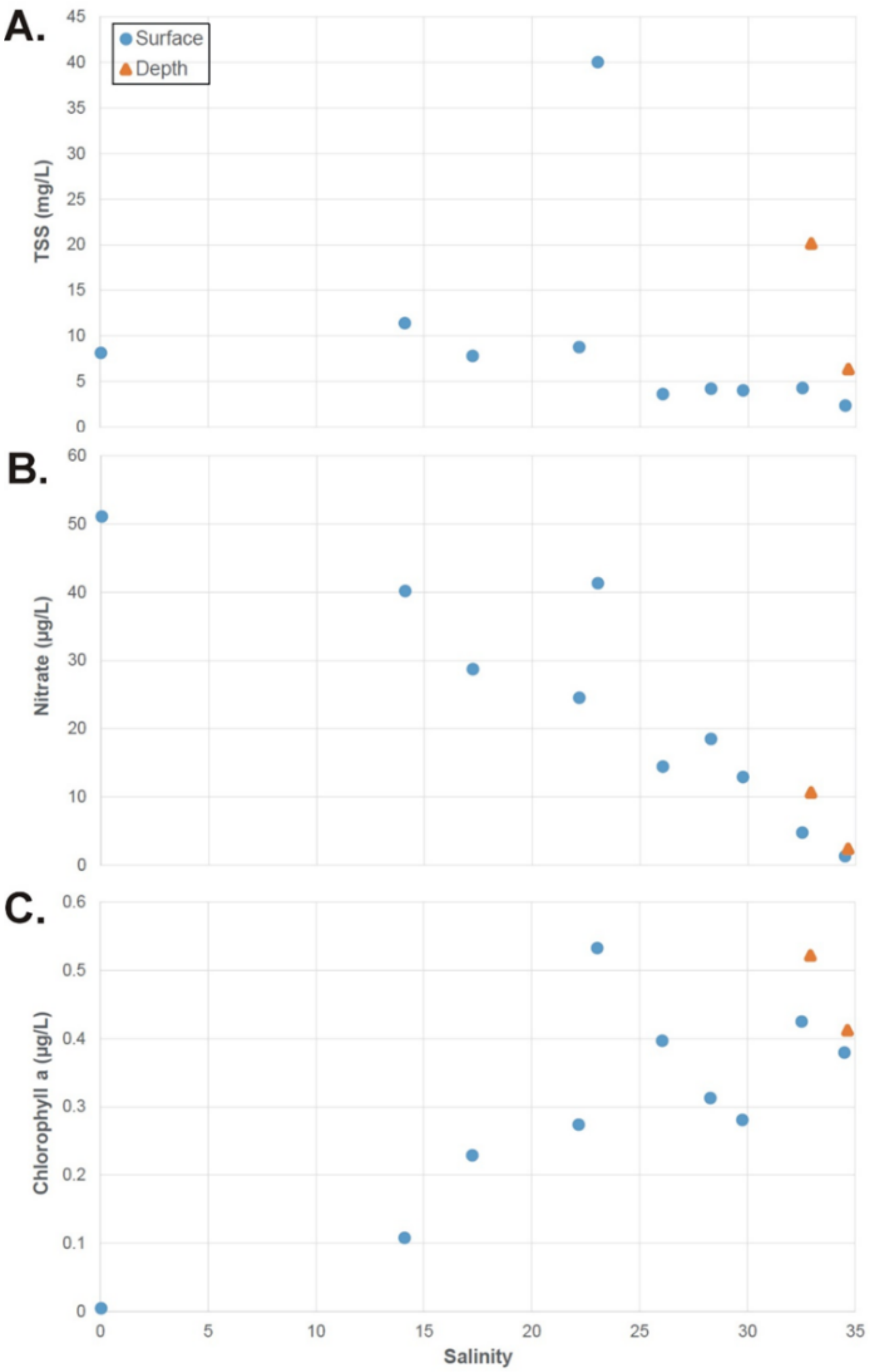


Figure 5-60: Water quality data from the Haughton focus region under the influence of flood plumes over the 2021–22 wet season including TSS (A), nitrate (B) and chlorophyll *a* (C) plotted over the salinity gradient. Surface samples are plotted as circles and depth samples as triangles.

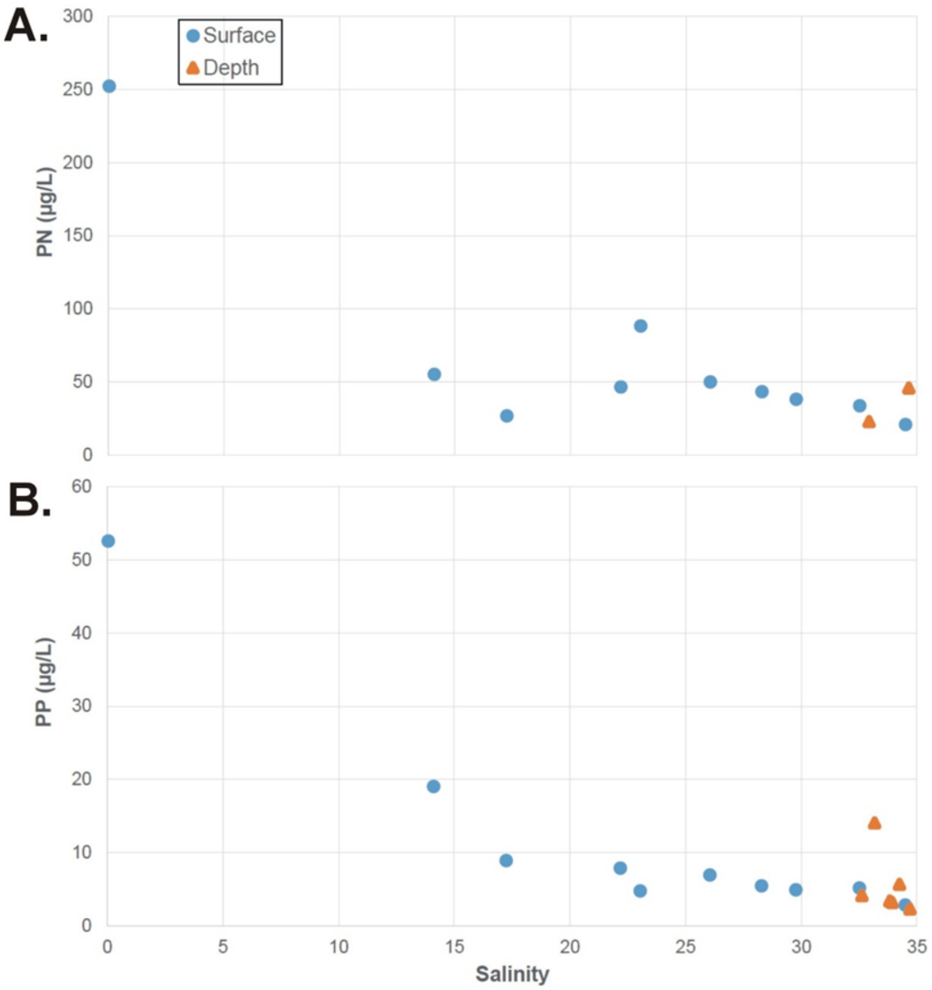


Figure 5-61: Water quality data from the Haughton focus region under the influence of flood plumes over the 2021–22 wet season including PN (A) and PP (B) plotted over the salinity gradient. Surface samples are plotted as circles and depth samples as triangles.

Event water quality: Burdekin River

There were no flood events in the downstream reaches of the Burdekin River that exceeded the minor flood level (= 9.0 m at the Clare gauge site) in the 2021–22 season. There was one strong flow event that peaked just below this flood level at 7.5 m on 15 May 2022 (Figure 5-62). The event did cause flooding (i.e., above minor/moderate flood levels) in some of the upstream tributaries of the Burdekin River. This flow event was subject to flood plume event sampling two days after this peak and the following section presents the water quality data from this sampling campaign.

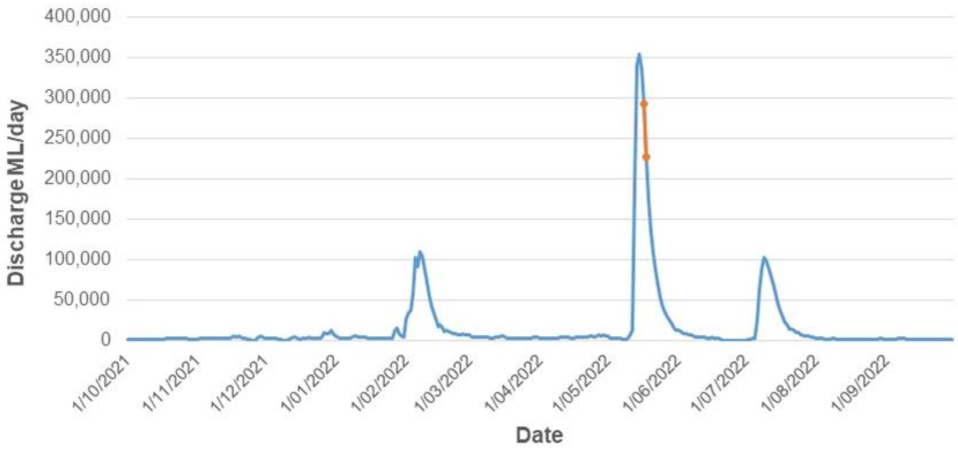


Figure 5-62: Burdekin River at Clare flow gauge record for the 2021–22 water year. The period of offshore sampling by JCU is marked as an orange dotted line.

All the standard event monitoring sites off the Burdekin region were sampled. Water column measurements using the Seabird CTD were performed at additional sites along the plume gradient where a distinct transition in the colour of the water was observed (i.e., the site locations highlighted in Figure 5-63). Selected results from the water column profiling are shown in Figure 5-63. The profiles of salinity show that the freshwater from the Burdekin River was concentrated in the upper ~5 m of the water column near the river mouth. Further offshore from the river mouth, the surface waters become relatively more saline but mix to a greater depths in the water column (Figure 5-63). For example, the BUR12 site near the Burdekin mouth had a surface salinity of ~20 PSU (note that the measured salinity in the surface sample taken at this site was 6 PSU) and the plume was constrained within the upper 5 m of the water column, while BUR3 off Acheron Island had a surface salinity of ~32 PSU and the presence of the plume was extended to within the upper ~10 m of the water column. All sampled sites revealed at least some reduction of salinity associated with the Burdekin flood plume, or in the case of the northern sites possibly also from additional river plumes. The light profiles show increasing PAR light available at greater depths from the river mouth to the more distal sites offshore, while the Forel Ule images from the sites show the brown turbid waters (i.e., Reef WT1) from the sites near or at the river mouth becoming greener (i.e., Reef WT2) in the sections that were further offshore, but still under the influence of plume waters, and becoming bluer (i.e., Reef WT3) in the sections that were still under some influence of the plume (Figure 5-63). Note that the different colours of blue from the Forel Ule images in Figure 5-63 are the result of sampling at different times of the day (early morning to midday), under different levels of cloud cover (i.e., direct/indirect sunlight) and at different water depths.

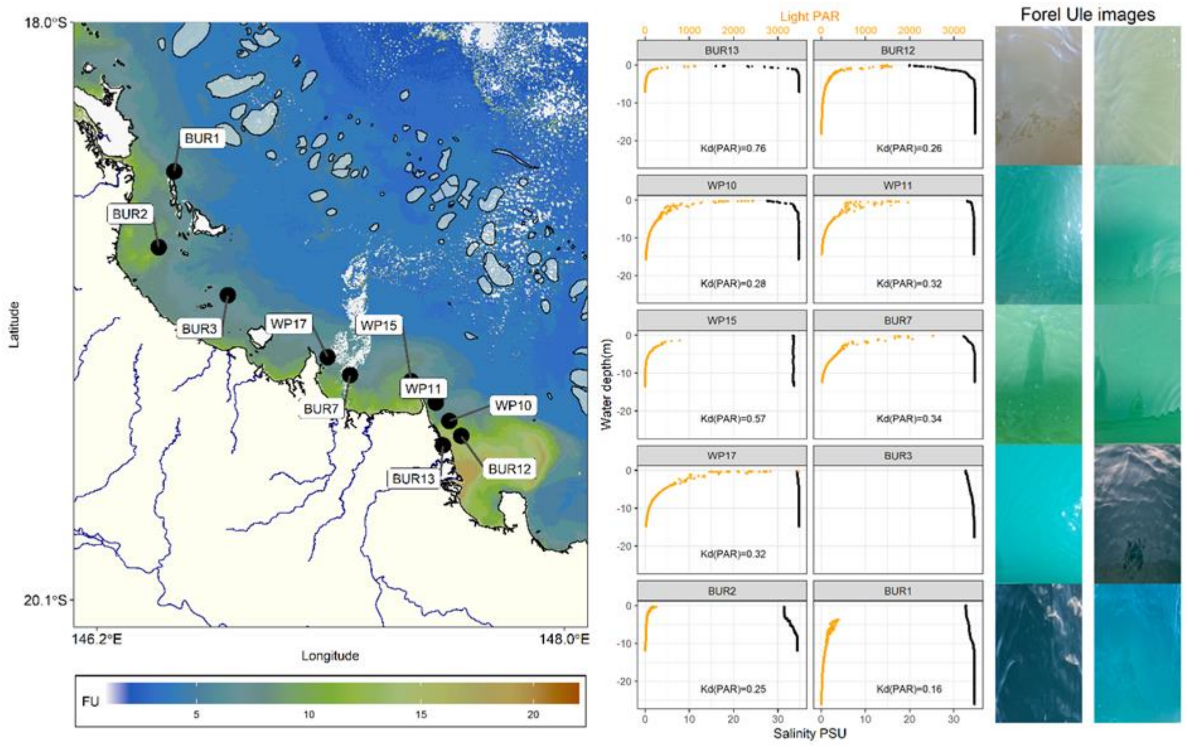


Figure 5-63: Event monitoring outputs for the Burdekin River. Left panel: map of the offshore area off the Burdekin River mouth (at the BUR13 site) overlaid on a Forel Ule (FU) colour map produced from the Sentinel 3 satellite image from the day of sampling; middle panel: plots of the water column profiles of salinity (black lines) and light (orange lines) at the sites shown on the map; right panel: corresponding images of the water colour at each sampled site.

The water quality data for the Burdekin focus area provides clear trends in the flood plume samples collected over the inshore-offshore sites and over the salinity gradient (Figure 5-64 and Figure 5-65). The sampling also provides important insights on the difference between the surface and depth samples (which have been separated in the plots). In general, the surface water samples taken over the salinity gradient (i.e. from the freshwater to marine waters) show that TSS, nitrate (Figure 5-64), PN, and PP (Figure 5-65) concentrations decline across the gradient. The elevated concentrations of TSS, PN and PP in the samples, coinciding with relatively low salinity (i.e., < 30 PSU), are primarily related to the influence from the Burdekin River as the depth samples all returned relatively lower concentrations and were all > 30 PSU. The TSS concentrations in the Burdekin River estuarine mixing zone are difficult to plot as concentrations rapidly declined from 0 PSU (316 mg L^{-1}) to 6 PSU (21 mg L^{-1}) to 9 PSU (9.7 mg L^{-1}) and mostly remained below 5 mg L^{-1} with salinities > 10 PSU. This finding is consistent with previous monitoring of the Burdekin plume. The nitrate concentrations generally followed a declining linear trend over the estuarine mixing zone from 0 to ~20 PSU before becoming rapidly depleted in the remaining 20 to 35 PSU salinity zone (Figure 5-64). The Chl-*a* concentrations were more variable in the Burdekin plume and show no obvious trend (Figure 5-64).

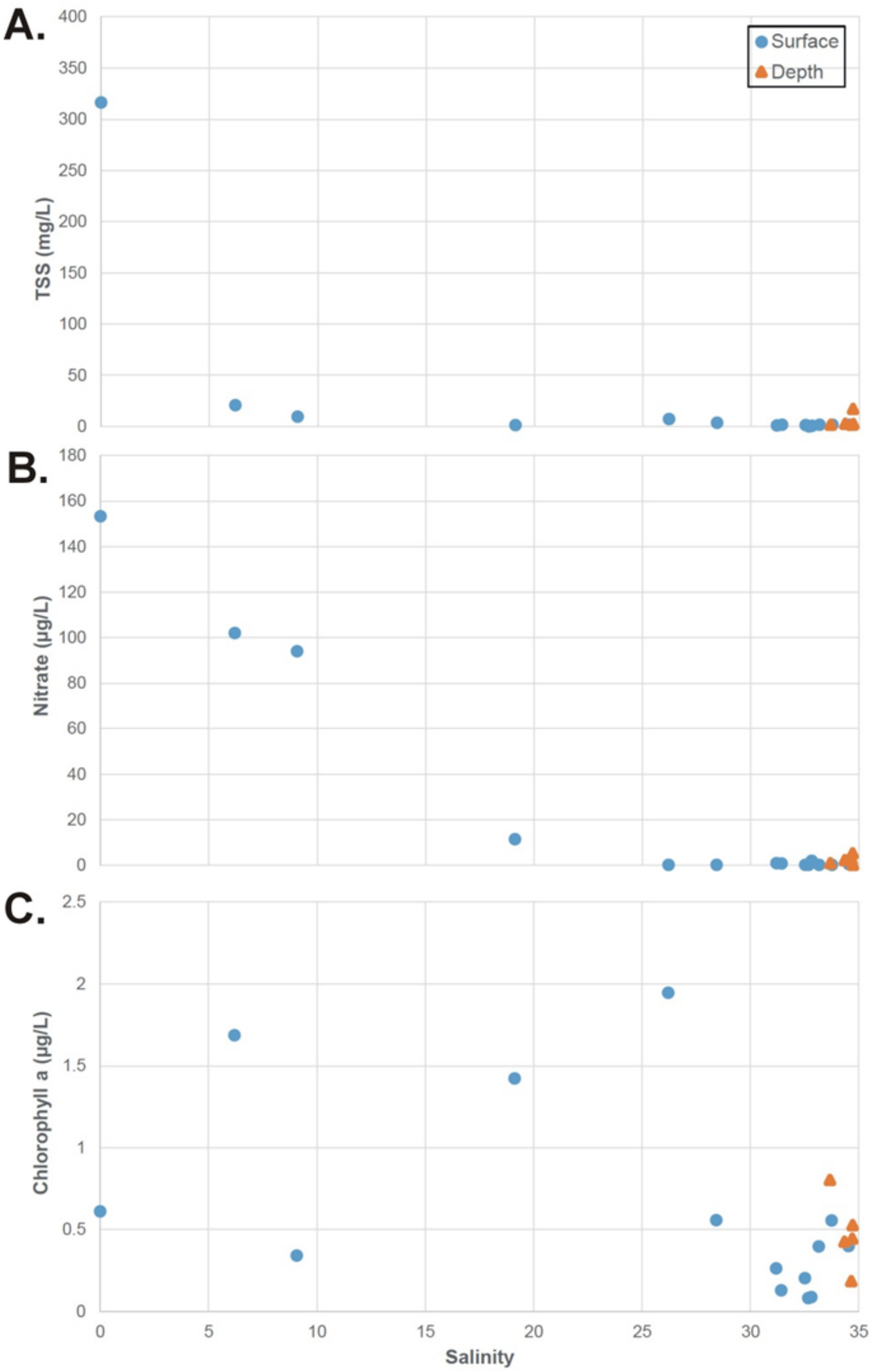


Figure 5-64: Water quality data from the Burdekin focus region under the influence of flood plumes over the 2021–22 wet season including TSS (A), nitrate (B) and chlorophyll *a* (C) plotted over the salinity gradient. Surface samples are plotted as circles and depth samples as triangles.

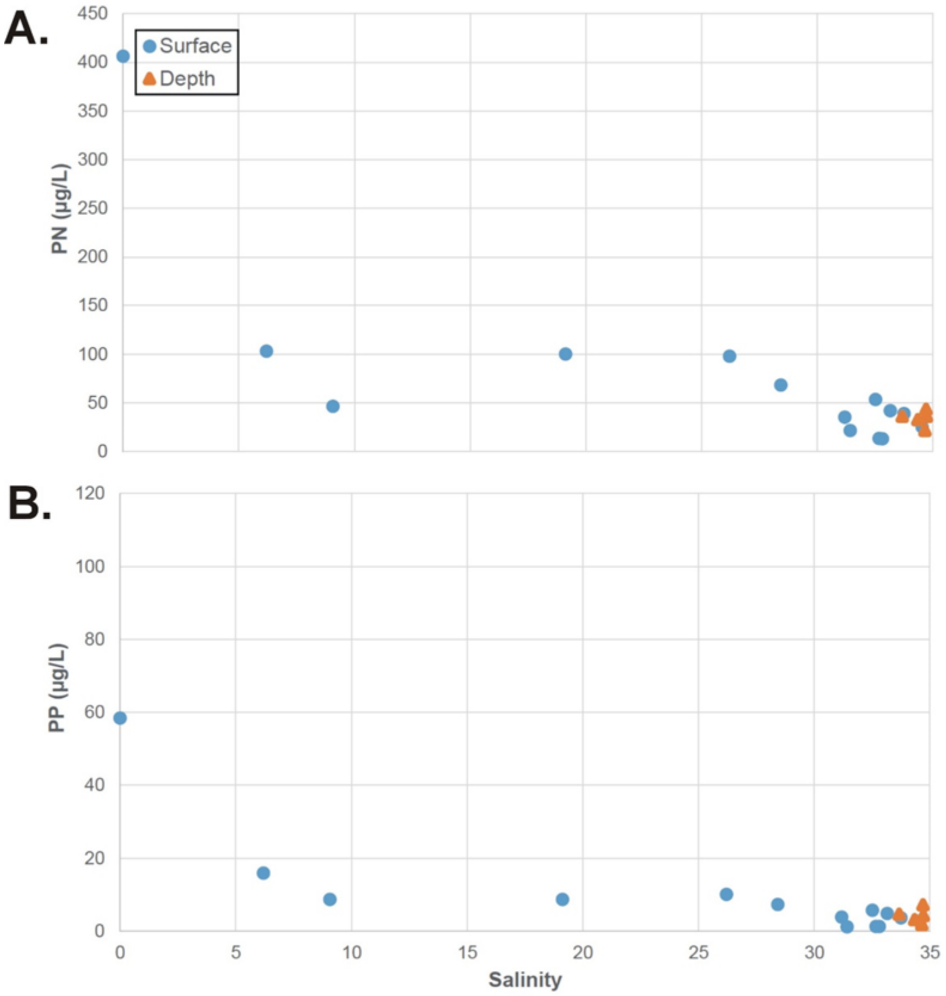


Figure 5-65: Water quality data from the Burdekin focus region under the influence of flood plumes over the 2021–22 wet season including PN (A) and PP (B) plotted over the salinity gradient. Surface samples are plotted as circles and depth samples as triangles.

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 area 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 5-66).

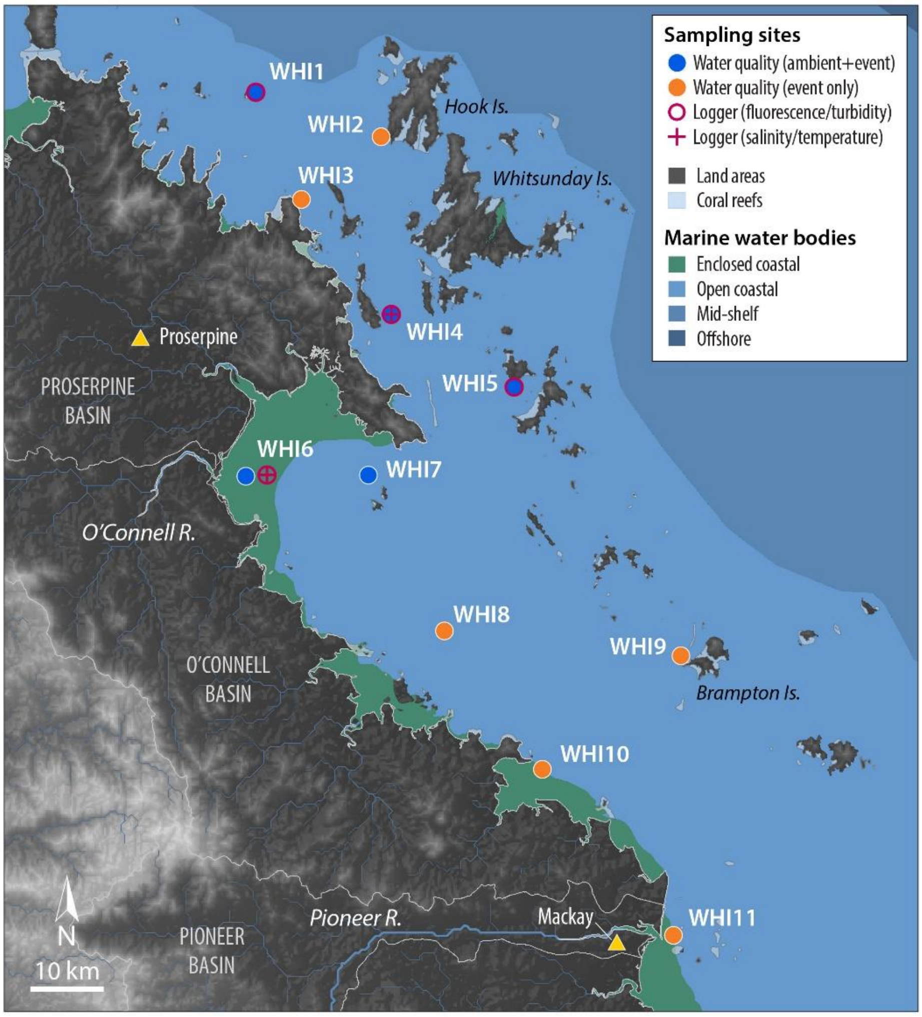


Figure 5-66: Sampling sites in the Mackay-Whitsunday focus area, shown with the water body boundaries.

Annual discharge for the Mackay-Whitsunday region this year was well below the long-term median level (Figure 5-67). Discharge levels were similar to discharge during the previous two seasons and the 2017–18 water year. Annual discharge from the individual basins were around or below half of the long-term median values (Table 3-1).

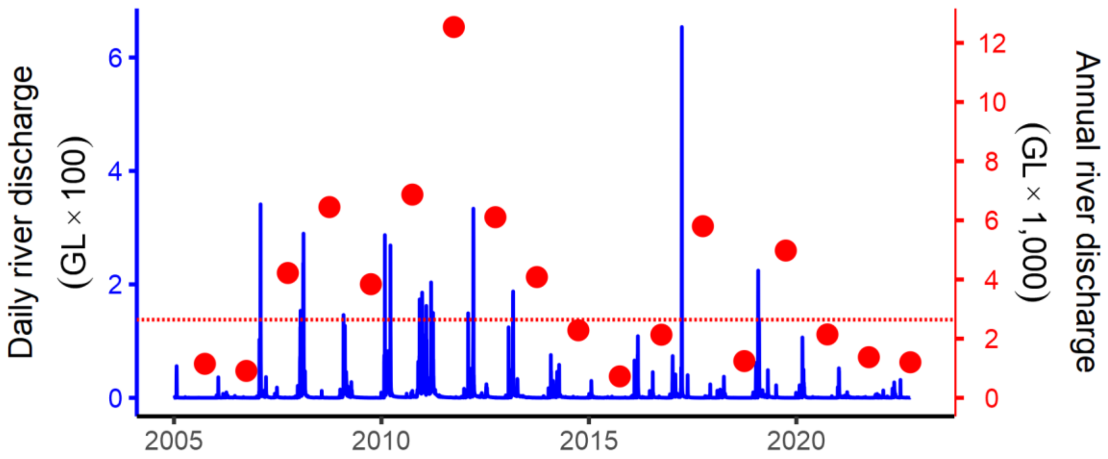


Figure 5-67: Combined discharge for the Mackay-Whitsunday focus region. Daily (blue) and water year (October to September, red) discharge is shown. Red dashed line represents the long-term median of the combined annual discharges. See Table 2-3 for a list of flow gauge data used. Please note as this is the combined discharge, high flows in one river will not necessarily be visible in the graph.

The combined discharge and loads calculated for the 2021–22 water year from the Proserpine, O'Connell, Pioneer and Plane Basins (Figure 5-68) were among the lowest recorded over the past decade. Over the 17-year period:

- Discharge has varied 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)
- PN loads ranged from 356 t (2014–15) to 8,564.

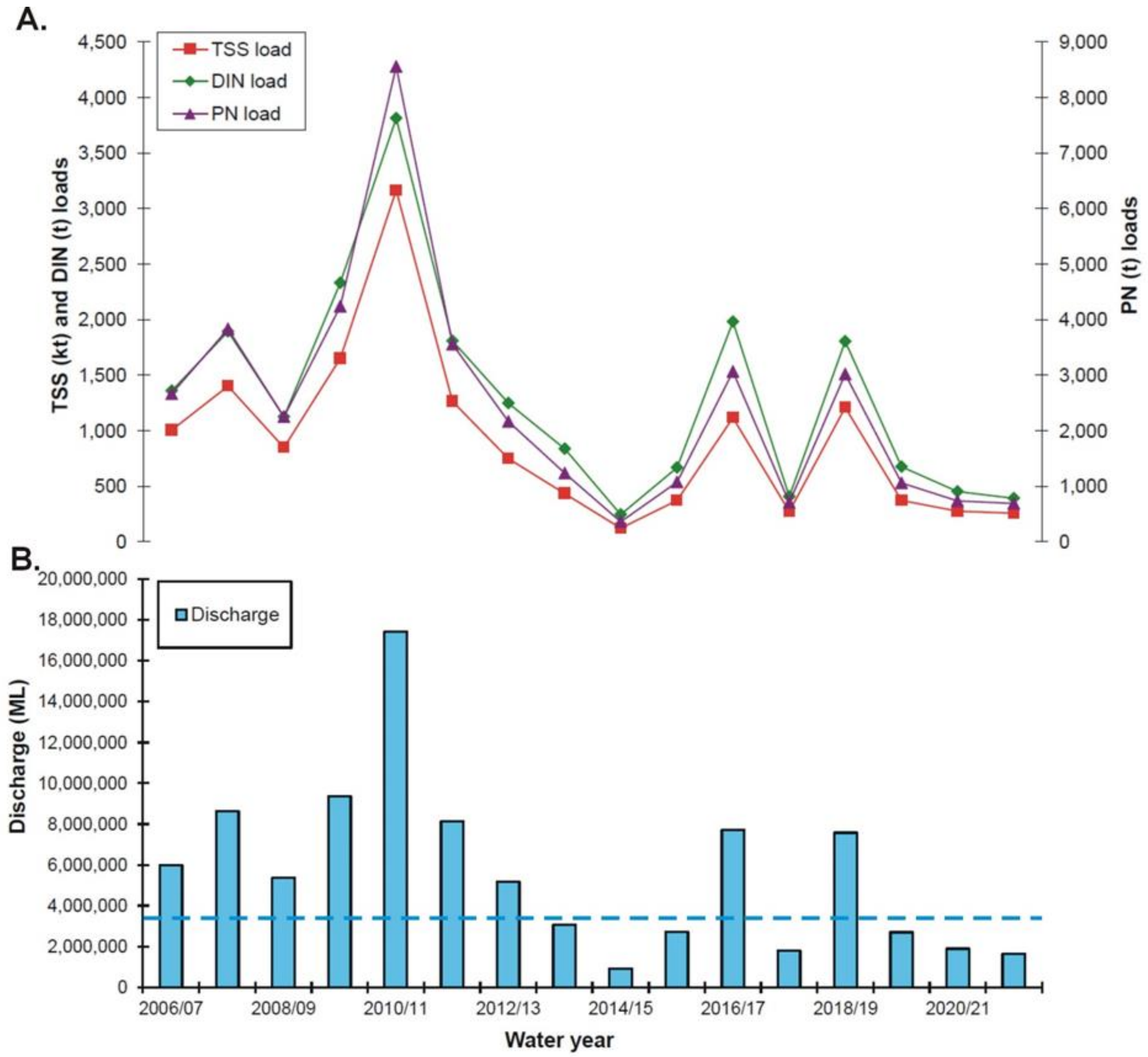


Figure 5-68: Loads of (A) TSS, DIN and PN and (B) discharge for the Proserpine, O'Connell, Pioneer, and Plane Basins from 2006 to 2022. The loads reported here are a combination of 'best estimates' for each basin based on 'up-scaled discharge data from gauging stations, monitoring data (O'Connell and 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 weak 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 higher concentrations of TSS, Chl-*a*, NO_x and particulate nutrients (PN and PP), which declined with distance away from the river mouth (Figure 5-69). Secchi depths were lower at sites near the river mouth (water clarity was poor) and increased (water clarity improved) with distance from the river mouth. Concentrations of most water quality parameters were highly variable in this focus region and across seasons, which is likely related to its large tidal range and physical oceanographic characteristics.

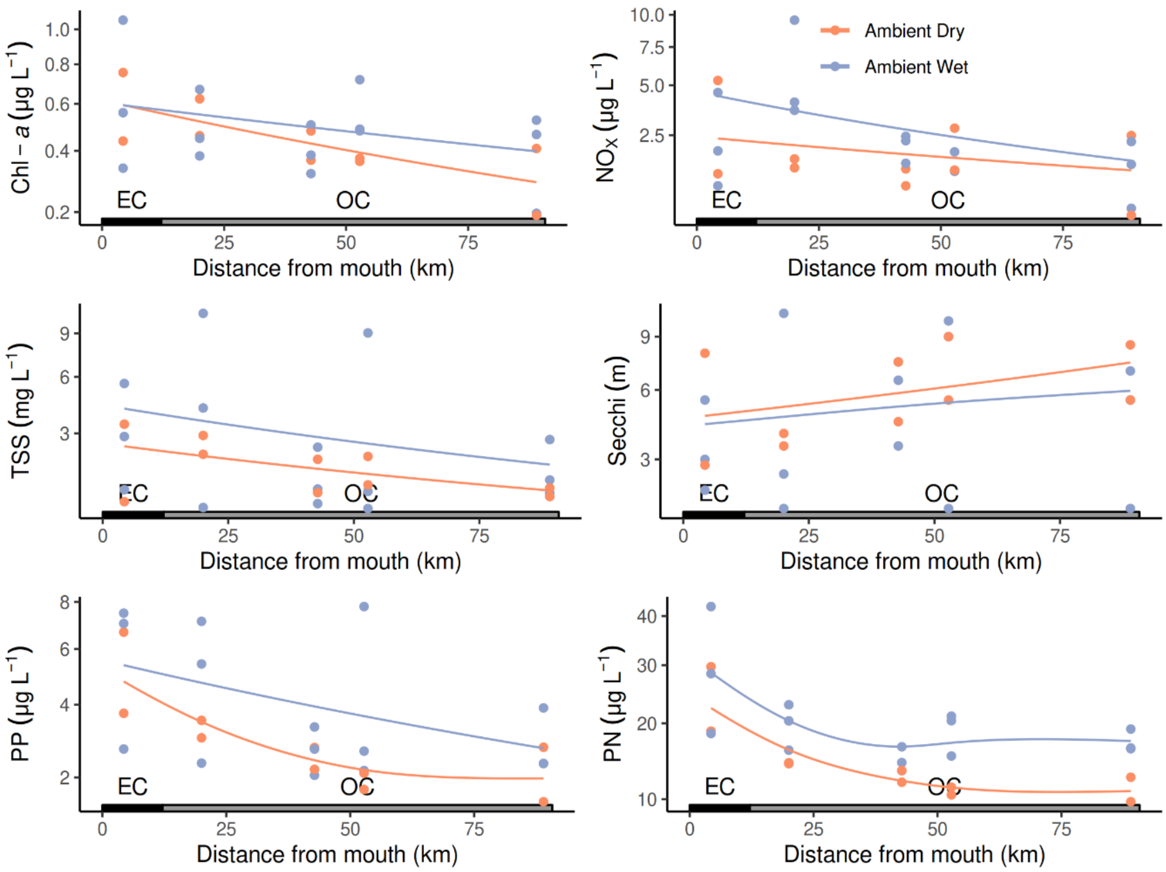


Figure 5-69: Water quality variables measured during ambient and event sampling in 2021–22 along the Mackay-Whitsunday focus region transect. Chlorophyll *a* (Chl-*a*), nitrate/nitrite (NO_x), total suspended solids (TSS), Secchi depth, particulate nitrogen (PN), and particulate phosphorus (PP) are shown 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.

There were seasonal differences in the concentrations for some variables - ambient monitoring during the wet season tended to show marginally poorer values (Figure 5-69).

Long-term trends in water quality variables, measured during ambient periods (for example, not during peak flood events) of the dry and wet seasons, are presented in Figure 5-70. It is important to note that this trend analysis removes variability associated with wind, tides, and seasons (see Methods). Thus, individual data points will have different values compared to raw data. This analysis is designed to detect **long-term** and **regional-scale** trends in water quality by removing the effect of short-term changes associated with weather and seasonal differences.

Distinct long-term trends (since 2005) were observed in some water quality variables, while others showed little change (Figure 5-70). Site-specific statistics and comparison to GVs for all variables are available in Appendix C Table C-1.

