Great Barrier Reef
MARINE MONITORING PROGRAM

Annual Report
INSHORE WATER QUALITY MONITORING
2019-20

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TropWATER

Cape York Water Monitoring Partnership

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Front cover image: Beach north of the mouth of the Pascoe River, Cape York, © GBRMPA, Photographer: D. Cameron.

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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Abbreviations, acronyms and definitions

AIMS	Australian Institute of Marine Science
Authority	Great Barrier Reef Marine Park Authority
BoM	Bureau of Meteorology
CDOM	colour dissolved organic matter
Chl-*a*	chlorophyll *a*
CTD	Conductivity Temperature Depth profiler
CYWMP	Cape York Water Monitoring Partnership
DIN	dissolved inorganic nitrogen
DOC	dissolved organic carbon
DON	dissolved organic nitrogen
DOP	dissolved organic phosphorus
ENSO	El Nino – Southern Oscillation cycle
FRP	Filterable reactive phosphorus
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
Reef	Great Barrier Reef
Reef 2050 WQIP	*Reef 2050 Water Quality Improvement Plan*
Reef Plan	Reef Water Quality Protection Plan
Reef 2050 Plan	*Reef 2050 Long-Term Sustainability Plan*
TSS	total suspended solids
WS colour scale	wet season colour scale
WQ Index	Water Quality Index

Units

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

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Executive summary

The water quality component of the Great Barrier Reef Marine Monitoring Program has monitored and reported on the annual and long-term condition of inshore water quality in the Great Barrier Reef for the last 15 years.

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. 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 in the Great Barrier Reef catchment.

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). Cape York trends are not assessed yet as there is not enough data for a robust assessment.

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

- **declined** gradually in the Wet Tropics region from 2008–2018 and is showing early signs of **improving** in recent years
- **declined** gradually in the Burdekin region since 2010
- **declined** steadily in the Mackay-Whitsunday region since 2008.

The annual condition Index showed that inshore water quality (sensitive to year-to-year variability) in 2019–20 was:

- **good** in the Wet Tropics and Burdekin regions, better than in 2018–19
- **poor** in the Mackay-Whitsunday region, worse than in 2018–19.

Improvements in annual Index scores in 2019–20 are most likely related to below-average river discharge during this year.

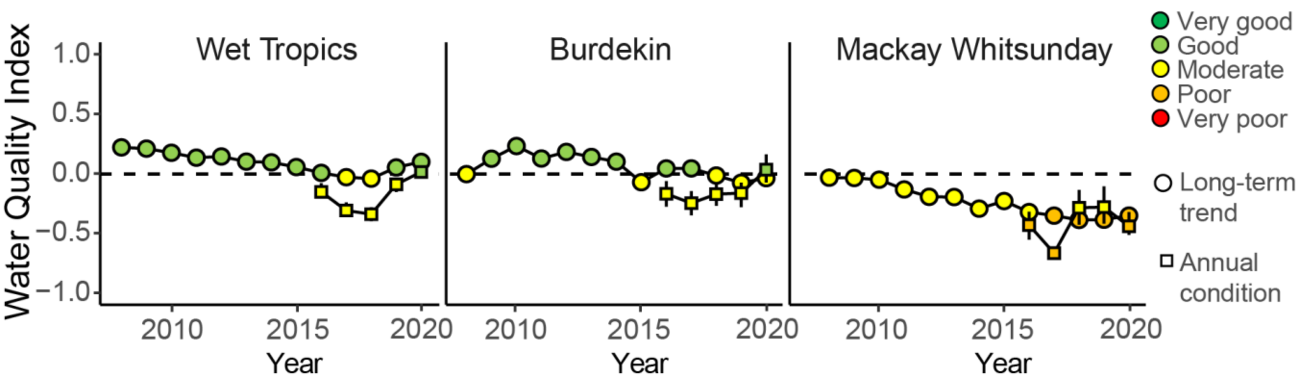

Figure i: Water Quality Index scores from 2008 to 2020 for the Wet Tropics, Burdekin and Mackay-Whitsunday regions. The Index is calculated to show the long-term trend in water quality since the start of monitoring (circles), where seasonal and short-term variability signals are removed. An updated Index 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*. Details of calculations are in Appendix B.

Individual water quality indicators are monitored for comparison against water quality guideline values. In general, concentrations of chlorophyll *a* are improving, while total suspended solids concentrations are stable or improving and both parameters met guideline values in most regions in the 2019–20 year. In contrast, these parameters exceed guideline values in most or all regions during 2019–20:

- dissolved and particulate nutrients (nitrate/nitrite, particulate nitrogen, and particulate phosphorus)
- Secchi depth (a proxy for water clarity).

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 2019–20 wet season involved rainfall below the long-term average, river discharge well below the long-term median, and no cyclone impact on the coast. A weak cyclone (cyclone Gretel) remained off the coast and had limited impact on the Great Barrier Reef.

End-of-catchment sediment and nutrient load estimates showed distinct variations between the focus areas, with the highest dissolved inorganic nitrogen exports from the Tully-Murray-Herbert basins followed by the Russell-Mulgrave-Johnstone and Burdekin-Haughton basins. This finding was largely due to the relatively low discharges from all focus areas. Loads of total suspended solids and particulate nitrogen were dominated by the Burdekin-Haughton basins. The loads in 2019–20 were much smaller compared to the 2018-19 season due to the lower rainfall and river discharge.

River-derived nutrient and sediment loads dispersion was similar to other years with below long-term median discharges. Comparison with modelled pre-development conditions identified limited anthropogenic influence in 2019–20.

There was a high frequency of exposure to the primary water type in inshore areas, with mid-shelf to offshore areas most frequently exposed to the tertiary water type only. Primary waters are brownish (enriched in sediment and dissolved organic matter), secondary waters are greenish (enriched in algae and dissolved organic matter), and tertiary waters have low risk of detrimental ecological effects. The area exposed to a potential risk in 2019–20 was spatially limited relative to the scale of the Great Barrier Reef. Eighty-five percent of the Great Barrier Reef was exposed to no or very low potential risk.

Conclusion

While this report presents some positive results for inshore water quality in the Great Barrier Reef for the 2019–20 sampling period, sustained improvements in the marine water quality of the inshore reef have not yet been observed. The complexity of the relationship between land-based runoff and water quality, the influence of inter-annual variability and external drivers and pressures, the progress of changed management practice adoption, and the expected slow response timeframes between land-based changes and marine water quality all contribute to this lack of observed change.

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 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, 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 on 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 (e.g. McKenzie et al., 2021; Thompson et al., 2021). In previous years, inshore pesticide monitoring has been presented in a separate report (e.g. Thai et al., 2020). Loads of sediments, nutrients, and pesticides within rivers are monitored by the Catchment Loads Monitoring Program (Ten Napel et al., 2019).

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 Authority since 2005; the Cape York Water Monitoring Partnership (CYWMP) was added as a collaborator in 2017. Pesticide monitoring has also been conducted by the University of Queensland.

1.3 Structure of the report

The following Section presents a summary of the program's methods. Section 3 describes the factors influencing marine water quality, referred to as drivers and pressures in the Driver-Pressure-State-Impact-Response (DPSIR) framework (Figure 1-1). Water quality results from satellite imagery and hydrodynamic modelling 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

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

loading. At the request of the Authority, the pesticide monitoring results for the Wet Tropics and Mackay-Whitsunday regions are included in the regional results. An overall Discussion and Conclusions are given in Sections 6 and 7, respectively. Detailed tables and figures of monitoring data are included in Appendix C.