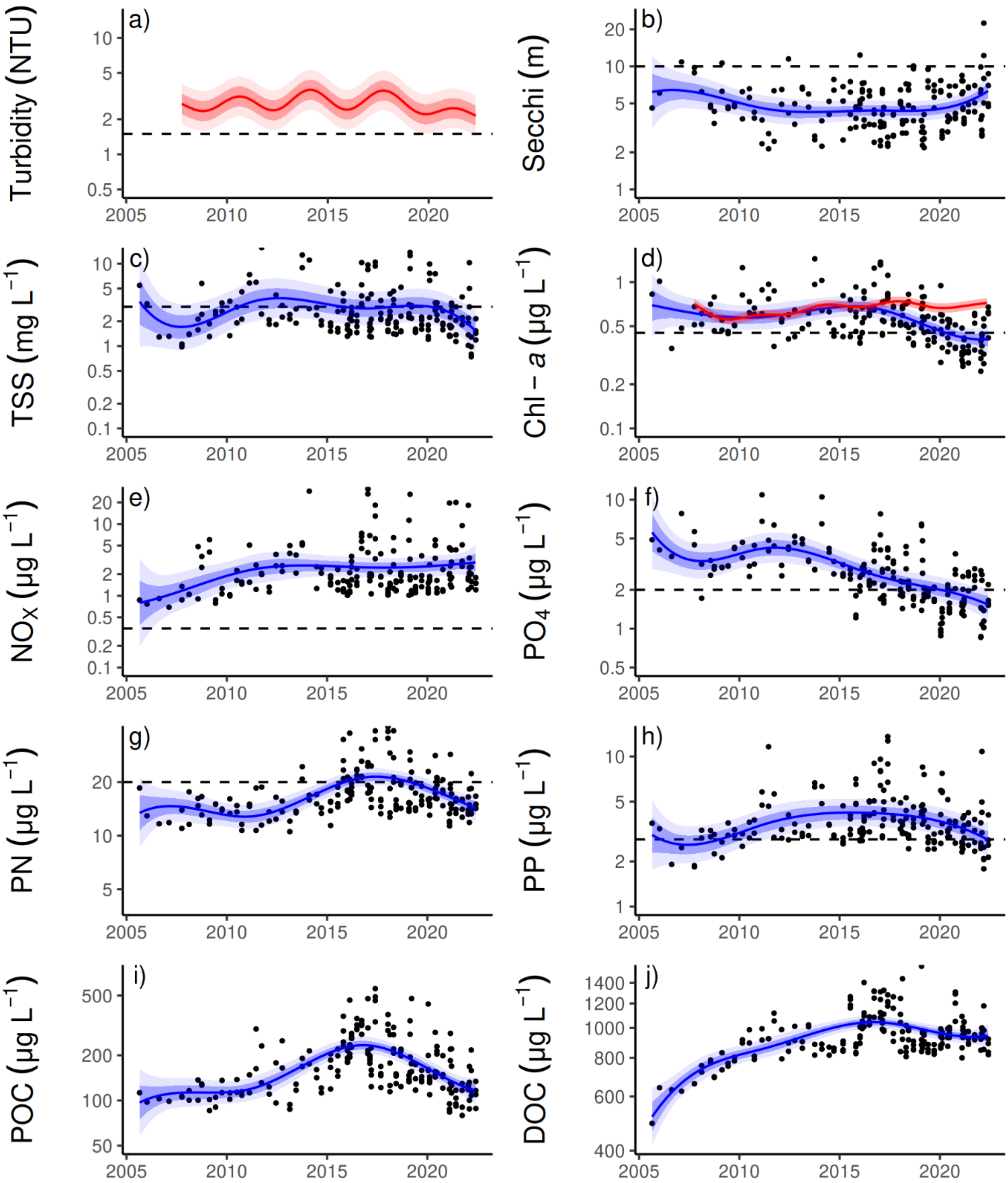


Figure 5-70: Temporal trends in water quality variables for the Mackay-Whitsunday focus region: a) turbidity, b) Secchi depth, c) total suspended solids (TSS), d) chlorophyll *a* (Chl-*a*), e) nitrate/nitrite (NO_x), f) phosphate (PO_4), g) particulate nitrogen (PN), h) particulate phosphorus (PP), i) 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 Appendix C Figure C-1. Dashed horizontal reference lines indicate annual guidelines.

Mean concentrations of TSS have generally fluctuated around GVs (Great Barrier Reef Marine Park Authority, 2010) since monitoring began in 2005. Analysis of trends shows that from 2017–2022, mean concentrations of TSS have improved slightly and are currently meeting Guideline Values (GVs) at most sites.

Mean Secchi depth has been relatively stable since 2008; however, analysis of trends shows that from 2017–22, Secchi depths have increased (improved) but are still currently below (not meeting) the GV.

Mean concentrations of Chl-*a* have generally remained stable, slightly exceeding the GVs (Great Barrier Reef Marine Park Authority, 2010) since 2005 until around 2017. Analysis of trends shows that from 2017–22, mean concentrations of Chl-*a* have improved, yet Chl-*a* is currently close to the GVs at many sites and is still generally exceeding the GVs overall.

Mean concentrations of PO_4 have markedly declined since the inception of the MMP, and analysis of trends shows that from 2017–22 concentrations have continued to decline (improve). PO_4 concentrations overall are close the GVs but are still exceeding the GVs at many sites.

Mean concentrations of NO_x have been relatively stable since 2010. Analysis of trends shows that from 2017–22 concentrations have remained stable but continue to be well above (exceeding) GVs.

Mean concentrations of PN and PP have varied around the GVs since the inception of the MMP. Analysis of trends shows that from 2017–22, mean concentrations of both PN and PP have decreased (improved) slightly and PN is now below (meeting) the GVs at most sites. PP is just above (exceeding) the GVs at some sites and is below (meeting) the GVs at others but overall is close to the GVs for the region.

Mean concentrations of POC have varied while concentrations of DOC have generally increased since 2005. However, analysis of trends shows that from 2017–22, POC and DOC have both decreased slightly. However, DOC continues to remain at some of the highest concentrations recorded since 2005.

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

The long-term WQ Index has scored water quality as 'moderate' or 'poor' since 2008 (Figure 5-71a). The long-term trend has shown a small (for example, change by a single grade) decline over the time-series since 2008 but has shown improvement over the last three years and is now 'moderate'. This downward trend and recent improvement have generally been driven by trends in water clarity, PN, and PP indicators.

The annual condition WQ Index scored water quality as 'moderate' for the previous five years and 'moderate' for the 2021–22 water year (Figure 5-71b). This version of the Index scores water quality parameters against GVs relevant to the season when samples are collected (wet versus dry GVs) and includes additional sites in the open coastal water body to better characterise areas affected by river discharge.

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

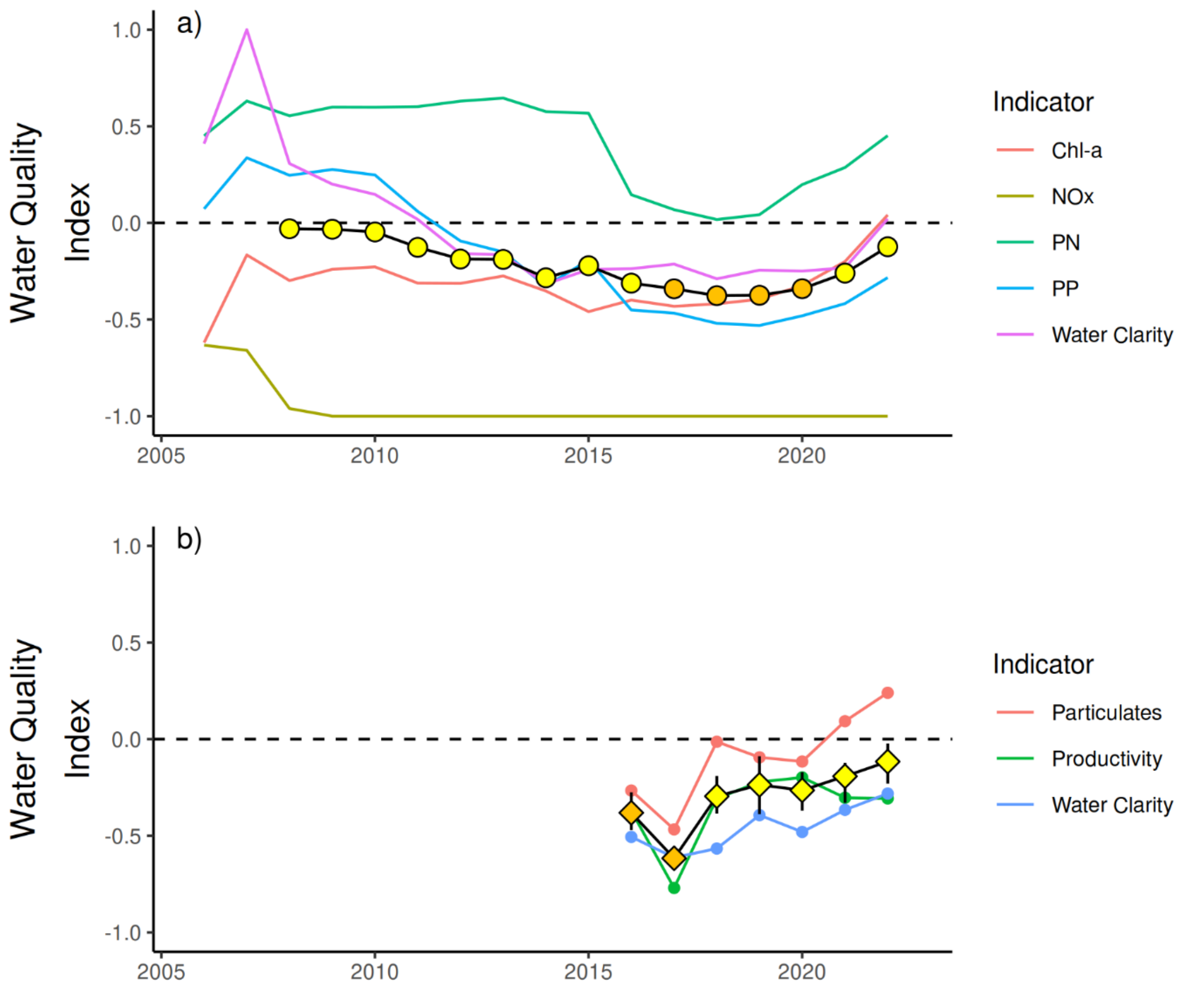


Figure 5-71: The Water Quality Index (WQ Index) for the Mackay-Whitsunday focus region. The WQ Index uses two formulations to communicate: a) long-term trend (based on pre-2015 sampling design) and b) the annual condition (based on post-2015 sampling design). WQ Index colour coding: ● / ◆– 'very good'; ● / ◆ – '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

No event sampling was conducted in the 2021–22 wet season in the Mackay-Whitsunday focus area.

6 Conclusions

This section provides major conclusions from water quality monitoring efforts in nine focus areas spanning four NRM regions.

The river discharges in most water quality focus regions of the Reef were close to the long-term median during the 2021–22 wet season. The exceptions to this were the Mackay-Whitsunday region, where discharge was around half of the long-term median, and the Burnett-Mary region, where very high discharge was recorded. There are currently no *in situ* water quality monitoring efforts in the Burnett-Mary region. The results from the 2021–22 year presented in this report reflect a water quality response to the near-median discharge conditions and associated end-of-catchment pollutant loads that were experienced in the 2021–22 water year. Long-term trends presented in this report reflect near- or below-median discharge conditions that have also been experienced over the past ~3 years for many of the Reef catchments.

In 2021–22, 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 ‘good’ or ‘moderate’ in most focus regions in 2021–22, with the Annan-Endeavour focus region receiving a ‘very good’ score.

Recent trend analysis based on the previous five years of monitoring data (presented in the GAMMs) indicates that many water quality indicators are showing signs of stability or improvement within the focus regions. This is likely a product of near- or below-median river discharge over the last ~3 years, with no major flood events impacting most of the Reef catchments in recent years.

In 2021–22, some indicators were generally meeting GVs including Chl-*a*, PO_4, and TSS. NO_x and Secchi depth typically exceeded GVs across all focus regions, despite recent trends of improvement in these parameters. PN and PP had variable results between focus regions, and were meeting GVs in some regions while exceeding GVs in others. 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, 2021–22. * 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 2021–22**	**Long-term**
Reef-wide	Cyclone Tiffany (early Jan) Ex-Cyclone Seth (early-mid Jan)	<1.5	Reef: 12% → • **Note** ↗ (+7%) in coral area exposed to lowest cat of risk (II). Likely related to ↗ in Cape York regions.	Reef: 3% → <2% → , 30% → →Only inshore Reef waters and habitats, with the largest proportion in the enclosed coastal waters.	NA	NA
Cape York	Cyclone Tiffany (early Jan) Ex-Cyclone Seth (early-mid Jan)	<1.5	Cape York: 14% → • **Note** ↗ (+17%) in coral area exposed to lowest cat of risk (II).	Cape York: 3% → 2% → , 19% → → Only inshore Cape York waters and habitats, with the largest proportion in the enclosed coastal waters.	Good	NA
Wet Tropics	Ex-Cyclone Seth (early-mid Jan)	<1.5	Wet Tropics: 15% →	Wet Tropics: 3% → <2% → , -59% ↘	Moderate	**Declined** 2008–2018, **improved** past 4 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 2021–22**	**Long-term**
				→ Only inshore Wet Tropics waters and habitats, with the largest proportion in the enclosed coastal waters.		all focus regions in 2021–22
Burdekin	NA	<1.5	Burdekin: -5% ↘	Burdekin: 3% → <2% → , 47% → → Only inshore Burdekin waters and habitats, with the largest proportion in the enclosed coastal waters.	Moderate	**Declined** gradually since 2010, **stable** in recent years and **improved** in 2021–22
Mackay-Whitsunday	NA	<1.5	Mackay-Whitsunday: -6% ↘	Mackay-Whitsunday: 3% → <2% → , 38% → → Only inshore Mackay-Whitsunday waters and habitats, with the largest proportion in the enclosed coastal waters.	Moderate	**Declined** since 2008, **stable** in recent years, and showing signs of **improvement** over the last two years
Fitzroy	NA	1.5–2	Fitzroy: 9% → • **Note** ↗ (+6%) in seagrass area exposed the category of risk III	Fitzroy: 4% → 2% → , 39% → → Only inshore Fitzroy waters and habitats, with the largest proportion in the enclosed coastal waters.	Good (see Appendix D)	Good (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 <u>highest</u> potential risk (categories III and IV)***	**Annual 2021–22**	**Long-term**
Burnett-Mary	Ex-Cyclone Seth (early-mid Jan)	>3	Burnett-Mary: 6% → • **Note:** large ↗ (+46%) in seagrass area exposed to category of risk II-IV with ↗ (+10%) in the highest cat. of risk IV	Burnett-Mary: 2% → 2% → , 36% ↗ → Only <u>inshore</u> 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 Index for the Cape York region was 'good' for the 2021–22 water year. No long-term trends have been evaluated yet in the Cape York region.

Discharge from rivers in the Cape York region was around the long-term median discharge for all focus regions, except for the Pascoe which had discharge of approximately 1.8 times the long-term median. Rainfall was generally consistent over the wet season. There were several small to moderate discharge events late in the wet season and in the early dry season, consistent with patterns seen further south in the Wet Tropics and Burdekin. These discharge events were documented in the Normanby and Endeavour basins but only resulted in below-average magnitude flood events. As a result of the relative lateness of these discharge events in 2021–22, water quality conditions were generally recorded to be in 'moderate' to 'good' condition. However, this is likely influenced by the timing of these events compared with the majority of the sampling effort, which is constrained to the wet season throughout Cape York (due to logistical constraints associated with strong South-East trade winds in the dry season). Overall, the annual Water Quality Index score for each focus region was 'moderate', except the Annan-Endeavour which scored 'very good'.

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

- Chl-*a*, TSS, PO_4 and PP met the water quality GVs at most sites.
- NO_x exceeded the GVs at most sites and focus regions.
- 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 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.
- Annan-Endeavour region received a 'very good' annual WQ Index score.

Table 6-2: Cape York summary information – Exceedance of guideline values: generally exceeding (✗) or meeting (✓) annual guideline values.

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

Event water quality

- The largest flood event for the Normanby Basin over the 2021–22 wet season occurred in mid-February and was a below average magnitude flood event. The resulting flood plume, combined with flood water from the Stewart River and other coastal inlets, is roughly estimated to have inundated over 3500 km^2. This area includes reefs in the mid-shelf and offshore waterbodies, based on MODIS Terra and Aqua satellite images. Sampling around the peak discharge period at Princess Charlotte Bay showed relatively low TSS concentrations at the mouth of the Normanby River (≤10 mg L^{-1}), with high TSS at the mouth of the Kennedy, and Secchi disk depths remaining relatively low (<5 m) up the coast and into the Stewart River region. NO_x concentrations across the Normanby transect were also elevated above ambient concentrations during the February flood, ranging from 2.0 to 6.3 µg L^{-1} in the enclosed coastal waterbody and >1.0 µg L^{-1} across the open coastal and mid-shelf waterbody.
- The largest magnitude flood event for the Annan-Endeavour Rivers occurred in April 2022. Satellite images from the event showed that the flood plume flowed north, inundating reefs in the mid-shelf waterbody, including Forrester Reef, approximately 30 km to the northeast of the Endeavour River mouth (Figure 5-30). Maximum TSS (74 mg L^{-1}) was measured in the enclosed coastal zone near the Endeavour River mouth, dropping to 2.6 mg L^{-1} at Forrester Reef at the time of sampling. Continuous dataloggers at Forrester Reef showed that Chl-*a* remained elevated at concentrations ranging between 1.0 µg L^{-1} to 2.2 µg L^{-1} for at least 5 days during the flood event (compared to an ambient mean of 0.10 µg L^{-1}).
- In the Cape York region, 86% of the area was not exposed to a potential risk category, in keeping with long-term patterns (89%), and only 1% (562 km^2) of the region was exposed to the highest risk category IV. Approximately 24% (2,439 km^2) of the region's coral reefs and 71% (1,898 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 an increase in the coral reef area exposed, with 19% of the reef area shifting to not exposed (-19%) to the lowest potential risk category (II: +17%). 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 were slightly higher than the long-term median in 2021–22, after near-median discharge in 2020–21 and very low discharge in 2019–20. Discharge from the Russell-Mulgrave and Johnstone basins was very close to the long-term median in 2021–22 and 2020–21 and was less than the long-term median in 2019–20. Discharge in the Tully region was slightly less than the long-term median in 2021–22 after discharge of around 1.5 times the long-term median in 2020–21 and just over half the long-term median in 2019–20.

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

- Concentrations of four water quality variables (NO_x, PN, PP, and Secchi depth) exceeded annual water quality GVs within the Wet Tropics.
- Chl-*a*, PO_4 and TSS met GVs for most sites.
- Over the period from 2017 to 2022, many water quality variables showed a trend of improvement (Table 6-3).
- Water Quality Index scores have shown a long-term trend of gradual decline but have shown improvement over the past two to four years. For the 2021–22 water year, the Annual Condition Water Quality Index score was ‘moderate’.

Table 6-3: Wet Tropics summary information – Exceedance of guideline values: exceeding ( ) or meeting ( ); annual guideline values and trend (2017–2022): Deteriorating ( ), improving ( ) or stable ( ).

Water quality variable	Barron-Daintree	Russel-Mulgrave	Tully
NO_x	exceeding, deteriorating	exceeding, stable	exceeding, improving
PO_4	meeting, improving	meeting, improving	meeting, improving
PN	meeting, stable	exceeding, stable	exceeding, deteriorating
PP	meeting, improving	meeting, improving	exceeding, improving
TSS	meeting, improving	meeting, improving	meeting, improving
Secchi depth	exceeding, improving	exceeding, improving	exceeding, improving
Chl-*a*	meeting, improving	meeting, improving	meeting, improving
DOC	stable	stable	stable
POC	improving	improving	improving

Wet season and event water quality

- There were three main flood events influencing the Wet Tropics region during the 2021–22 wet season.
- In the Wet Tropics 85% of the region was not exposed to a potential risk, in keeping with long-term patterns, and only 1% (or 405 km^2) of the region was exposed to the highest risk category IV. Approximately 4% (91 km^2) of the region’s coral reefs and

98% (229 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 coral reef area exposed from higher potential risk (IV: -14%) to lower potential risk (II: +22%). 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 (> 73%).

6.3 Burdekin

The combined discharge and loads calculated for the 2021–22 water year from the Burdekin and Haughton basins were around 1.2 times the long-term median, after a very low discharge year in 2019–20 and a slightly above discharge year (1.5 times the long-term median) in 2020–21.

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

- Concentrations of four water quality variables (NO_x, PN, TSS, and Secchi depth) exceeded annual water quality GVs within the Burdekin region.
- Chl-*a*, PO_4 and PP met GVs at most monitoring sites.
- Over the period from 2017 to 2022, most water quality variables showed a trend of improvement, with Secchi depth remaining relatively stable (Table 6-4).
- Water Quality Index scores have shown a long-term trend of decline since 2008 but have been stable over the past few years and have improved in 2021–22. For the 2021–22 water year, the Annual Condition Water Quality Index score was 'moderate' which is consistent with a 'moderate' score in 2020–21.

Table 6-4: Burdekin summary information – exceedance of guideline values: exceeding (✖) or meeting (✔); annual guideline values and trend (2016–2021): Deteriorating (⬇), improving (⬆) or stable (○).

Water quality variable	Burdekin
NO_x	✖ ⬆
PO_4	✔ ⬆
PN	✖ ⬆
PP	✔ ⬆
TSS	✖ ⬆
Secchi depth	✖ ○
Chl-*a*	✔ ⬆
DOC	○
POC	⬆

Wet season and event water quality

- There was one major flood event influencing the Burdekin region during the 2021–22 wet season with two at smaller scale in the Haughton basin.

- In the Burdekin region, approximately 91% of the area was not exposed to a potential risk, slightly above long-term patterns (86%), and only 1% (or 599km^2) of the region was exposed to the highest risk category IV. Approximately 1% (32 km^2) of the region's coral reefs and 90% (637 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 slight decrease in the coral reef area exposed, with 5% of the reef area shifting from the lowest potential risk category (II: -5%) to not exposed: (+5%).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.

6.4 Mackay-Whitsunday

The combined discharge and loads calculated for the 2021–22 water year from the Proserpine, O'Connell, Pioneer, and Plane Basins were around half of the long-term median values and were once again amongst the lowest recorded over the past decade.

Ambient water quality - Enclosed coastal and open coastal waters:

- Concentrations of five water quality variables (NO_x, PO_4, PP, Secchi depth, and Chl-*a*) exceeded annual water quality GVs within the Mackay-Whitsunday region.
- PN and TSS met GVs for all monitoring sites.
- Over the period from 2017 to 2022, all water quality variables showed a trend of improvement with the exception of NO_x, which was stable (Table 6-5).
- Water Quality Index scores have shown a long-term trend of decline since 2008 but have been stable over the past few years. For the 2021–22 water year, the Annual Condition Water Quality Index score was 'moderate'.

Table 6-5: Mackay-Whitsunday summary information – Exceedance of guideline values: exceeding ( ) or meeting ( ); annual guideline values and trend (2016–2021): Deteriorating ( ), improving ( ) or stable ( ).

Water quality variable	Mackay-Whitsunday
NO_x	Exceeding; Stable
PO_4	Exceeding; Improving
PN	Meeting; Improving
PP	Exceeding; Improving
TSS	Meeting; Improving
Secchi depth	Exceeding; Improving
Chl-*a*	Exceeding; Improving
DOC	Improving
POC	Improving

Wet season and event water quality

- There were no major flood events in the Mackay-Whitsunday region during the 2021–22 wet season.
- In the Mackay-Whitsunday region, 85% of the area was not exposed to a potential risk, slightly above long-term patterns (79%) and only 1% (or 426 km^2) of the region was exposed to the highest risk category IV. Approximately 6% (199 km^2) of the region's coral reefs and 94% (290 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. 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 largely exposed to no / very low risk.

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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 2021–22. Sites in bold font were part of the ambient monitoring design from 2005 to 2015. The proposed number of visits is shown in black text, while the actual number of visits is shown in brackets in red text. 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					3 (Surface sampling only)
Kennedy inshore					2 (Surface sampling only)
Cliff Islands				4 (Sampling 2 depths) (4)	
Bizant River mouth					1 (Surface sampling only)
Normanby River mouth					1 (Surface sampling only)
Normanby inshore				4 (Sampling 2 depths) (4)	1 (Surface sampling only)
NR-03				4 (Sampling 2 depths) (4)	
NR-04				4 (Sampling 2 depths) (4)	
NR-05				4 (Sampling 2 depths) (4)	
Corbett Reef				4 (Sampling 2 depths) (4)	
Pascoe transect					
Pascoe mouth north					
Pascoe mouth south				5 (Sampling 2 depths) (5)	
PR-N2				5 (Sampling 2 depths) (5)	
PR-N3					
PR-N4				5 (Sampling 2 depths) (1)	
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)	
Annan and Endeavour transect					
Annan mouth					2 (Surface sampling only)
Walker Bay				5 (Sampling 2 depths) (5)	2 (Surface sampling only)
Dawson Reef	√			5 (Sampling 2 depths) (5)	2 (Surface sampling only)
Endeavour mouth					2 (Surface sampling only)

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**
Endeavour north shore				5 (Sampling 2 depths) (5)	2 (Surface sampling only)
Endeavour offshore				5 (Sampling 2 depths) (5)	2 (Surface sampling only)
Egret and Boulder Reef				5 (Sampling 2 depths) (5)	2 (Surface sampling only)
Forrester Reef	√				
Stewart transect					
Stewart mouth					
SR-02				5 (Sampling 2 depths) (4)	
SR-03				5 (Sampling 2 depths) (4)	
SR-04				5 (Sampling 2 depths) (4)	
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 Area					
Fitzroy Island West	√		5 (Sampling 2 depths) (5)		
RM2					
RM3			5 (Sampling 2 depths) (5)	5 (Sampling 2 depths) (4)	
RM4					
High Island East					
Normanby Island					
Frankland Group West (Russell Island)	√		5 (Sampling 2 depths) (5)	5 (Sampling 2 depths) (5)	
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 Area					
King Reef					1 (Surface sampling only)

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**
East Clump Point			5 (Sampling 2 depths) (5)	5 (Sampling 2 depths) (5)	1 (Sampling 2 depths)
Dunk Island North	√	√	5 (Sampling 2 depths) (5)	5 (Sampling 2 depths) (5)	1 (Sampling 2 depths)
South Mission Beach					1 (Surface sampling only)
Dunk Island South East			5 (Sampling 2 depths) (5)	5 (Sampling 2 depths) (5)	1 (Sampling 2 depths)
Between Tam O'Shanter and Timana			5 (Sampling 2 depths) (5)	5 (Sampling 2 depths) (5)	1 (Sampling 2 depths)
Hull River mouth					1 (Surface sampling only)
Bedarra Island			5 (Sampling 2 depths) (5)	5 (Sampling 2 depths) (5)	1 (Sampling 2 depths)
Triplets					1 (Surface sampling only)
Tully River mouth mooring	√	√	5 (Sampling 2 depths) (5)	5 (Sampling 2 depths) (5)	1 (Sampling 2 depths)
Tully River					1 (Surface sampling only)
Burdekin					
Burdekin Focus Area					
Pelorus and Orpheus Island West	√		4 (Sampling 2 depths) (4)	5 (Sampling 2 depths) (5)	
Pandora Reef	√		4 (Sampling 2 depths) (4)	5 (Sampling 2 depths) (5)	
Cordelia Rocks					
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) (4)	
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 area					
Double Cone Island	√		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
Hook Island W					
North Molle Island					
Pine Island	√	√	5 (Sampling 2 depths) (5)		
Seaforth Island	√		5 (Sampling 2 depths) (5)		
OConnell River mouth	√	√	5 (Sampling 2 depths) (5)		
Repulse Islands dive mooring			5 (Sampling 2 depths) (5)		
Rabbit Island NE					
Brampton Island					
Sand Bay					
Pioneer River mouth					

The 2021–22 water year is the second year of sampling for the Cape York region since sampling design changes were implemented for the Cape York region in 2020. In consultation between CYWP, AIMS and the Reef Authority, both the analytical laboratory and the number of sites sampled in Cape York changed in 2020. The site changes were made because:

- AIMS and CYWP assessed the sites at each focus region and determined that there was little variability between some sites; therefore a reduction in the number of sites within each focus region was reasonable;
- Some sites in the enclosed coastal zone (particularly the Normanby sites) were impossible to access during low or mid-tides, thus these sites were being skipped on occasion; and
- Shallow enclosed coastal sites were subject to highly variable conditions, including tidal flushing and wind and tide-driven sediment resuspension. This made it difficult to interpret data during "ambient" periods.
- The switch to the AIMS laboratory methods required more intensive sampling effort including extra samples collected at each site, and more labour-intensive filtering (PN, PP, PC, TSS). The additional time requirements made it impossible to sample all sites and filter samples the same day (a QC requirement).

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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). The MMP design prior to 2015 included sites in the open coastal and mid-shelf water bodies. The MMP design post-2015 now includes sites from all four water bodies.

At present, the Water Quality Guidelines do not define GVs for dissolved inorganic nutrients (nitrate and phosphate) in the Reef lagoon as these nutrients are rapidly cycled through uptake and release by biota and are variable on small spatial and temporal scales (Furnas *et al.*, 2005, 2011). Due to this high variability, their concentrations did not show as clear spatial patterns or correlations with coral reef attributes as the other water quality parameters that were included in the Guidelines and are considered to be more representative of nutrient availability integrated over time (De'ath and Fabricius, 2010). However, the Queensland Water Quality Guidelines (Department of Environment and Resource Management [DERM], 2009) identify GVs for dissolved inorganic nutrients in marine water bodies. Guideline values for dissolved inorganic nutrients and turbidity (in enclosed coastal waters) were drawn from Queensland Water Quality Guidelines or provided by the Reef Authority. Site-specific GVs for all water quality variables are shown in Appendix C Table C-8.

Table B-1: Guidelines values for four cross-shelf water bodies from the Water Quality Guidelines for the Great Barrier Reef Marine Park (Great Barrier Reef Marine Park Authority, 2010). Guidelines for some values come from 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**	µg L^{-1}	2.0	2.0	0.45	0.45	0.45	0.45	0.40	0.40
Particulate nitrogen*	µg L^{-1}	n/a	n/a	20.0	20.0	20.0	20.0	17.0	17.0
Particulate phosphorus*	µg L^{-1}	n/a	n/a	2.8	2.8	2.8	2.8	1.9	1.9
Suspended solids*	mg L^{-1}	5.0	15.0	2.0	2.0	2.0	2.0	0.7	0.7
Turbidity	NTU	10.0^{QLD}	6.0^{QLD}	1.5**	1.5**	1.5**	1.5**	<1^{QLD}	<1^{QLD}
Secchi depth	m	1.0	1.5	10.0	10.0	10.0	10.0	17.0	17.0
NO_x	µg L^{-1}	10.0^{QLD}	3.0^{QLD}	0.35***	0.35***	0.35***	0.35***	2.0^{QLD}	2.0^{QLD}
PO_4	µg L^{-1}	5.0^{QLD}	6.0^{QLD}	4.0^{QLD}	6.0^{QLD}	4.0^{QLD}	6.0^{QLD}	4.0^{QLD}	5.0^{QLD}

^{QLD} Indicates these 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).

** The turbidity trigger value for open coastal and mid-shelf water bodies (1.5 NTU) was derived for the MMP reporting by transforming the suspended solids GVs (2 mg L^{-1}) using an equation based on a comparison between direct water samples and instrumental turbidity readings (see QA/QC Report 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:
3. $\text{Ratio} = \log_2(V) - \log_2(GV)$
4. 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.

5. 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.
6. A combined water clarity ratio is generated by averaging the ratios of TSS and turbidity from loggers (where available).
7. 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.
8. 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.
9. 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-8). 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-8).
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:

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

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. 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 confirmed 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.

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 (SNAP, URL: URL: 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, primary waters (FU ≥ 10). 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) and normalised, 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 1 to 22; with a value of 22 meaning that one pixel has been exposed 22 weeks out of 22 weeks of the wet season. Annual frequency maps are normalised (0–1) and overlaid in ArcGIS to create multi-annual normalised frequency composites of occurrence of Reef water types.
- Multi-annual composites are also calculated over different time frames, using the archive of MODIS weekly water type maps (2002-03 to 2019-20). This includes (i) a long-term period (2002–03 to 2017–18: 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 wettest and driest years in each NRM region. Wet years are defined as those in the top quartile for total catchment discharge in the NRM region; dry years as those in the bottom quartile (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) are updated regularly (and/or in the case of extremely wet year or specific event patterns) to ensure they remains valid as a representative period and to improve their accuracy as more satellite data are available. Last update was in 2019 and next update will be in 2023.

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.

Region	Wet years				Dry years				
Cape York	2004	2006	2011	2019	2003	2005	2007	2012	2016
Wet Tropics	2009	2011	2018	2019	2003	2005	2015	2016	2017
Burdekin	2008	2009	2011	2019	2003	2004	2014	2015	2016
Mackay-Whitsunday	2008	2010	2011	2012	2003	2004	2006	2015	2018
Fitzroy	2008	2010	2011	2013	2004	2005	2006	2007	2019
Burnett-Mary	2010	2011	2012	2013	2005	2006	2007	2014	2019

Table B-3: 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 %									
		2021–22 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	**59,925**	**17%**	**60,768**	**17%**	**58,870**	**17%**	**87,660**	**25%**	**42,366**	**12%**
	EC	6,378	2% *(77%)*	7,848	2% *(95%)*	7,826	2% *(95%)*	7,851	2% (95%)	7,852	2% *(95%)*
	OC	30,129	9% *(91%)*	32,058	9% *(97%)*	32,085	9% *(97%)*	32,723	9% (99%)	27,645	8% *(84%)*
	Mid	17,452	5% *(21%)*	18,045	5% *(22%)*	16,296	5% *(20%)*	35,290	10% (43%)	6,291	2% *(8%)*
	Off	5,966	2% *(3%)*	2,818	1% *(1%)*	2,664	1% *(1%)*	11,797	3% (5%)	577	0%
WT1	Reef	**10,726**	**3%**	**10,381**	**3%**	**10,140**	**3%**	**19,501**	**6%**	**7,127**	**2%**
	EC	5,941	2% *(72%)*	6,045	2% *(73%)*	6,147	2% *(75%)*	6,589	2% (80%)	5,219	1% *(63%)*
	OC	4,716	1% *(14%)*	4,336	1% *(13%)*	3,989	1% *(12%)*	10,510	3% (32%)	1,908	1% *(6%)*
	Mid	69	0%	-	0%	4	0%	2,402	1% (3%)	-	0%
	Off	-	0%	-	0%	-	0%	-	0%	-	0%
WT2	Reef	**58,001**	**17%**	**56,797**	**16%**	**55,074**	**16%**	**81,921**	**23%**	**39,742**	**11%**

	EC	4,798	1% *(58%)*	6,595	2% *(80%)*	6,431	2% *(78%)*	6,849	2% (83%)	6,193	2% *(75%)*
	OC	30,055	9% *(91%)*	31,822	9% *(96%)*	31,894	9% *(97%)*	32,700	9% (99%)	27,459	8% *(83%)*
	Mid	17,217	5% *(21%)*	15,647	4% *(19%)*	14,387	4% *(18%)*	31,592	9% (39%)	5,513	2% *(7%)*
	Off	5,932	2% *(3%)*	2,734	1% *(1%)*	2,363	1% *(1%)*	10,782	3% (5%)	577	0%
WT3	Reef	**211,900**	**61%**	**165,460**	**47%**	**165,582**	**47%**	**195,072**	**56%**	**136,990**	**39%**
	EC	272	0% *(3%)*	149	0% *(2%)*	91	0% *(1%)*	249	0% (3%)	75	0% *(1%)*
	OC	26,399	8% *(80%)*	26,357	8% *(80%)*	25,620	7% *(78%)*	26,984	8% (82%)	25,516	7% *(77%)*
	Mid	81,230	23% *(99%)*	70,255	20% *(86%)*	71,728	21% *(87%)*	76,350	22% (93%)	54,679	16% *(67%)*
	Off	104,000	30% *(47%)*	68,700	20% *(31%)*	68,143	20% *(31%)*	91,489	26% (41%)	56,721	16% *(25%)*

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* water quality concentrations 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. This tool interpolates from the values of the four nearest raster cells (R Core Team, 2019). Several land-sourced pollutants are investigated through match-ups between *in situ* data and the six colour class maps, including DIN, PO_4, PP, PN, TSS, Chl-*a*, CDOM and K_D or Secchi depth. 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 water quality concentrations across the three wet season water types in all focus regions (Figure B-2) are presented.

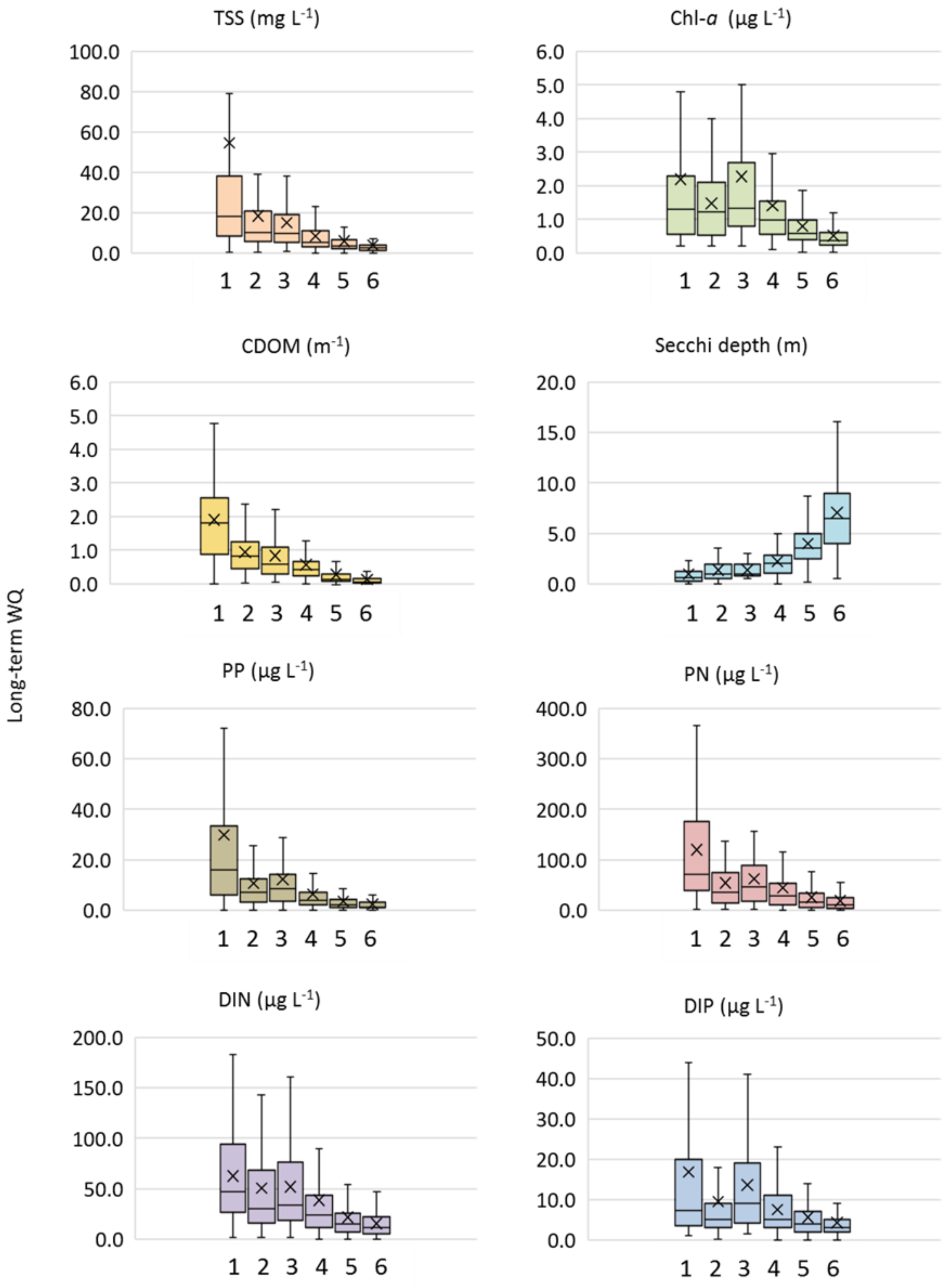

Figure B-1: Long-term water quality (WQ) concentration and Secchi disk depth boxplots for each wet season colour class. The mean is plotted as a cross and its numerical value is indicated. The interquartile range is delimited by the box and the median by the line inside the box. Whiskers indicate variability 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 characterisation remains valid as a representative period, and to improve its accuracy as more field data are collected every wet seasons. Last update was in 2019, using all field data available (from 2004 to 2019).

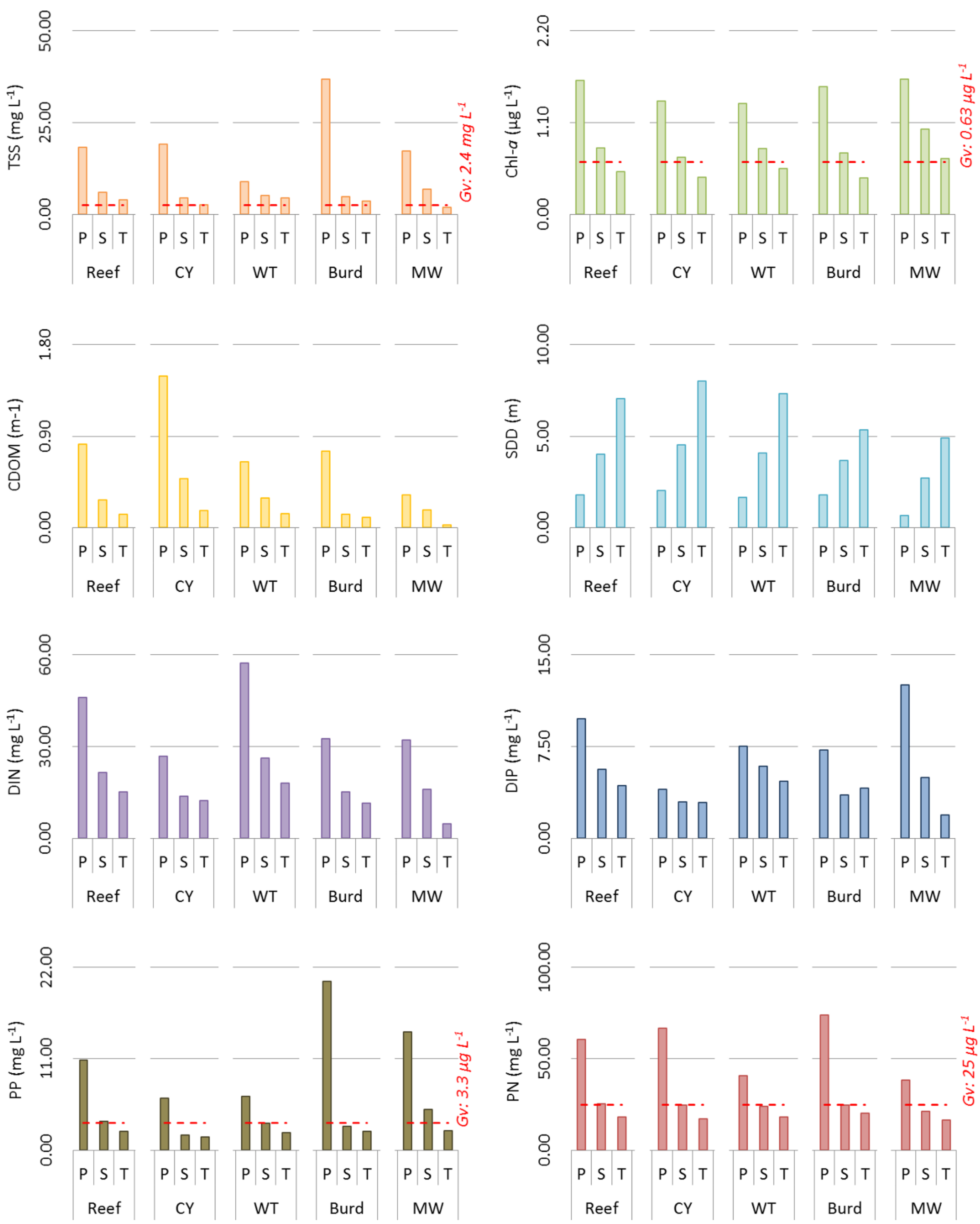

Figure B-2: Mean long-term (2004–2019) water quality concentrations across the three wet season water types in all focus regions . Red lines show the Reef-wide wet season GVs (Table B-4). The Burdekin region has the greatest average TSS, PP, and PN concentrations in the primary water type, which exceeded the long-term Reef-scale average. The greatest mean DIN and CDOM concentrations are measured in the primary water types of the Wet Tropics and Cape York regions, respectively. The greatest mean Chl-*a* concentrations are measured in the primary water types of the Mackay-Whitsunday and Burdekin regions. Except for CDOM and PN concentrations, the Cape York region shows the lowest concentrations of water quality parameters of all regions. Mean long-term water quality concentrations includes 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 pollutant 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 GBR.

Exposure maps and exposure assessment

Information on the long-term pollutant 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-sourced pollutant during wet season conditions and focuses on the TSS, Chl-*a*, PP and PN concentrations.

- The *‘magnitude of the exposure’* corresponds to the 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-4: 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*	µg L^{-1}	0.63
Particulate nitrogen	µg L^{-1}	25
Particulate phosphorus	µg 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 water quality concentrations 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 the Marine area reflects the geographic focus of the MMP design which is largely constrained to the inshore and mid-shelf waters. The last update in the mean long-term concentrations was in the 2018–19 reporting year (Gruber et al., 2020), using field data collected from 2004 to 2019. Note also that the long-term and GBR wide water quality concentrations 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-5: 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 2019.

Region	Reef Water type	Number of samples								
		Salinity	Secchi depth	TSS	Chl-*a*	CDOM	DIN	PO4	PP	PN
Cape York	WT1 (Primary)	125	109	125	136	101	138	137	91	135
	WT2 (Secondary)	124	120	124	132	51	131	132	98	131
	WT3 (Tertiary)	61	47	61	61	25	63	63	52	63
	WT4 (Marine)	9	4	9	9	3	9	9	8	9
Wet Tropics	WT1 (Primary)	224	164	375	368	357	321	324	301	309
	WT2 (Secondary)	244	289	482	495	438	475	476	446	447
	WT3 (Tertiary)	109	121	172	172	141	169	169	166	167
	WT4 (Marine)	17	22	29	29	27	28	28	20	20
Burdekin	WT1 (Primary)	100	81	132	131	86	129	131	126	127
	WT2 (Secondary)	104	146	188	187	132	187	187	177	176
	WT3 (Tertiary)	28	35	47	45	37	47	47	43	45
	WT4 (Marine)	14	16	18	21	15	22	22	19	19
Mackay - Whitsunday	WT1 (Primary)	12	9	26	23	25	26	26	24	24
	WT2 (Secondary)	44	34	86	81	53	86	86	77	78
	WT3 (Tertiary)	10	9	18	18	9	17	17	17	17
Fitzroy	WT1 (Primary)	15		76	77	56	77	78	75	76
	WT2 (Secondary)	13		34	48	43	52	54	53	53
	WT3 (Tertiary)	2		2	7	4	7	7	6	7
	WT4 (Marine)			6	6	1	6	6	6	6
Burnett-Mary	WT1 (Primary)	7	7	20	20	11	11	20	20	11
	WT2 (Secondary)	2	5	12	12	5	8	12	11	8
	WT3 (Tertiary)	1		1	1		1	1	1	1
	WT4 (Marine)			3	3	1	3	3	3	3
Reef-wide	WT1 (Primary)	483	370	754	755	636	702	716	637	682
	WT2 (Secondary)	531	594	926	955	722	939	947	862	893
	WT3 (Tertiary)	211	212	301	304	216	304	304	285	300
	WT4 (Marine)	40	42	65	68	47	68	68	56	57

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:

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

For example, using the long-term mean Chl-*a* values measured during high flow conditions in the Reef WT1, WT2 and WT3 (primary, secondary and tertiary water type):

$$Chla\_exp_{WT1} = \frac{1.61-0.63}{0.63} \times frequency_{water\ type\ (0-1, cell-specific)}$$

$$Chla\_exp_{WT2} = \frac{0.80-0.63}{0.63} \times frequency_{water\ type\ (0-1, cell-specific)}$$

$Chla\_exp_{WT3}$ = 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 to 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, 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, [0.9–3.2] = cat. II, [3.2–7.5] = cat III and >7.5 = 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 water quality concentrations 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 water quality concentrations 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-2 FU imagery), and over several multi-years period (using the archive of MODIS WS imagery): the long-term (2002–03 to 2018–19: 16 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) are updated regularly (and/or in the case of extremely wet year or specific event patterns) to ensure they remain valid as a representative period and to improve their accuracy as more satellite data are available. Last update was in 2019 and next one will be in 2022.

- 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.

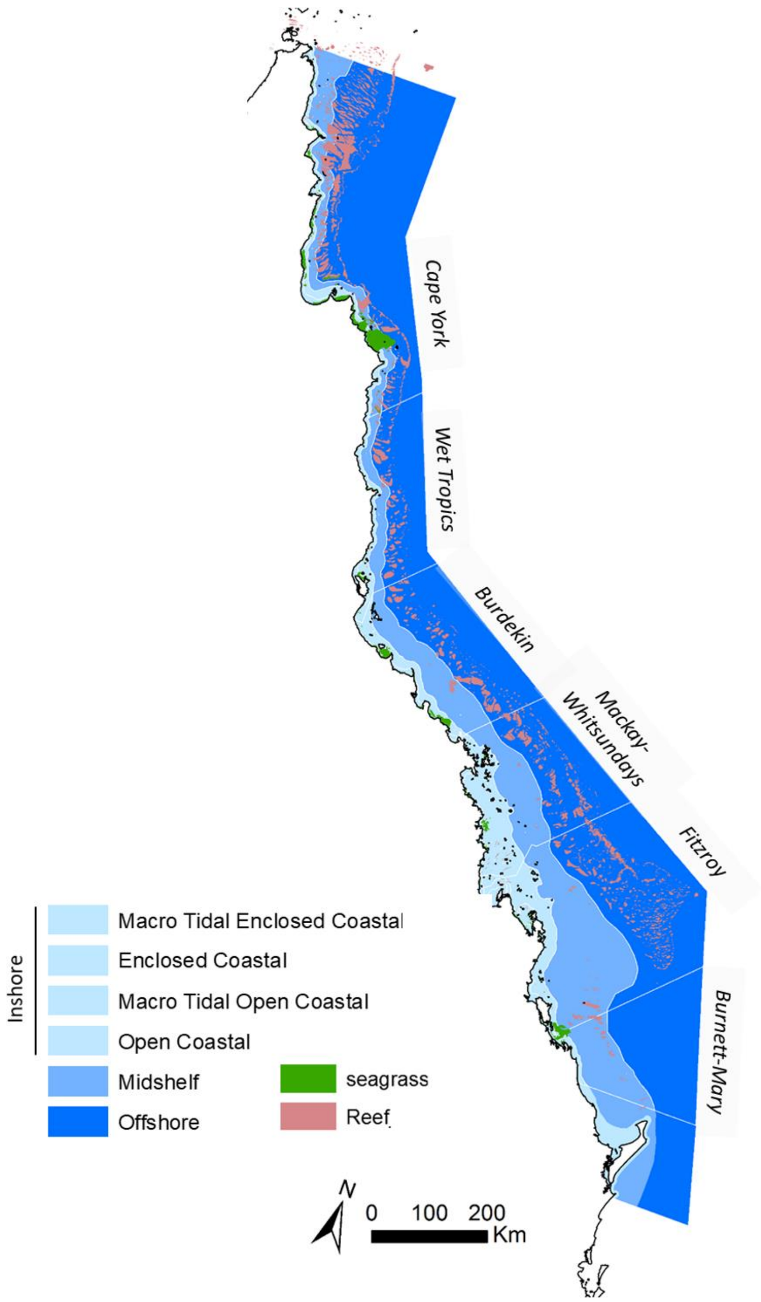

Figure B-3: Boundaries used for the Marine Park, each NRM region and the coral reefs and seagrass ecosystems. Coral reef and NRM layers derived from the Reef Authority, supplied 2013. Seagrass layer is a composite of surveys conducted by Department of Agriculture and Fisheries, Qld.

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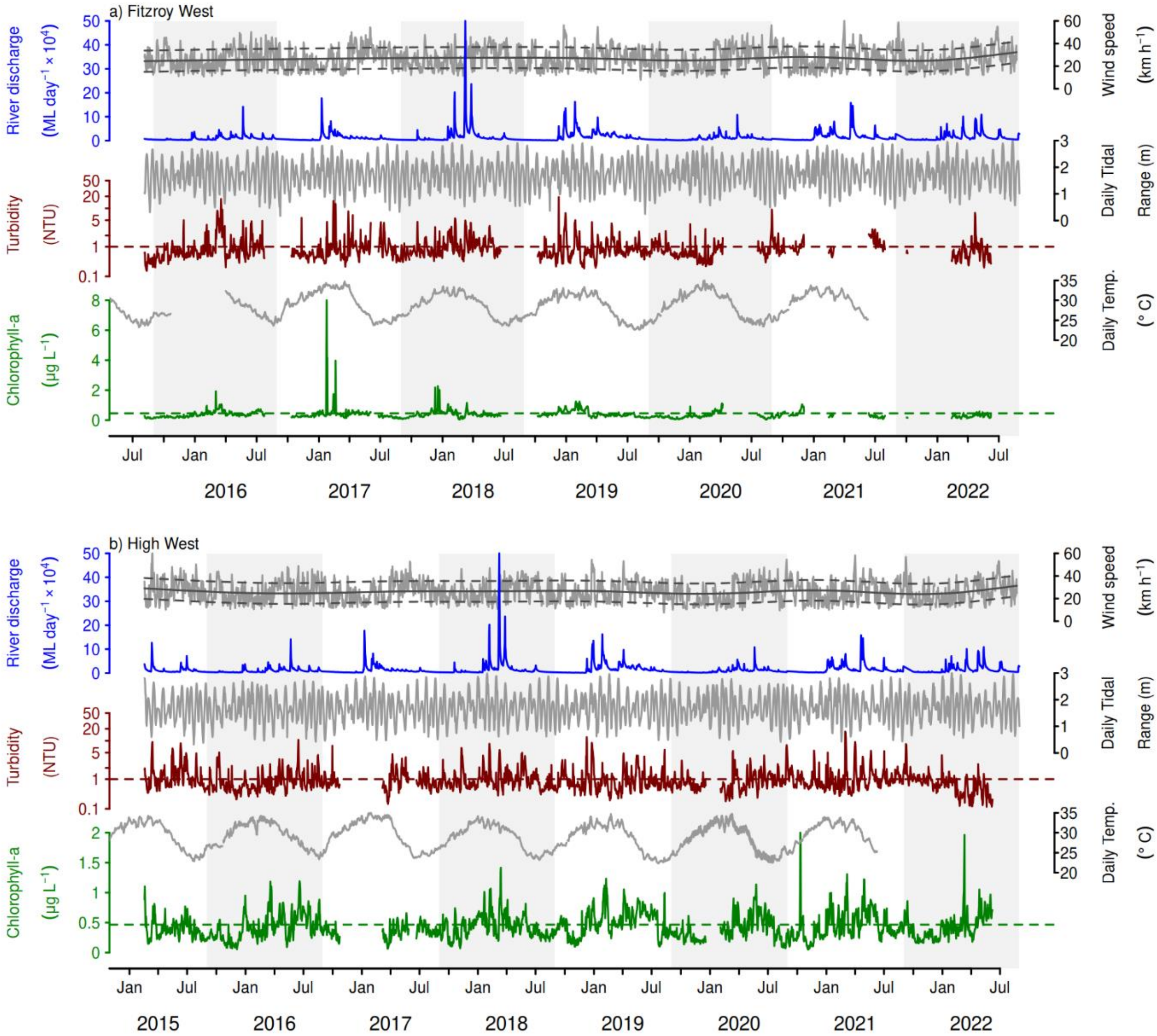
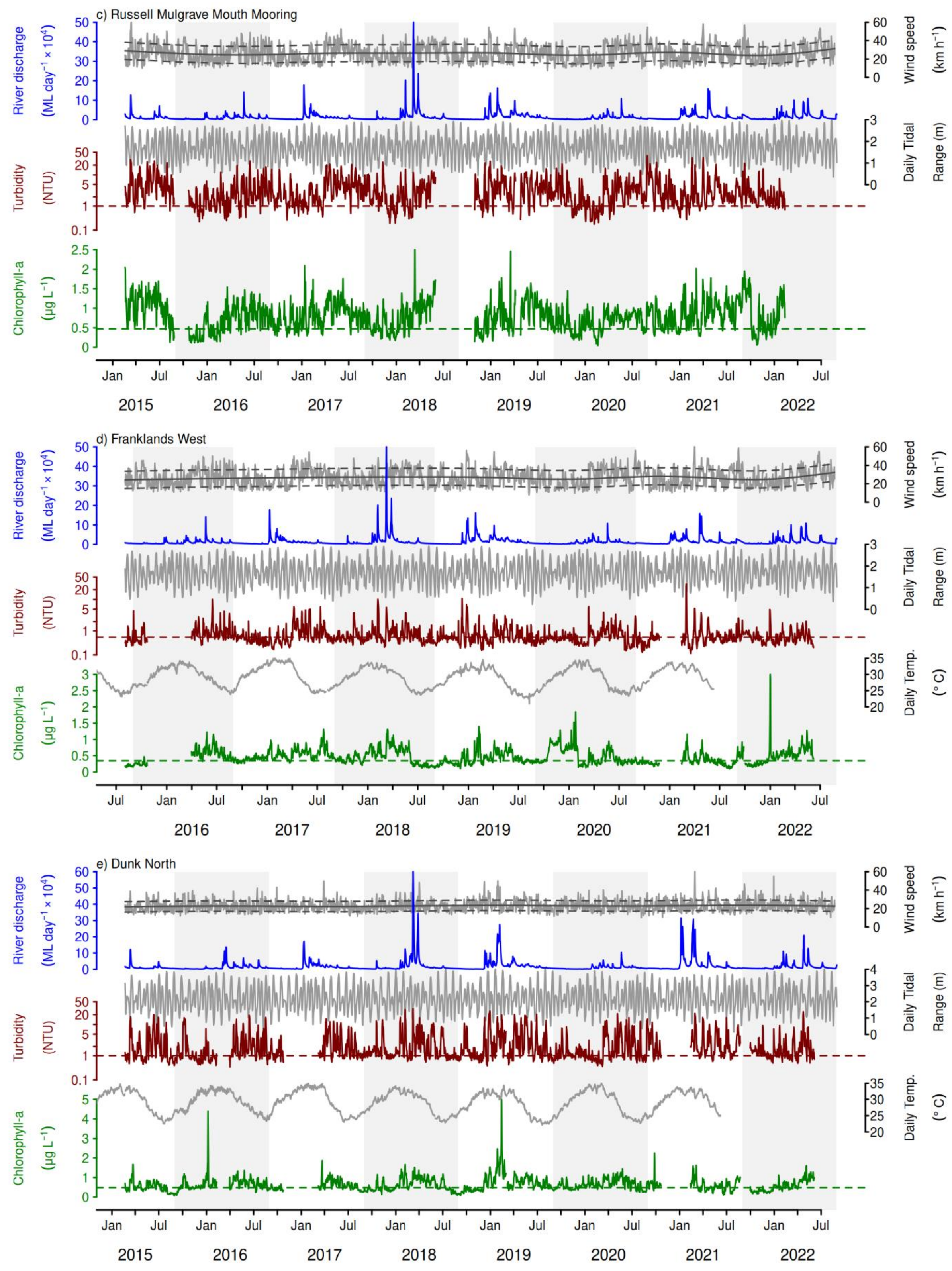
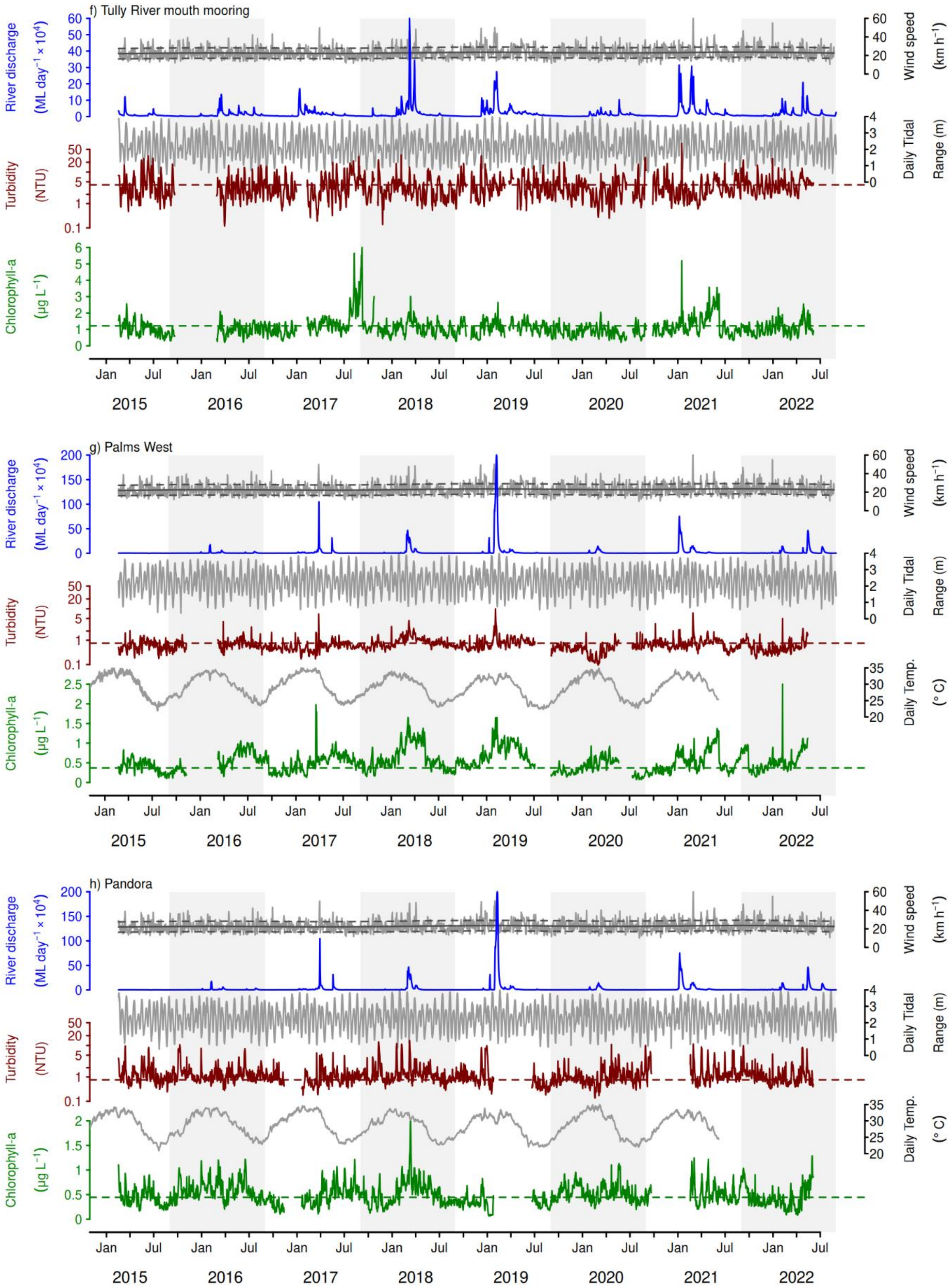
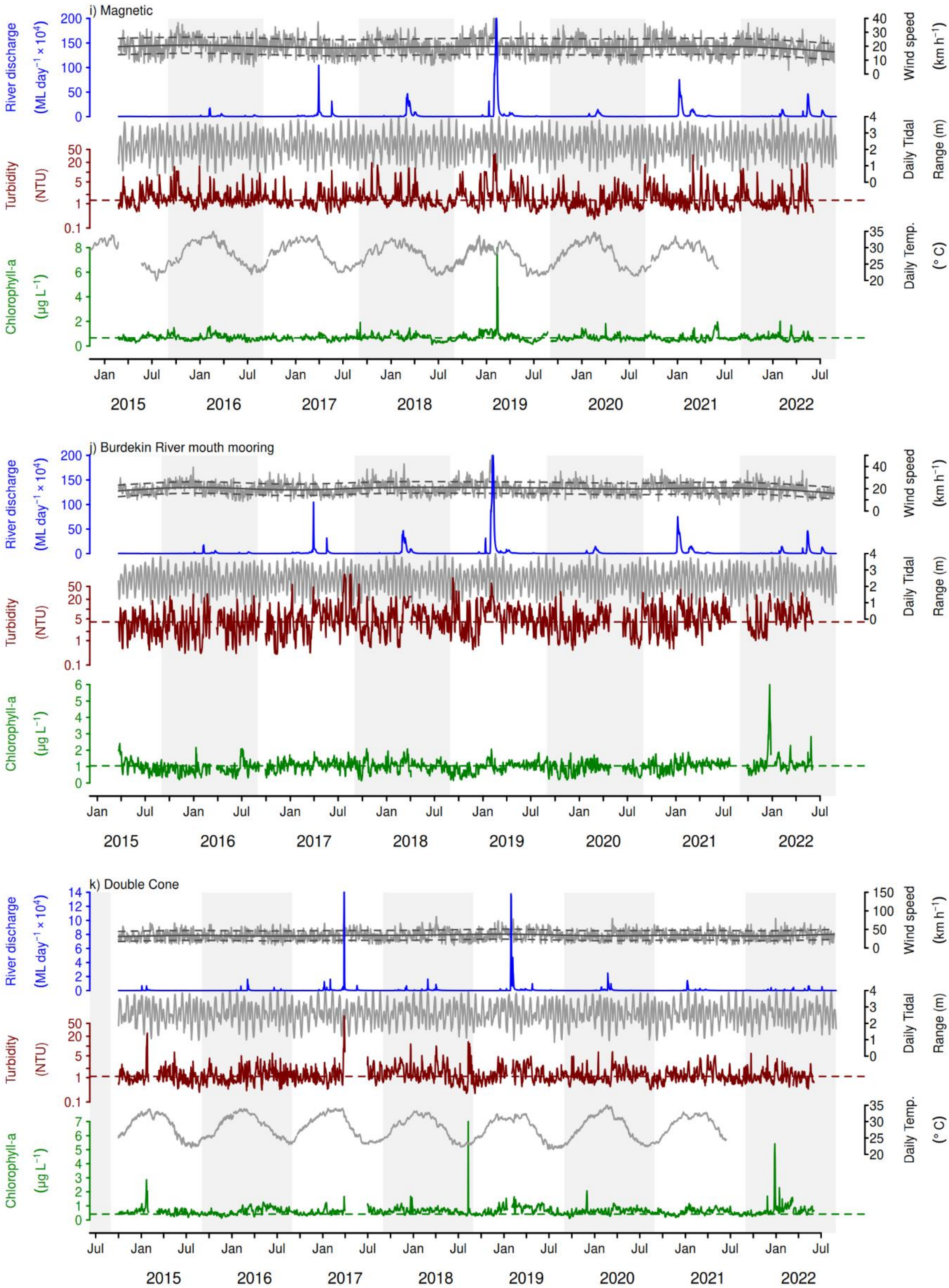
Appendix C: Additional information

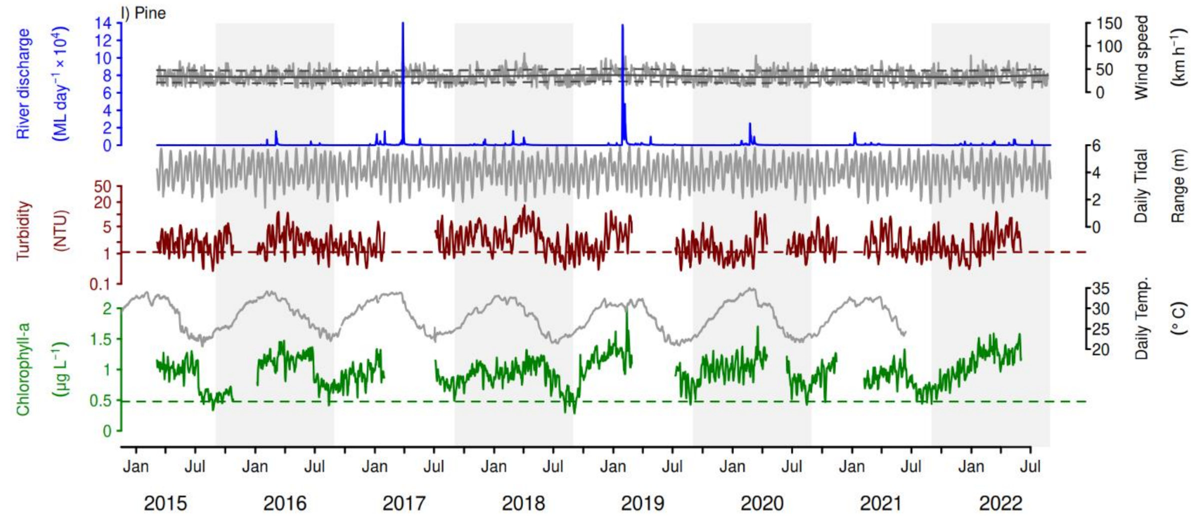
C-1 Continuous FLNTU data

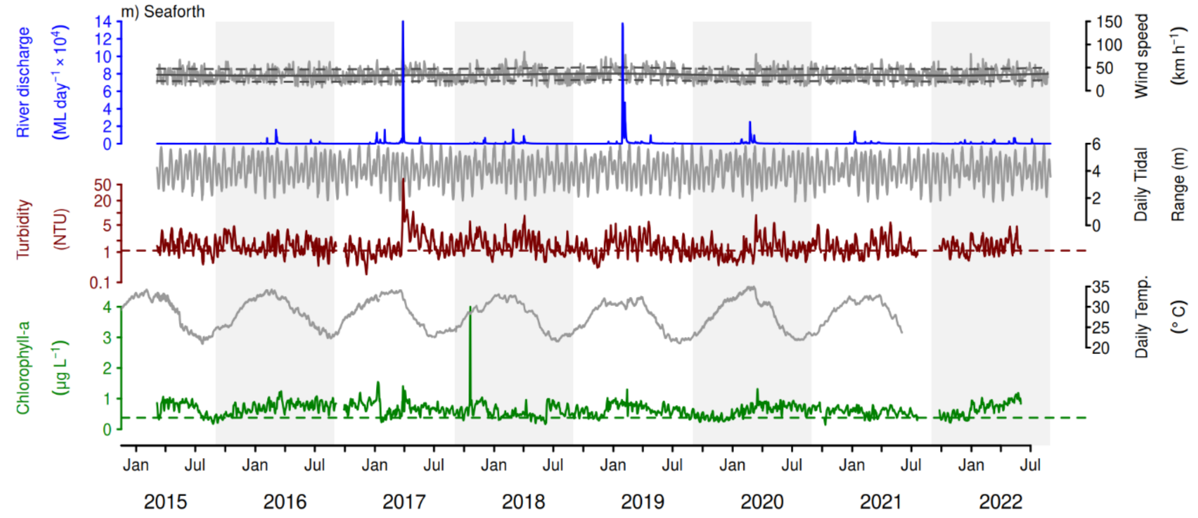



c) Russell Mulgrave Mouth Mooring
River discharge
(ML day⁻¹ × 10⁴)
Wind speed
(km h⁻¹)
Daily Tidal
Range (m)
Turbidity
(NTU)
Chlorophyll-a
(µg L⁻¹)
2015
2016
2017
2018
2019
2020
2021
2022
d) Franklands West
River discharge
(ML day⁻¹ × 10⁴)
Wind speed
(km h⁻¹)
Daily Tidal
Range (m)
Turbidity
(NTU)
Daily Temp.
(° C)
Chlorophyll-a
(µg L⁻¹)
2016
2017
2018
2019
2020
2021
2022
e) Dunk North
River discharge
(ML day⁻¹ × 10⁴)
Wind speed
(km h⁻¹)
Daily Tidal
Range (m)
Turbidity
(NTU)
Daily Temp.
(° C)
Chlorophyll-a
(µg L⁻¹)
2015
2016
2017
2018
2019
2020
2021
2022


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)
Daily Temp.
(° C)
Jan
Jul
2015
2016
2017
2018
2019
2020
2021
2022


i) Magnetic
j) Burdekin River mouth mooring
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)
Daily Temp. (° C)
Jan Jul
2015 2016 2017 2018 2019 2020 2021 2022


l) Pine
River discharge
(ML day⁻¹ × 10⁴)
Wind speed
(km h⁻¹)
Daily Tidal
Range (m)
Turbidity
(NTU)
Daily Temp.
(° C)
Chlorophyll-a
(µg L⁻¹)
2015
2016
2017
2018
2019
2020
2021
2022


m) Seaforth
River discharge
(ML day⁻¹ × 10⁴)
Wind speed
(km h⁻¹)
Daily Tidal
Range (m)
Turbidity
(NTU)
Daily Temp.
(° C)
Chlorophyll-a
(µg L⁻¹)
2015
2016
2017
2018
2019
2020
2021
2022

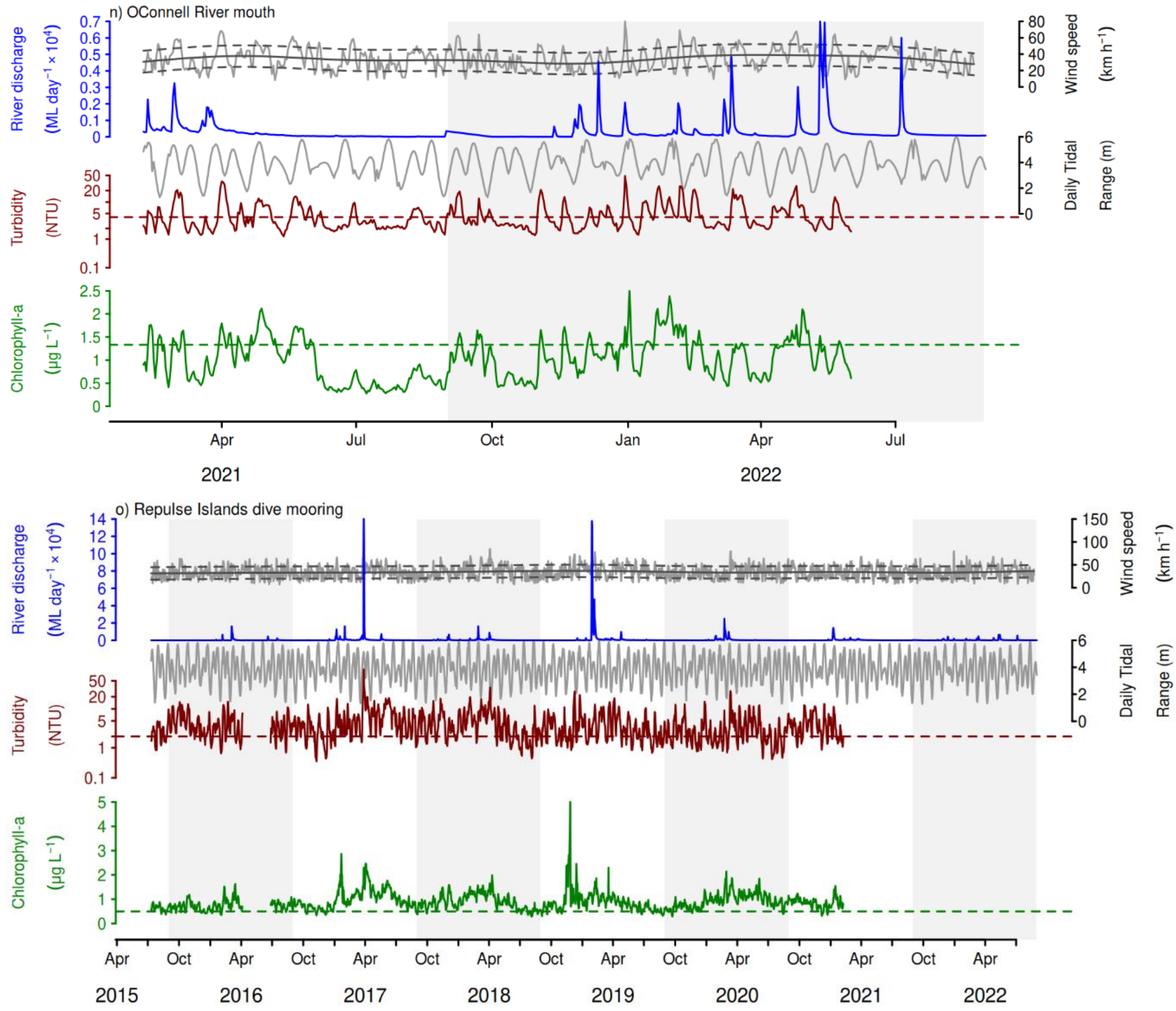


Figure C-1: Time-series of daily means of chlorophyll fluorescence and turbidity measured by moored ECO FLNTUSB instruments; coloured dashed lines represent the water quality GVs. Daily river discharge from the nearest river, daily wind speeds from the nearest weather stations, daily tidal range from the nearest tidal gauge, and daily temperature are also shown. Locations of loggers are shown in Figure 2-1 and Section 5 and panels continue on additional pages below: a) Fitzroy West; b) High West; c) Russell-Mulgrave Mouth Mooring; d) Franklands West; e) Dunk North; f) Tully Mouth Mooring; g) Palms West; h) Pandora; i) Magnetic; j) Burdekin Mouth Mooring; k) Double Cone; l) Pine; m) Seaforth; n) O'Connell River, and o) Repulse Island (discontinued).