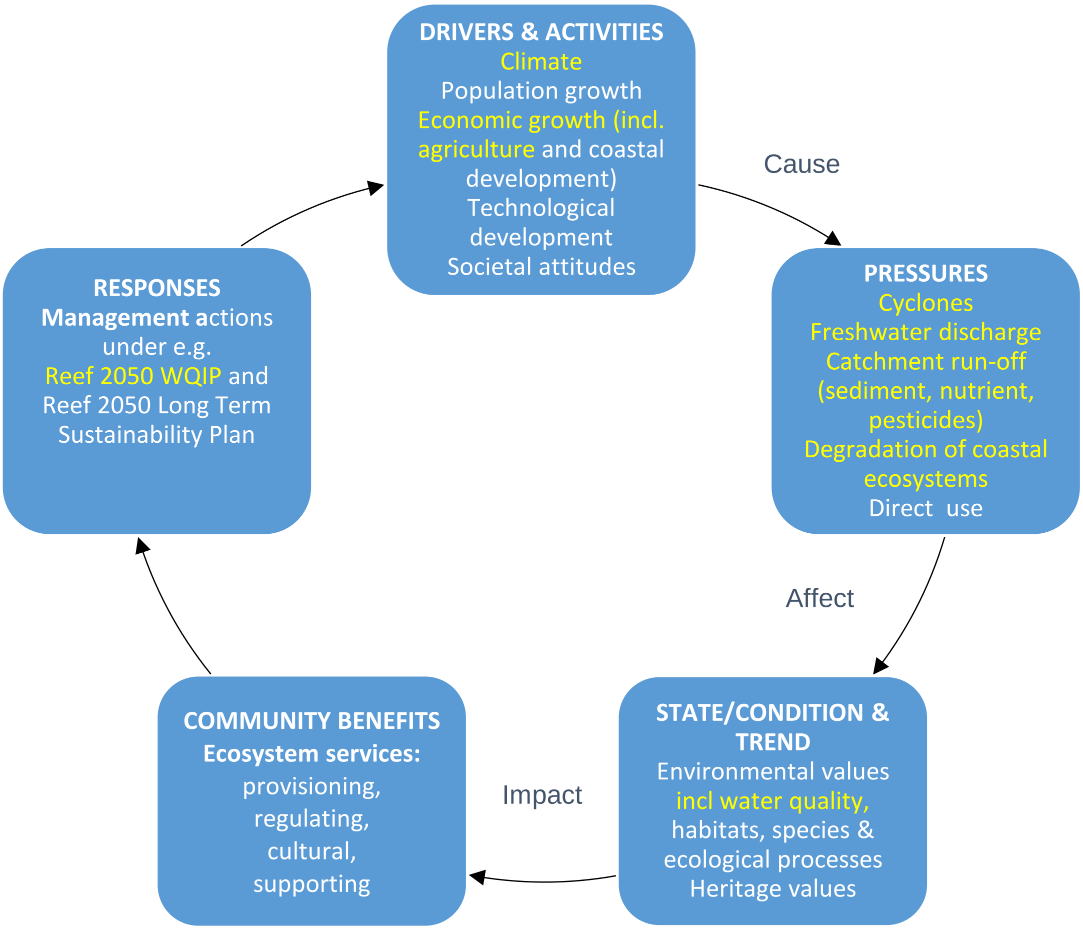

Figure 1-1: DPSIR framework used to guide the structure of the MMP derived from the Great Barrier Reef Strategic Assessment (Great Barrier Reef Marine Park Authority, 2014). The aspects highlighted in yellow are included in this report.

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 the Appendices and in a separate quality assurance/quality control (QA/QC) report published annually (Great Barrier Reef Marine Park Authority, 2020).

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, and the monitoring frequency depends on the number of flood events each year.

The program currently covers four NRM regions including Cape York, the Wet Tropics, Burdekin and Mackay-Whitsunday, chosen based on 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.

The program currently includes nine focus areas, each with 5 to 6 sites measured routinely: Pascoe, Normanby-Kennedy, Annan-Endeavour and Stewart Rivers (all added in 2017), Barron-Daintree, Russell Mulgrave, Tully, 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.

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.

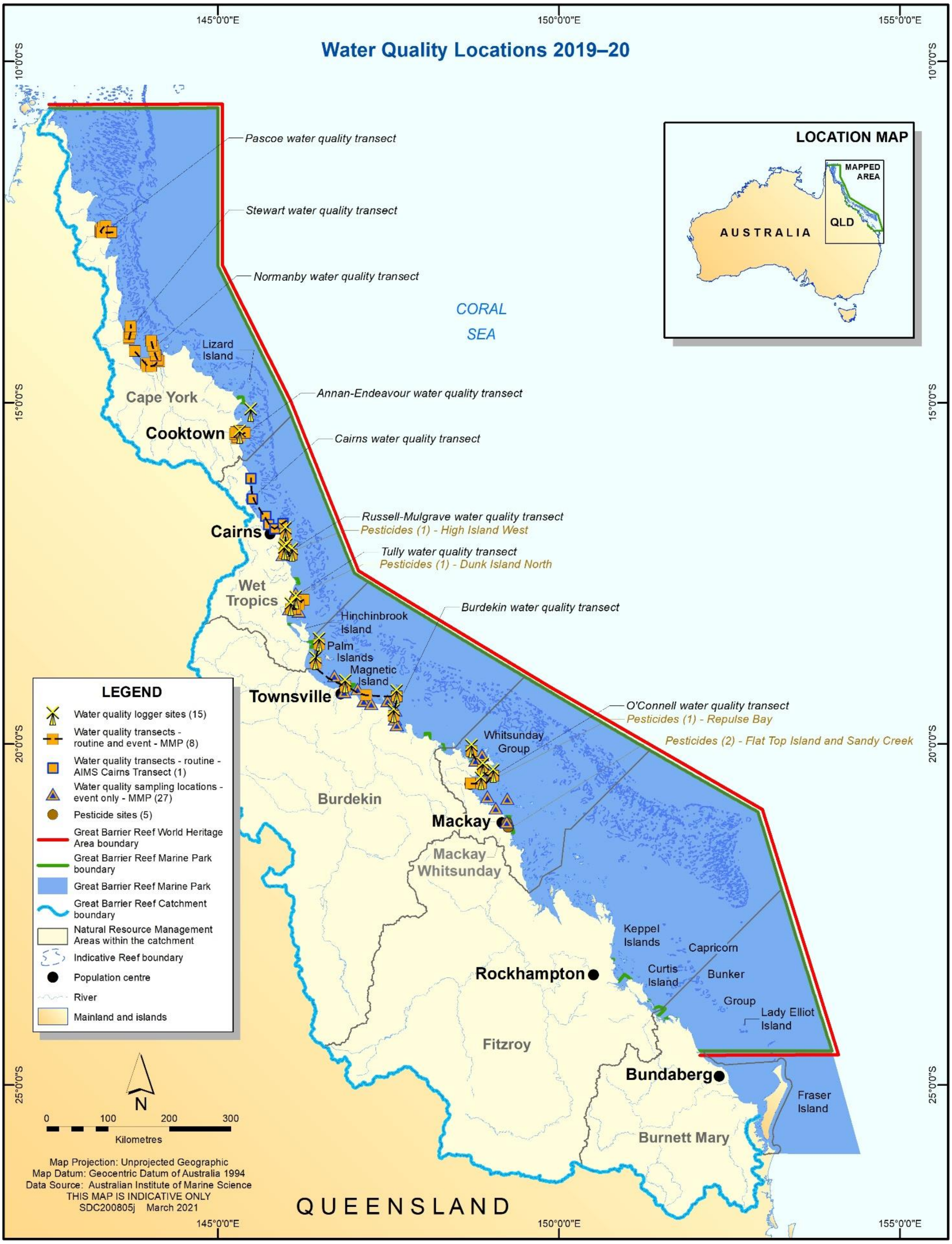

Figure 2-1: Sampling locations of the water quality monitoring sampled from 2015 onwards. Note that the Cape York transects were added in 2017.

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 15 sites
- 58 ambient sites with more frequent sampling during the wet season (85 sites in total)
- 27 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 L^{-1}
	Nitrite[2]	NO_2	µg L^{-1}
	Nitrate[2]	NO_3	µg L^{-1}
	Dissolved inorganic phosphorus	PO_4	µg L^{-1}
	Silica	Si	µg L^{-1}
	Particulate nitrogen	PN	µg L^{-1}
	Particulate phosphorus	PP	µg L^{-1}
	Total dissolved nitrogen	TDN	µg L^{-1}
	Total dissolved phosphorus	TDP	µg L^{-1}
	Particulate organic carbon	POC	µg L^{-1}
	Dissolved organic carbon	DOC	µg L^{-1}
Biological	Chlorophyll-*a*	Chl-*a*	µg L^{-1}

[1]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, 2020).

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 broad suite of water quality parameters (Table 2-1). Detailed descriptions of analytical chemistry techniques can be found in the QA/QC report (Great Barrier Reef Marine Park Authority, 2020). Values of water quality variables presented in this report are depth-weighted means calculated using surface and bottom samples.

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

- **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 (e.g. plankton uptake, upwelling, nitrogen fixation, and remineralisation) and anthropogenic (e.g. dredging and nutrient inputs from changed land use) processes.
- **Particulate nutrients (POC, PN and PP)** are a measure of the suspended material retained on a filter with a pore size of approximately 0.7 µm. This material consists of a minor fraction of living biomass (e.g. bacteria, phytoplankton) and a major fraction of detritus (e.g. dead cells, faecal pellets). Particulate nutrient concentrations are affected by oceanographic processes (primary production, bacterial production, resuspension, and remineralisation) as well as sources such as dredging and land-based 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** includes 13 photosystem II (PSII) inhibiting herbicides (such as diuron, atrazine (and its metabolites), ametryn, hexazinone, tebuthiuron), which all affect photosynthesis, and are commonly detected due to their high usage in adjacent catchments, and their high solubility. Seventeen other pesticides monitored include those that have non-photosynthetic effects (such as imidacloprid and metolachlor) and knockdown herbicides (such as 2,4-D) (Thai et al 2020).

Pesticides at fixed monitoring sites are sampled using passive samplers deployed for approximately one month in the wet season (Thai et al 2020). Pesticide concentration data are evaluated in two ways:

- Individual estimates of concentration are checked against relevant water quality guidelines and exceedances noted
- Measured concentrations in a given sample are assessed against a pesticide exposure risk metric which predicts the percentage of species that may be affected by mixtures of pesticides detected. The risk metric used is the multi-substance potentially affected fraction (ms-PAF method).

2.3 *In situ* loggers

Continuous *in situ* Chl-*a* fluorescence and turbidity were measured using WET Labs ECO FLNTUSB Combination Fluorometer and Turbidity Sensors located at 15 sites (Appendix A), which were deployed 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 eight locations, with three of these being placed on fixed moorings near the Russell-Mulgrave, Tully and Burdekin River mouths (Figure 2-1; Appendix A). See the QA/QC report (Great Barrier Reef Marine Park Authority, 2020) 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 instrumental 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. Concentrations were compared to site-specific GVs (Appendix C Table C-9), which are defined for Chl-*a*, PN, PP, TSS, Secchi depth, NO_x, and PO_4. 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, 2019).

In order 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.

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 (TSS concentrations, Secchi depth, and turbidity measurements by FLNTUSB instruments, where available)
- Chl-*a* concentrations
- PN concentrations
- PP concentrations
- NOx 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 5 indicators (water clarity, 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-9)
   - both AIMS and JCU monitoring data are used
   - a running mean is not applied
   - the Index is a hierarchical combination of scores for 5 indicators [water clarity, 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.

2.6 Data analyses – Remote sensing monitoring products

Several monitoring products have been developed combining MODIS satellite imagery and the water quality variables measured. They focus on the wet season period (December to April) and aim to:

- map Reef water types and water quality gradients during the wet season and assess the extent of river flood plumes during high flow conditions
- characterise the composition of the Reef wet season 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-3)
- 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 longer-term or reference trends in water composition.

2.6.1 Characterising composition of Reef water types

The colour class category and water type corresponding to the location and week of acquisition of each water quality sample were extracted (see method in Appendix B); therefore, the water quality parameters measured during this (2019–20) and previous (2002–03 to 2018–19) wet seasons could be associated with a wet season water type (and colour class) category, i.e. to primary (colour classes 1 to 4), secondary (colour class 5) or tertiary (colour class 6) water types (Appendix B and following Section for description of the wet season water types and colour classes). The transport and transformation of water quality parameters as well as the pollutant concentrations relative to the Reef-wide wet season GVs derived from De'ath and Fabricius (2008) (Appendix B Table B-3) were investigated by plotting mean long-term and boxplots of water quality concentration and Secchi disk depth against their water type and colour class categories.

To minimise data loss to due to the dense cloud cover in the Reef, match ups between field water quality data and MODIS colour class/water types categories were made using the weekly wet season water type composites (see Section 2.6.2). The long-term water quality concentrations were calculated using all surface data (<0.2 m) collected between December and April by JCU (since 2004), and since the 2016-17 reporting, included the AIMS (since 2016–17) and the CYWMP data (since 2016–17). The mean TSS, Chl-*a*, PP and PN concentrations were assessed against wet season GVs as a relative measure to assign potential risk grading for each water type (exposure maps, see Section 2.6.2).

Long-term water quality values are now 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 appropriate, and to improve its accuracy as more field data are collected every wet seasons. The last update was in 2019 (Gruber et al., 2020), using field data collected from 2003-04 to 2018-19. Wet season water type (and colour class) categories for all these sites and sampling weeks were extracted from the archive of weekly wet season water type composite (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.

2.6.2 Wet season water type, frequency and exposure maps

Several summary maps were produced 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.

- **Wet season water type maps** were produced using daily MODIS-Aqua (hereafter, MODIS) quasi true colour (hereafter true colour) imagery (see Appendix B) reclassified to six distinct colour classes defined by their colour properties (Álvarez-Romero et al., 2013). These colour classes are typical of broad colour gradients existing across coastal waters, including river plumes during the wet season (Figure 2-2). To complement this dataset, MODIS-Terra true colour images are also occasionally downloaded from the National Aeronautics and Space Administration (NASA)'s EOSDIS worldview website (https://worldview.earthdata.nasa.gov/) and processed to daily water type maps. MODIS-Terra are only used when MODIS data are too cloudy or unavailable, and when satellite information are required in near-real-time (rapid response mapping of flood events. Only MODIS-Aqua data were used in 2019–20.