C-2 Continuous temperature and salinity

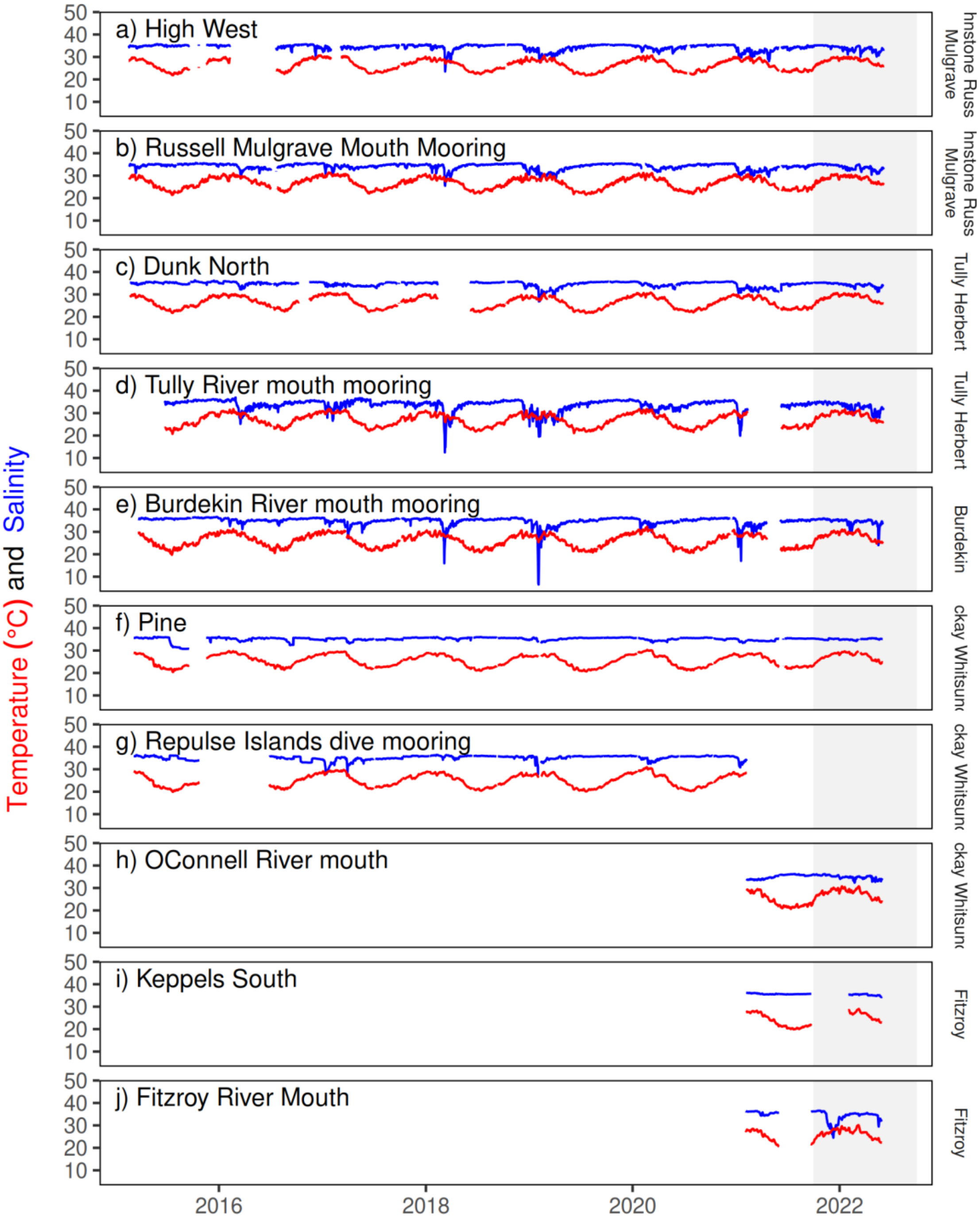


Figure C-2: Time-series of daily means of temperature and salinity derived from moored loggers (Sea-Bird Electronics SBE37s). Sub-figures represent instrument locations at: a) High West, b) Russel Mulgrave Mouth Mooring, c) Dunk North, d) Tully River Mouth Mooring, e) Burdekin Mouth Mooring, f) Pine, 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 September 2021 to 31 August 2022. 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				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
Cape York	PRN04 (PRN04)	DIN (µg L⁻¹)	1	2.10	2.10	2.10	2.10	2.10	2.10					
		DOC (µg L⁻¹)	1											
		DON (µg L⁻¹)	1	102.35	102.35	102.35	102.35	102.35	102.35					
		DOP (µg L⁻¹)	1	5.34	5.34	5.34	5.34	5.34	5.34					
		Chl-a (µg L⁻¹)	1	0.23	0.23	0.23	0.23	0.23	0.23	H	Median	0.27		
		NO_x (µg L⁻¹)	1	0.95	0.95	0.95	0.95	0.95	0.95	H	Median	0.35		
		PN (µg L⁻¹)	1	39.94	39.94	39.94	39.94	39.94	39.94	H	Mean			
			1	39.94	39.94	39.94	39.94	39.94	39.94	H	Median	18.00		
		PO_4 (µg L⁻¹)	1	0.31	0.31	0.31	0.31	0.31	0.31	H	Median	0.62		
		POC (mg L⁻¹)	1	162.84	162.84	162.84	162.84	162.84	162.84					
		PP (µg L⁻¹)	1	1.77	1.77	1.77	1.77	1.77	1.77	H	Mean			
			1	1.77	1.77	1.77	1.77	1.77	1.77	H	Median	2.00		
		Secchi (m)	1	8.82	8.82	8.82	8.82	8.82	8.82	L	Mean	10.00		
			1	8.82	8.82	8.82	8.82	8.82	8.82	L	Median			
		SiO_4	1	79.09	79.09	79.09	79.09	79.09	79.09					
		TSS (mg L⁻¹)	1	0.85	0.85	0.85	0.85	0.85	0.85	H	Mean			
			1	0.85	0.85	0.85	0.85	0.85	0.85	H	Median	1.50		
	PRN02 (PRN02)	DIN (µg L⁻¹)	5	5.38	3.78	3.19	3.53	6.22	10.16					
		DOC (µg L⁻¹)	5											
		DON (µg L⁻¹)	5	93.33	85.83	79.97	84.26	98.76	117.83					

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		DOP (µg L⁻¹)	5	4.96	5.26	4.34	4.34	5.33	5.51					
		Chl-a (µg L⁻¹)	5	0.20	0.24	0.12	0.14	0.25	0.26	H	Median	0.36	0.25	0.46
		NO_x (µg L⁻¹)	5	1.74	0.98	0.34	0.50	2.13	4.73	H	Median	0.35	0.32	0.45
		PN (µg L⁻¹)	5	23.68	20.64	19.44	20.04	24.04	34.24	H	Mean		16.00	
			5	23.68	20.64	19.44	20.04	24.04	34.24	H	Median	18.00		20.00
		PO_4 (µg L⁻¹)	5	0.56	0.31	0.31	0.31	0.74	1.11	H	Median	1.40	1.86	0.93
		POC (mg L⁻¹)	5	136.28	113.94	94.09	100.57	150.86	221.96					
		PP (µg L⁻¹)	5	1.94	1.51	1.35	1.41	2.26	3.18	H	Mean		2.30	
			5	1.94	1.51	1.35	1.41	2.26	3.18	H	Median	2.60		3.00
		Secchi (m)	5	3.70	3.70	3.52	3.58	3.82	3.88	L	Mean	10.00		
			5	3.70	3.70	3.52	3.58	3.82	3.88	L	Median			
		SiO_4	5	498.60	249.16	132.76	181.32	562.92	1366.86					
		TSS (mg L⁻¹)	5	1.10	0.53	0.40	0.47	1.24	2.87	H	Mean		1.60	
			5	1.10	0.53	0.40	0.47	1.24	2.87	H	Median	1.90		1.70
	Pascoe River mouth south (PRS01)	DIN (µg L⁻¹)	5	9.88	7.84	2.24	5.18	12.38	21.79					
		DOC (µg L⁻¹)	5											
		DON (µg L⁻¹)	5	95.71	101.79	67.18	72.55	118.14	118.90					
		DOP (µg L⁻¹)	5	4.65	4.65	3.41	3.41	5.70	6.07					
		Chl-a (µg L⁻¹)	5	0.20	0.17	0.10	0.14	0.29	0.32	H	Median			0.70
		NO_x (µg L⁻¹)	5	3.86	1.96	1.04	1.62	5.04	9.66	H	Median			1.50

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		PN (µg L⁻¹)	5	39.29	43.84	19.32	29.76	47.73	55.80	H	Mean			
			5	39.29	43.84	19.32	29.76	47.73	55.80	H	Median			
		PO_4 (µg L⁻¹)	5	1.67	1.24	0.31	0.31	3.16	3.34	H	Median			3.00
		POC (mg L⁻¹)	5	267.25	267.89	106.90	151.82	377.43	432.23					
		PP (µg L⁻¹)	5	3.31	2.95	2.23	2.63	3.80	4.92	H	Mean			
			5	3.31	2.95	2.23	2.63	3.80	4.92	H	Median			
		Secchi (m)	5	2.52	2.52	1.83	2.06	2.99	3.22	L	Mean			
			5	2.52	2.52	1.83	2.06	2.99	3.22	L	Median			3.00
		SiO_4	5	2147.31	872.76	177.96	188.59	3979.23	5518.00					
		TSS (mg L⁻¹)	5	3.01	2.85	0.62	0.80	4.08	6.72	H	Median			4.00
	PRS05 (PRS05)	DIN (µg L⁻¹)	5	5.22	5.88	2.74	2.79	7.22	7.48					
		DOC (µg L⁻¹)	5											
		DON (µg L⁻¹)	5	86.92	78.76	64.00	70.55	101.05	120.24					
		DOP (µg L⁻¹)	5	4.99	4.96	4.71	4.89	5.14	5.23					
		Chl-a (µg L⁻¹)	5	0.41	0.41	0.34	0.34	0.44	0.50	H	Median	0.27		
		NO_x (µg L⁻¹)	5	1.16	1.19	0.36	0.62	1.61	2.03	H	Median	0.35		
		PN (µg L⁻¹)	5	21.98	22.34	19.88	21.20	22.76	23.72	H	Mean			
			5	21.98	22.34	19.88	21.20	22.76	23.72	H	Median	18.00		
		PO_4 (µg L⁻¹)	5	0.99	0.93	0.93	0.93	1.08	1.08	H	Median	0.62		
		POC (mg L⁻¹)	5	119.07	111.64	100.99	106.28	132.72	143.71					

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		PP (µg L^{-1})	5	1.92	1.79	1.67	1.69	2.13	2.32	H	Mean			
			5	1.92	1.79	1.67	1.69	2.13	2.32	H	Median	2.00		
		Secchi (m)	5	9.86	10.25	6.39	8.33	11.80	12.55	L	Mean	10.00		
			5	9.86	10.25	6.39	8.33	11.80	12.55	L	Median			
		SiO_4	5	84.18	71.91	33.15	43.68	135.48	136.68					
		TSS (mg L^{-1})	5	1.49	0.81	0.63	0.72	2.29	2.98	H	Mean			
			5	1.49	0.81	0.63	0.72	2.29	2.98	H	Median	1.50		
	PRS2.5 (PRS2.5)	DIN (µg L^{-1})	5	2.77	2.73	1.91	2.08	3.52	3.58					
		DOC (µg L^{-1})	5											
		DON (µg L^{-1})	5	82.65	82.47	70.51	72.97	89.24	98.10					
		DOP (µg L^{-1})	5	5.08	5.42	4.20	4.71	5.47	5.61					
		Chl-a (µg L^{-1})	5	0.32	0.30	0.17	0.21	0.47	0.47	H	Median	0.36	0.25	0.46
		NO_x (µg L^{-1})	5	0.55	0.39	0.28	0.28	0.80	0.99	H	Median	0.35	0.32	0.45
		PN (µg L^{-1})	5	24.89	22.84	22.59	22.74	26.97	29.31	H	Mean		16.00	
			5	24.89	22.84	22.59	22.74	26.97	29.31	H	Median	18.00		20.00
		PO_4 (µg L^{-1})	5	0.46	0.31	0.31	0.31	0.65	0.74	H	Median	1.40	1.86	0.93
		POC (mg L^{-1})	5	130.91	120.15	108.01	117.08	147.25	162.06					
		PP (µg L^{-1})	5	2.54	2.54	1.75	1.80	2.90	3.69	H	Mean		2.30	
			5	2.54	2.54	1.75	1.80	2.90	3.69	H	Median	2.60		3.00
		Secchi (m)	5	7.00	7.00	6.08	6.47	7.31	8.14	L	Mean	10.00		

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
			5	7.00	7.00	6.08	6.47	7.31	8.14	L	Median			
		SiO_4	5	145.19	123.18	84.24	102.07	188.41	228.02					
		TSS (mg L^{-1})	5	1.35	1.36	0.69	0.76	1.85	2.11	H	Mean		1.60	
		TSS (mg L^{-1})	5	1.35	1.36	0.69	0.76	1.85	2.11	H	Median	1.90		1.70
	Middle Reef (PRBB)	DIN (µg L^{-1})	5	3.16	2.31	1.83	1.88	4.10	5.70					
		DOC (µg L^{-1})	5											
		DON (µg L^{-1})	5	72.55	71.62	62.16	63.00	79.19	86.79					
		DOP (µg L^{-1})	5	5.17	5.42	4.40	4.58	5.64	5.82					
		Chl-a (µg L^{-1})	5	0.39	0.36	0.31	0.34	0.46	0.49	H	Median	0.27		
		NO_x (µg L^{-1})	5	0.55	0.42	0.29	0.34	0.67	1.01	H	Median	0.35		
		PN (µg L^{-1})	5	22.74	21.54	18.62	18.86	26.62	28.06	H	Mean			
		PN (µg L^{-1})	5	22.74	21.54	18.62	18.86	26.62	28.06	H	Median	18.00		
		PO_4 (µg L^{-1})	5	0.53	0.31	0.31	0.31	0.81	0.90	H	Median	0.62		
		POC (mg L^{-1})	5	132.90	125.45	101.51	111.06	153.36	173.12					
		PP (µg L^{-1})	5	2.08	1.89	1.75	1.79	2.31	2.67	H	Mean			
		PP (µg L^{-1})	5	2.08	1.89	1.75	1.79	2.31	2.67	H	Median	2.00		
		Secchi (m)	5	9.41	9.75	7.42	8.96	10.42	10.48	L	Mean	10.00		
		Secchi (m)	5	9.41	9.75	7.42	8.96	10.42	10.48	L	Median			
		SiO_4	5	85.13	66.57	42.44	52.22	110.90	153.50					
		TSS (mg L^{-1})	5	0.93	0.97	0.52	0.75	1.08	1.31	H	Mean			

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
			5	0.93	0.97	0.52	0.75	1.08	1.31	H	Median	1.50		
	Hannah Island (SR05)	DIN (µg L⁻¹)	4	5.08	3.83	2.20	2.61	7.04	9.69					
		DOC (µg L⁻¹)	4											
		DON (µg L⁻¹)	4	95.22	79.88	65.73	69.51	114.79	146.20					
		DOP (µg L⁻¹)	4	5.57	5.38	5.26	5.26	5.81	6.16					
		Chl-a (µg L⁻¹)	4	0.26	0.24	0.20	0.21	0.30	0.34	H	Median	0.27		
		NO_x (µg L⁻¹)	4	0.63	0.51	0.29	0.30	0.91	1.15	H	Median	0.35		
		PN (µg L⁻¹)	4	19.78	19.12	17.16	17.97	21.32	23.32	H	Mean			
			4	19.78	19.12	17.16	17.97	21.32	23.32	H	Median	18.00		
		PO_4 (µg L⁻¹)	4	0.64	0.43	0.32	0.36	0.84	1.25	H	Median	0.62		
		POC (mg L⁻¹)	4	107.65	107.89	90.48	98.29	117.11	124.49					
		PP (µg L⁻¹)	4	1.81	1.79	1.49	1.64	1.98	2.16	H	Mean			
			4	1.81	1.79	1.49	1.64	1.98	2.16	H	Median	2.00		
		Secchi (m)	4	9.18	9.20	4.54	4.68	13.68	13.77	L	Mean	10.00		
			4	9.18	9.20	4.54	4.68	13.68	13.77	L	Median			
		SiO_4	4	137.76	114.84	56.33	63.93	202.42	251.27					
		TSS (mg L⁻¹)	4	0.96	0.89	0.50	0.51	1.39	1.52	H	Mean			
			4	0.96	0.89	0.50	0.51	1.39	1.52	H	Median	1.50		
	Burkitt Island (SR04)	DIN (µg L⁻¹)	4	7.39	6.90	3.00	3.19	11.38	12.45					
		DOC (µg L⁻¹)	4											

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		DON (µg L⁻¹)	4	85.23	84.18	62.58	68.44	101.61	109.35					
		DOP (µg L⁻¹)	4	5.65	5.65	5.44	5.51	5.79	5.86					
		Chl-a (µg L⁻¹)	4	0.22	0.22	0.16	0.18	0.26	0.28	H	Median	0.36	0.25	0.46
		NO_x (µg L⁻¹)	4	2.14	2.28	0.41	0.78	3.54	3.67	H	Median	0.35	0.32	0.45
		PN (µg L⁻¹)	4	16.04	16.04	14.30	15.06	17.02	17.79	H	Mean		16.00	
			4	16.04	16.04	14.30	15.06	17.02	17.79	H	Median	18.00		20.00
		PO_4 (µg L⁻¹)	4	0.46	0.39	0.31	0.31	0.59	0.73	H	Median	1.40	1.86	0.93
		POC (mg L⁻¹)	4	95.35	98.18	76.58	85.50	106.34	110.17					
		PP (µg L⁻¹)	4	1.94	1.93	1.38	1.62	2.25	2.50	H	Mean		2.30	
			4	1.94	1.93	1.38	1.62	2.25	2.50	H	Median	2.60		3.00
		Secchi (m)	4	8.86	9.15	4.16	5.24	12.60	13.16	L	Mean	10.00		
			4	8.86	9.15	4.16	5.24	12.60	13.16	L	Median			
		SiO_4	4	140.21	129.14	78.89	79.06	196.94	217.04					
		TSS (mg L⁻¹)	4	1.29	0.87	0.51	0.65	1.75	2.64	H	Mean		1.60	
			4	1.29	0.87	0.51	0.65	1.75	2.64	H	Median	1.90		1.70
	SR03 (SR03)	DIN (µg L⁻¹)	4	5.72	3.78	2.06	2.56	8.11	12.11					
		DOC (µg L⁻¹)	4											
		DON (µg L⁻¹)	4	82.13	81.10	64.98	68.79	95.07	100.74					
		DOP (µg L⁻¹)	4	5.73	5.73	5.42	5.42	6.04	6.04					
		Chl-a (µg L⁻¹)	4	0.29	0.26	0.23	0.23	0.34	0.40	H	Median	0.36	0.25	0.46

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		NO_x (µg L^{-1})	4	1.31	0.70	0.33	0.49	1.89	3.15	H	Median	0.35	0.32	0.45
		PN (µg L^{-1})	4	23.34	21.94	18.96	19.00	27.12	29.69	H	Mean		16.00	
			4	23.34	21.94	18.96	19.00	27.12	29.69	H	Median	18.00		20.00
		PO_4 (µg L^{-1})	4	0.39	0.31	0.31	0.31	0.43	0.57	H	Median	1.40	1.86	0.93
		POC (mg L^{-1})	4	118.12	109.69	100.18	102.11	130.76	147.88					
		PP (µg L^{-1})	4	2.59	2.44	1.83	1.97	3.16	3.56	H	Mean		2.30	
			4	2.59	2.44	1.83	1.97	3.16	3.56	H	Median	2.60		3.00
		Secchi (m)	4	5.40	6.22	2.31	3.84	7.29	7.33	L	Mean	10.00		
			4	5.40	6.22	2.31	3.84	7.29	7.33	L	Median			
		SiO_4	4	167.00	159.48	103.62	127.14	203.85	240.89					
		TSS (mg L^{-1})	4	2.10	1.22	0.67	0.88	2.96	4.74	H	Mean		1.60	
			4	2.10	1.22	0.67	0.88	2.96	4.74	H	Median	1.90		1.70
	SR02 (SR02)	DIN (µg L^{-1})	4	6.06	4.46	2.99	3.33	8.16	11.38					
		DOC (µg L^{-1})	4											
		DON (µg L^{-1})	4	80.52	80.14	72.11	72.33	88.56	89.48					
		DOP (µg L^{-1})	4	5.57	5.73	4.92	5.26	5.95	6.02					
		Chl-a (µg L^{-1})	4	0.27	0.26	0.21	0.21	0.33	0.36	H	Median			0.40
		NO_x (µg L^{-1})	4	2.58	1.59	0.43	0.89	3.88	6.11	H	Median			1.50
		PN (µg L^{-1})	4	24.27	24.69	20.11	22.40	26.30	27.83	H	Mean			
			4	24.27	24.69	20.11	22.40	26.30	27.83	H	Median			

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		PO_4 (µg L^{-1})	4	0.46	0.35	0.31	0.31	0.57	0.78	H	Median			2.00
		POC (mg L^{-1})	4	125.45	127.56	106.79	112.93	138.82	141.18					
		PP (µg L^{-1})	4	2.43	2.36	1.97	2.02	2.81	2.98	H	Mean			
			4	2.43	2.36	1.97	2.02	2.81	2.98	H	Median			
		Secchi (m)	4	7.50	7.50	7.50	7.50	7.50	7.50	L	Mean			
			4	7.50	7.50	7.50	7.50	7.50	7.50	L	Median			3.10
		SiO_4	4	249.19	181.08	91.75	132.29	338.85	502.01					
		TSS (mg L^{-1})	4	1.17	1.16	0.80	0.94	1.39	1.54	H	Mean			
			4	1.17	1.16	0.80	0.94	1.39	1.54	H	Median			5.00
	Corbett Reef (NR06)	DIN (µg L^{-1})	4	4.27	4.36	3.22	3.74	4.84	5.20					
		DOC (µg L^{-1})	4											
		DON (µg L^{-1})	4	80.86	78.81	73.56	75.49	85.41	91.05					
		DOP (µg L^{-1})	4	5.46	5.42	4.89	5.17	5.73	6.08					
		Chl-a (µg L^{-1})	4	0.32	0.30	0.19	0.23	0.40	0.48	H	Median	0.26		
		NO_x (µg L^{-1})	4	0.46	0.46	0.36	0.39	0.53	0.58	H	Median	0.42		
		PN (µg L^{-1})	4	19.60	18.47	16.23	17.08	21.67	24.57	H	Median	16.00		
		PO_4 (µg L^{-1})	4	0.68	0.62	0.55	0.59	0.74	0.88	H	Median	0.39		
		POC (mg L^{-1})	4	97.14	95.78	81.62	87.50	106.24	114.57					
		PP (µg L^{-1})	4	1.68	1.61	1.46	1.47	1.85	1.99	H	Mean			
			4	1.68	1.61	1.46	1.47	1.85	1.99	H	Median	1.90		

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		Secchi (m)	4	10.38	9.70	8.17	8.98	11.50	13.52	L	Mean	17.00		
			4	10.38	9.70	8.17	8.98	11.50	13.52	L	Median			
		SiO_4	4	93.42	91.19	49.61	69.93	116.01	140.34					
		TSS (mg L^{-1})	4	0.77	0.79	0.60	0.69	0.85	0.91	H	Mean			
			4	0.77	0.79	0.60	0.69	0.85	0.91	H	Median	0.50		
	NR05 (NR05)	DIN (µg L^{-1})	4	3.50	3.57	2.65	3.02	4.00	4.26					
		DOC (µg L^{-1})	4											
		DON (µg L^{-1})	4	83.53	86.07	72.83	79.19	88.89	90.69					
		DOP (µg L^{-1})	4	5.54	5.65	5.18	5.39	5.73	5.73					
		Chl-a (µg L^{-1})	4	0.35	0.28	0.24	0.25	0.42	0.56	H	Median	0.27		
		NO_x (µg L^{-1})	4	0.44	0.35	0.28	0.28	0.56	0.72	H	Median	0.35		
		PN (µg L^{-1})	4	17.12	17.34	11.69	13.62	20.70	22.23	H	Mean			
			4	17.12	17.34	11.69	13.62	20.70	22.23	H	Median	18.00		
		PO_4 (µg L^{-1})	4	0.70	0.70	0.49	0.56	0.84	0.91	H	Median	0.62		
		POC (mg L^{-1})	4	86.64	81.86	70.38	71.83	99.55	109.60					
		PP (µg L^{-1})	4	1.61	1.70	0.70	1.03	2.23	2.40	H	Mean			
			4	1.61	1.70	0.70	1.03	2.23	2.40	H	Median	2.00		
		Secchi (m)	4	11.11	11.50	5.16	8.36	14.02	16.51	L	Mean	10.00		
			4	11.11	11.50	5.16	8.36	14.02	16.51	L	Median			
		SiO_4	4	112.34	101.79	79.58	87.83	132.64	159.88					

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		TSS (mg L⁻¹)	4	0.95	0.90	0.34	0.48	1.39	1.61	H	Mean			
			4	0.95	0.90	0.34	0.48	1.39	1.61	H	Median	1.50		
	NR04 (NR04)	DIN (μg L⁻¹)	4	2.64	2.52	1.96	2.18	3.05	3.49					
		DOC (μg L⁻¹)	4											
		DON (μg L⁻¹)	4	88.82	87.16	81.74	82.09	94.88	98.22					
		DOP (μg L⁻¹)	4	5.65	5.50	5.13	5.20	6.04	6.39					
		Chl-a (μg L⁻¹)	4	0.27	0.26	0.19	0.23	0.31	0.36	H	Median	0.36	0.25	0.46
		NO_x (μg L⁻¹)	4	0.28	0.28	0.28	0.28	0.28	0.28	H	Median	0.35	0.32	0.45
		PN (μg L⁻¹)	4	18.14	18.09	16.76	17.12	19.14	19.59	H	Mean		16.00	
			4	18.14	18.09	16.76	17.12	19.14	19.59	H	Median	18.00		20.00
		PO_4 (μg L⁻¹)	4	0.50	0.46	0.31	0.31	0.68	0.75	H	Median	1.40	1.86	0.93
		POC (mg L⁻¹)	4	84.54	87.92	75.32	81.67	88.76	89.03					
		PP (μg L⁻¹)	4	1.93	1.95	1.27	1.41	2.46	2.57	H	Mean		2.30	
			4	1.93	1.95	1.27	1.41	2.46	2.57	H	Median	2.60		3.00
		Secchi (m)	4	8.16	8.27	6.25	6.70	9.67	9.92	L	Mean	10.00		
			4	8.16	8.27	6.25	6.70	9.67	9.92	L	Median			
		SiO_4	4	143.52	135.56	51.90	68.99	214.86	246.27					
		TSS (mg L⁻¹)	4	1.74	1.54	0.71	1.09	2.31	3.04	H	Mean		1.60	
			4	1.74	1.54	0.71	1.09	2.31	3.04	H	Median	1.90		1.70
	Cliff Isles (CI01)	DIN (μg L⁻¹)	4	5.27	4.34	2.84	3.60	6.57	8.99					

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		DOC (µg L⁻¹)	4											
		DON (µg L⁻¹)	4	75.78	79.46	59.49	69.72	83.31	86.93					
		DOP (µg L⁻¹)	4	6.31	5.73	5.18	5.39	7.00	8.25					
		Chl-a (µg L⁻¹)	4	0.30	0.28	0.19	0.23	0.37	0.44	H	Median	0.36	0.25	0.46
		NO_x (µg L⁻¹)	4	0.44	0.28	0.28	0.28	0.53	0.82	H	Median	0.35	0.32	0.45
		PN (µg L⁻¹)	4	23.42	22.74	16.99	19.82	26.74	30.79	H	Mean		16.00	
			4	23.42	22.74	16.99	19.82	26.74	30.79	H	Median	18.00		20.00
		PO_4 (µg L⁻¹)	4	0.74	0.54	0.31	0.31	1.08	1.43	H	Median	1.40	1.86	0.93
		POC (mg L⁻¹)	4	130.76	124.05	103.09	109.26	149.58	167.82					
		PP (µg L⁻¹)	4	2.57	2.51	1.57	1.89	3.22	3.65	H	Mean		2.30	
			4	2.57	2.51	1.57	1.89	3.22	3.65	H	Median	2.60		3.00
		Secchi (m)	4	4.38	4.55	2.62	3.30	5.52	5.88	L	Mean	10.00		
			4	4.38	4.55	2.62	3.30	5.52	5.88	L	Median			
		SiO_4	4	123.92	116.78	76.53	96.54	148.46	181.32					
		TSS (mg L⁻¹)	4	1.91	1.58	1.10	1.35	2.33	3.18	H	Mean		1.60	
			4	1.91	1.58	1.10	1.35	2.33	3.18	H	Median	1.90		1.70
	NR03 (NR03)	DIN (µg L⁻¹)	4	2.83	2.91	2.14	2.38	3.30	3.40					
		DOC (µg L⁻¹)	4											
		DON (µg L⁻¹)	4	88.72	87.86	83.66	85.66	91.44	95.00					
		DOP (µg L⁻¹)	4	5.92	6.08	5.37	5.68	6.22	6.26					

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		Chl-a (µg L^{-1})	4	0.44	0.46	0.31	0.38	0.51	0.56	H	Median	0.36	0.25	0.46
		NO_x (µg L^{-1})	4	0.36	0.37	0.32	0.34	0.39	0.39	H	Median	0.35	0.32	0.45
		PN (µg L^{-1})	4	27.50	27.62	26.34	26.63	28.42	28.51	H	Mean		16.00	
			4	27.50	27.62	26.34	26.63	28.42	28.51	H	Median	18.00		20.00
		PO_4 (µg L^{-1})	4	0.60	0.39	0.31	0.31	0.81	1.19	H	Median	1.40	1.86	0.93
		POC (mg L^{-1})	4	141.22	145.07	121.62	129.32	154.66	155.43					
		PP (µg L^{-1})	4	3.38	3.29	3.02	3.16	3.57	3.85	H	Mean		2.30	
			4	3.38	3.29	3.02	3.16	3.57	3.85	H	Median	2.60		3.00
		Secchi (m)	4	4.05	4.10	3.32	3.68	4.44	4.71	L	Mean	10.00		
			4	4.05	4.10	3.32	3.68	4.44	4.71	L	Median			
		SiO_4	4	189.95	172.16	106.26	111.01	261.77	298.55					
		TSS (mg L^{-1})	4	2.91	2.54	1.77	2.14	3.53	4.57	H	Mean		1.60	
			4	2.91	2.54	1.77	2.14	3.53	4.57	H	Median	1.90		1.70
	Normanby inshore (NR02)	DIN (µg L^{-1})	4	4.24	3.68	2.46	2.90	5.35	6.80					
		DOC (µg L^{-1})	4											
		DON (µg L^{-1})	4	106.43	93.25	86.91	89.75	117.83	144.39					
		DOP (µg L^{-1})	4	8.21	7.36	6.09	6.72	9.35	11.51					
		Chl-a (µg L^{-1})	4	1.08	1.07	0.79	0.80	1.36	1.39	H	Median			0.70
		NO_x (µg L^{-1})	4	0.63	0.42	0.28	0.28	0.90	1.27	H	Median			1.00
		PN (µg L^{-1})	4	56.25	52.68	38.98	45.39	65.69	78.53	H	Mean			

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
			4	56.25	52.68	38.98	45.39	65.69	78.53	H	Median			
		PO_4 (µg L^{-1})	4	0.93	0.93	0.31	0.31	1.55	1.55	H	Median			2.00
		POC (mg L^{-1})	4	297.77	257.92	195.22	225.87	353.73	456.12					
		PP (µg L^{-1})	4	7.51	7.03	5.75	5.96	8.87	9.94	H	Mean			
			4	7.51	7.03	5.75	5.96	8.87	9.94	H	Median			
		Secchi (m)	4	1.41	1.60	0.92	1.28	1.62	1.64	L	Mean			
			4	1.41	1.60	0.92	1.28	1.62	1.64	L	Median			1.50
		SiO_4	4	378.91	297.42	190.85	245.14	480.08	681.05					
		TSS (mg L^{-1})	4	8.02	6.01	4.84	5.39	9.85	14.03	H	Mean			
			4	8.02	6.01	4.84	5.39	9.85	14.03	H	Median			6.00
	Endeavour offshore (ER03)	DIN (µg L^{-1})	5	4.20	4.41	1.99	2.28	5.53	6.79					
		DOC (µg L^{-1})	5											
		DON (µg L^{-1})	5	80.98	77.57	59.36	59.99	93.68	114.30					
		DOP (µg L^{-1})	5	5.45	5.26	4.86	5.05	5.85	6.22					
		Chl-a (µg L^{-1})	5	0.18	0.15	0.13	0.14	0.24	0.27	H	Median	0.36	0.25	0.46
		NO_x (µg L^{-1})	5	0.80	0.77	0.29	0.34	1.23	1.36	H	Median	0.35	0.32	0.45
		PN (µg L^{-1})	5	13.52	14.04	9.42	12.66	15.56	15.92	H	Mean		16.00	
			5	13.52	14.04	9.42	12.66	15.56	15.92	H	Median	18.00		20.00
		PO_4 (µg L^{-1})	5	0.84	0.31	0.31	0.31	1.39	1.86	H	Median	1.40	1.86	0.93
		POC (mg L^{-1})	5	59.61	65.80	32.65	55.71	71.27	72.65					

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		PP (µg L^{-1})	5	1.42	1.46	0.98	1.23	1.66	1.76	H	Mean		2.30	
			5	1.42	1.46	0.98	1.23	1.66	1.76	H	Median	2.60		3.00
		Secchi (m)	5	9.86	9.40	8.14	8.86	10.40	12.50	L	Mean	10.00		
			5	9.86	9.40	8.14	8.86	10.40	12.50	L	Median			
		SiO_4	5	142.14	115.31	96.86	107.93	183.29	207.30					
		TSS (mg L^{-1})	5	1.05	0.68	0.56	0.62	1.19	2.18	H	Mean		1.60	
			5	1.05	0.68	0.56	0.62	1.19	2.18	H	Median	1.90		1.70
	Endeavour north shore (ER02b)	DIN (µg L^{-1})	5	3.04	2.52	1.95	2.11	3.95	4.66					
		DOC (µg L^{-1})	5											
		DON (µg L^{-1})	5	76.75	72.04	61.31	66.10	86.60	97.73					
		DOP (µg L^{-1})	5	5.13	5.11	4.13	4.46	5.73	6.19					
		Chl-a (µg L^{-1})	5	0.21	0.20	0.15	0.19	0.24	0.25	H	Median	0.36	0.25	0.46
		NO_x (µg L^{-1})	5	0.53	0.35	0.28	0.28	0.77	0.98	H	Median	0.35	0.32	0.45
		PN (µg L^{-1})	5	15.98	14.34	11.32	13.06	20.14	21.04	H	Mean		16.00	
			5	15.98	14.34	11.32	13.06	20.14	21.04	H	Median	18.00		20.00
		PO_4 (µg L^{-1})	5	0.77	0.77	0.37	0.56	0.99	1.18	H	Median	1.40	1.86	0.93
		POC (mg L^{-1})	5	78.58	68.20	59.52	59.91	94.59	110.68					
		PP (µg L^{-1})	5	1.61	1.64	1.09	1.30	1.90	2.13	H	Mean		2.30	
			5	1.61	1.64	1.09	1.30	1.90	2.13	H	Median	2.60		3.00
		Secchi (m)	5	7.86	8.00	7.18	7.42	8.32	8.38	L	Mean	10.00		

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
			5	7.86	8.00	7.18	7.42	8.32	8.38	L	Median			
		SiO_4	5	146.72	124.72	78.05	87.99	218.68	224.16					
		TSS (mg L^{-1})	5	0.80	0.80	0.50	0.52	0.99	1.20	H	Mean		1.60	
			5	0.80	0.80	0.50	0.52	0.99	1.20	H	Median	1.90		1.70
	Egret and Boulder Reef (AE04)	DIN (µg L^{-1})	5	3.14	2.35	2.09	2.15	3.97	5.17					
		DOC (µg L^{-1})	5											
		DON (µg L^{-1})	5	71.85	65.52	55.98	60.75	83.74	93.23					
		DOP (µg L^{-1})	5	5.74	5.34	4.46	4.83	6.16	7.93					
		Chl-a (µg L^{-1})	5	0.23	0.19	0.09	0.12	0.33	0.41	H	Median	0.27		
		NO_x (µg L^{-1})	5	0.81	0.49	0.28	0.28	1.08	1.90	H	Median	0.35		
		PN (µg L^{-1})	5	12.77	14.39	8.68	10.00	14.82	15.96	H	Mean			
			5	12.77	14.39	8.68	10.00	14.82	15.96	H	Median	18.00		
		PO_4 (µg L^{-1})	5	0.81	0.62	0.31	0.31	1.39	1.39	H	Median	0.62		
		POC (mg L^{-1})	5	58.34	60.25	45.38	50.94	65.91	69.24					
		PP (µg L^{-1})	5	1.18	1.15	0.79	0.87	1.54	1.55	H	Mean			
			5	1.18	1.15	0.79	0.87	1.54	1.55	H	Median	2.00		
		Secchi (m)	5	13.36	12.30	9.40	10.00	17.52	17.58	L	Mean	10.00		
			5	13.36	12.30	9.40	10.00	17.52	17.58	L	Median			
		SiO_4	5	83.20	93.12	58.59	59.31	99.94	105.04					
		TSS (mg L^{-1})	5	0.45	0.38	0.21	0.32	0.67	0.67	H	Mean			