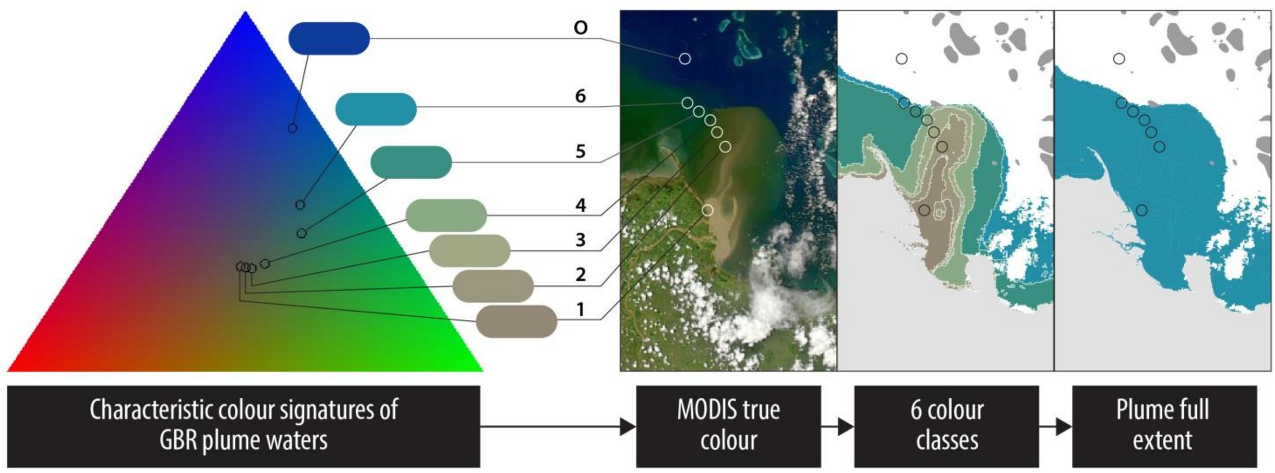

Figure 2-2: Triangular colour plot showing the characteristic colour signatures of the wet season water types in the Red-Green-Blue (RGB or true colour) space. Álvarez-Romero et al. (2013) developed a method to map these characteristic coastal water masses in the Reef using a supervised classification of MODIS true colour data (modified from Devlin et al., 2015).

Available MODIS data are biased toward clear, non-cloudy days, and may underrepresent water quality conditions in regions of higher rainfall and cloudiness like the Wet Tropics and Cape York.

Colour classes are characterised by different colour and concentrations of optically active components (e.g. TSS, CDOM, and Chl-*a*), which influence light attenuation (Petus et al., 2018), as well as different pollutant concentrations (Devlin et al., 2015; Petus et al., 2019). These characteristics vary the impact on the underlying ecological systems.

Wet season colour classes were further grouped into three wet season water types described in Table 2-2.

Table 2-2: Description of the wet season water types and groupings of colour classes.

Colour Class	Wet Season Water Type	Description
1 to 4	Primary	Brownish to brownish-green turbid waters typical of inshore regions of the Reef that receive land-based discharge and have high concentrations of resuspended sediments during the wet season. These water bodies in flood waters typically contain high nutrient and phytoplankton concentrations but are also enriched in sediment and dissolved organic matter resulting in reduced light levels
5	Secondary	Greenish to greenish-blue turbid water typical of coastal waters rich in algae (Chl-*a*) and containing dissolved organic matter and fine sediment. This water body is found in open coastal waters of the Reef as well as in the mid-water plumes where relatively high nutrient availability and increased light levels due to sedimentation favour coastal productivity (Bainbridge et al., 2012).
6	Tertiary	Greenish-blue waters correspond to waters with slightly above ambient water quality concentrations. This water body is typical of areas towards the open sea or offshore regions of river flood plumes, and the ecological relevance of these conditions is likely to be minimal although not well researched.

- **Weekly wet season 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 minimum colour-class value of each cell/week were used to map the colour class with the maximum turbidity per pixel for each week of the wet season (i.e., assuming the colour classes represented a gradient in turbidity i.e., CC1 > CC2 > CC3 > CC4 > CC5 > CC6). All weekly composites were automatically cleaned and extra cleaning steps were applied to weeks 1, 18, 20 and 21 to remove large misclassified areas offshore (see Appendix B3). MODIS-Aqua images of the 2 and 3 December 2019 and of the 4, 14, 17, 20, 25 April 2020 were corrupted by sun glint and/or very low quality images and were removed from the 2019–20 satellite database. Weekly composites for weeks 1, 18, 20 and 21 were reprocessed without those images (see Appendix B3).

Panels summarising weekly environmental (wind, rainfall and river discharge) and marine (wet season colour classes) conditions were produced for each focus region to illustrate the link between environmental drivers and marine conditions across the wet season.

- **Frequency maps** were produced to predict the areas affected by the primary and secondary water types combined (previously a combination of all water types, this has been modified to recognise that the ecological relevance of the water quality concentrations in the tertiary water type is not well understood but expected to be relatively minor) and the three wet season water types (primary, secondary and tertiary water types) individually (i.e., of the brownish, greenish and greenish-blue waters, respectively).

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 (2019–20), (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, taking into account the wettest and driest years for each NRM region. This is explained further in Appendix B. Except for the coral recovery period, reference maps (long-term, Wet and Dry frequency maps) are now updated every 4 years (and/or in the case of extremely wet year or specific event patterns) to ensure they remains 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 wet season water type is the result of the complex physico-chemical transformations occurring within river plumes, but also of resuspension, transport and other hydrodynamic processes. As a result, the extent of the secondary and tertiary water type frequencies is rarely attributed to an individual river and is usually merged into one heterogeneous area.

Exposure maps were produced for the whole of the Reef, for all focus regions and over the same time frames 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). Except for the coral recovery period, reference maps (long-term, Wet and Dry frequency maps) are now updated every 4 years (and/or in the case of extremely wet year or specific event patterns) to ensure they remain valid as representative periods and to improve their accuracy as more satellite data are available. The last update was in the 2018-19 reporting (Gruber et al., 2020).

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 (proportional exceedance of the Reef-wide wet season GV) mapped through the primary, secondary and tertiary water types (section 2.6.1). The *'likelihood of the exposure'* is estimated by calculating the frequency of occurrence of each wet season 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 wet season water types.

1. Calculation of the exposure scores: The long-term mean concentrations of water quality parameters (Reef-wide) measured across the wet season water types (section 2.6.1) are assessed against Reef-wide wet season GVs to calculate magnitude scores for TSS, Chl-*a*, PP and PN. The GVs are 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-3). 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-4). The only GV presently available for Secchi depth is an annual mean, and thus comparison with wet season Secchi depth data is not possible.

2. Production of the exposure maps: these magnitude scores are used in combination with the seasonal, long-term, coral recovery, wet-year and dry-year frequency maps (above) to derive seasonal, long-term, coral recovery, wet-year and dry-year exposure maps, respectively. Exposure from each map produced is 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.

3. Exposure assessment: Exposure maps are overlaid with information on the spatial distribution of coral reefs and surveyed seagrass meadows to help 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 NRM regions. Exposure maps are presented in the context of the long-term reference period (average of 16 wet seasons), the representative coral

[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).

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 MODIS data on cloud-free days, with the likelihood of exposure likely to be underestimated in higher rainfall and cloudy regions like the Wet Tropics and Cape York.

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 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 Natural Resources and Mines [DNRM], 2020). The total annual discharge for each gauge was then up-scaled using the best information available. Note that the estimates were improved in the 2018-19 report (Gruber et al., 2020) with a thorough reanalysis of the available flow gauges to cover a greater basin area. The upscale area corrections (previous method) were compared to the Bureau of Meteorology's G2G model (covering basins from the Normanby to Mary: Bureau of Meteorology [BoM], 2017; Wells et al., 2018) over a common period (1 January 2007–31 July 2018) and relevant adjustments to the upscale (correction) factor were made where required. Where a flow gauge did not exist in a basin (e.g. Jacky Jacky Creek, Lockhart River, Jeannie River, Proserpine River, Styx River, Shoalwater Creek and Boyne River—marked with an asterisk), the gauge from the nearest neighbouring basin was used coupled with the correction factor informed by either area (northern Cape York basins) or the BoM G2G model. The calculation of the long-term medians for each basin has been anchored to cover the 30-year period from 1986–87 to 2015–16 water years.