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
			5	0.45	0.38	0.21	0.32	0.67	0.67	H	Median	1.50		
	Dawson Reef (AR03b)	DIN (µg L⁻¹)	5	2.66	1.96	1.90	1.95	3.51	3.98					
		DOC (µg L⁻¹)	5											
		DON (µg L⁻¹)	5	81.08	85.20	64.60	72.54	87.94	95.12					
		DOP (µg L⁻¹)	5	5.45	5.88	4.43	4.71	5.98	6.26					
		Chl-a (µg L⁻¹)	5	0.17	0.14	0.12	0.12	0.24	0.25	H	Median	0.36	0.25	0.46
		NO_x (µg L⁻¹)	5	0.41	0.35	0.28	0.28	0.43	0.69	H	Median	0.35	0.32	0.45
		PN (µg L⁻¹)	5	13.08	13.54	10.70	10.88	14.96	15.32	H	Mean		16.00	
			5	13.08	13.54	10.70	10.88	14.96	15.32	H	Median	18.00		20.00
		PO_4 (µg L⁻¹)	5	0.87	0.62	0.31	0.31	1.46	1.64	H	Median	1.40	1.86	0.93
		POC (mg L⁻¹)	5	66.32	65.90	49.33	57.55	73.53	85.30					
		PP (µg L⁻¹)	5	1.29	1.28	0.99	1.15	1.49	1.52	H	Mean		2.30	
			5	1.29	1.28	0.99	1.15	1.49	1.52	H	Median	2.60		3.00
		Secchi (m)	5	8.89	9.10	7.38	8.22	9.43	10.31	L	Mean	10.00		
			5	8.89	9.10	7.38	8.22	9.43	10.31	L	Median			
		SiO_4	5	143.65	152.61	86.09	109.59	183.79	186.15					
		TSS (mg L⁻¹)	5	0.63	0.67	0.28	0.39	0.89	0.90	H	Mean		1.60	
			5	0.63	0.67	0.28	0.39	0.89	0.90	H	Median	1.90		1.70
	Walker Bay (AR02b)	DIN (µg L⁻¹)	5	3.65	3.82	2.25	3.42	4.09	4.70					
		DOC (µg L⁻¹)	5											

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		DON (µg L⁻¹)	5	88.69	78.41	61.90	64.15	99.02	139.97					
		DOP (µg L⁻¹)	5	5.95	5.81	4.94	5.59	6.49	6.91					
		Chl-a (µg L⁻¹)	5	0.17	0.14	0.13	0.13	0.19	0.26	H	Median	0.36	0.25	0.46
		NO_x (µg L⁻¹)	5	0.43	0.32	0.29	0.31	0.50	0.76	H	Median	0.35	0.32	0.45
		PN (µg L⁻¹)	5	14.58	14.29	13.65	13.98	15.43	15.55	H	Mean		16.00	
			5	14.58	14.29	13.65	13.98	15.43	15.55	H	Median	18.00		20.00
		PO_4 (µg L⁻¹)	5	0.84	0.62	0.31	0.31	1.42	1.52	H	Median	1.40	1.86	0.93
		POC (mg L⁻¹)	5	71.33	69.45	65.03	65.72	76.26	80.16					
		PP (µg L⁻¹)	5	1.67	1.60	1.50	1.57	1.78	1.91	H	Mean		2.30	
			5	1.67	1.60	1.50	1.57	1.78	1.91	H	Median	2.60		3.00
		Secchi (m)	5	6.88	6.80	5.14	5.26	8.18	9.02	L	Mean	10.00		
			5	6.88	6.80	5.14	5.26	8.18	9.02	L	Median			
		SiO_4	5	133.87	140.87	68.78	86.29	186.29	187.09					
		TSS (mg L⁻¹)	5	1.04	1.16	0.65	0.66	1.28	1.45	H	Mean		1.60	
			5	1.04	1.16	0.65	0.66	1.28	1.45	H	Median	1.90		1.70
Wet Tropics	Cape Tribulation (C1)	DIN (µg L⁻¹)	3	3.79	3.71	2.95	3.21	4.36	4.69					
		DOC (µg L⁻¹)	3	900	882	845	858	938	966					
		DON (µg L⁻¹)	3	64.29	61.50	55.73	57.66	70.36	74.79					
		DOP (µg L⁻¹)	3	4.88	4.80	4.66	4.71	5.03	5.15					
		Chl-a (µg L⁻¹)	3	0.27	0.23	0.16	0.18	0.35	0.42	H	Mean	0.45		

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
			3	0.27	0.23	0.16	0.18	0.35	0.42	H	Median		0.32	0.63
		NOx (µg L⁻¹)	3	0.89	0.74	0.55	0.61	1.13	1.33	H	Median	0.35		
		PN (µg L⁻¹)	3	11.16	11.59	10.09	10.59	11.81	11.93	H	Mean	20.00		
			3	11.16	11.59	10.09	10.59	11.81	11.93	H	Median		16.00	25.00
		PO4 (µg L⁻¹)	3	1.32	1.24	0.68	0.87	1.75	2.01	H	Median	2.00		
		POC (mg L⁻¹)	3	76.13	74.91	66.85	69.53	82.48	86.26					
		PP (µg L⁻¹)	3	2.13	2.09	1.91	1.97	2.28	2.38	H	Mean	2.80		
			3	2.13	2.09	1.91	1.97	2.28	2.38	H	Median		2.30	3.30
		Secchi (m)	3	9.00	5.50	4.60	4.90	12.40	15.85	L	Mean	10.00		
			3	9.00	5.50	4.60	4.90	12.40	15.85	L	Median			
		SiO4	3	105.01	123.88	68.26	86.80	126.99	128.55					
		TSS (mg L⁻¹)	3	0.97	1.22	0.24	0.57	1.42	1.53	H	Mean	2.00		
			3	0.97	1.22	0.24	0.57	1.42	1.53	H	Median		1.60	2.40
	Port Douglas (C4)	DIN (µg L⁻¹)	3	4.49	3.82	2.81	3.14	5.71	6.65					
		DOC (µg L⁻¹)	3	897	907	848	867	929	941					
		DON (µg L⁻¹)	3	66.89	62.27	57.61	59.16	73.69	79.41					
		DOP (µg L⁻¹)	3	5.11	5.19	4.84	4.96	5.28	5.33					
		Chl-a (µg L⁻¹)	3	0.22	0.23	0.15	0.18	0.27	0.29	H	Median	0.30	0.32	0.63
		NOx (µg L⁻¹)	3	0.93	0.84	0.49	0.61	1.24	1.44	H	Median	0.31		
		PN (µg L⁻¹)	3	9.78	9.96	8.61	9.06	10.54	10.82	H	Median	14.00	16.00	25.00

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		PO_4 (µg L^{-1})	3	1.06	1.08	0.53	0.71	1.41	1.57	H	Median	2.00		
		POC (mg L^{-1})	3	55.42	60.80	42.78	48.78	63.14	64.31					
		PP (µg L^{-1})	3	1.87	1.67	1.35	1.45	2.25	2.54	H	Median	2.00	2.30	3.30
		Secchi (m)	3	7.33	9.00	4.50	6.00	9.00	9.00	L	Median	13.00		
		SiO_4	3	117.95	119.03	63.48	81.99	154.13	171.68					
		TSS (mg L^{-1})	3	0.91	1.05	0.22	0.50	1.36	1.51	H	Median	1.20	1.60	2.40
	Double Island (C5)	DIN (µg L^{-1})	3	5.09	4.73	3.12	3.65	6.45	7.31					
		DOC (µg L^{-1})	3	909	880	859	866	945	978					
		DON (µg L^{-1})	3	76.34	79.63	63.60	68.94	84.40	86.78					
		DOP (µg L^{-1})	3	5.42	5.73	4.82	5.13	5.78	5.80					
		Chl-a (µg L^{-1})	3	0.29	0.26	0.23	0.24	0.33	0.37	H	Median	0.30	0.32	0.63
		NO_x (µg L^{-1})	3	2.56	1.02	0.61	0.74	4.06	5.58	H	Median	0.31		
		PN (µg L^{-1})	3	11.84	11.98	11.44	11.62	12.10	12.15	H	Median	14.00	16.00	25.00
		PO_4 (µg L^{-1})	3	1.11	1.32	0.41	0.71	1.55	1.66	H	Median	2.00		
		POC (mg L^{-1})	3	79.95	79.11	74.34	75.93	83.80	86.14					
		PP (µg L^{-1})	3	2.20	2.12	2.00	2.04	2.36	2.48	H	Median	2.00	2.30	3.30
		Secchi (m)	3	7.67	9.00	5.40	6.60	9.00	9.00	L	Median	13.00		
		SiO_4	3	109.50	123.95	81.98	95.97	125.93	126.92					
		TSS (mg L^{-1})	3	0.97	0.96	0.61	0.72	1.21	1.33	H	Median	1.20	1.60	2.40
		DIN (µg L^{-1})	3	2.86	3.29	1.15	1.86	3.94	4.27					

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
	Green Island (C11)	DOC (µg L⁻¹)	3	867	866	849	855	879	885					
		DON (µg L⁻¹)	3	58.05	54.50	52.89	53.43	61.95	65.68					
		DOP (µg L⁻¹)	3	5.24	5.11	4.83	4.92	5.53	5.74					
		Chl-a (µg L⁻¹)	3	0.24	0.28	0.14	0.18	0.31	0.33	H	Median	0.30	0.32	0.63
		NO_x (µg L⁻¹)	3	0.70	0.77	0.52	0.60	0.81	0.83	H	Median	0.31		
		PN (µg L⁻¹)	3	10.29	10.73	9.25	9.74	10.93	11.02	H	Median	14.00	16.00	25.00
		PO_4 (µg L⁻¹)	3	2.27	2.32	1.00	1.44	3.11	3.51	H	Median	2.00		
		POC (mg L⁻¹)	3	52.11	51.04	44.69	46.80	57.21	60.30					
		PP (µg L⁻¹)	3	1.84	1.97	1.29	1.52	2.19	2.30	H	Median	2.00	2.30	3.30
		Secchi (m)	3	17.00	18.00	11.70	13.80	20.40	21.60	L	Median	13.00		
		SiO_4	3	83.87	102.04	51.10	68.08	103.30	103.93					
		TSS (mg L⁻¹)	3	0.45	0.23	0.20	0.21	0.66	0.87	H	Median	1.20	1.60	2.40
	Yorkey's Knob (C6)	DIN (µg L⁻¹)	3	4.12	4.10	2.74	3.19	5.04	5.51					
		DOC (µg L⁻¹)	3	984	968	916	933	1032	1064					
		DON (µg L⁻¹)	3	71.71	72.35	68.00	69.45	74.09	74.96					
		DOP (µg L⁻¹)	3	5.45	5.34	5.20	5.25	5.62	5.76					
		Chl-a (µg L⁻¹)	3	0.35	0.37	0.28	0.31	0.40	0.42	H	Mean	0.45		
			3	0.35	0.37	0.28	0.31	0.40	0.42	H	Median		0.32	0.63
		NO_x (µg L⁻¹)	3	1.06	0.88	0.50	0.62	1.46	1.76	H	Median	0.35		
		PN (µg L⁻¹)	3	13.33	13.42	12.48	12.80	13.89	14.12	H	Mean	20.00		

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
			3	13.33	13.42	12.48	12.80	13.89	14.12	H	Median		16.00	25.00
		PO_4 (µg L^{-1})	3	1.24	1.16	0.74	0.88	1.58	1.79	H	Median	2.00		
		POC (mg L^{-1})	3	102.13	99.83	93.44	95.57	108.24	112.44					
		PP (µg L^{-1})	3	3.24	3.25	2.67	2.86	3.62	3.80	H	Mean	2.80		
			3	3.24	3.25	2.67	2.86	3.62	3.80	H	Median		2.30	3.30
		Secchi (m)	3	6.00	5.00	4.10	4.40	7.40	8.60	L	Mean	10.00		
			3	6.00	5.00	4.10	4.40	7.40	8.60	L	Median			
		SiO_4	3	163.25	137.71	112.37	120.82	200.58	232.01					
		TSS (mg L^{-1})	3	1.77	2.05	0.79	1.21	2.38	2.55	H	Mean	2.00		
			3	1.77	2.05	0.79	1.21	2.38	2.55	H	Median		1.60	2.40
	Fairlead Buoy (C8)	DIN (µg L^{-1})	3	3.21	2.80	2.42	2.55	3.79	4.28					
		DOC (µg L^{-1})	3	956	923	921	922	983	1012					
		DON (µg L^{-1})	3	68.24	61.39	59.82	60.34	74.77	81.46					
		DOP (µg L^{-1})	3	5.26	5.34	4.44	4.74	5.81	6.04					
		Chl-a (µg L^{-1})	3	0.50	0.52	0.30	0.38	0.63	0.68	H	Mean	0.45		
			3	0.50	0.52	0.30	0.38	0.63	0.68	H	Median		0.32	0.63
		NO_x (µg L^{-1})	3	1.39	0.70	0.61	0.64	2.00	2.65	H	Median	0.35		
		PN (µg L^{-1})	3	15.84	15.24	14.56	14.79	16.78	17.55	H	Mean	20.00		
			3	15.84	15.24	14.56	14.79	16.78	17.55	H	Median		16.00	25.00
		PO_4 (µg L^{-1})	3	1.39	1.86	0.46	0.93	1.95	2.00	H	Median	2.00		

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		POC (mg L⁻¹)	3	152.38	147.17	130.91	136.33	167.38	177.48					
		PP (µg L⁻¹)	3	4.12	3.70	3.43	3.52	4.64	5.10	H	Mean	2.80		
			3	4.12	3.70	3.43	3.52	4.64	5.10	H	Median		2.30	3.30
		Secchi (m)	3	3.17	3.50	2.15	2.60	3.80	3.95	L	Mean	10.00		
			3	3.17	3.50	2.15	2.60	3.80	3.95	L	Median			
		SiO_4	3	141.43	137.43	99.64	112.23	169.83	186.03					
		TSS (mg L⁻¹)	3	2.85	2.42	2.13	2.23	3.38	3.86	H	Mean	2.00		
			3	2.85	2.42	2.13	2.23	3.38	3.86	H	Median		1.60	2.40
	Fitzroy West (RM1)	DIN (µg L⁻¹)	5	5.24	3.57	2.59	2.80	8.17	9.05					
		DOC (µg L⁻¹)	5	919	912	860	897	948	978					
		DON (µg L⁻¹)	5	74.32	68.95	60.48	65.52	77.69	98.97					
		DOP (µg L⁻¹)	5	5.39	5.50	4.75	5.31	5.57	5.81					
		Chl-a (µg L⁻¹)	5	0.22	0.21	0.13	0.15	0.28	0.33	H	Mean	0.45		
			5	0.22	0.21	0.13	0.15	0.28	0.33	H	Median		0.32	0.63
		NO_x (µg L⁻¹)	5	2.52	1.33	0.44	0.71	4.80	5.32	H	Median	0.35		
		PN (µg L⁻¹)	5	13.21	11.48	10.86	11.25	13.51	18.97	H	Mean	20.00		
			5	13.21	11.48	10.86	11.25	13.51	18.97	H	Median		16.00	25.00
		PO_4 (µg L⁻¹)	5	1.08	0.54	0.31	0.31	1.97	2.29	H	Median	2.00		
		POC (mg L⁻¹)	5	92.64	78.31	49.89	59.64	103.47	171.91					
		PP (µg L⁻¹)	5	1.75	1.82	1.37	1.37	2.09	2.10	H	Mean	2.80		

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
			5	1.75	1.82	1.37	1.37	2.09	2.10	H	Median		2.30	3.30
		Secchi (m)	5	12.90	15.00	6.80	10.70	15.40	16.60	L	Mean	10.00		
			5	12.90	15.00	6.80	10.70	15.40	16.60	L	Median			
		SiO_4	5	115.11	87.99	77.15	80.01	153.64	176.77					
		TSS (mg L^{-1})	5	0.54	0.54	0.12	0.34	0.66	1.04	H	Mean	2.00		
			5	0.54	0.54	0.12	0.34	0.66	1.04	H	Median		1.60	2.40
	RM3 (RM3)	DIN (µg L^{-1})	9	5.50	5.71	4.30	4.47	6.39	7.15					
		DOC (µg L^{-1})	9	913	921	850	864	940	988					
		DON (µg L^{-1})	9	75.92	73.05	62.25	64.77	84.22	98.33					
		DOP (µg L^{-1})	9	5.76	6.04	4.58	5.28	6.27	6.64					
		Chl-a (µg L^{-1})	9	0.36	0.33	0.26	0.28	0.44	0.52	H	Median	0.30	0.32	0.63
		NO_x (µg L^{-1})	9	2.96	2.03	0.90	1.13	4.99	5.94	H	Median	0.31		
		PN (µg L^{-1})	9	22.94	15.32	11.68	11.84	34.38	40.29	H	Median	14.00	16.00	25.00
		PO_4 (µg L^{-1})	9	0.83	0.70	0.37	0.46	1.08	1.55	H	Median	2.00		
		POC (mg L^{-1})	9	154.66	128.61	84.31	88.78	218.33	263.01					
		PP (µg L^{-1})	9	2.38	2.28	1.79	2.18	2.66	3.06	H	Median	2.00	2.30	3.30
		Secchi (m)	9	10.88	12.50	4.44	5.10	14.80	16.00	L	Median	13.00		
		SiO_4	9	163.55	171.35	81.70	98.39	231.15	252.39					
		TSS (mg L^{-1})	9	1.49	1.31	0.61	0.87	1.78	2.90	H	Median	1.20	1.60	2.40
		DIN (µg L^{-1})	10	6.08	5.64	2.35	4.19	8.41	11.05					

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
	High West (RM8)	DOC (µg L⁻¹)	10	975	929	923	925	1028	1070					
		DON (µg L⁻¹)	10	87.19	85.32	66.37	69.79	101.69	119.38					
		DOP (µg L⁻¹)	10	5.97	5.85	4.80	5.51	6.66	7.25					
		Chl-a (µg L⁻¹)	10	0.41	0.40	0.25	0.27	0.54	0.57	H	Mean	0.45		
			10	0.41	0.40	0.25	0.27	0.54	0.57	H	Median		0.32	0.63
		NO_x (µg L⁻¹)	10	2.95	2.00	0.56	0.83	4.84	7.63	H	Median	0.35		
		PN (µg L⁻¹)	10	27.12	20.36	13.02	14.44	39.64	51.28	H	Mean	20.00		
			10	27.12	20.36	13.02	14.44	39.64	51.28	H	Median		16.00	25.00
		PO_4 (µg L⁻¹)	10	1.05	0.89	0.38	0.53	1.64	2.18	H	Median	2.00		
		POC (mg L⁻¹)	10	161.04	139.42	90.78	103.50	205.45	287.80					
		PP (µg L⁻¹)	10	2.55	2.67	1.62	2.11	2.94	3.33	H	Mean	2.80		
			10	2.55	2.67	1.62	2.11	2.94	3.33	H	Median		2.30	3.30
		Secchi (m)	10	7.52	8.00	2.81	4.24	10.60	11.00	L	Mean	10.00		
			10	7.52	8.00	2.81	4.24	10.60	11.00	L	Median			
		SiO_4	10	226.29	195.71	120.58	153.55	284.05	390.99					
		TSS (mg L⁻¹)	10	1.45	1.16	0.72	0.80	1.98	2.84	H	Mean	2.00		
			10	1.45	1.16	0.72	0.80	1.98	2.84	H	Median		1.60	2.40
	Russell Mulgrave Mouth Mooring (RM10)	DIN (µg L⁻¹)	10	25.24	17.61	3.67	5.03	50.88	59.33					
		DOC (µg L⁻¹)	10	992	949	861	905	1100	1146					
		DON (µg L⁻¹)	10	88.00	84.02	62.44	69.93	99.03	126.61					

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		DOP (μg L⁻¹)	10	5.40	5.34	4.42	4.97	5.88	6.48					
		Chl-a (μg L⁻¹)	10	0.55	0.46	0.34	0.36	0.74	0.88	H	Mean	0.45		
			10	0.55	0.46	0.34	0.36	0.74	0.88	H	Median		0.32	0.63
		NO_x (μg L⁻¹)	10	20.79	14.68	0.34	2.41	44.38	51.29	H	Median	0.35		
		PN (μg L⁻¹)	10	32.48	27.69	16.78	18.98	50.15	57.99	H	Mean	20.00		
			10	32.48	27.69	16.78	18.98	50.15	57.99	H	Median		16.00	25.00
		PO_4 (μg L⁻¹)	10	1.88	1.86	0.76	1.50	2.56	2.85	H	Median	2.00		
		POC (mg L⁻¹)	10	237.77	211.64	129.52	151.07	348.97	384.85					
		PP (μg L⁻¹)	10	5.05	5.13	3.65	3.92	6.29	6.49	H	Mean	2.80		
			10	5.05	5.13	3.65	3.92	6.29	6.49	H	Median		2.30	3.30
		Secchi (m)	10	4.35	3.50	1.95	2.50	6.10	7.32	L	Mean	10.00		
			10	4.35	3.50	1.95	2.50	6.10	7.32	L	Median			
		SiO_4	10	726.75	533.94	236.22	277.08	1141.03	1504.86					
		TSS (mg L⁻¹)	10	2.87	2.53	0.97	1.52	4.06	5.44	H	Mean	2.00		
			10	2.87	2.53	0.97	1.52	4.06	5.44	H	Median		1.60	2.40
	Franklands West (RM7)	DIN (μg L⁻¹)	10	5.81	5.18	3.42	4.00	7.57	9.23					
		DOC (μg L⁻¹)	10	955	947	845	863	1058	1063					
		DON (μg L⁻¹)	10	87.96	81.47	68.90	73.04	104.25	116.33					
		DOP (μg L⁻¹)	10	5.67	5.96	4.60	4.97	6.35	6.52					
		Chl-a (μg L⁻¹)	10	0.26	0.22	0.12	0.18	0.36	0.46	H	Median	0.30	0.32	0.63

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		NO_x (µg L^{-1})	10	2.64	1.58	0.93	1.09	4.03	6.33	H	Median	0.31		
		PN (µg L^{-1})	10	23.82	20.55	10.92	12.52	37.08	43.84	H	Median	14.00	16.00	25.00
		PO_4 (µg L^{-1})	10	1.02	1.01	0.34	0.57	1.35	1.77	H	Median	2.00		
		POC (mg L^{-1})	10	139.42	146.32	59.80	73.28	190.59	231.38					
		PP (µg L^{-1})	10	1.81	1.64	1.48	1.53	2.02	2.55	H	Median	2.00	2.30	3.30
		Secchi (m)	10	11.28	11.75	5.29	8.10	14.20	16.10	L	Median	13.00		
		SiO_4	10	173.96	163.06	74.00	95.70	243.54	290.50					
		TSS (mg L^{-1})	10	1.11	0.99	0.19	0.47	1.58	2.36	H	Median	1.20	1.60	2.40
	Clump Point East (TUL2)	DIN (µg L^{-1})	10	4.92	4.52	2.59	3.07	5.94	8.83					
		DOC (µg L^{-1})	10	939	901	857	857	1040	1041					
		DON (µg L^{-1})	10	90.22	77.71	65.47	69.77	107.10	139.12					
		DOP (µg L^{-1})	10	5.63	5.69	4.71	5.33	5.99	6.50					
		Chl-a (µg L^{-1})	10	0.27	0.25	0.15	0.19	0.35	0.42	H	Median	0.30	0.32	0.63
		NO_x (µg L^{-1})	10	1.11	0.60	0.36	0.48	2.07	2.69	H	Median	0.31		
		PN (µg L^{-1})	10	27.79	32.99	10.70	12.66	42.84	46.17	H	Median	14.00	16.00	25.00
		PO_4 (µg L^{-1})	10	1.19	1.08	0.31	0.68	1.55	2.37	H	Median	2.00		
		POC (mg L^{-1})	10	162.01	182.86	60.57	81.55	233.82	252.20					
		PP (µg L^{-1})	10	1.72	1.59	1.10	1.35	2.17	2.57	H	Median	2.00	2.30	3.30
		Secchi (m)	10	12.27	12.75	6.26	10.80	14.30	17.42	L	Median	13.00		
		SiO_4	10	114.72	104.49	62.04	73.78	155.11	196.17					

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		TSS (mg L⁻¹)	10	1.27	0.82	0.18	0.32	1.49	3.76	H	Median	1.20	1.60	2.40
	Dunk North (TUL3)	DIN (µg L⁻¹)	10	5.75	5.55	3.27	3.51	7.60	9.37					
		DOC (µg L⁻¹)	10	1017	1037	922	982	1068	1077					
		DON (µg L⁻¹)	10	92.14	86.88	72.78	79.82	105.36	116.66					
		DOP (µg L⁻¹)	10	5.67	5.73	5.02	5.17	6.19	6.19					
		Chl-a (µg L⁻¹)	10	0.33	0.28	0.15	0.18	0.41	0.70	H	Mean	0.45		
			10	0.33	0.28	0.15	0.18	0.41	0.70	H	Median		0.32	0.63
		NO_x (µg L⁻¹)	10	1.96	1.33	0.69	0.92	2.67	4.49	H	Median	0.35		
		PN (µg L⁻¹)	10	30.47	26.54	12.80	17.86	45.90	54.41	H	Mean	20.00		
			10	30.47	26.54	12.80	17.86	45.90	54.41	H	Median		16.00	25.00
		PO_4 (µg L⁻¹)	10	1.31	1.16	0.59	0.99	1.69	2.23	H	Median	2.00		
		POC (mg L⁻¹)	10	193.93	188.61	104.60	165.36	231.09	284.32					
		PP (µg L⁻¹)	10	3.00	2.64	1.37	1.66	3.82	5.92	H	Mean	2.80		
			10	3.00	2.64	1.37	1.66	3.82	5.92	H	Median		2.30	3.30
		Secchi (m)	10	6.35	6.50	3.67	4.90	7.20	9.37	L	Mean	10.00		
			10	6.35	6.50	3.67	4.90	7.20	9.37	L	Median			
		SiO_4	10	238.12	187.85	92.90	140.73	284.83	511.51					
		TSS (mg L⁻¹)	10	2.24	1.44	0.27	0.87	2.67	6.19	H	Mean	2.00		
			10	2.24	1.44	0.27	0.87	2.67	6.19	H	Median		1.60	2.40
		DIN (µg L⁻¹)	10	4.21	3.96	2.88	3.09	5.78	5.95					

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
	Dunk Island South East (TUL5)	DOC (µg L⁻¹)	10	973	951	878	916	1026	1093					
		DON (µg L⁻¹)	10	82.18	74.94	57.37	70.26	95.06	119.82					
		DOP (µg L⁻¹)	10	5.87	5.92	5.14	5.45	6.35	6.39					
		Chl-a (µg L⁻¹)	10	0.28	0.27	0.18	0.23	0.35	0.37	H	Mean	0.45		
			10	0.28	0.27	0.18	0.23	0.35	0.37	H	Median		0.32	0.63
		NO_x (µg L⁻¹)	10	1.15	0.86	0.58	0.62	1.39	2.58	H	Median	0.35		
		PN (µg L⁻¹)	10	26.78	26.66	11.37	12.02	39.34	46.40	H	Mean	20.00		
			10	26.78	26.66	11.37	12.02	39.34	46.40	H	Median		16.00	25.00
		PO_4 (µg L⁻¹)	10	0.98	1.01	0.31	0.43	1.35	1.60	H	Median	2.00		
		POC (mg L⁻¹)	10	165.30	184.46	69.52	79.09	219.76	251.69					
		PP (µg L⁻¹)	10	2.18	2.01	1.75	1.85	2.48	2.90	H	Mean	2.80		
			10	2.18	2.01	1.75	1.85	2.48	2.90	H	Median		2.30	3.30
		Secchi (m)	10	9.07	9.25	4.01	5.00	11.60	15.10	L	Mean	10.00		
			10	9.07	9.25	4.01	5.00	11.60	15.10	L	Median			
		SiO_4	10	186.94	144.52	78.00	115.04	227.98	399.69					
		TSS (mg L⁻¹)	10	1.59	1.68	0.24	0.84	2.20	3.08	H	Mean	2.00		
			10	1.59	1.68	0.24	0.84	2.20	3.08	H	Median		1.60	2.40
	Between Tam O'Shanter and Timana (TUL6)	DIN (µg L⁻¹)	10	6.47	3.94	2.71	2.98	10.11	14.21					
		DOC (µg L⁻¹)	10	1125	1062	959	1035	1180	1390					
		DON (µg L⁻¹)	10	92.40	89.69	62.07	77.66	106.16	128.14					

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		DOP (µg L⁻¹)	10	5.61	5.81	4.65	4.83	6.22	6.52					
		Chl-a (µg L⁻¹)	10	0.41	0.36	0.26	0.29	0.58	0.60	H	Mean	0.45		
			10	0.41	0.36	0.26	0.29	0.58	0.60	H	Median		0.32	0.63
		NO_x (µg L⁻¹)	10	2.27	1.37	0.57	0.63	3.21	6.31	H	Median	0.35		
		PN (µg L⁻¹)	10	28.76	22.09	14.80	15.83	42.58	51.69	H	Mean	20.00		
			10	28.76	22.09	14.80	15.83	42.58	51.69	H	Median		16.00	25.00
		PO_4 (µg L⁻¹)	10	1.18	1.05	0.38	0.71	1.58	2.32	H	Median	2.00		
		POC (mg L⁻¹)	10	180.34	173.46	90.51	139.45	223.25	271.92					
		PP (µg L⁻¹)	10	3.14	3.12	2.11	2.50	4.03	4.12	H	Mean	2.80		
			10	3.14	3.12	2.11	2.50	4.03	4.12	H	Median		2.30	3.30
		Secchi (m)	10	5.24	5.50	2.52	3.30	6.60	8.40	L	Mean	10.00		
			10	5.24	5.50	2.52	3.30	6.60	8.40	L	Median			
		SiO_4	10	413.35	369.77	116.66	190.17	625.34	747.97					
		TSS (mg L⁻¹)	10	1.98	1.36	0.37	0.64	3.07	5.19	H	Mean	2.00		
			10	1.98	1.36	0.37	0.64	3.07	5.19	H	Median		1.60	2.40
	Bedarra (TUL8)	DIN (µg L⁻¹)	10	4.58	4.59	3.21	3.51	5.66	5.97					
		DOC (µg L⁻¹)	10	1083	1058	969	978	1133	1279					
		DON (µg L⁻¹)	10	96.93	94.93	65.96	85.06	104.73	137.02					
		DOP (µg L⁻¹)	10	5.79	5.65	5.33	5.48	6.13	6.45					
		Chl-a (µg L⁻¹)	10	0.37	0.38	0.20	0.29	0.46	0.54	H	Mean	0.45		

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
			10	0.37	0.38	0.20	0.29	0.46	0.54	H	Median		0.32	0.63
		NO_x (µg L^{-1})	10	1.43	1.33	0.44	0.87	2.17	2.40	H	Median	0.35		
		PN (µg L^{-1})	10	29.87	25.29	13.76	14.64	43.60	54.87	H	Mean	20.00		
			10	29.87	25.29	13.76	14.64	43.60	54.87	H	Median		16.00	25.00
		PO_4 (µg L^{-1})	10	0.94	0.97	0.31	0.43	1.29	1.68	H	Median	2.00		
		POC (mg L^{-1})	10	185.07	199.67	92.03	101.11	219.70	284.16					
		PP (µg L^{-1})	10	3.23	2.58	1.91	2.22	4.66	5.42	H	Mean	2.80		
			10	3.23	2.58	1.91	2.22	4.66	5.42	H	Median		2.30	3.30
		Secchi (m)	10	5.93	6.50	2.39	2.50	8.20	9.55	L	Mean	10.00		
			10	5.93	6.50	2.39	2.50	8.20	9.55	L	Median			
		SiO_4	10	399.66	391.93	123.45	189.61	609.83	742.92					
		TSS (mg L^{-1})	10	2.05	1.46	0.54	0.85	3.42	4.78	H	Mean	2.00		
			10	2.05	1.46	0.54	0.85	3.42	4.78	H	Median		1.60	2.40
	Tully River mouth mooring (TUL10)	DIN (µg L^{-1})	10	16.56	7.86	3.12	3.90	34.93	45.02					
		DOC (µg L^{-1})	10	1130	1111	955	973	1267	1345					
		DON (µg L^{-1})	10	89.95	89.40	66.25	79.18	96.42	120.78					
		DOP (µg L^{-1})	10	5.74	5.77	4.75	5.31	6.18	6.64					
		Chl-a (µg L^{-1})	10	0.58	0.52	0.34	0.47	0.70	0.91	H	Median	1.10		
		NO_x (µg L^{-1})	10	11.98	3.89	0.59	0.92	26.27	38.43	H	Median	3.00		
		PN (µg L^{-1})	10	45.97	46.02	16.67	18.88	69.86	72.24	H	Median			

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		PO_4 (µg L^{-1})	10	1.44	1.28	0.38	0.71	2.32	2.37	H	Median	3.00		
		POC (mg L^{-1})	10	312.85	354.74	123.01	168.41	431.17	441.06					
		PP (µg L^{-1})	10	6.25	5.41	3.68	4.09	7.96	10.30	H	Median			
		Secchi (m)	10	3.38	3.25	1.36	1.98	4.20	6.10	L	Median	1.60		
		SiO_4	10	867.01	658.11	227.51	298.35	1580.46	1965.60					
		TSS (mg L^{-1})	10	5.23	3.77	0.89	2.00	9.85	12.18	H	Median	5.00		
Burdekin	Palms West (BUR1)	DIN (µg L^{-1})	9	4.62	3.99	2.25	3.17	6.67	7.49					
		DOC (µg L^{-1})	9	946	942	907	918	973	993					
		DON (µg L^{-1})	9	75.14	75.24	63.31	63.45	86.11	89.61					
		DOP (µg L^{-1})	9	5.79	5.96	4.81	5.39	6.22	6.40					
		Chl-a (µg L^{-1})	9	0.28	0.29	0.13	0.17	0.36	0.44	H	Median	0.35	0.32	0.63
		NO_x (µg L^{-1})	9	1.80	1.37	0.36	0.89	2.32	4.14	H	Median	0.28		
		PN (µg L^{-1})	9	22.06	20.69	10.93	11.62	27.63	40.71	H	Median	12.00	16.00	25.00
		PO_4 (µg L^{-1})	9	1.01	0.85	0.40	0.59	1.32	1.87	H	Median	1.00		
		POC (mg L^{-1})	9	127.73	113.14	69.16	74.06	174.16	217.82					
		PP (µg L^{-1})	9	1.93	1.90	1.37	1.69	2.20	2.56	H	Median	2.20	2.30	3.30
		Secchi (m)	9	6.90	7.00	1.88	4.40	8.70	12.00	L	Mean	10.00		
			9	6.90	7.00	1.88	4.40	8.70	12.00	L	Median			
		SiO_4	9	71.62	68.47	29.59	54.28	90.08	118.19					
		TSS (mg L^{-1})	9	1.57	1.03	0.33	0.57	1.37	4.75	H	Median	1.20	1.60	2.40

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
	Pandora (BUR2)	DIN (µg L⁻¹)	9	5.16	4.13	1.88	2.34	6.92	12.50					
		DOC (µg L⁻¹)	9	991	1003	905	939	1047	1060					
		DON (µg L⁻¹)	9	77.36	75.12	63.07	67.19	87.14	95.29					
		DOP (µg L⁻¹)	9	5.61	5.65	4.83	5.16	6.01	6.24					
		Chl-a (µg L⁻¹)	9	0.26	0.22	0.17	0.18	0.31	0.43	H	Median	0.35	0.32	0.63
		NO_x (µg L⁻¹)	9	2.15	0.91	0.41	0.49	3.44	6.82	H	Median	0.28		
		PN (µg L⁻¹)	9	25.27	20.94	10.94	13.02	37.22	52.10	H	Median	12.00	16.00	25.00
		PO_4 (µg L⁻¹)	9	1.01	0.77	0.34	0.53	1.46	1.78	H	Median	1.00		
		POC (mg L⁻¹)	9	140.09	126.51	79.21	95.13	184.79	232.53					
		PP (µg L⁻¹)	9	2.20	2.18	1.26	1.72	2.84	2.96	H	Median	2.20	2.30	3.30
		Secchi (m)	9	5.22	5.00	2.84	3.68	6.00	8.40	L	Mean	10.00		
			9	5.22	5.00	2.84	3.68	6.00	8.40	L	Median			
		SiO_4	9	93.83	76.74	50.25	61.84	133.37	168.39					
		TSS (mg L⁻¹)	9	1.61	1.54	0.62	0.89	2.01	3.22	H	Median	1.20	1.60	2.40
	Magnetic (BUR4)	DIN (µg L⁻¹)	9	5.48	4.59	1.98	2.72	7.49	12.49					
		DOC (µg L⁻¹)	9	1010	1008	930	950	1070	1093					
		DON (µg L⁻¹)	9	85.76	86.49	71.69	74.62	88.35	106.50					
		DOP (µg L⁻¹)	9	5.26	5.26	4.83	4.94	5.36	5.87					
		Chl-a (µg L⁻¹)	9	0.37	0.32	0.24	0.29	0.47	0.57	H	Median	0.59	0.32	0.63
		NO_x (µg L⁻¹)	9	2.81	1.33	0.31	0.75	4.84	8.62	H	Median	0.28		