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	1.2
	Olive Pascoe River	102	4,180	Pascoe River at Garraway Creek	31	3.0
	Lockhart River	103	2,883	Pascoe River at Garraway Creek*	0	1.9
	Stewart River	104	2,743	Stewart River at Telegraph Road	17	5.8
	Normanby River	105	24,399	Normanby River at Kalpowar Crossing (from 2005/06; previous upscale using Battle Camp gauge)	53	1.9
	Jeannie River	106	3,638	Endeavour River at Flaggy*	0	10.0
	Endeavour River	107	2,182	Endeavour River at Flaggy + Annan at Beesbike (from 1989/90 previous upscale from Endeavour at Flaggy)	27	3.7

NRM Region	Basin	AWRC No.	Basin area (km^2)	Relevant gauges	Percentage of Basin covered by key gauges	Correction factor
Wet Tropics	Daintree River	108	2,107	Daintree River at Bairds + Bloomfield River at China Camp	56	1.3**
	Mossman River	109	473	Mossman River at Mossman	22	3.2**
	Barron River	110	2,188	Barron River at Myola	89	1.2**
	Mulgrave-Russell River	111	1,983	Mulgrave River at Peets Bridge + Russell River at Bucklands	42	1.4**
	Johnstone River	112	2,325	South Johnstone River at Upstream Central Mill + North Johnstone at Tung Oil	57	1.5**
	Tully River	113	1,683	Tully River at Euramo	86	1.1**
	Murray River	114	1,107	Murray River at Upper Murray	14	2.2**
	Herbert River	116	9,844	Herbert River at Ingham	87	1.1
Burdekin	Black River	117	1,057	Black River at Bruce Highway + Bluewater Creek at Bluewater	32	2.2**
	Ross River	118	1,707	Ross River at Aplins Weir + Alligator Creek at Allendale (from 2001/02 previous upscale from Alligator and Bohle)	52	1.9
	Haughton River	119	4,051	Haughton River at Powerline + Barratta at Northcote	62	1.2**
	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 1998/99 previous Don + Elliot)	46	2.2
Mackay-Whitsunday	Proserpine River	122	2,494	O'Connell River at Staffords Crossing*	0	2.5**
	O'Connell River	124	2,387	O'Connell River at Staffords Crossing + Andromache River at Jochheims + St Helens Creek at Calen	29	1.7**
	Pioneer River	125	1,572	Pioneer River at Dumbleton Weir T/W	95	1.1
	Plane Creek	126	2,539	Sandy Creek at Homebush + Carmila Creek at Carmila	16	1.8**
Fitzroy	Styx River	127	3,013	Waterpark Creek at Byfield*	0	2.4**
	Shoalwater Creek	128	3,601	Waterpark Creek at Byfield*	0	2.0**
	Water Park Creek	129	1,836	Waterpark Creek at Byfield	12	1.5**
	Fitzroy River	130	142,552	Fitzroy River at The Gap	95	1.0
	Calliope River	132	2,241	Calliope River at Castlehope	57	1.7
	Boyne River	133	2,496	Calliope River at Castlehope*	0	0.43
Burnett-Mary	Baffle Creek	134	4,085	Baffle Creek at Mimdale	34	1.7**
	Kolan River	135	2,901	Kolan River at Springfield + Gin Gin Creek at Brushy Creek	37	1.3**
	Burnett River	136	33,207	Burnett River at Figtree Creek	92	1.1
	Burrum River	137	3,362	Gregory River at Leesons + Elliott River at Dr Mays Crossing + Isis River at Bruce Highway	40	2.5
	Mary River	138	9,466	Mary River at Home Park	72	1.2**

*Gauges used which are not in the basin area
**informed using the BoM G2G model

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 were calculated using the model 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 remaining basins were calculated using an annual mean concentration which was multiplied by the corresponding 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 year were unavailable, a mean of the long-term annual mean concentration from the previous monitoring data was coupled with the discharge to calculate a load. For other basins with monitoring data where the area monitored was <95%, a median of the long-term annual mean concentration was coupled with the corresponding water year discharge to calculate a load (e.g. Normanby, Barron, Johnstone, Tully, Herbert, Black, Ross, Haughton, Don, O'Connell, Plane and Burnett). The annual mean concentrations from the Source Catchments data were also used to help inform the load estimates for these basins. Finally, for the basins that have little to no monitoring data, the annual mean concentration from the Source Catchments data was applied and rounded to 1 significant figure. 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 and rounded to 1 significant figure. The corresponding discharge was used as calculated previously to produce a pre-development load for the water year.

2.8 Zones of influence for river discharge

Hydrodynamic models are a valuable tool for identifying, quantifying, and communicating the spatial impact of discharges from various rivers into the Reef lagoon. Hydrodynamic models can simulate the three-dimensional transport and fate of material delivered to the marine environment and can deliver benefits over traditional static observations of river plume distributions especially in relation to the scale and frequency at which they can operate. While remote sensing can track the visual extent of river plumes, it is generally difficult to quantify the contribution of individual rivers to the overall observed spatial impact. The impact of the rivers is often confounded by a number of factors including plumes from adjacent rivers that spatially overlap and mix, and inputs of low salinity tropical water advected from the north and low surface salinity due to rainfall, which is rapidly mixed. Numerical models provide a number of solutions to this problem. During flood events, discharges of freshwater are resolved by the model's salinity solution. Passive tracers overcome the problems of using salinity alone as a tracer, as they allow the freshwater from the individual rivers to be tagged and assessed. Passive tracers act as virtual markers and are conservatively advected and diffused in an identical fashion to physical variables such as temperature and salinity; however, they play no dynamic role in physical or biogeochemical processes. Importantly, simulation of the transport of unique tracers 'released' from different rivers enables the identification of marine regions influenced by individual catchments and provides insight into the mixing and retention of river water along various regions within the Reef lagoon.

As part of the eReefs project (http://ereefs.org.au/ereefs), a regional implementation of a three-dimensional, baroclinic hydrodynamic model was developed for the Reef lagoon. Outputs from the model include three-dimensional distributions of velocity, temperature, salinity, density, passive tracer concentrations, mixing coefficients, and sea level. Inputs required by the model include forcing due to wind, atmospheric pressure gradients, surface heat and rainfall fluxes and open-boundary conditions such as tides, low frequency ocean currents and riverine inputs. The model is described in detail by Schiller et al. (2015). The MMP used outputs from the regional ~4 km horizontal spatial resolution model.

Hindcast simulations were performed over the period 1 October until 1 May of the following year to capture all potential river discharge that occurred during that water year. River-tagged passive tracers were modelled as being released from each of the major gauged rivers discharging into the Reef lagoon. The influence of the Normanby, Annan, Endeavour, Baron, Russell-Mulgrave, Tully, Burdekin and O'Connell Rivers was examined. The discharge concentration of each river's unique tracer was set at 1.0 at the river mouth, while the starting tracer concentration in the Reef lagoon (time = 0 for each wet season) was set to 0.

Cumulative exposure index

A cumulative exposure index was defined that integrates the tracer concentration above a defined threshold. It is a cumulative measurement of the exposure concentration and duration of exposure to dissolved inputs from individual river sources. It is expressed as Concentration × Days (Conc.Days). For example, if a grid cell was exposed to concentrations of 5% river water for 2 days, this gives an exposure index of 0.1 (0.05 x 2). If a grid cell was exposed to concentrations of 50% river water for 10 days, this gives an exposure index of 5 (0.5 x 10). Whenever river water concentration is greater than 1%, the exposure index is calculated and added to all other exposures in that wet season (i.e., it is cumulative). This index provides a consistent approach to assessing relative differences in exposure of Reef shelf waters to inputs from various rivers.