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		PN (µg L⁻¹)	9	30.13	34.64	14.33	15.54	40.44	48.60	H	Median	17.00	16.00	25.00
		PO_4 (µg L⁻¹)	9	1.20	0.93	0.31	0.31	1.97	2.48	H	Median	1.00		
		POC (mg L⁻¹)	9	187.65	181.43	96.34	117.78	252.97	287.50					
		PP (µg L⁻¹)	9	3.44	3.38	2.46	2.84	3.90	4.65	H	Mean	2.80		
			9	3.44	3.38	2.46	2.84	3.90	4.65	H	Median		2.30	3.30
		Secchi (m)	9	4.19	4.00	2.40	3.00	4.50	7.50	L	Median	4.00		
		SiO_4	9	152.94	147.96	85.93	112.06	188.01	245.90					
		TSS (mg L⁻¹)	9	2.51	1.91	0.54	1.01	3.84	5.67	H	Median	1.90	1.60	2.40
	Haughton 2 (BUR7)	DIN (µg L⁻¹)	8	4.06	4.22	2.07	2.97	5.29	5.66					
		DOC (µg L⁻¹)	8	940	925	880	885	989	1023					
		DON (µg L⁻¹)	8	76.99	74.56	61.27	65.38	91.27	97.03					
		DOP (µg L⁻¹)	8	6.61	5.65	5.16	5.31	5.73	11.04					
		Chl-a (µg L⁻¹)	8	0.34	0.31	0.21	0.23	0.41	0.55	H	Mean	0.45		
			8	0.34	0.31	0.21	0.23	0.41	0.55	H	Median		0.32	0.63
		NO_x (µg L⁻¹)	8	1.47	1.26	0.45	0.80	1.70	3.17	H	Median	1.00		
		PN (µg L⁻¹)	8	25.90	19.25	12.47	14.90	38.56	47.33	H	Median	13.00	16.00	25.00
		PO_4 (µg L⁻¹)	8	0.90	0.74	0.31	0.31	1.33	1.90	H	Median	2.00		
		POC (mg L⁻¹)	8	152.78	132.69	96.89	117.40	195.06	233.75					
		PP (µg L⁻¹)	8	2.94	2.96	1.92	2.59	3.34	3.89	H	Median	2.10	2.30	3.30
		Secchi (m)	8	4.45	3.50	2.94	3.20	5.46	7.45	L	Mean	10.00		

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
			8	4.45	3.50	2.94	3.20	5.46	7.45	L	Median			
		SiO_4	8	145.96	102.00	58.99	77.73	223.71	287.38					
		TSS (mg L^{-1})	8	2.18	2.02	1.22	1.47	2.75	3.46	H	Median	1.20	1.60	2.40
	Yongala (BUR10)	DIN (µg L^{-1})	4	3.91	3.90	2.62	2.81	5.01	5.22					
		DOC (µg L^{-1})	4	931	958	880	906	961	962					
		DON (µg L^{-1})	4	69.27	64.86	62.46	63.68	73.10	82.25					
		DOP (µg L^{-1})	4	5.38	5.57	4.76	5.11	5.73	5.73					
		Chl-a (µg L^{-1})	4	0.24	0.27	0.13	0.19	0.30	0.33	H	Median	0.33	0.32	0.63
		NO_x (µg L^{-1})	4	1.38	1.09	0.47	0.72	1.93	2.71	H	Median	0.28		
		PN (µg L^{-1})	4	11.46	12.13	9.05	10.39	12.79	12.92	H	Median	14.00	16.00	25.00
		PO_4 (µg L^{-1})	4	0.99	0.81	0.38	0.59	1.32	1.84	H	Median	1.00		
		POC (mg L^{-1})	4	70.85	75.06	46.79	59.13	84.26	89.03					
		PP (µg L^{-1})	4	1.32	1.17	1.02	1.02	1.57	1.84	H	Median	2.00	2.30	3.30
		Secchi (m)	4	13.75	12.00	9.30	10.20	16.60	20.65	L	Mean	10.00		
			4	13.75	12.00	9.30	10.20	16.60	20.65	L	Median			
		SiO_4	4	57.20	60.29	42.69	49.83	65.80	67.38					
		TSS (mg L^{-1})	4	0.26	0.18	0.07	0.08	0.40	0.55	H	Median	0.80	1.60	2.40
	Burdekin River mouth mooring (BUR13)	DIN (µg L^{-1})	9	7.91	6.34	2.57	3.89	12.96	14.67					
		DOC (µg L^{-1})	9	1224	1201	1030	1095	1345	1452					
		DON (µg L^{-1})	9	111.01	107.83	86.25	92.32	128.24	149.79					

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		DOP (µg L⁻¹)	9	6.46	6.54	5.35	5.59	6.98	7.75					
		Chl-a (µg L⁻¹)	9	0.50	0.53	0.25	0.41	0.63	0.73	H	Median	1.00		
		NO_x (µg L⁻¹)	9	4.76	2.80	0.52	1.11	9.46	10.23	H	Median	4.00		
		PN (µg L⁻¹)	9	47.35	48.44	18.77	25.01	69.90	79.67	H	Mean			
			9	47.35	48.44	18.77	25.01	69.90	79.67	H	Median			
		PO_4 (µg L⁻¹)	9	1.77	1.24	0.34	0.85	2.17	4.26	H	Median	1.00		
		POC (mg L⁻¹)	9	316.43	266.88	159.65	220.60	413.71	516.39					
		PP (µg L⁻¹)	9	7.73	7.15	4.23	5.06	9.88	12.57	H	Median			
		Secchi (m)	9	1.37	1.00	0.58	0.70	1.90	2.80	L	Median	1.50		
		SiO_4	9	344.32	335.46	111.11	139.59	510.40	646.32					
		TSS (mg L⁻¹)	9	10.67	6.75	1.27	2.03	19.24	25.91	H	Median	2.00		
Mackay Whitsunday	Double Cone (WHI1)	DIN (µg L⁻¹)	5	4.21	3.78	1.92	2.74	5.46	7.14					
		DOC (µg L⁻¹)	5	915	960	786	841	992	994					
		DON (µg L⁻¹)	5	75.23	72.28	51.87	66.78	81.84	103.39					
		DOP (µg L⁻¹)	5	5.56	5.73	5.08	5.45	5.74	5.79					
		Chl-a (µg L⁻¹)	5	0.36	0.41	0.19	0.20	0.48	0.51	H	Median	0.36	0.32	0.63
		NO_x (µg L⁻¹)	5	1.37	1.44	0.30	0.36	2.29	2.44	H	Median	1.00		
		PN (µg L⁻¹)	5	14.81	16.27	10.29	11.98	16.93	18.58	H	Mean	14.00		
			5	14.81	16.27	10.29	11.98	16.93	18.58	H	Median		16.00	25.00
		PO_4 (µg L⁻¹)	5	1.15	0.93	0.37	0.56	1.75	2.12	H	Median	1.00		

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		POC (mg L^{-1})	5	113.46	115.59	61.25	82.42	144.78	163.28					
		PP (µg L^{-1})	5	2.56	2.33	1.65	2.16	2.98	3.67	H	Median	2.30	2.30	3.30
		Secchi (m)	5	5.60	5.50	2.30	4.70	7.30	8.20	L	Mean	10.00		
			5	5.60	5.50	2.30	4.70	7.30	8.20	L	Median			
		SiO_4	5	71.81	73.53	58.23	58.90	84.11	84.27					
		TSS (mg L^{-1})	5	1.39	1.08	0.88	0.93	1.59	2.45	H	Median	1.40	1.60	2.40
	Pine (WHI4)	DIN (µg L^{-1})	5	6.34	4.90	3.85	4.38	6.90	11.65					
		DOC (µg L^{-1})	5	950	878	806	857	1062	1147					
		DON (µg L^{-1})	5	76.80	69.62	66.01	68.22	81.06	99.10					
		DOP (µg L^{-1})	5	5.20	5.26	4.46	5.06	5.59	5.64					
		Chl-a (µg L^{-1})	5	0.48	0.48	0.36	0.37	0.53	0.67	H	Median	0.36	0.32	0.63
		NO_x (µg L^{-1})	5	2.60	1.86	1.23	1.25	3.42	5.26	H	Median	1.00		
		PN (µg L^{-1})	5	15.73	15.28	10.66	11.18	20.56	20.99	H	Mean	14.00		
			5	15.73	15.28	10.66	11.18	20.56	20.99	H	Median		16.00	25.00
		PO_4 (µg L^{-1})	5	1.78	2.01	1.01	1.01	2.37	2.51	H	Median	1.00		
		POC (mg L^{-1})	5	128.54	130.86	64.30	65.65	184.58	197.29					
		PP (µg L^{-1})	5	3.29	2.16	1.81	2.03	3.67	6.76	H	Median	2.30	2.30	3.30
		Secchi (m)	5	7.00	9.00	2.30	4.70	9.20	9.80	L	Mean	10.00		
			5	7.00	9.00	2.30	4.70	9.20	9.80	L	Median			
		SiO_4	5	77.72	77.18	60.31	72.49	89.24	89.39					

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		TSS (mg L⁻¹)	5	2.77	1.16	0.68	0.91	3.46	7.64	H	Median	1.40	1.60	2.40
	Seaforth (WHI5)	DIN (µg L⁻¹)	5	4.43	5.36	2.70	2.80	5.58	5.73					
		DOC (µg L⁻¹)	5	921	938	843	869	954	1002					
		DON (µg L⁻¹)	5	79.88	73.72	71.28	72.06	89.59	92.78					
		DOP (µg L⁻¹)	5	5.39	5.03	4.88	4.88	5.73	6.43					
		Chl-a (µg L⁻¹)	5	0.41	0.38	0.33	0.36	0.48	0.50	H	Median	0.36	0.32	0.63
		NO_x (µg L⁻¹)	5	1.67	1.47	0.93	1.20	2.31	2.42	H	Median	1.00		
		PN (µg L⁻¹)	5	13.93	13.38	12.23	13.08	14.83	16.12	H	Mean	14.00		
			5	13.93	13.38	12.23	13.08	14.83	16.12	H	Median		16.00	25.00
		PO_4 (µg L⁻¹)	5	1.38	1.08	0.50	0.82	2.11	2.38	H	Median	1.00		
		POC (mg L⁻¹)	5	107.88	104.54	89.85	92.49	119.08	133.43					
		PP (µg L⁻¹)	5	2.60	2.70	2.08	2.16	2.86	3.20	H	Median	2.30	2.30	3.30
		Secchi (m)	5	5.90	6.50	3.70	4.30	7.50	7.50	L	Mean	10.00		
			5	5.90	6.50	3.70	4.30	7.50	7.50	L	Median			
		SiO_4	5	72.33	70.79	55.70	58.90	83.12	93.16					
		TSS (mg L⁻¹)	5	1.42	1.05	0.76	0.91	2.06	2.33	H	Median	1.40	1.60	2.40
	OConnell River mouth (WHI6)	DIN (µg L⁻¹)	5	6.37	7.39	3.00	3.19	8.74	9.53					
		DOC (µg L⁻¹)	5	1208	1219	1057	1074	1343	1348					
		DON (µg L⁻¹)	5	106.22	93.46	89.49	91.97	115.56	140.62					
		DOP (µg L⁻¹)	5	6.40	6.19	5.51	5.79	6.94	7.54					

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		Chl-a (µg L⁻¹)	5	0.63	0.56	0.36	0.42	0.82	1.00	H	Median	1.30		
		NO_x (µg L⁻¹)	5	2.75	1.89	0.90	1.09	4.73	5.15	H	Median	4.00		
		PN (µg L⁻¹)	5	27.50	28.41	18.54	18.75	32.18	39.62	H	Mean			
			5	27.50	28.41	18.54	18.75	32.18	39.62	H	Median			
		PO_4 (µg L⁻¹)	5	3.45	3.48	0.74	1.11	5.40	6.52	H	Median	3.00		
		POC (mg L⁻¹)	5	220.46	223.68	131.90	161.60	284.86	300.23					
		PP (µg L⁻¹)	5	5.53	6.68	2.91	3.52	7.14	7.41	H	Median			
		Secchi (m)	5	4.26	3.00	2.16	2.64	6.00	7.50	L	Median	1.60		
		SiO_4	5	259.72	229.31	38.41	97.82	385.75	547.33					
		TSS (mg L⁻¹)	5	2.73	2.86	0.81	0.98	3.85	5.16	H	Median	5.00		
	Repulse Islands dive mooring (WHI7)	DIN (µg L⁻¹)	5	6.86	5.92	2.91	3.14	9.55	12.78					
		DOC (µg L⁻¹)	5	957	942	909	918	1003	1015					
		DON (µg L⁻¹)	5	91.15	87.40	76.32	82.98	101.06	108.01					
		DOP (µg L⁻¹)	5	5.37	5.11	4.66	4.94	5.82	6.33					
		Chl-a (µg L⁻¹)	5	0.52	0.46	0.39	0.44	0.63	0.66	H	Mean	0.45		
			5	0.52	0.46	0.39	0.44	0.63	0.66	H	Median		0.32	0.63
		NO_x (µg L⁻¹)	5	4.04	3.64	1.39	1.55	5.16	8.46	H	Median	0.25		
		PN (µg L⁻¹)	5	17.61	16.08	14.28	14.36	20.90	22.45	H	Median	18.00	16.00	25.00
		PO_4 (µg L⁻¹)	5	2.59	2.32	1.98	2.12	3.02	3.48	H	Median	2.00		
		POC (mg L⁻¹)	5	148.03	151.53	114.09	119.35	175.04	180.14					

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		PP (µg L⁻¹)	5	4.28	3.51	2.47	2.87	5.77	6.80	H	Median	2.10	2.30	3.30
		Secchi (m)	5	4.40	3.50	1.70	2.30	5.30	9.20	L	Mean	10.00		
			5	4.40	3.50	1.70	2.30	5.30	9.20	L	Median			
		SiO_4	5	123.65	119.52	75.72	85.03	168.45	169.52					
		TSS (mg L⁻¹)	5	4.10	2.91	0.93	1.85	5.49	9.32	H	Median	1.60	1.60	2.40
Fitzroy	North Keppel Island (FTZ4)	DIN (µg L⁻¹)	10	6.31	6.11	3.73	5.12	6.92	9.58					
		DOC (µg L⁻¹)	10	1046	1081	966	1004	1096	1103					
		DON (µg L⁻¹)	10	86.79	87.56	64.01	68.57	100.59	108.07					
		DOP (µg L⁻¹)	10	5.70	5.57	4.99	5.22	6.29	6.56					
		Chl-a (µg L⁻¹)	10	0.32	0.28	0.19	0.24	0.36	0.54	H	Mean	0.45		
			10	0.32	0.28	0.19	0.24	0.36	0.54	H	Median		0.32	0.63
		NO_x (µg L⁻¹)	10	1.08	0.75	0.42	0.48	1.25	2.75	H	Median	0.50		
		PN (µg L⁻¹)	10	16.02	15.54	11.92	12.91	18.56	21.39	H	Median	15.00	16.00	25.00
		PO_4 (µg L⁻¹)	10	0.93	0.77	0.34	0.45	0.99	2.19	H	Median	2.00		
		POC (mg L⁻¹)	10	115.49	110.29	78.42	91.16	145.02	160.65					
		PP (µg L⁻¹)	10	2.82	2.58	1.94	2.35	3.33	4.17	H	Median	2.50	2.30	3.30
		Secchi (m)	10	7.38	7.50	4.72	6.20	8.70	9.77	L	Median	10.00		
		SiO_4	10	75.61	74.75	24.80	48.60	99.30	123.52					
		TSS (mg L⁻¹)	10	1.15	1.05	0.33	0.70	1.37	2.34	H	Median	1.00	1.60	2.40
	Barren (FTZ1)	DIN (µg L⁻¹)	10	5.78	6.04	2.83	4.90	6.69	8.12					

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		DOC (µg L^{-1})	10	1029	1035	978	997	1063	1076					
		DON (µg L^{-1})	10	89.22	85.55	70.29	72.06	105.10	117.40					
		DOP (µg L^{-1})	10	5.73	5.65	5.22	5.45	6.10	6.39					
		Chl-a (µg L^{-1})	10	0.25	0.21	0.13	0.15	0.33	0.48	H	Median	0.27	0.32	0.63
		NO_x (µg L^{-1})	10	1.57	0.74	0.45	0.52	1.73	5.22	H	Median	0.50		
		PN (µg L^{-1})	10	13.92	13.14	10.40	11.24	17.77	18.96	H	Median	12.00	16.00	25.00
		PO_4 (µg L^{-1})	10	0.87	0.77	0.31	0.37	1.05	1.79	H	Median	2.00		
		POC (mg L^{-1})	10	98.04	88.87	54.87	65.24	133.23	160.63					
		PP (µg L^{-1})	10	1.99	1.61	1.31	1.46	2.59	3.35	H	Median	1.90	2.40	3.40
		Secchi (m)	10	10.10	9.75	6.17	7.40	11.60	15.30	L	Median	12.00		
		SiO_4	10	57.65	52.32	27.43	41.15	78.48	99.09					
		TSS (mg L^{-1})	10	1.24	0.97	0.15	0.32	2.15	3.12	H	Median	0.40	1.70	2.50
	Keppels South (FTZ2)	DIN (µg L^{-1})	10	5.99	6.06	3.30	3.91	6.80	9.56					
		DOC (µg L^{-1})	10	1045	1059	982	1008	1085	1098					
		DON (µg L^{-1})	10	96.43	95.21	79.52	82.01	105.25	122.17					
		DOP (µg L^{-1})	10	5.81	5.65	5.18	5.33	6.36	6.55					
		Chl-a (µg L^{-1})	10	0.31	0.29	0.17	0.23	0.41	0.47	H	Mean	0.45		
			10	0.31	0.29	0.17	0.23	0.41	0.47	H	Median		0.32	0.63
		NO_x (µg L^{-1})	10	1.22	0.79	0.28	0.59	2.07	2.63	H	Median	0.50		
		PN (µg L^{-1})	10	16.04	15.00	11.80	13.04	19.97	22.13	H	Mean	20.00		

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
			10	16.04	15.00	11.80	13.04	19.97	22.13	H	Median		16.00	25.00
		PO_4 (µg L^{-1})	10	0.80	0.46	0.31	0.37	1.10	1.99	H	Mean	2.00		
			10	0.80	0.46	0.31	0.37	1.10	1.99	H	Median			
		POC (mg L^{-1})	10	120.66	104.49	81.68	94.45	168.88	176.61					
		PP (µg L^{-1})	10	2.97	2.59	1.72	2.13	3.79	4.90	H	Mean	2.80		
			10	2.97	2.59	1.72	2.13	3.79	4.90	H	Median		2.40	3.40
		Secchi (m)	10	7.50	7.00	4.62	6.00	9.20	11.10	L	Mean	10.00		
			10	7.50	7.00	4.62	6.00	9.20	11.10	L	Median			
		SiO_4	10	67.32	63.17	23.96	45.27	94.42	116.85					
		TSS (mg L^{-1})	10	1.26	0.94	0.28	0.59	1.63	3.05	H	Mean	2.00		
			10	1.26	0.94	0.28	0.59	1.63	3.05	H	Median		1.70	2.50
	Pelican (FTZ3)	DIN (µg L^{-1})	10	7.40	6.35	3.07	3.67	11.05	13.15					
		DOC (µg L^{-1})	10	1167	1190	1087	1121	1218	1231					
		DON (µg L^{-1})	10	98.34	92.70	77.98	85.40	109.63	128.95					
		DOP (µg L^{-1})	10	6.09	5.73	5.25	5.48	6.30	7.90					
		Chl-a (µg L^{-1})	10	0.45	0.40	0.18	0.23	0.59	0.86	H	Mean	0.45		
			10	0.45	0.40	0.18	0.23	0.59	0.86	H	Median		0.32	0.63
		NO_x (µg L^{-1})	10	1.65	0.93	0.28	0.39	1.25	5.77	H	Median	0.50		
		PN (µg L^{-1})	10	18.60	18.95	11.20	14.79	22.80	24.41	H	Mean	20.00		
			10	18.60	18.95	11.20	14.79	22.80	24.41	H	Median		16.00	25.00

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		PO₄ ($\mu g\ L^{-1}$)	10	1.87	1.90	0.73	1.33	2.12	3.19	H	Mean	2.00		
			10	1.87	1.90	0.73	1.33	2.12	3.19	H	Median			
		POC ($mg\ L^{-1}$)	10	147.41	135.78	68.04	116.87	197.32	217.63					
		PP ($\mu g\ L^{-1}$)	10	4.02	4.19	2.05	2.89	5.20	6.10	H	Mean	2.80		
			10	4.02	4.19	2.05	2.89	5.20	6.10	H	Median		2.40	3.40
		Secchi (m)	10	4.33	3.75	2.09	2.90	6.00	7.65	L	Mean	10.00		
			10	4.33	3.75	2.09	2.90	6.00	7.65	L	Median			
		SiO_4	10	141.42	120.30	36.29	72.08	216.87	276.11					
		TSS ($mg\ L^{-1}$)	10	2.50	1.88	0.73	1.10	2.99	6.14	H	Mean	2.00		
			10	2.50	1.88	0.73	1.10	2.99	6.14	H	Median		1.70	2.50
	Peak West (FTZ5)	DIN ($\mu g\ L^{-1}$)	10	6.77	5.27	2.85	3.32	9.19	14.25					
		DOC ($\mu g\ L^{-1}$)	10	1159	1239	1011	1087	1248	1252					
		DON ($\mu g\ L^{-1}$)	10	102.73	102.45	75.98	80.32	118.47	140.27					
		DOP ($\mu g\ L^{-1}$)	10	5.86	5.54	4.90	5.11	6.36	7.58					
		Chl-a ($\mu g\ L^{-1}$)	10	0.54	0.59	0.25	0.33	0.68	0.81	H	Mean	0.45		
			10	0.54	0.59	0.25	0.33	0.68	0.81	H	Median		0.32	0.63
		NO_x ($\mu g\ L^{-1}$)	10	2.28	1.28	0.35	0.78	3.28	6.43	H	Median	0.50		
		PN ($\mu g\ L^{-1}$)	10	20.22	19.03	13.54	16.08	24.02	30.22	H	Mean	20.00		
			10	20.22	19.03	13.54	16.08	24.02	30.22	H	Median		16.00	25.00
		PO_4 ($\mu g\ L^{-1}$)	10	2.24	2.28	0.64	0.91	2.91	4.23	H	Median	2.00		

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		POC (mg L⁻¹)	10	161.20	139.61	99.90	116.88	192.86	272.19					
		PP (µg L⁻¹)	10	4.68	4.59	2.96	3.33	4.93	7.63	H	Mean	2.80		
			10	4.68	4.59	2.96	3.33	4.93	7.63	H	Median		2.40	3.40
		Secchi (m)	10	2.73	2.75	1.36	2.30	3.50	3.77	L	Mean	10.00		
			10	2.73	2.75	1.36	2.30	3.50	3.77	L	Median			
		SiO_4	10	140.54	121.15	46.37	98.67	190.93	244.77					
		TSS (mg L⁻¹)	10	3.82	2.88	1.65	2.09	4.25	9.17	H	Mean	2.00		
			10	3.82	2.88	1.65	2.09	4.25	9.17	H	Median		1.70	2.50
	Fitzroy River Mouth (FTZ6)	DIN (µg L⁻¹)	10	20.19	21.16	8.60	11.42	26.36	29.57					
		DOC (µg L⁻¹)	10	1258	1279	1070	1140	1380	1430					
		DON (µg L⁻¹)	10	107.05	103.54	84.71	89.73	118.26	144.14					
		DOP (µg L⁻¹)	10	6.42	6.04	4.73	5.28	6.21	9.93					
		Chl-a (µg L⁻¹)	10	0.87	0.81	0.60	0.70	1.01	1.23	H	Median	1.00		
		NO_x (µg L⁻¹)	10	15.38	17.12	4.27	6.35	20.62	25.59	H	Median	3.00		
		PN (µg L⁻¹)	10	39.46	33.57	22.70	27.39	54.07	64.01	H	Median			
		PO_4 (µg L⁻¹)	10	6.55	6.35	4.13	5.39	7.85	9.25	H	Median	3.00		
		POC (mg L⁻¹)	10	415.88	357.91	188.17	215.82	514.65	830.01					
		PP (µg L⁻¹)	10	12.11	11.13	6.55	7.61	15.70	20.60	H	Median			
		Secchi (m)	10	0.82	0.90	0.25	0.45	1.04	1.50	L	Median			
		SiO_4	10	255.83	254.99	70.97	157.81	395.97	412.55					

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
		TSS (mg L^{-1})	10	20.38	13.78	5.40	8.24	29.54	51.30	H	Median			

Table C-2: Summary of turbidity measurements from moored loggers (site locations in Section 5) 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-8). 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 2019 - Sept 2020						Oct 2020 - Sept 2021						Oct 2021 - Sept 2022					
		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	128	1.00	0.06	0.68	38.28	0.00	225	1.39	0.15	0.64	41.78	3.56	253	1.11	0.08	0.64	37.15	1.98
	Forrester	215	0.46	0.45	0.01	38.14	0.00	222	0.31	0.01	0.25	3.60	0.00	224	0.37	0.01	0.29	14.73	0.00
Johnstone Russell Mulgrave	Fitzroy West	263	0.97	0.05	0.79	28.52	0.76	118	1.28	0.05	1.10	67.80	0.00	121	0.96	0.08	0.76	26.45	1.65
	Franklands West	366	0.82	0.03	0.65	59.84	0.55	282	1.04	0.15	0.63	56.38	1.77	249	0.79	0.03	0.66	59.84	0.00
	High West	320	1.16	0.05	0.89	39.06	1.25	365	1.44	0.09	1.00	49.32	3.56	250	0.84	0.03	0.81	33.60	0.00
	Russell Mulgrave Mouth Mooring	366	3.81	0.24	2.12	77.60	22.95	365	3.99	0.24	2.43	90.68	22.19	134	2.54	0.20	1.88	96.27	6.72
Tully Herbert	Dunk North	366	2.81	0.17	1.25	70.22	17.21	215	3.38	0.24	1.87	89.30	20.47	248	2.18	0.17	1.40	79.44	7.66
	Tully River mouth mooring	318	3.82	0.21	2.79	29.25	20.13	364	4.26	0.26	2.97	35.44	26.37	248	4.49	0.18	3.95	49.19	31.05
Burdekin	Burdekin River mouth mooring	322	5.39	0.29	3.72	46.58	38.82	301	7.71	0.36	5.95	63.79	55.81	233	7.89	0.42	6.15	66.09	54.51
	Magnetic	366	1.77	0.09	1.21	43.99	4.64	365	2.11	0.14	1.32	51.51	6.85	247	1.94	0.17	1.12	36.84	6.07
	Palms West	313	0.66	0.02	0.64	23.96	0.00	365	0.93	0.03	0.85	56.44	0.27	226	0.70	0.03	0.61	18.14	0.44
	Pandora	357	1.43	0.07	1.04	73.95	1.96	226	1.90	0.12	1.23	87.17	7.52	247	1.34	0.07	1.01	69.23	2.43
Mackay-Whitsunday	Double Cone	366	1.42	0.04	1.14	54.64	0.82	365	1.43	0.04	1.15	54.25	1.10	244	1.29	0.04	1.16	54.51	0.41
	OConnell River mouth							236	4.98	0.32	3.06	37.71	29.24	244	5.82	0.38	3.24	42.62	33.61

Subregion	Site	Oct 2019 - Sept 2020						Oct 2020 - Sept 2021						Oct 2021 - Sept 2022					
		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
	Pine	306	2.17	0.11	1.50	67.97	8.50	281	2.28	0.10	1.63	77.58	8.54	245	2.53	0.13	1.89	75.51	12.65
	Repulse Islands dive mooring	366	3.59	0.17	2.72	62.84	19.13	130	4.56	0.27	3.46	78.46	36.15						
	Seaforth	363	1.54	0.05	1.21	57.58	2.20	292	1.62	0.05	1.28	64.38	0.68	244	1.66	0.05	1.52	75.00	0.00

C-4 Data used to generate remote sensing maps

Table C-3: Summary of water quality data collected across the MODIS wet season colour classes (WS1–6) and Reef WT1, WT2 and WT3 (primary, secondary, tertiary) as part of the wet season event sampling of the MMP. Multi-years samples were collected between December–April by AIMS and CYWP since 2016–17 and by JCU since 2003–04 and up to 2018–19. No Data = nd

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})
	WS1	mean	54.63	2.20	1.90	0.95	62.52	16.87	29.83	119.32
		SD	101.36	3.41	1.24	1.05	48.38	22.09	40.53	115.83
		min	0.50	0.20	0.00	0.00	2.00	1.00	0.00	1.00
		max	590.00	26.70	6.03	5.00	325.00	98.00	167.00	573.00
		count	117	125	91	66	112	116	93	113
	WS2	mean	18.30	1.48	0.94	1.35	50.36	9.50	10.66	53.80
		SD	23.91	1.12	0.69	1.68	50.71	13.89	11.77	60.96
		min	0.43	0.20	0.03	0.00	2.00	0.21	0.00	1.00
		max	150.00	5.41	4.40	12.00	237.00	80.00	73.00	282.00
		count	104	101	85	57	93	94	86	91
	WS3	mean	15.11	2.28	0.84	1.37	51.75	13.59	12.25	61.79
		SD	14.14	2.98	0.83	0.74	47.76	13.86	13.68	61.82
		min	0.80	0.20	0.05	0.50	2.00	1.55	0.00	1.00
		max	67.00	22.43	4.19	3.00	218.00	75.00	75.00	296.00
		count	78	78	63	21	68	71	62	66
	WS4	mean	8.30	1.41	0.56	2.20	38.38	7.47	6.25	43.96
		SD	8.95	2.09	0.57	1.66	45.59	6.56	7.66	54.93

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	0.10	0.00	0.00	0.14	0.00	0.00	0.00
		max	73.00	30.90	3.71	11.50	357.00	55.00	63.00	374.00
		count	424	420	366	197	398	404	365	381
	Reef WT1 (primary or WS1-4)	mean	18.27	1.61	0.82	1.78	46.05	9.77	10.87	60.55
		SD	45.70	2.37	0.88	1.75	49.86	12.73	19.44	76.73
		min	0.00	0.10	0.00	0.00	0.14	0.00	0.00	0.00
		max	590.00	30.90	6.03	16.00	357.00	98.00	167.00	573.00
		count	754	755	636	370	702	716	637	682
	Reef WT2 (secondary or WS5)	mean	5.92	0.80	0.27	4.00	21.51	5.62	3.45	25.49
		SD	7.99	0.84	0.41	2.33	28.51	5.75	4.36	33.62
		min	0.00	0.02	0.00	0.20	0.00	0.00	0.00	0.00
		max	130.00	12.50	3.25	16.00	369.00	63.00	47.90	456.00
		count	926	955	722	594	939	947	862	893
	Reef WT3 (tertiary or WS6)	mean	3.92	0.51	0.13	7.05	15.22	4.27	2.27	18.17
		SD	5.10	0.51	0.23	3.76	15.04	3.84	2.82	21.44
		min	0.00	0.02	0.00	0.50	0.04	0.02	0.00	0.00
		max	31.00	5.34	2.00	19.00	104.00	21.00	18.00	174.00
		count	301	304	216	212	304	304	285	300

Table C-4: Summary of water quality data collected in the Cape York region across the MODIS wet season colour classes (WS1–6) and Reef WT1, WT2 and WT3 (primary, secondary, tertiary) as part of the wet season event sampling of the MMP. Multi-years samples were collected between December and April by CYWP since 2016–17 and up to 2018–19. No Data = nd.

	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	WS1	mean	28.73	1.56	2.82	1.11	34.38	4.74	11.83	97.63
		SD	49.00	1.23	1.50	1.01	17.24	2.95	10.63	93.58
		min	0.50	0.20	0.00	0.10	4.00	1.00	1.00	14.00
		max	250.00	5.34	6.03	4.15	83.18	12.00	35.00	532.25
		count	32	37	27	31	37	37	18	36
	WS2	mean	24.69	1.32	1.38	2.40	32.26	3.99	8.21	49.91
		SD	36.59	0.97	1.20	2.84	22.69	25.33	56.19	
		min	0.35	1.00	0.31	1.40	0.03	3.67	1.60	0.00
		max	150.00	3.90	4.40	12.00	80.00	10.00	35.00	244.00
		count	20	19	12	14	21	20	14	21
	WS3	mean	11.50	3.41	2.15	1.55	27.99	4.90	7.00	77.75
		SD	17.09	2.48	1.27	0.74	25.78	2.16	2.55	79.27
		min	0.80	0.79	0.47	0.75	4.33	2.71	3.00	2.00
		max	53.00	8.82	4.19	2.80	89.00	9.00	10.00	253.00
		count	7	9	9	6	9	9	4	8
	WS4	mean	5.44	1.14	1.21	3.02	20.91	3.26	2.94	50.61
		SD	5.54	1.00	1.20	2.14	17.64	1.79	1.94	58.97
		min	0.10	0.10	0.00	0.25	2.80	1.00	0.00	2.00
		max	34.00	5.18	3.71	9.50	73.00	11.00	7.00	318.00
		count	44	49	31	36	49	49	33	48
	Reef WT1 (primary or WS1-4)	mean	19.13	1.36	1.49	2.03	26.72	3.98	6.22	66.59

	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})
		SD	38.36	1.30	1.53	1.94	20.47	2.34	7.56	77.80
		min	0.10	0.10	0.00	0.10	2.10	1.00	0.00	0.00
		max	250.00	8.82	6.03	12.00	89.00	12.00	35.00	532.25
		count	125	136	101	109	138	137	91	135
	Reef WT2 (secondary or WS5)	mean	4.47	0.68	0.48	4.51	13.71	2.99	1.79	24.80
		SD	7.06	0.60	0.78	2.63	15.36	1.40	2.31	29.75
		min	0.10	0.07	0.00	0.20	2.32	1.00	0.00	0.00
		max	60.00	3.26	3.25	16.00	131.25	8.00	13.00	179.00
		count	124	132	51	120	131	132	98	131
	Reef WT3 (tertiary or WS6)	mean	2.48	0.45	0.17	8.01	12.27	2.93	1.60	17.22
		SD	2.37	0.46	0.42	4.08	13.99	1.47	1.51	19.40
		min	0.10	0.02	0.00	0.80	2.94	1.00	0.00	0.00
		max	14.00	1.95	2.00	17.40	104.00	7.14	5.00	84.00
		count	61	61	25	47	63	63	52	63

Table C-5: Summary of water quality data collected in the Wet Tropics region across the MODIS wet season colour classes (WS1–6) and Reef WT1, WT2 and WT3 (primary, secondary, tertiary) 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 2018–19. No Data = nd.

	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	WS1	mean	0.90	11.52	1.09	1.10	68.89	4.23	10.04	40.09
		SD	0.59	8.04	1.40	0.46	45.18	1.91	9.51	43.24
		min	0.00	2.10	0.20	0.26	18.00	1.78	0.00	1.00
		max	2.00	38.00	6.14	1.82	140.00	8.00	32.00	167.00
		count	13	18	18	18	10	11	10	11
	WS2	mean	0.89	14.02	1.43	1.00	72.87	6.82	9.83	50.26
		SD	0.71	15.65	1.08	0.43	62.16	4.43	9.85	53.41
		min	0.00	2.30	0.20	0.33	11.16	1.97	0.00	2.00
		max	2.25	92.00	5.34	2.37	237.00	18.00	52.00	263.00
		count	27	50	48	49	40	40	39	39
	WS3	mean	1.13	11.20	1.53	0.55	64.15	10.89	6.85	46.71
		SD	0.69	8.29	1.53	0.31	57.72	6.02	5.16	35.57
		min	0.50	1.40	0.20	0.10	6.00	1.55	0.00	2.00
		max	2.50	34.00	7.48	1.43	218.00	21.00	21.00	134.00
		count	7	38	37	34	30	30	26	28
	WS4	mean	2.01	7.10	1.31	0.54	49.08	7.30	5.53	36.73
		SD	1.55	7.53	2.08	0.44	54.86	4.95	7.72	52.39
		min	0.00	0.00	0.20	0.00	0.14	0.00	0.00	0.00
		max	11.50	70.00	30.90	3.11	357.00	21.00	63.00	374.00
		count	112	262	258	249	234	236	219	224

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})
	Reef WT1 (Primary or WS1-4)	mean	1.65	8.86	1.33	0.65	57.28	7.54	6.48	40.87
		SD	1.44	9.60	1.88	0.48	60.16	5.12	8.06	53.78
		min	0.00	0.00	0.20	0.00	0.14	0.00	0.00	0.00
		max	11.50	92.00	30.90	3.11	357.00	21.00	63.00	374.00
		count	164	375	368	357	321	324	301	309
	Reef WT2 (Secondary or WS5)	mean	4.09	5.09	0.79	0.29	26.12	5.89	3.25	23.92
		SD	2.34	5.20	0.70	0.40	34.99	4.74	3.63	30.47
		min	0.50	0.00	0.02	0.00	0.08	0.00	0.00	0.00
		max	13.00	33.00	11.24	2.74	369.00	22.00	29.00	372.00
		count	289	482	495	438	475	476	446	447
	Reef WT3 (Tertiary or WS6)	mean	7.33	4.42	0.55	0.14	18.03	4.68	2.14	18.32
		SD	3.85	5.79	0.60	0.19	16.56	4.18	2.56	23.40
		min	0.50	0.00	0.02	0.00	0.04	0.03	0.00	0.00
		max	19.00	31.00	5.34	1.38	82.00	21.00	17.00	174.00
		count	121	172	172	141	169	169	166	167

Table C-6: Summary of water quality data collected in the Burdekin region across the MODIS wet season colour classes (WS1–6) and Reef WT1, WT2 and WT3 (primary, secondary, tertiary) 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 2018–19. No Data = nd.