The mathematical formulation that expresses this concept is given below:

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

where,

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

and $\text{Conc}_{threshold}$ is defined here as 1% of the river concentration, Conc(t) represents the time-varying tracer concentration, and t is time in days from the beginning of the wet season (t_0 = 1 October), and $T_{\text{end of wet season}}$ = 1 May. Cumulative exposure is calculated for each grid point in the model domain.

2.9 Load mapping

In 2018-19 a revised approach was developed for estimating the dispersion of river-derived DIN, TSS and PN loads in to the Reef lagoon, improving the method developed in previous reports by using the eReefs marine models (Margvelashvili et al., 2018; Skerratt et al., 2019; Steven et al., 2019) to estimate river dispersion (Gruber et al., 2020).

The first step involved generation of tracer maps, which followed the same method as described above for the cumulative exposure index. By taking the cumulative sum of each river tracer concentration over the course of a water year (1 October to 30 September), the cumulative exposure of each map location to water from each river in that year was estimated.

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

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

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

The difference between the estimated wet season fine sediment, DIN, and PN loadings (tonnes km^2) in the Reef lagoon for the 2019 water year (1 October 2018 to 30 September 2019) was calculated and compared to the pre-development loads derived from the Source Catchments model (which have a degree of uncertainty; refer to McCloskey et al., 2021). This can be interpreted as 'anthropogenic' fine sediment, DIN or PN loadings, highlighting the areas of greatest change with current land use characteristics.

A similar approach to the tracer maps can be taken to calculate the total effective 'dose' of TSS, DIN or PN received by each map location. The dose maps were produced by taking the cumulative sum of the concentrations of a constituent (e.g. DIN) predicted to occur at each location. As these outputs are preliminary, they are not presented in this report but can be provided on request.

3. Drivers and pressures influencing water quality in 2019–20

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., 2017a) 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, locals advise that there is no longer any active grazing within the Pascoe catchment (Polglase pers. comm. November 2018). 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 Reef catchments (Cape York NRM and South Cape York Catchments, 2016).
  - The Stewart River catchment has an area of 2770 km^2 and is mostly nature/conservation land use (94%) with approximately 2% grazing (QLUMP, 2015). Current and historic cattle grazing 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, and road construction 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 Endeavour and Annan River Basin is 2186 km^2 and has a high proportion of nature/conservation land use (52% as of 2015) and closed grazing (40%) (Queensland Land Use Mapping Program [QLUMP], 2015). Additional grazing land has been converted to conservation land use since 2015 and approximately 80% of the Annan catchment is now under conservation or Aboriginal freehold. Sources of pollution 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), and road erosion are the primary sources of pollution to the Annan River (Shellberg et al., 2016a).
- 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., 2017a). 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 2189 km^2 and consists of 29% natural/minimal use lands, 31% grazing,

18% forestry, 11% cropping (including bananas and sugarcane), and smaller areas of dairy and urban land uses (Terrain NRM, 2015). The Barron River is the most hydrologically modified river in the Wet Tropics region and is heavily regulated by water supply infrastructure.

- The Russell-Mulgrave Basins contain a high proportion of upland National Park and forest (72%), with 13% of the area used for sugarcane production on the coastal floodplain (Terrain NRM, 2015). The Johnstone Basin 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 1115 km^2 and has a high proportion of natural/minimal use lands (64%). The remaining area is comprised of 14% sugarcane, 10% forestry, 6% grazing and smaller areas of bananas, other crops and urban land uses. The Herbert River Basin 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, 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 with the catchment land use 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).

During the 2019–20 wet season, there was very limited cyclone activity in the Reef. In March 2020, cyclone Gretel remained off the coast as a weak system and had limited impact (Figure 3-1).

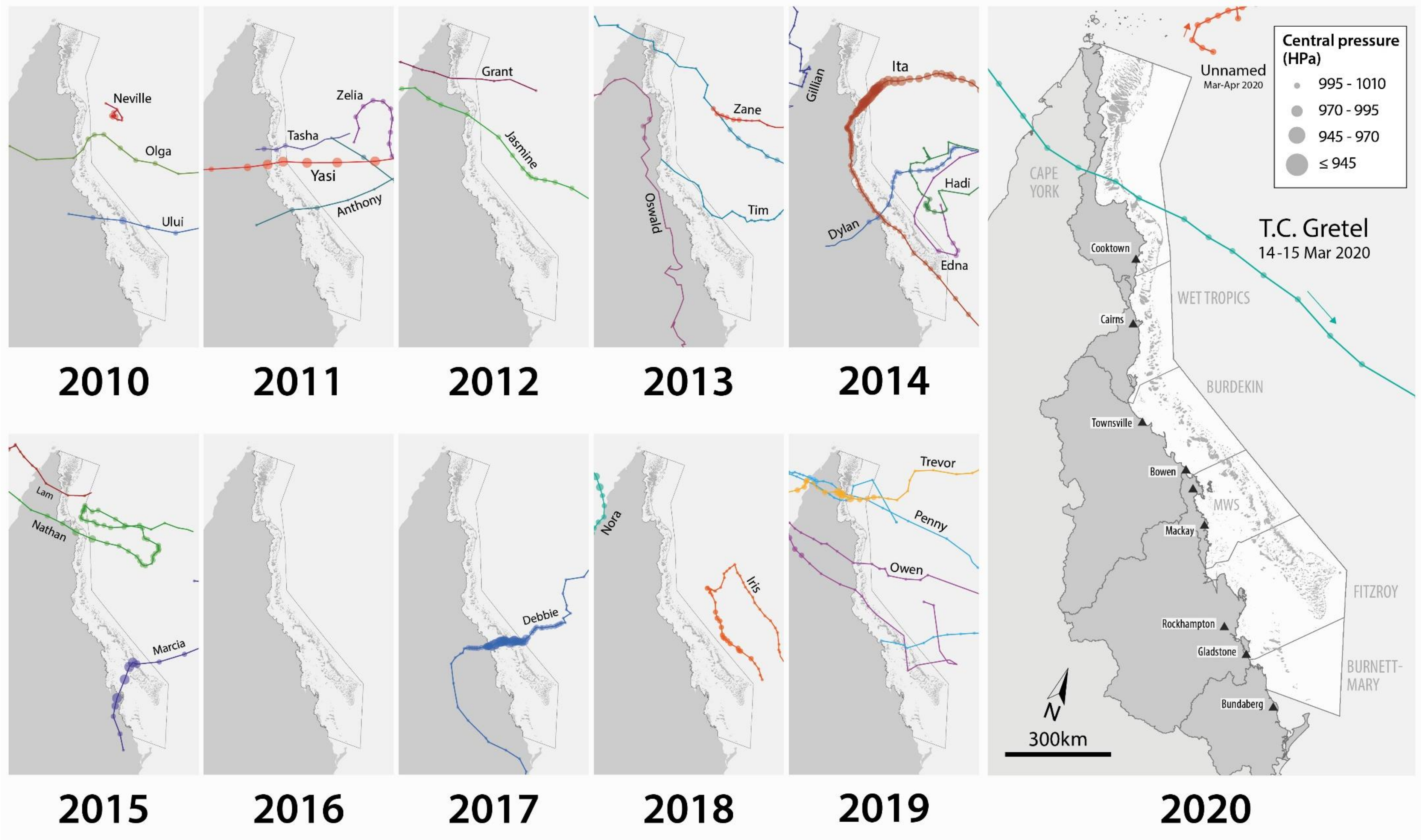

Figure 3-1: Trajectories of tropical cyclones affecting the Reef in 2019–20 and in previous years (2010 to 2019).

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 rainfall in 2019–20 for all of the basins was below the long-term average of wet seasons from 1961–1990 (Figure 3-2 and Figure 3-3). In all focus regions, 2019–20 was drier than 2018–19. In particular, all of the Wet Tropics basins had well-below-average rainfall (Figure 3-2 and Figure 3-3). The basins south of the Styx also had below average rainfall, similar to 2018-19.

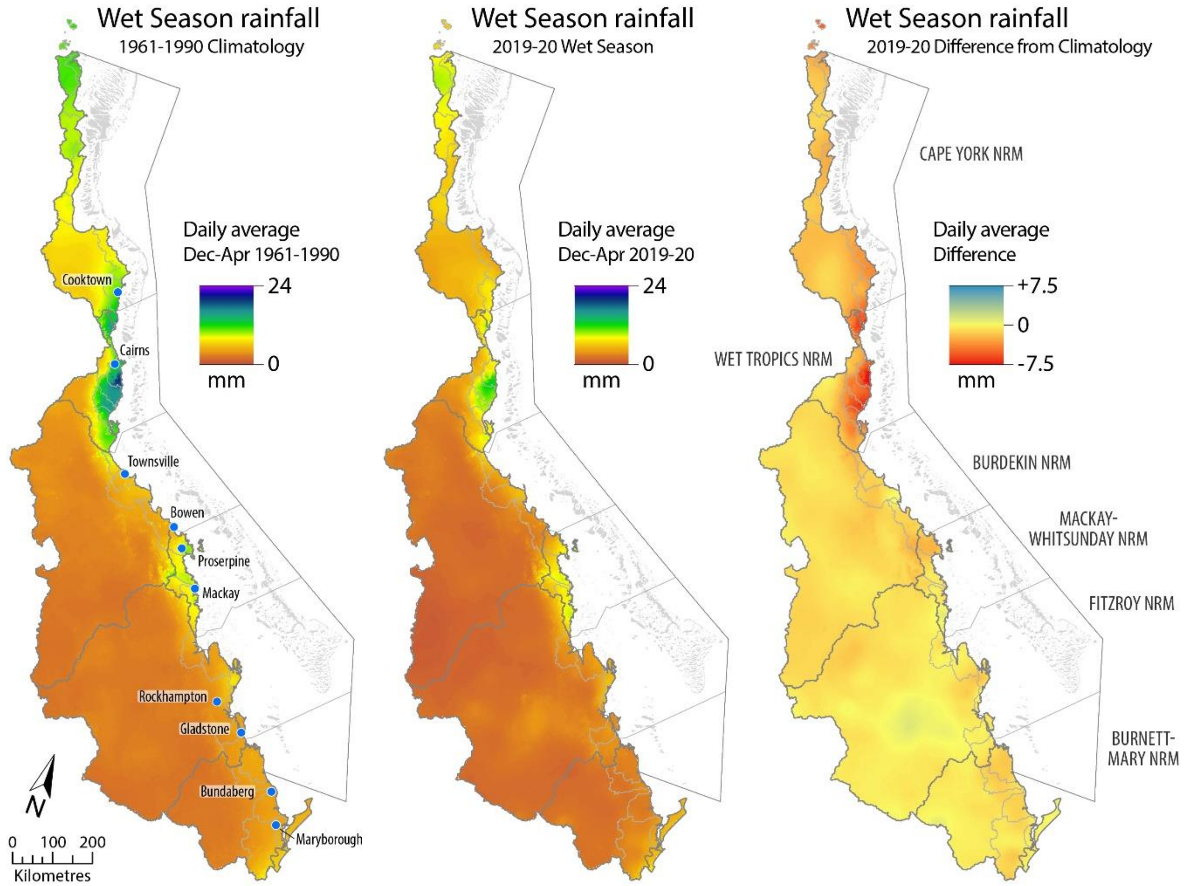

Figure 3-2: Average daily wet season rainfall (mm d^{-1}) in the Reef catchment: (left) long-term daily average (1961–1990; time period produced by BoM), (centre) 2019–20 and (right) the difference between the long-term average and 2019–20 rainfall. Source data: Bureau of Meteorology (2020).

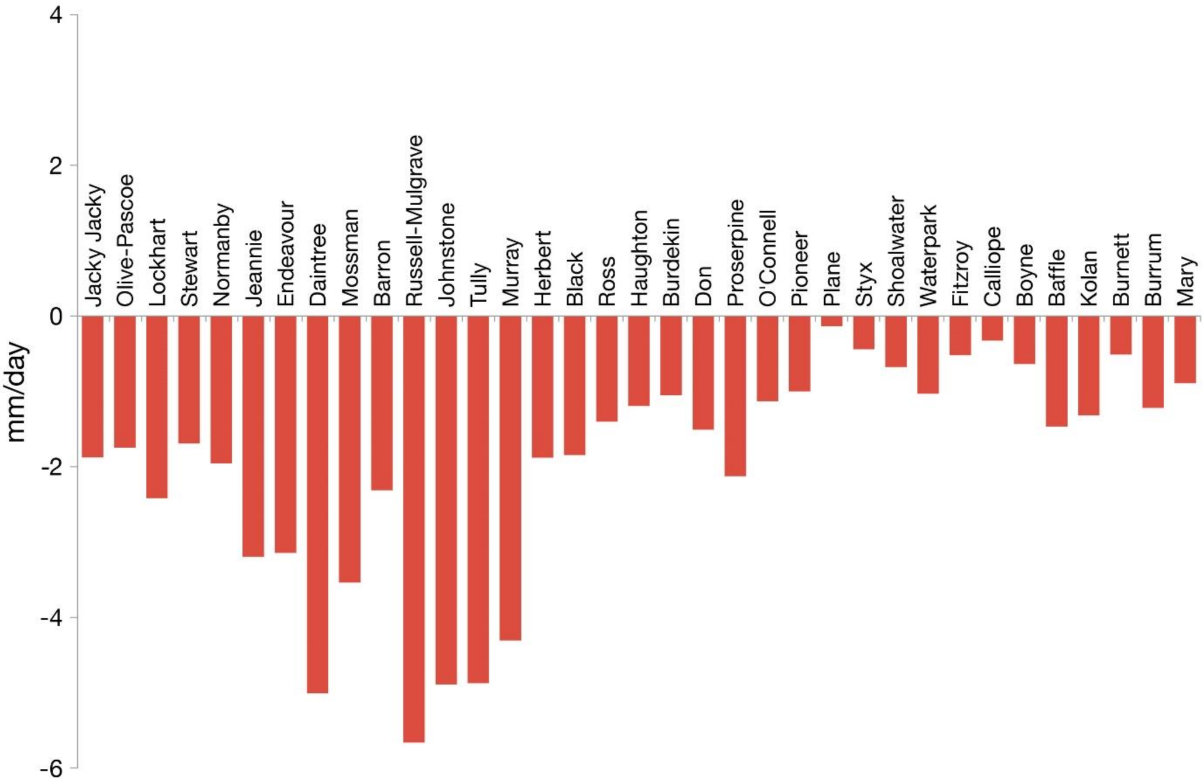

Figure 3-3: Difference between daily average wet season rainfall (December 2019–April 2020) and the long-term wet season rainfall average (from 1961–1990). Red and blue bars (none shown in this period) denote basins with rainfall below and above the long-term average, respectively. Note that the basins are ordered from north to south (left to right). Source data: Bureau of Meteorology (2020).

3.2.2 Freshwater discharge for the Reef, NRM regions and basins

Freshwater discharge volumes into the Reef lagoon are closely related to rainfall during the wet season and have a significant influence on coastal water quality. The total annual freshwater discharge for all of the Reef basins relative to long-term medians (based on water year, calculated using the methods described in Section 2.7) is shown in Figure 3-4. Discharge at the regional level is shown in Figure 3-5.