	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	WS1	mean	105.00	1.45	1.68	0.90	75.14	11.58	45.48	141.23
		SD	146.58	1.13	1.02	1.41	58.07	7.48	52.84	132.97
		min	1.35	0.20	0.07	0.00	2.00	1.00	0.00	14.00
		max	590.00	5.48	3.48	5.00	325.00	29.00	167.00	573.00
		count	37	40	25	17	37	39	37	38
	WS2	mean	17.74	1.71	0.39	1.23	21.09	7.13	12.87	50.59
		SD	25.48	1.21	0.37	0.88	21.70	9.12	16.89	52.99
		min	0.43	0.20	0.04	0.20	2.00	0.21	0.00	1.00
		max	120.00	5.41	1.34	3.50	90.00	46.00	73.00	255.00
		count	22	23	16	16	22	22	21	21
	WS3	mean	11.85	2.09	0.59	1.08	27.78	6.74	15.87	64.50
		SD	15.72	2.33	0.54	0.36	29.41	5.62	20.09	74.71
		min	2.70	0.53	0.05	0.50	2.00	2.00	0.00	3.00
		max	66.00	9.25	1.66	1.50	96.00	20.00	75.00	289.00
		count	14	13	7	6	12	12	12	12
	WS4	mean	7.52	1.42	0.34	2.10	11.07	4.48	7.72	39.86
		SD	10.55	2.15	0.40	1.17	8.57	4.32	8.32	40.14
		min	0.05	0.20	0.02	0.30	0.26	0.09	0.00	2.00
		max	73.00	13.78	1.81	4.50	62.00	30.00	37.90	239.00
		count	57	53	36	40	56	56	54	54

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})
	Reef WT1 (Primary or WS1-4)	mean	36.91	1.53	0.75	1.79	32.63	7.21	20.33	73.85
		SD	89.58	1.77	0.88	2.02	43.77	7.13	34.74	94.74
		min	0.05	0.14	0.00	0.00	0.26	0.09	0.00	1.00
		max	590.00	13.78	3.48	16.00	325.00	46.00	167.00	573.00
		count	132	131	86	81	129	131	126	127
	Reef WT2 (Secondary or WS5)	mean	4.86	0.74	0.13	3.68	15.15	3.55	2.90	24.65
		SD	9.64	0.90	0.24	2.08	21.61	3.51	4.20	23.98
		min	0.20	0.10	-0.02	0.20	0.00	0.01	0.00	0.00
		max	130.00	8.69	1.98	14.00	245.68	27.90	47.90	146.00
		count	188	187	132	146	187	187	177	176
	Reef WT3 (Tertiary or WS6)	mean	3.60	0.44	0.10	5.34	11.49	4.09	2.30	20.34
		SD	2.55	0.24	0.20	2.50	8.93	3.15	2.49	20.54
		min	0.15	0.17	0.00	1.40	0.11	0.02	0.00	0.00
		max	12.00	1.14	1.11	13.00	40.00	12.00	11.00	80.96
		count	47	45	37	35	47	47	43	45

Table C-7: Summary of water quality data collected in the Mackay-Whitsunday region across the MODIS wet season colour classes (WS1–CC6) and Reef WT1, WT2 and WT3 (primary, secondary, tertiary) 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 2018–19. No Data = nd.

	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	WS1	mean	73.00	3.69	1.13	0.35	44.00	13.67	25.67	73.67
		SD	36.12	2.26	0.44	0.12	26.99	8.38	7.72	40.20
		min	24.00	1.42	0.76	0.20	15.00	5.00	15.00	32.00
		max	110.00	6.78	1.75	0.50	80.00	25.00	33.00	128.00
		count	3	3	3	3	3	3	3	3
	WS2	mean	22.35	0.92	0.11	Nd.	27.50	8.00	14.50	32.00
		SD	16.65	0.65	0.03		5.50	2.00	9.50	27.00
		min	5.70	0.27	0.07		22.00	6.00	5.00	5.00
		max	39.00	1.56	0.14		33.00	10.00	24.00	59.00
		count	2	2	2		2	2	2	2
	WS3	mean	14.00	1.35	0.14	Nd.	58.50	8.00	12.50	15.00
		SD	0.00	0.05	0.00		25.50	6.00	3.50	5.00
		min	14.00	1.30	0.14		33.00	2.00	9.00	10.00
		max	14.00	1.40	0.15		84.00	14.00	16.00	20.00
		count	2	2	2		2	2	2	2
	WS4	mean	8.19	1.35	0.24	0.84	28.04	13.29	12.41	35.76
		SD	7.09	1.01	0.13	0.38	9.08	5.30	8.28	44.60
		min	1.00	0.27	0.03	0.35	2.80	2.00	3.00	2.00
		max	22.00	4.81	0.45	1.50	40.00	23.00	30.00	169.00
		count	19	16	18	6	19	19	17	17

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})
	Reef WT1 (Primary or WS1-4)	mean	17.21	1.62	0.32	0.68	32.18	12.52	14.25	38.46
		SD	25.10	1.44	0.35	0.39	16.74	5.96	9.13	43.40
		min	1.00	0.27	0.03	0.20	2.80	2.00	3.00	2.00
		max	110.00	6.78	1.75	1.50	84.00	25.00	33.00	169.00
		count	26	23	25	9	26	26	24	24
	Reef WT2 (Secondary or WS5)	mean	6.75	1.02	0.17	2.73	15.95	4.95	4.89	21.37
		SD	7.89	0.61	0.17	1.44	14.39	3.75	5.16	17.24
		min	0.10	0.24	0.01	0.40	0.00	0.00	0.10	0.00
		max	41.00	3.88	0.88	6.00	64.00	15.00	37.00	85.00
		count	86	81	53	34	86	86	77	78
	Reef WT3 (Tertiary or WS6)	mean	1.88	0.67	0.03	4.89	4.77	1.89	2.33	16.46
		SD	2.70	0.21	0.01	1.05	8.08	1.79	2.33	9.99
		min	0.11	0.25	0.01	4.00	0.10	0.02	0.09	2.20
		max	12.00	1.19	0.05	7.00	35.00	7.00	10.00	36.87
		count	18	18	9	9	17	17	17	17

C-5 Site-specific Guideline Values for MMP sites

Table C-8: Site-specific Guideline Values (GVs) used for comparison with water quality monitoring data These GVs are used to calculate the annual condition version of the WQ Index for each water quality sampling location and are derived from the Water Quality Guidelines for the Great Barrier Reef Marine Park (Great Barrier Reef Marine Park Authority, 2010, see Table 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 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, et cetera). 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, PRN05, PRN06, PRBB, PRS05	Chl-*a* (µg L^{-1})	Mid-shelf waters	H		0.27		
		NO_x (µg L^{-1})	Mid-shelf waters	H		0.35		
		PN (µg L^{-1})	Mid-shelf waters	H		18.00		

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		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
		PO_4 (µg L⁻¹)	Mid-shelf waters	H		2.00		

GBRMPA group	GBRMPA sites	Measure	Water body	DOF	Annual Mean	Annual Median	Dry Median	Wet Median
		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		
		PP (μg L^{-1})	Open Coastal waters	H	2.80		2.30	3.30

GBRMPA group	GBRMPA sites	Measure	Water body	DOF	Annual Mean	Annual Median	Dry Median	Wet Median
		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					
		Secchi (m)	Enclosed Coastal waters	L		1.50		

GBRMPA group	GBRMPA sites	Measure	Water body	DOF	Annual Mean	Annual Median	Dry Median	Wet Median
		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			
		TSS (mg L⁻¹)	Open Coastal waters	H		1.40	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		1.10		
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
		Turbidity (NTU)	Open Coastal waters	H	1.00			

GBRMPA group	GBRMPA sites	Measure	Water body	DOF	Annual Mean	Annual Median	Dry Median	Wet Median
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
	FTZ2, FTZ3, FTZ4, FTZ5		Open Coastal waters	H	0.45		0.32	0.63
	FTZ6		Enclosed Coastal waters	H		1.00		
	SR01, SR02		Enclosed Coastal waters	H				0.40
	FTZ1	NO_x (µg L⁻¹)	Mid-shelf waters	H		0.50		
	FTZ2, FTZ3, FTZ4, FTZ5		Open Coastal waters	H		0.50		
	FTZ6		Enclosed Coastal waters	H		3.00		
	SR01, SR02		Enclosed Coastal waters	H				1.50
	FTZ1	PN (µg L⁻¹)	Mid-shelf waters	H		12.00	16.00	25.00
	FTZ2, FTZ3, FTZ5		Open Coastal waters	H	20.00		16.00	25.00
	FTZ4		Open Coastal waters	H		15.00	16.00	25.00
	FTZ6		Enclosed Coastal waters					
	SR01, SR02		Enclosed Coastal waters					
	FTZ1		Mid-shelf waters	H		2.00		
	FTZ2, FTZ3	PO_4 (µg L⁻¹)	Open Coastal waters	H	2.00			
	FTZ4, FTZ5	PP (µg L⁻¹)	Open Coastal waters	H		2.00		
	FTZ6		Enclosed Coastal waters	H		3.00		
	SR01, SR02		Enclosed Coastal waters	H				2.00
	FTZ1		Mid-shelf waters	H		1.90	2.40	3.40
	FTZ2, FTZ3, FTZ5		Open Coastal waters	H	2.80		2.40	3.40
	FTZ4	PP (µg L⁻¹)	Open Coastal waters	H		2.50	2.30	3.30
	FTZ6	Secchi (m)	Enclosed Coastal waters					
	SR01, SR02	Secchi (m)	Enclosed Coastal waters					
	ER01, AR01, SR01, SR02	TSS (mg L⁻¹)	Enclosed Coastal waters					

GBRMPA group	GBRMPA sites	Measure	Water body	DOF	Annual Mean	Annual Median	Dry Median	Wet Median
	FTZ1		Mid-shelf waters	L		12.00		
	FTZ2, FTZ3, FTZ5		Open Coastal waters	L	10.00			
	FTZ4	Secchi (m) TSS (mg L^{-1}) TSS (mg L^{-1}) Turbidity (NTU) TSS (mg L^{-1}) Turbidity (NTU) Turbidity (NTU)	Open Coastal waters	L		10.00		
	FTZ6		Enclosed Coastal waters					
	SR01, SR02		Enclosed Coastal waters	L				3.10
	FTZ1		Mid-shelf waters	H		0.40	1.70	2.50
	FTZ2, FTZ3		Open Coastal waters	H	2.00		1.70	2.50
	FTZ4		Open Coastal waters	H		1.00	1.60	2.40
	FTZ5	TSS (mg L^{-1}) Turbidity (NTU) Turbidity (NTU) Turbidity (NTU)	Open Coastal waters	H	2.00		1.70	2.50
	FTZ6		Enclosed Coastal waters					
	SR01, SR02		Enclosed Coastal waters	H				5.00
	FTZ1		Mid-shelf waters	H		0.30		
	FTZ2, FTZ3		Open Coastal waters	H	1.50			
	FTZ4		Open Coastal waters	H		0.50		
	FTZ5	Turbidity (NTU)	Open Coastal waters	H	1.50			
	FTZ6		Enclosed Coastal waters	H			7.00	15.00
	SR01, SR02		Enclosed Coastal waters	H		10.00		

C-6 Regional exposure assessments for waterbodies

Regional results of the exposure assessment are shown for each waterbody in Appendix C-4.

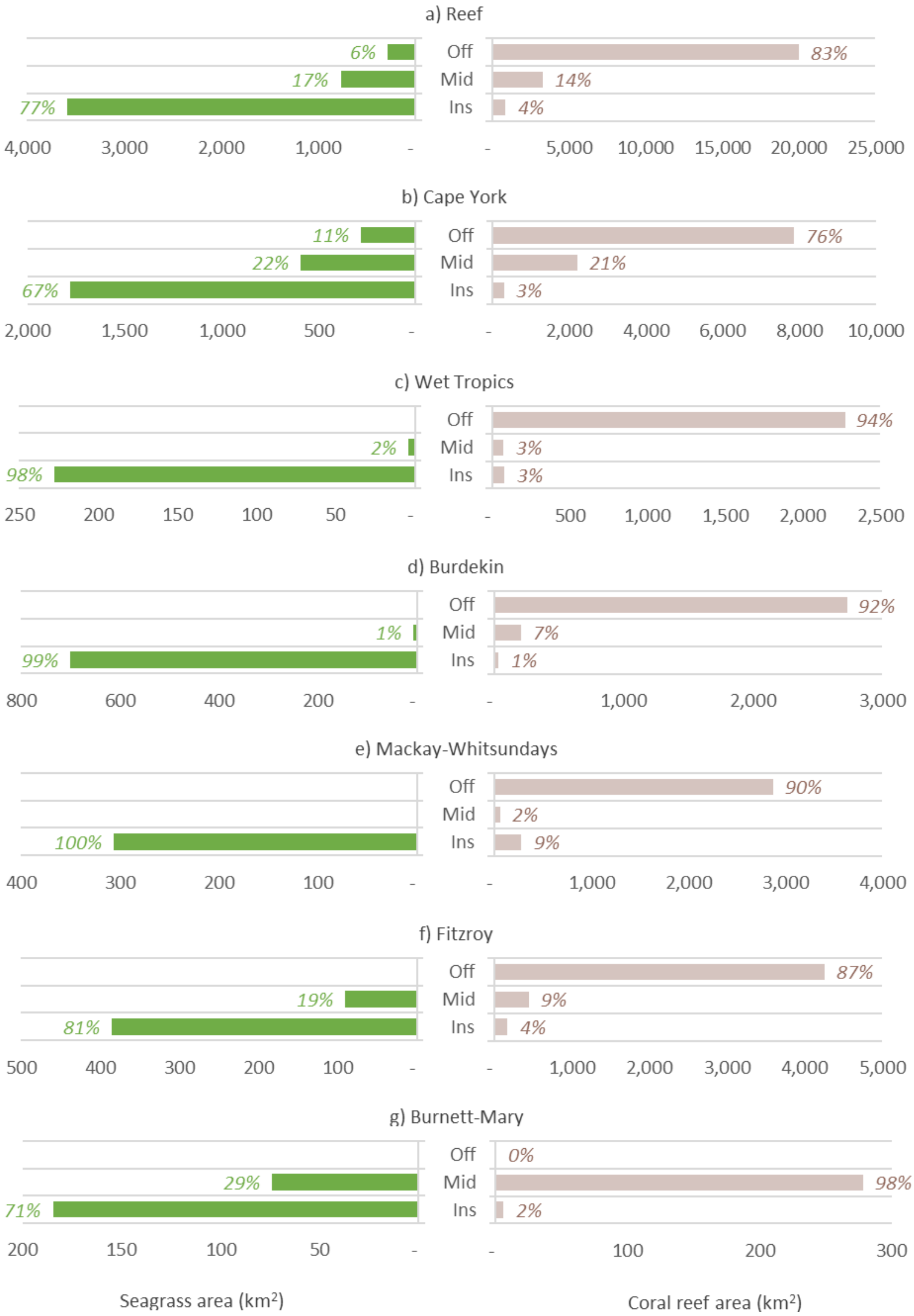


Figure C-3: Areas (in km^2 and represented as horizontal bars) of seagrass (left) and coral reefs (right) in the a) Reef and regional waterbodies; b) Cape York, c) Wet Tropics, d) Burdekin, e) Mackay-Whitsunday, f) Fitzroy, g) Burnett-Mary. Percentages of total Reef habitats or total regional habitats are indicated in italics.

C-8 References

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Appendix D: Water Quality Monitoring in the Fitzroy NRM region 2021–22

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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 newly formed Darumbal TUMRA steering committee.

We are grateful to everyone involved in field and labwork this year including Ulysse Bove, Keeley Glasson, Samantha Jaworski, Carine Lefevre, Alex Macadam, Daniel Moran, Mikaela Nordborg, 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), while rain in Winter and Autumn months is unreliable. 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 north-east 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 2014 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 to continue 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 2020 (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 Methods Section of the main report, Appendix A, B and C, and in a separate quality assurance/quality control (QA/QC) report (Great Barrier Reef Marine Park Authority, 2022).

Sampling design

This monitoring 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 2021–22. 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). An independent statistical review of the MMP in 2014 (Kuhnert *et al.*, 2015) showed that additional sites and higher sampling frequency would provide better 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.

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

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 run-off.

- **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 run-off.
- **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 D-3. Concentrations were compared to site-specific GVs (Table D-2), 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).

To provide a more quantitative assessment of trend, linear change in values of GAMMs was measured starting in 2015 to the present sampling year. This period was chosen as it covers the MMP re-design, which began in 2015; using earlier data would unbalance this analysis as the amount of sampling greatly changed in 2015. As GAMMs are de-trended to remove the effects of seasons, tides, and wind, this analysis aims to quantify trends occurring outside of these cycles. The outputs for the Fitzroy region are complicated in that they do not include data since the MMP re-design. GAMMs are 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.

For each monitoring site, these indicators are compared to GVs, scored based on performance relative to guidelines, 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).

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 condition that ecosystems are exposed to, which both affect the response of those ecosystems but in different ways. Changes in the MMP design that occurred in 2015 also needed to be accommodated. 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 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 (Appendix B)
- only AIMS monitoring data are used
- a four-year running mean is applied to data to reduce the effect of sampling time on the Index
- the Index is an average of scores for five indicators: water clarity (average of TSS and turbidity from loggers, where available), Chl-*a*, NO_x, PN, and PP weighted equally.

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 for scoring monitoring data (i.e., wet season data are compared to a wet season GV and dry season data are compared to a dry season GV) (Table D-2)
- both AIMS and JCU monitoring data are used
- a running mean is not applied
- the Index is a hierarchical combination of scores for five indicators: water clarity (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) are weighted equally.

Details of Index calculation are in Appendix B.

D-4 Drivers and pressures influencing water quality in 2021–22

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 total suspended solids (TSS) export from The Fitzroy Basin into the Great Barrier Reef (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 GBRCA. 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 chlorophyll *a* (Chl-*a*) annual mean values in the sector regularly exceed the water quality guideline values (Tracey *et al.,* 2017). Dissolved organic carbon (DOC) was the dominant component of the TOC load in these areas and particle size was small, with ~90% measuring <14 microns (Packett *et al.,* 2009). These small particles, once discharged and settled in the marine environment, are more easily resuspended during adverse weather events.

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 GBR inner-shelf waters (Wooldridge *et al.,* 2006). Estimated anthropogenic derived total nitrogen (TN) and total phosphorus (TP) in the Fitzroy Region is the highest of the GBRCA (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 the GBRCA (Baird *et al.,* 2021). Herbicides, most notably photosystem-II (PSII) herbicides, affect the relationship between corals and their symbiotic algae. Seventy-eight percent of pesticide samples taken in the Fitzroy Region were classed as 'Category 5' for PSII pesticides from 2005 to 2014, the lowest index level (Gallen *et al.,* 2014). Spikes of the pesticide Tebuthiuron were observed during several years, but the relative potency of this pesticide is significantly lower than other pesticides, presenting a lower risk to coastal ecosystems (Gallen *et al.,* 2014).

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). Elevated levels of DIN have been linked to destabilisation of the coral-symbiont relationship that underpins coral health (Fabricius, 2005).

Given that benthic communities of the inshore reefs of the Great Barrier Reef 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 2020–21 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 D-1. Discharge at the regional level is shown in Figure D-2. In 2021–22 the overall Reef catchment area had discharge just above the long-term average while discharge in the Fitzroy region was slightly higher than average (1.5 times higher than the long-term median).

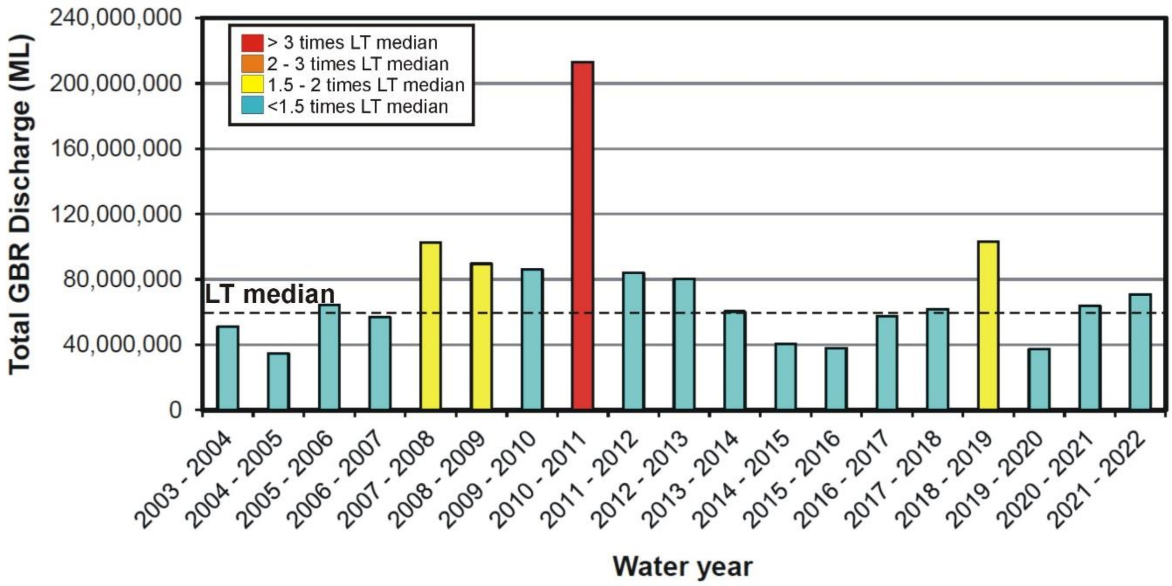


Figure D-1 Long-term total discharge in ML (water year: 1 October to 30 September) for the 35 main Reef basins. Source: DRMW (2022).

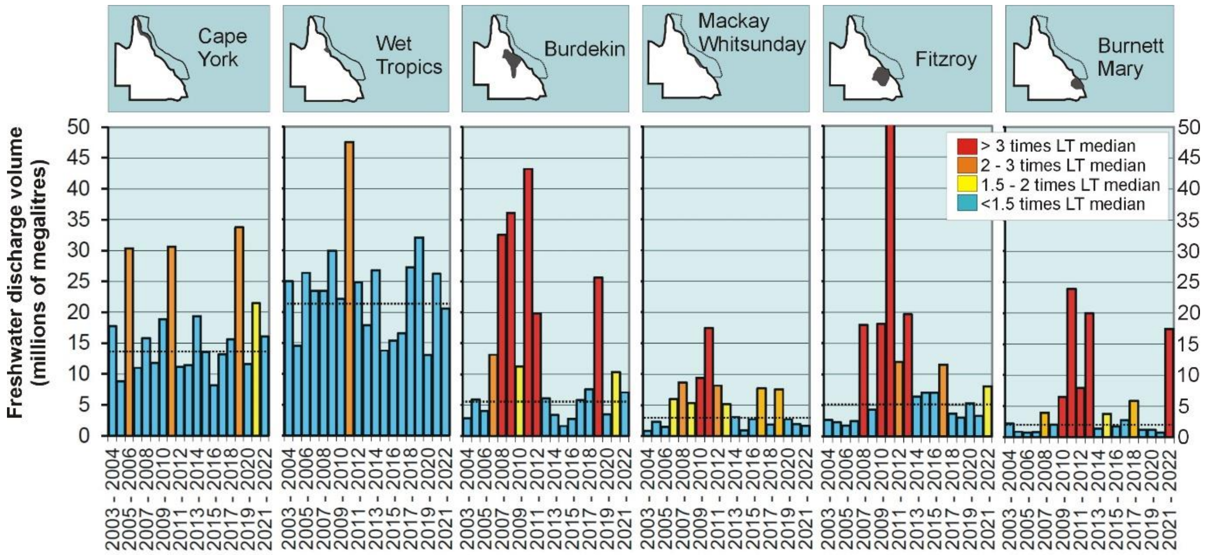


Figure D-2: Corrected annual water year (1 October to 30 September) discharge from each NRM region (using the correction factors in Table 2-3) for 2003–04 to 2021–22 in (ML per year). Data derived from DRMW (2022).

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. In the Wet Tropics region, the mid shelf reefs are closer to the coast (<30 km), and 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 2021 (Moran *et al.,* 2022). 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 has 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 low 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 and 2022 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 2010–2011, 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. Monitoring sites are sampled in this focus region ten times per year, with six sites sampled in ambient conditions during both 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-3).

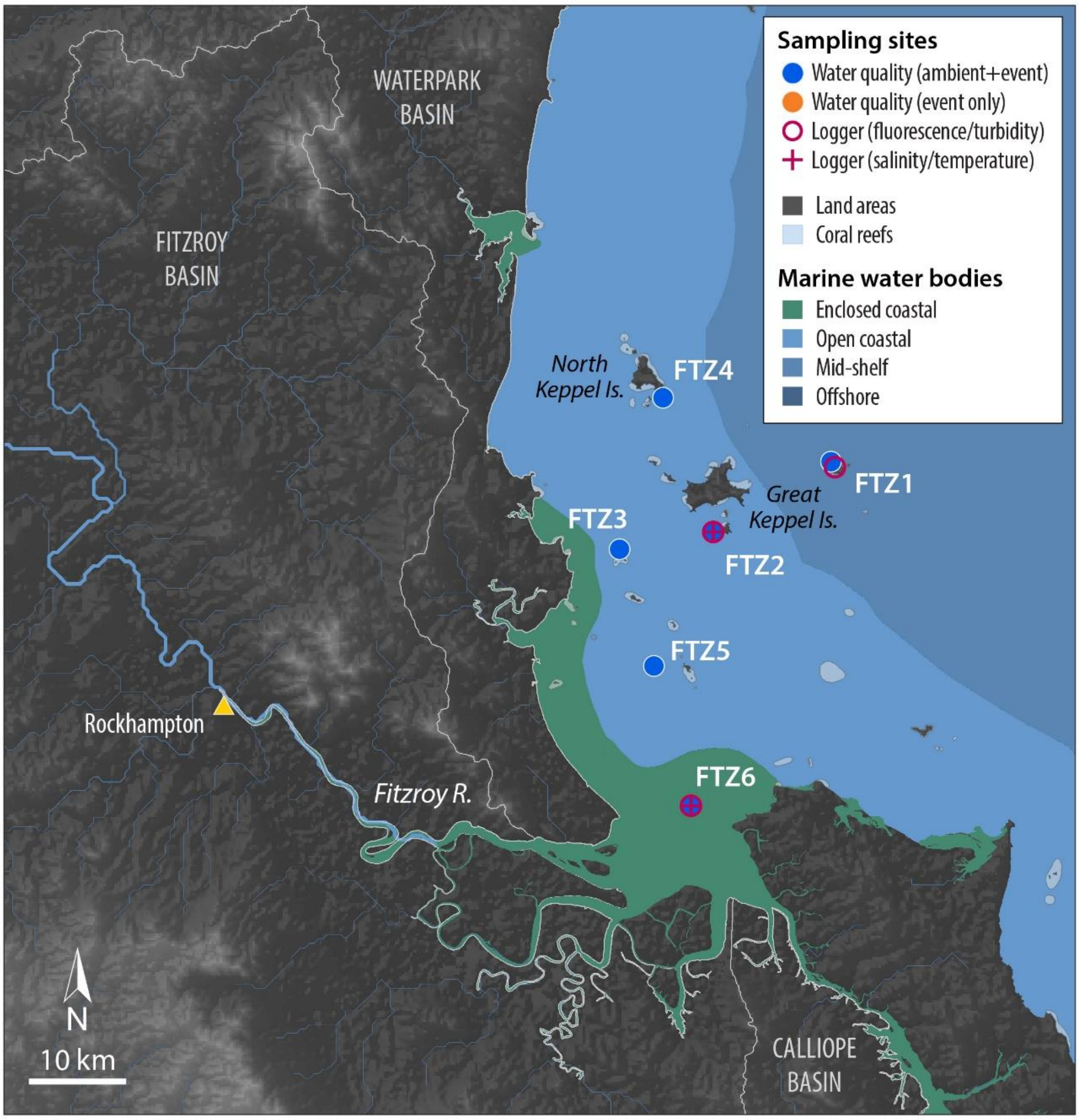


Figure D-3: Sampling sites in the Fitzroy focus area, shown with the water body boundaries. Sites FTZ1–FTZ3 were monitored from 2005–2014 under the Marine Monitoring Program.

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-4, 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 3-5). Annual discharge of the Fitzroy River from 2014–2021 was generally close to or less than the long-term median (Figure D-4). Annual discharge for the Fitzroy Basin in 2021–22 was slightly greater than (approximately 1.5 times) the long-term median (Figure D-4; Table 3-1). The combined discharge and loads calculated for the 2021–22 water year were around the long-term average. Over the 16-year period:

- Discharge has varied 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)
- PN loads ranged from 100 t (2020–21) to 17,000 t (2010–11).

The total discharge for the Fitzroy region in 2021–22 was close to (slightly above) the long-term median (Figure D-5; Table 3-1).

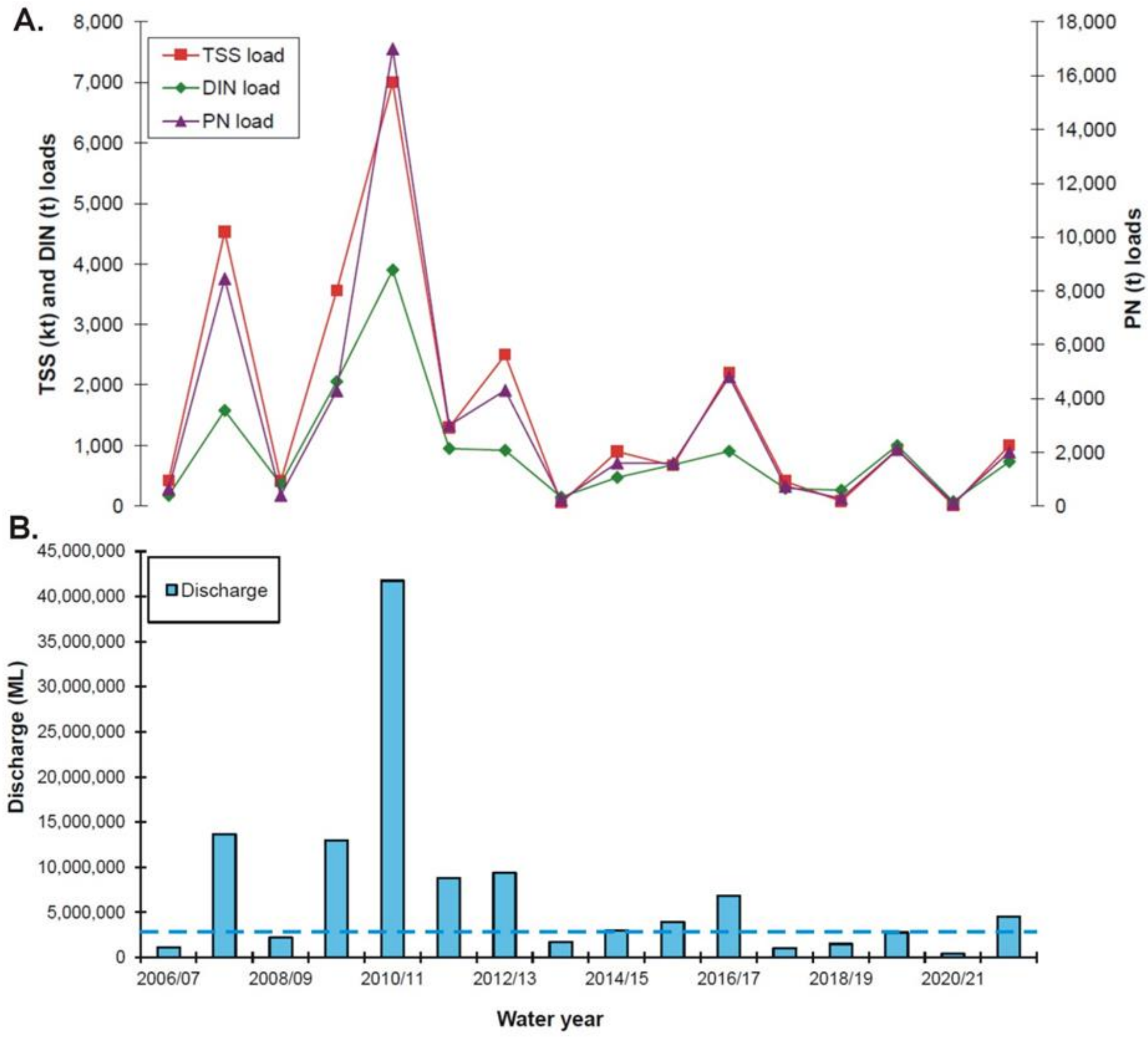


Figure D-4: Loads of (A) TSS, DIN and PN and (B) discharge for the Fitzroy Basin. The loads reported here are based on the monitoring data from the Fitzroy River as reported in the Great Barrier Reef catchment loads program with a long-term annual mean concentration of the existing data calculated to produce a load for the 2021–22 water year (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.

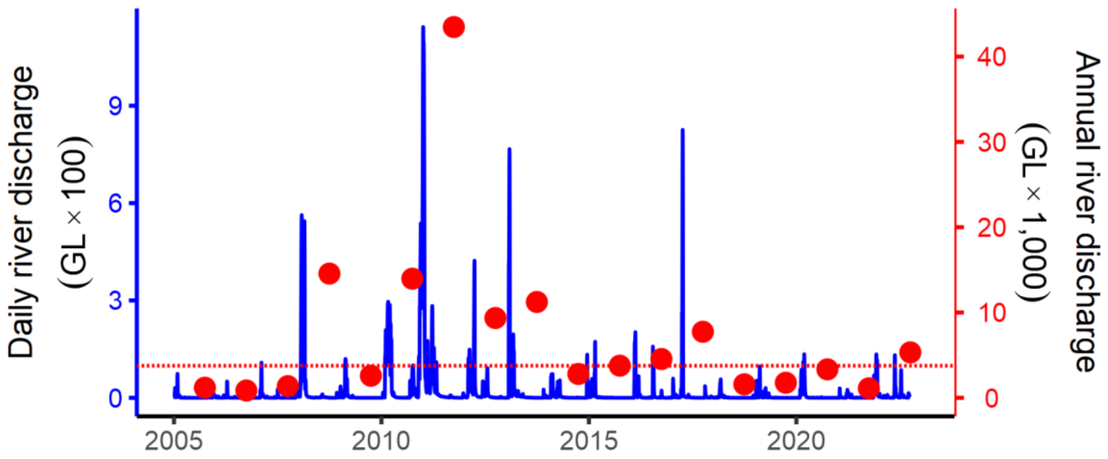


Figure D-5: Total discharge for the Fitzroy region (Table 2-3). Daily (blue) and water year (1 October to 30 September, red) discharge is shown. Red dashed line represents the long-term median annual discharge.

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

Water quality showed trends along the sampling transect (Fitzroy River Mouth (FTZ6) to Barren Island (FTZ1)). Sites located nearest to the river mouth (distance from river mouth = 0 km) had high concentrations of TSS, Chl-*a*, NO_x and particulate nutrients (PN and PP), which declined with distance away from the river mouth (Figure D-6). 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. In the Fitzroy region, wet season and dry season water quality variables are typically similar close to the river mouth but diverge with season along the transect. High turbidity, TSS, and nutrient concentrations are typical near the river mouth throughout the dry season. In the 2021–22 water year, higher river discharge occurred during the dry season (April - September) compared with other years. This dry season river discharge tended to minimise the differences between wet and dry season trends over the length of the transect (Figure D-6).

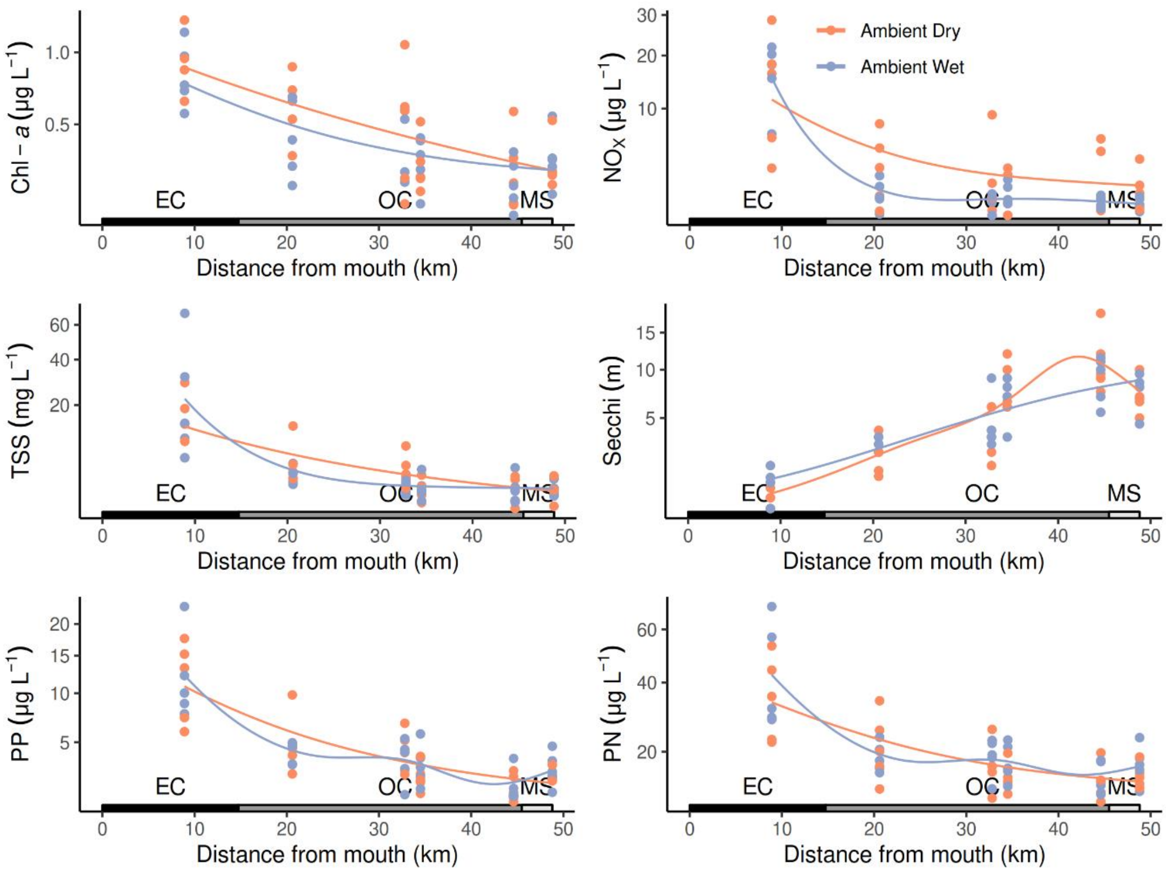


Figure D-6: Water quality variables measured during ambient and event sampling in 2021–22 along the Fitzroy focus region transect. Chlorophyll *a* (Chl-*a*), nitrate/nitrite (NO_x), total suspended solids (TSS), Secchi depth, particulate nitrogen (PN), and particulate phosphorus (PP) are shown with distance from the 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 D-3. During the 2021–22 water year, concentrations of Chl-*a* and PO_4 were generally below (meeting) the GVs at most sites except Fitzroy River Mouth FTZ6 (PO_4) and Peak West FTZ5 (Chl-*a* and PO_4). All other variables exceeded the GVs at most sites. Concentrations of NO_x exceeded (did not meet) the GVs at all sites in the Fitzroy region, and Secchi depth did not meet GVs at any site monitored. Concentrations of PN exceeded (did not meet) GVs at North Keppel FTZ4, Barren Island FTZ1, and Peak West FTZ5, while PP exceeded GVs at all monitoring sites except Barren Island FTZ1.

Long-term trends in water quality variables measured during ambient periods (i.e., not during flood events) of the dry and wet seasons are presented in Figure D-7. It is important to note that this trend analysis removes variability associated with wind, tides, and seasons (see Methods). Thus, individual data points will have different values compared to raw data. This analysis is designed to detect long-term and regional-scale trends in water quality by removing the effect of short-term changes associated with weather and seasonal differences.

The gap in observational data between 2015 and 2020 limits the utility of the GAMM models in detecting long-term trends over this interval. The apparent sharp gradients in some water quality variables since the reinstatement of monitoring (2020–22) (Figure D-7) are almost certainly a statistical artefact of the limited recent data available and are likely to disappear 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, Chl-*a*, and POC are relatively consistent with concentrations seen around the time MMP monitoring ended in the region (2015). Trend analysis suggests that turbidity and TSS have potentially increased (water clarity has worsened) since MMP monitoring ended in 2015, 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).

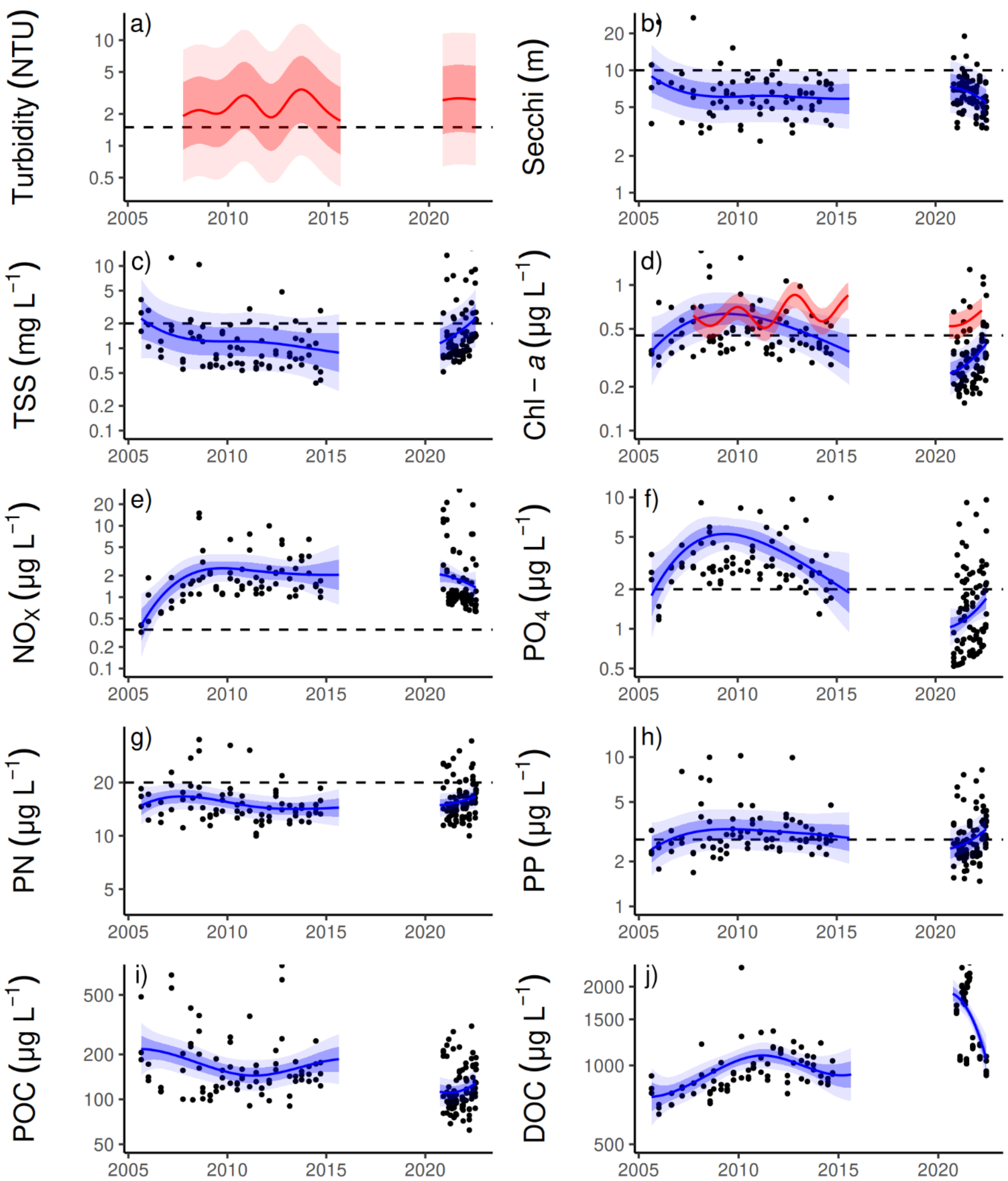


Figure D-7: Temporal trends in water quality variables for the Fitzroy focus region: a) turbidity, b) Secchi depth, c) total suspended solids (TSS), d) chlorophyll *a* (Chl-*a*), e) nitrate/nitrite (NO_x), f) phosphate (PO_4), g) particulate nitrogen (PN), h) particulate phosphorus (PP), i) particulate 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 Appendix D-6. Dashed horizontal reference lines indicate annual guidelines. The apparent steep gradients in some variables during 2020–2022 are likely statistical artefacts of the lack of data from 2016–2019 and will improve as more monitoring data are collected.

The WQ Index is calculated using two different formulations to communicate: a) the long-term trend in water quality (based on the pre-2015 sampling design) and b) the annual condition of water quality (based on the post-2015 sampling design, which increased the power to detect change). The Methods section and Appendix B-2 contain details of the calculations for both indices.

The long-term WQ Index has historically scored water quality as 'moderate' to 'good', with some fluctuations (Figure D-8a). The long-term trend has shown a small (for example, change by a single grade) improvement over the time-series since 2010, possibly indicating a gradual recovery from the impacts of large floods in 2008 and 2011. This trend has generally been driven by improvements in PN, PP, and Chl-*a* indicators (Figure D-8a). In recent years we have seen a number of low-discharge seasons and although the long-term score is designed to be independent of annual conditions, consecutive years of low discharge (and associated loads) are likely to influence patterns in the long-term trend.

The annual condition WQ Index scored water quality as 'good' for the 2021–22 water year. This is the second year for which it is possible to calculate this Index (Figure D-8b). This version of the Index scores water quality parameters against GVs relevant to the season when samples are collected (wet versus dry GVs) and includes additional sites in the open coastal water body to better characterise areas affected by river discharge. River discharge was around the long-term median level in the Fitzroy focus region this year, which likely contributed to a 'good' annual condition score. Discharge in 2021–22 was slightly greater than that seen in 2020–21 (the lowest discharge year in the previous decade).

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.

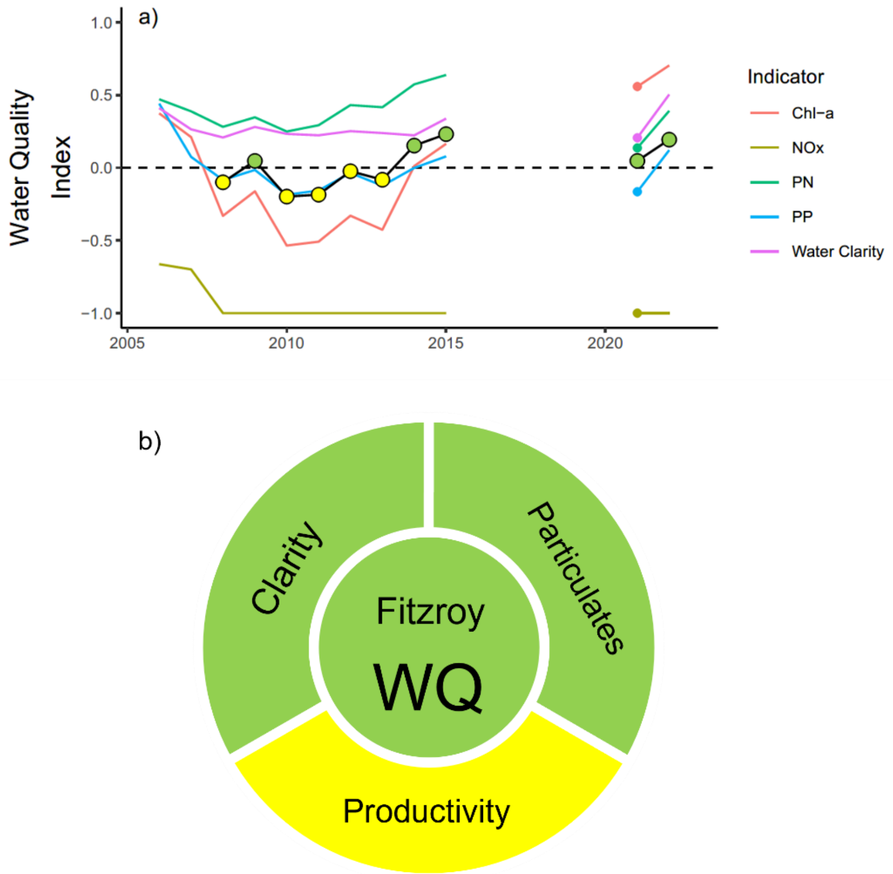


Figure D-8: The Water Quality Index (WQ Index) for the Fitzroy focus region. The WQ Index uses two formulations to communicate: a) long-term trend (based on pre-2015 sampling design) and b) the annual condition (based on post-2015 sampling design). WQ Index colour coding: ● / ◆– 'very good'; ● / ◆ – 'good'; ● / ◆ – 'moderate; ● / ◆ – 'poor'; ● / ◆ – 'very poor'. Indicators or sub-indicators that are used to calculate the WQ Index are shown as coloured lines (a) or in the coaster perimeter (b). 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 2021–22 water year from the Fitzroy River were slightly above (around 1.6 times) the long-term median (Figure D-2; Figure D-4; Table 3-1). The discharge has been below-median for the previous four 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 exceeded (did not meet) water quality GVs at any monitoring sites within the Fitzroy region. Secchi depth did not meet GVs at any monitoring site.
- Concentrations of PN, PP, and TSS exceeded (did not meet) GVs at most monitoring sites in the region.
- Concentrations of Chl-*a* and PO_4 were below (meeting) GVs at most monitoring sites in the region (except Peak West for both variables and Fitzroy River Mouth for PO_4).
- 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:

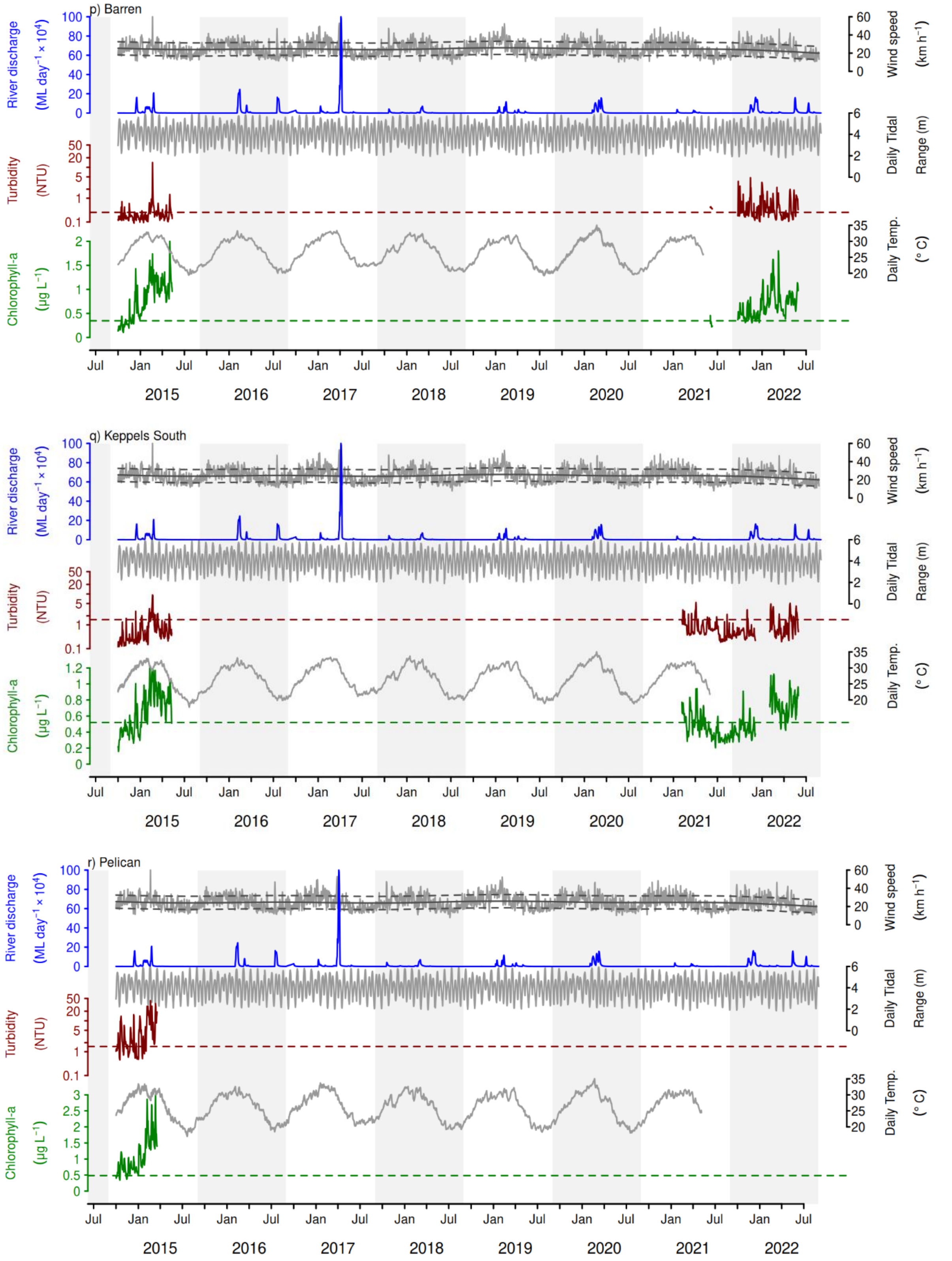
- TSS and turbidity have increased (water clarity has worsened) since monitoring under the MMP ended in 2015.
- Other variables (NO_x, PO_4, PP, PN, Secchi depth, and Chl-*a*) show signs of stability since MMP monitoring ended in 2015 although more data are needed to confirm this conclusion.

- 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 previous two years of monitoring, a trend of stability has also been seen, although more data are needed to confirm this. For the 2021–22 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 2021–22 wet season.

D-7 Additional information



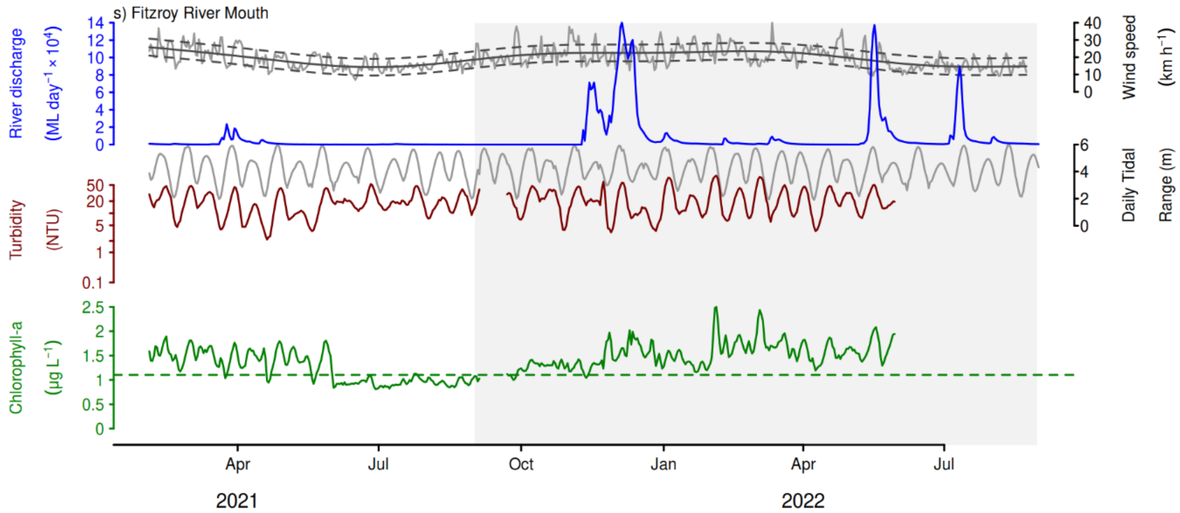


Figure D-9: Time-series of daily means of chlorophyll and turbidity collected by moored ECO FLNTUSB instruments; coloured dashed lines represent the Water Quality GVs. Daily river discharge from the nearest river, daily wind speeds from the nearest weather stations, daily tidal range from the nearest tidal gauge, and daily temperature are also shown. Locations of loggers are shown in Figure D-3: Barren Island (top), Pelican Island (second), Keppels South (third), and Fitzroy River mouth (bottom).

Table D-2: Site-specific Guideline Values (GVs) used for comparison with water quality monitoring data. These GVs are used to calculate the annual condition version of the WQ Index for each water quality sampling location and are derived from the Water Quality Guidelines for the Great Barrier Reef Marine Park (Great Barrier Reef Marine Park Authority, 2010, see Table 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. See Appendix B for details on 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, *et cetera*). Bold GVs are those applied to monitoring data.

				Annual		Dry	Wet
Short Names	Water Body	Measure	DOF	Mean	Median	Median	Median
FTZ1	Mid-shelf waters	Chl-*a* (µg L⁻¹)	H		0.27	**0.32**	**0.63**
		NO_x (µg L⁻¹)	H		**0.50**		
		Turbidity (NTU)	H		**0.30**		
		PN (µg L⁻¹)	H		12.00	**16.00**	**25.00**
		PO_4 (µg L⁻¹)	H		**2.00**		
		PP (µg L⁻¹)	H		1.90	**2.40**	**3.40**
		Secchi (m)	L		**12.00**		
		TSS (mg L⁻¹)	H		0.40	**1.70**	**2.50**
FTZ2, FTZ3	Open Coastal waters	Chl-*a* (µg L⁻¹)	H	0.45		**0.32**	**0.63**
		NO_x (µg L⁻¹)	H		**0.50**		
		Turbidity (NTU)	H	**1.50**			
		PN (µg L⁻¹)	H	20.00		**16.00**	**25.00**

				Annual		Dry	Wet
Short Names	Water Body	Measure	DOF	Mean	Median	Median	Median
		PO_4 (µg L⁻¹)	H	**2.00**			
		PP (µg L⁻¹)	H	2.80		**2.40**	**3.40**
		Secchi (m)	L	**10.00**			
		TSS (mg L⁻¹)	H	2.00		**1.70**	**2.50**
FTZ4	Open Coastal waters	Chl-*a* (µg L⁻¹)	H	0.45		**0.32**	**0.63**
		NO_x (µg L⁻¹)	H		**0.50**		
		Turbidity (NTU)	H		**0.50**		
		PN (µg L⁻¹)	H		15.00	**16.00**	**25.00**
		PO_4 (µg L⁻¹)	H		**2.00**		
		PP (µg L⁻¹)	H		2.50	**2.30**	**3.30**
		Secchi (m)	L		**10.00**		
		TSS (mg L⁻¹)	H		1.00	**1.60**	**2.40**
FTZ5	Open Coastal waters	Chl-*a* (µg L⁻¹)	H	0.45		**0.32**	**0.63**
		NO_x (µg L⁻¹)	H		**0.50**		
		Turbidity (NTU)	H	**1.50**			
		PN (µg L⁻¹)	H	20.00		**16.00**	**25.00**
		PO_4 (µg L⁻¹)	H		**2.00**		
		PP (µg L⁻¹)	H	2.80		**2.40**	**3.40**
		Secchi (m)	L	**10.00**			
		TSS (mg L⁻¹)	H	2.00		**1.70**	**2.50**
FTZ6	Enclosed Coastal waters	Chl-*a* (µg L⁻¹)	H		**1.00**		
		NO_x (µg L⁻¹)	H		**3.00**		
		Turbidity (NTU)	H			**7.00**	**15.00**
		PN (µg L⁻¹)					
		PO_4 (µg L⁻¹)	H		**3.00**		
		PP (µg L⁻¹)					
		Secchi (m)					
		TSS (mg L⁻¹)					

Table D-3: Summary statistics for water quality parameters at individual monitoring sites from 1 September 2021 to 31 August 2022. N = number of sampling occasions. See Section 5 for descriptions of each analyte and its abbreviation. Mean and median values that exceed available Water Quality Guidelines (DERM, 2009; Great Barrier Reef Marine Park Authority, 2010) are shaded in red. Averages that exceed wet season guidelines are shaded in yellow.

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines				
						Q05	Q20	Q80	Q95	DOF	Location	Annual	Dry	Wet
Fitzroy	North Keppel Island (FTZ4)	DIN (µg L⁻¹)	10	6.31	6.11	3.73	5.12	6.92	9.58					
		DOC (µg L⁻¹)	10	1046	1081	966	1004	1096	1103					
		DON (µg L⁻¹)	10	86.79	87.56	64.01	68.57	100.59	108.07					
		DOP (µg L⁻¹)	10	5.70	5.57	4.99	5.22	6.29	6.56					
		Chl-a (µg L⁻¹)	10	0.32	0.28	0.19	0.24	0.36	0.54	H	Mean	0.45		
			10	0.32	0.28	0.19	0.24	0.36	0.54	H	Median		0.32	0.63
		NO_x (µg L⁻¹)	10	1.08	0.75	0.42	0.48	1.25	2.75	H	Median	0.50		
		PN (µg L⁻¹)	10	16.02	15.54	11.92	12.91	18.56	21.39	H	Median	15.00	16.00	25.00
		PO_4 (µg L⁻¹)	10	0.93	0.77	0.34	0.45	0.99	2.19	H	Median	2.00		
		POC (mg L⁻¹)	10	115.49	110.29	78.42	91.16	145.02	160.65					
		PP (µg L⁻¹)	10	2.82	2.58	1.94	2.35	3.33	4.17	H	Median	2.50	2.30	3.30
		Secchi (m)	10	7.38	7.50	4.72	6.20	8.70	9.77	L	Median	10.00		
		SiO_4	10	75.61	74.75	24.80	48.60	99.30	123.52					
		TSS (mg L⁻¹)	10	1.15	1.05	0.33	0.70	1.37	2.34	H	Median	1.00	1.60	2.40
	Barren (FTZ1)	DIN (µg L⁻¹)	10	5.78	6.04	2.83	4.90	6.69	8.12					
		DOC (µg L⁻¹)	10	1029	1035	978	997	1063	1076					
		DON (µg L⁻¹)	10	89.22	85.55	70.29	72.06	105.10	117.40					
		DOP (µg L⁻¹)	10	5.73	5.65	5.22	5.45	6.10	6.39					
		Chl-a (µg L⁻¹)	10	0.25	0.21	0.13	0.15	0.33	0.48	H	Median	0.27	0.32	0.63
		NO_x (µg L⁻¹)	10	1.57	0.74	0.45	0.52	1.73	5.22	H	Median	0.50		

		PN (µg L⁻¹)	10	13.92	13.14	10.40	11.24	17.77	18.96	H	Median	12.00	16.00	25.00
		PO_4 (µg L⁻¹)	10	0.87	0.77	0.31	0.37	1.05	1.79	H	Median	2.00		
		POC (mg L⁻¹)	10	98.04	88.87	54.87	65.24	133.23	160.63					
		PP (µg L⁻¹)	10	1.99	1.61	1.31	1.46	2.59	3.35	H	Median	1.90	2.40	3.40
		Secchi (m)	10	10.10	9.75	6.17	7.40	11.60	15.30	L	Median	12.00		
		SiO_4	10	57.65	52.32	27.43	41.15	78.48	99.09					
		TSS (mg L⁻¹)	10	1.24	0.97	0.15	0.32	2.15	3.12	H	Median	0.40	1.70	2.50
	Keppels South (FTZ2)	DIN (µg L⁻¹)	10	5.99	6.06	3.30	3.91	6.80	9.56					
		DOC (µg L⁻¹)	10	1045	1059	982	1008	1085	1098					
		DON (µg L⁻¹)	10	96.43	95.21	79.52	82.01	105.25	122.17					
		DOP (µg L⁻¹)	10	5.81	5.65	5.18	5.33	6.36	6.55					
		Chl-a (µg L⁻¹)	10	0.31	0.29	0.17	0.23	0.41	0.47	H	Mean	0.45		
			10	0.31	0.29	0.17	0.23	0.41	0.47	H	Median		0.32	0.63
		NO_x (µg L⁻¹)	10	1.22	0.79	0.28	0.59	2.07	2.63	H	Median	0.50		
		PN (µg L⁻¹)	10	16.04	15.00	11.80	13.04	19.97	22.13	H	Mean	20.00		
			10	16.04	15.00	11.80	13.04	19.97	22.13	H	Median		16.00	25.00
		PO_4 (µg L⁻¹)	10	0.80	0.46	0.31	0.37	1.10	1.99	H	Mean	2.00		
			10	0.80	0.46	0.31	0.37	1.10	1.99	H	Median			
		POC (mg L⁻¹)	10	120.66	104.49	81.68	94.45	168.88	176.61					
		PP (µg L⁻¹)	10	2.97	2.59	1.72	2.13	3.79	4.90	H	Mean	2.80		
			10	2.97	2.59	1.72	2.13	3.79	4.90	H	Median		2.40	3.40
		Secchi (m)	10	7.50	7.00	4.62	6.00	9.20	11.10	L	Mean	10.00		

			10	7.50	7.00	4.62	6.00	9.20	11.10	L	Median			
		SiO_4	10	67.32	63.17	23.96	45.27	94.42	116.85					
		TSS (mg L^{-1})	10	1.26	0.94	0.28	0.59	1.63	3.05	H	Mean	2.00		
			10	1.26	0.94	0.28	0.59	1.63	3.05	H	Median		1.70	2.50
	Pelican (FTZ3)	DIN (µg L^{-1})	10	7.40	6.35	3.07	3.67	11.05	13.15					
		DOC (µg L^{-1})	10	1167	1190	1087	1121	1218	1231					
		DON (µg L^{-1})	10	98.34	92.70	77.98	85.40	109.63	128.95					
		DOP (µg L^{-1})	10	6.09	5.73	5.25	5.48	6.30	7.90					
		Chl-a (µg L^{-1})	10	0.45	0.40	0.18	0.23	0.59	0.86	H	Mean	0.45		
			10	0.45	0.40	0.18	0.23	0.59	0.86	H	Median		0.32	0.63
		NO_x (µg L^{-1})	10	1.65	0.93	0.28	0.39	1.25	5.77	H	Median	0.50		
		PN (µg L^{-1})	10	18.60	18.95	11.20	14.79	22.80	24.41	H	Mean	20.00		
			10	18.60	18.95	11.20	14.79	22.80	24.41	H	Median		16.00	25.00
		PO_4 (µg L^{-1})	10	1.87	1.90	0.73	1.33	2.12	3.19	H	Mean	2.00		
			10	1.87	1.90	0.73	1.33	2.12	3.19	H	Median			
		POC (mg L^{-1})	10	147.41	135.78	68.04	116.87	197.32	217.63					
		PP (µg L^{-1})	10	4.02	4.19	2.05	2.89	5.20	6.10	H	Mean	2.80		
			10	4.02	4.19	2.05	2.89	5.20	6.10	H	Median		2.40	3.40
		Secchi (m)	10	4.33	3.75	2.09	2.90	6.00	7.65	L	Mean	10.00		
			10	4.33	3.75	2.09	2.90	6.00	7.65	L	Median			
		SiO_4	10	141.42	120.30	36.29	72.08	216.87	276.11					
		TSS (mg L^{-1})	10	2.50	1.88	0.73	1.10	2.99	6.14	H	Mean	2.00		

			10	2.50	1.88	0.73	1.10	2.99	6.14	H	Median		1.70	2.50
	Peak West (FTZ5)	DIN (µg L⁻¹)	10	6.77	5.27	2.85	3.32	9.19	14.25					
		DOC (µg L⁻¹)	10	1159	1239	1011	1087	1248	1252					
		DON (µg L⁻¹)	10	102.73	102.45	75.98	80.32	118.47	140.27					
		DOP (µg L⁻¹)	10	5.86	5.54	4.90	5.11	6.36	7.58					
		Chl-a (µg L⁻¹)	10	0.54	0.59	0.25	0.33	0.68	0.81	H	Mean	0.45		
			10	0.54	0.59	0.25	0.33	0.68	0.81	H	Median		0.32	0.63
		NO_x (µg L⁻¹)	10	2.28	1.28	0.35	0.78	3.28	6.43	H	Median	0.50		
		PN (µg L⁻¹)	10	20.22	19.03	13.54	16.08	24.02	30.22	H	Mean	20.00		
			10	20.22	19.03	13.54	16.08	24.02	30.22	H	Median		16.00	25.00
		PO_4 (µg L⁻¹)	10	2.24	2.28	0.64	0.91	2.91	4.23	H	Median	2.00		
		POC (mg L⁻¹)	10	161.20	139.61	99.90	116.88	192.86	272.19					
		PP (µg L⁻¹)	10	4.68	4.59	2.96	3.33	4.93	7.63	H	Mean	2.80		
			10	4.68	4.59	2.96	3.33	4.93	7.63	H	Median		2.40	3.40
		Secchi (m)	10	2.73	2.75	1.36	2.30	3.50	3.77	L	Mean	10.00		
			10	2.73	2.75	1.36	2.30	3.50	3.77	L	Median			
		SiO_4	10	140.54	121.15	46.37	98.67	190.93	244.77					
		TSS (mg L⁻¹)	10	3.82	2.88	1.65	2.09	4.25	9.17	H	Mean	2.00		
			10	3.82	2.88	1.65	2.09	4.25	9.17	H	Median		1.70	2.50
	Fitzroy River Mouth (FTZ6)	DIN (µg L⁻¹)	10	20.19	21.16	8.60	11.42	26.36	29.57					
		DOC (µg L⁻¹)	10	1258	1279	1070	1140	1380	1430					
		DON (µg L⁻¹)	10	107.05	103.54	84.71	89.73	118.26	144.14					

		DOP (µg L⁻¹)	10	6.42	6.04	4.73	5.28	6.21	9.93					
		Chl-a (µg L⁻¹)	10	0.87	0.81	0.60	0.70	1.01	1.23	H	Median	1.00		
		NO_x (µg L⁻¹)	10	15.38	17.12	4.27	6.35	20.62	25.59	H	Median	3.00		
		PN (µg L⁻¹)	10	39.46	33.57	22.70	27.39	54.07	64.01	H	Median			
		PO_4 (µg L⁻¹)	10	6.55	6.35	4.13	5.39	7.85	9.25	H	Median	3.00		
		POC (mg L⁻¹)	10	415.88	357.91	188.17	215.82	514.65	830.01					
		PP (µg L⁻¹)	10	12.11	11.13	6.55	7.61	15.70	20.60	H	Median			
		Secchi (m)	10	0.82	0.90	0.25	0.45	1.04	1.50	L	Median			
		SiO_4	10	255.83	254.99	70.97	157.81	395.97	412.55					
		TSS (mg L⁻¹)	10	20.38	13.78	5.40	8.24	29.54	51.30	H	Median			

Table D-4: Summary of turbidity measurements from moored loggers (site locations in Figure D-3) for the past two 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 D-2). 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. There are limited data available for Barren due to an instrument failure.

Subregion	Site	Oct 2020 - Sept 2021						Oct 2021 - Sept 2022					
		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	241	0.65	0.04	0.43	78.01	0.00
	Fitzroy River Mouth	223	19.42	0.78	17.61		92.83	242	24.07	1.12	19.74		94.21
	Keppels South	238	0.90	0.04	0.67	11.76	0.42	184	1.16	0.07	0.73	22.83	0.54

D-8 References

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Appendix E. Scientific publications and presentations associated with the program, 2021–22

E-1 Publications

Reports and scientific publications

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, pp.

Moran, D., Robson, B., Gruber, R., Waterhouse, J., Logan, M., Petus, C., Howley, C., Lewis, S., Tracey, D., James, C., Mellors, J., Bove, U., Davidson, J., Glasson, K., Jaworski, S., Lefevre, C., Macadam, A., Shanahan, M., Vasile, R., Zagorskis, I., Shellberg, J., (2022). Marine Monitoring Program: Annual Report for Inshore Water Quality Monitoring 2020–21. Report for the Great Barrier Reef Marine Park Authority, Great Barrier Reef Marine Park Authority, Townsville.

Data used for model validation and external investigations:

During the 2021–22 financial year, MMP Water quality data has been used by several external groups, including:

- Validation of the eReefs marine models for the Great Barrier Reef, led by Mark Baird at CSIRO. An extensive list of resulting publications is available from: https://research.csiro.au/ereefs/models/further-reading/
- Validation of remote sensing ocean colour algorithms, led by Thomas Schroeder at CSIRO.
- Contributions to the Global coastal water DOM database - Christian Lønborg, Cátia Carreira, Xosé Antón Álvarez-Salgado. MMP data to be included in the Global coastal water DOM database, data paper to follow in Earth System Science Data.
- 2021–22 water quality data provided to NRM technical officers at the Mackay-Whitsunday-Isaac Healthy Rivers to Reef Partnership; Dry Tropics Partnership for Healthy Waters; and Wet Tropics Healthy Waterways Partnership to be used in preparation of the latest NRM report cards.

Related papers – linking to MMP data/methods:

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

Fronkova, L.; Greenwood, N.; Martinez, R.; Graham, J.A.; Harrod, R.; Graves, C.A.; Devlin, M.J.; Petus, C. (2022). Can Forel–Ule Index Act as a Proxy of Water Quality in Temperate Waters? Application of Plume Mapping in Liverpool Bay, UK. Remote Sens. 2022, 14, 2375. https://doi.org/10.3390/rs14102375

Jahanbakht M, Xiang W, Robson B, Rahimi Azghadi M (2022) Nitrogen prediction in the Great Barrier Reef using finite element analysis with deep neural networks. Environmental

Modelling & Software 150 (105311) ISSN 1364-8152. https://doi.org/10.1016/j.envsoft.2022.105311.

Jahanbakht M, Xiang W, Rahimi Azghadi M (2022) Sediment Prediction in the Great Barrier Reef using Vision Transformer with finite element analysis. Neural Networks 152 (311-321) ISSN 0893-6080. https://doi.org/10.1016/j.neunet.2022.04.022.

Patricio-Valerio L, Schroeder T, Devlin MJ, Qin Y, Smithers S. A Machine Learning Algorithm for Himawari-8 Total Suspended Solids Retrievals in the Great Barrier Reef. Remote Sensing. 2022; 14(14):3503. https://doi.org/10.3390/rs14143503

Petus, C., Waterhouse, J., Tracey, D., Wolanski, E., & Brodie, J. (2022). Using Optical Water-Type Classification in Data-Poor Water Quality Assessment: A Case Study in the Torres Strait. Remote Sensing, 14(9), 2212.

Caroline Petus also co-edited the special issue "Advances in Remote Sensing and Mapping for Integrated Studies of Reef Ecosystems in Oceania (Great Barrier Reef and Beyond)" https://www.mdpi.com/journal/remotesensing/special_issues/rs_great_barrier_reef which contains papers relevant to the MMP remote sensing methods.

E-2 Presentations

MMP Synthesis Workshop October 2022 – Presentations from Christina Howley and Jane Waterhouse

Howley C. et al., *Inshore Water Quality in the Cape York Region* (MERI Workshop 17 November 2022)

Howley C. *Inshore Water Quality Cape York Region*. 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.

Lewis S. et al., *Inshore water quality wet season monitoring in the Great Barrier Reef 2021-22* (MERI Workshop 17 November 2022)

Moran D. et al., *Great Barrier Reef Marine Monitoring Program - Inshore water quality condition and long-term trends*. (MERI Workshop 17 November 2022)

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. *Inshore water quality monitoring for ambient condition at AIMS and links between WQ science and management*. Presented to AIMS Indigenous partnerships team along with Gurambilbarra Wulgurukaba Mada Claimants including 7 representatives present: Aunty Virginia Wyles, Aunty Christina George, Brenton Creed, Petrina Pam Hegarty, Aunty Iris Glenbar, Gail Ambrym, Esalyn Ambrym at AIMS site visit, Townsville, QLD. 13 July 2022

Moran D. *Water Quality monitoring and research at AIMS*. Presented to 20 indigenous students and teachers from the Indigenous Education Resource Centre (IERC) Winter School during AIMS site visit, Townsville, QLD. 28 June 2022.

Moran D. *Fitzroy Marine Monitoring Program: Inshore water quality 2020-21 overview (including integration with GBRMP MMP)*. Presented to 30 + landholders/stakeholders from the Fitzroy catchment along with Catchment Solutions staff and government/NRM representatives from Fitzroy Basin Association, DAWE, QLD DAF and others at Korte's Conference Centre Rockhampton, QLD, for the Reef Trust 4 Catchment Solutions Fitzroy Review Workshop. 18 May 2022.

Moran D., Zagorskis I. *AIMS water quality data access (including MMP)*. Presented to NRM technical officers: Brie Sherow and Michelle Perez (Mackay-Whitsunday-Isaac Healthy Rivers to Reef Partnership), Dinny Taylor and Adam Shand (Dry Tropics Partnership for Healthy Waters) during online meeting. 28 April 2022

Waterhouse J. *Great Barrier Reef Marine Monitoring Program - Routine Monitoring for Wet Season 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.