In 2019–20, the Reef catchment area had well below average discharge (1.7 times below the long-term median) which was the lowest since the 2015–16 season. The Wet Tropics NRM region recorded the lowest water year discharge since the start of the MMP in 2005, while the Cape York and Burdekin NRM regions had their lowest discharge since the 2015–16 season. Below average discharge also occurred in the Mackay-Whitsunday and Burnett-Mary NRM regions and discharge in the Fitzroy NRM region was the closest to the long-term median. The only three basins that recorded discharge 1.5 to 2.0 times higher than the long-term median were the Styx, Shoalwater Creek and Water Park Creek basins within the Fitzroy NRM region.

Annual discharge for each of the 35 Reef basins in 2019–20 is shown in Table 3-1 and compared to long-term median annual flows.

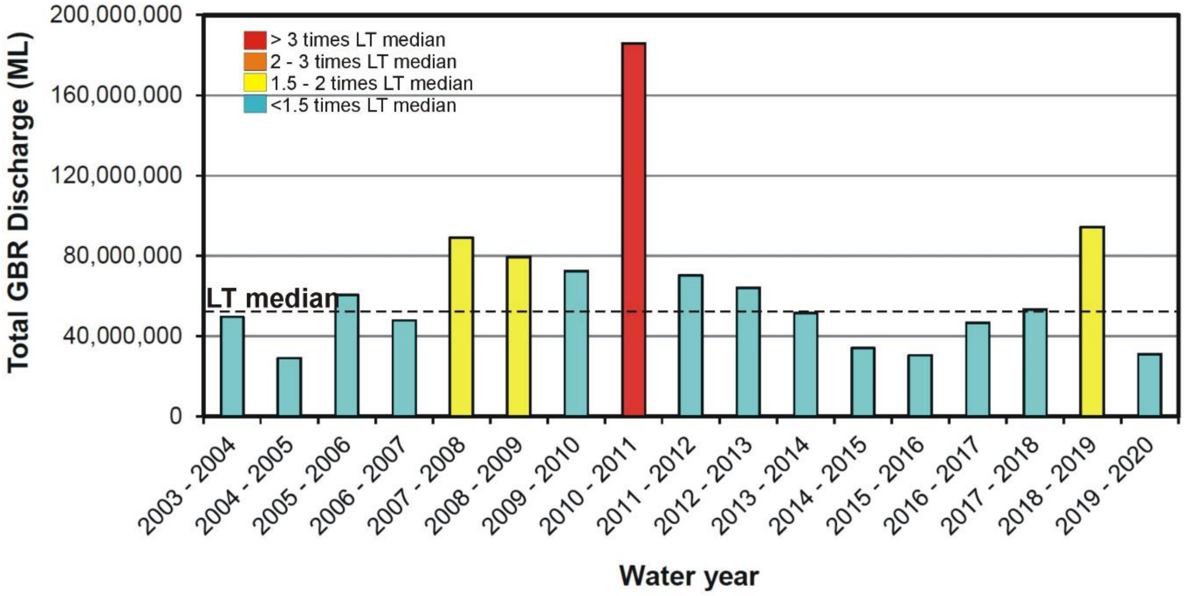

Figure 3-4: Long-term total discharge in ML (water year: 1 October to 30 September) for the 35 main Reef basins. Source: DNRM, http://watermonitoring.dnrm.qld.gov.au/host.htm.

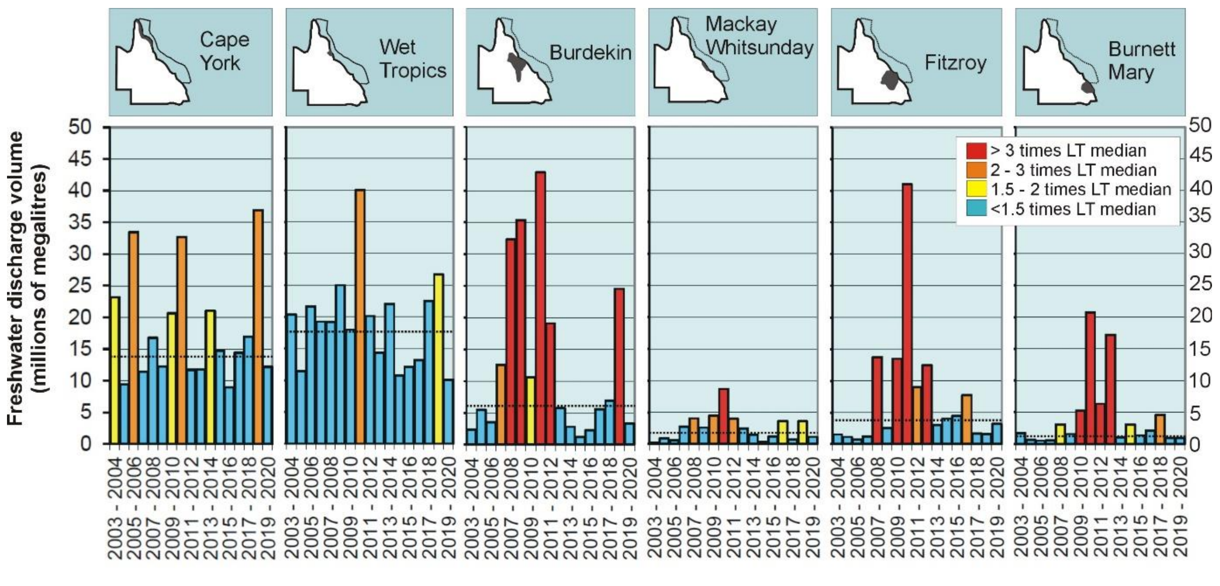

Figure 3-5: Corrected annual water year (1 October to 30 September) discharge from each NRM region (using the correction factors in Table 2-3) for 2003–04 to 2019–20 in (ML per year). Data derived from DNRM (2020).

Table 3-1: Annual water year discharge (ML) of the 35 main Reef basins (1 October 2016 to 30 September 2020, inclusive) and 30-year long-term (LT) median discharge (1986–87 to 2015–16). Colours indicate levels above the long-term median: yellow for 1.5 to 2 times, orange for 2 to 3 times and red greater than 3 times.

Basin	LT median	2016 - 2017	2017 - 2018	2018 - 2019	2019 - 2020
Jacky Jacky Creek	2,047,129	1,701,199	2,689,450	3,124,009	1,920,007
Olive Pascoe River	2,580,727	2,978,821	3,424,596	6,992,798	3,189,195
Lockhart River	1,634,460	1,886,587	2,168,911	4,428,772	2,019,824
Stewart River	674,618	685,263	826,499	3,109,052	584,988
Normanby River	4,159,062	3,780,651	4,333,023	12,102,053	2,792,858
Jeannie River	1,263,328	1,746,929	1,721,175	3,350,682	932,300
Endeavour River	1,393,744	1,665,116	1,796,913	3,847,478	773,315
Daintree River	1,512,054	1,590,225	1,439,220	4,752,327	901,248
Mossman River	858,320	812,585	1,069,336	1,885,921	555,280
Barron River	574,567	313,952	946,635	1,535,892	320,056
Mulgrave-Russell River	2,600,465	1,759,178	3,359,834	3,550,093	1,694,470
Johnstone River	3,953,262	3,348,014	4,950,329	4,774,747	2,743,805
Tully River	3,241,383	2,840,476	3,883,954	4,020,452	2,200,744
Murray River	380,472	293,742	521,465	519,739	199,630
Herbert River	3,556,376	2,248,436	6,385,655	5,707,209	1,472,338
Black River	208,308	64,449	386,030	965,544	102,296
Ross River	377,011	41,177	83,113	2,371,556	371,019
Haughton River	419,051	283,551	598,668	2,363,209	251,321
Burdekin River	4,406,780	4,165,129	5,542,306	17,451,417	2,203,056
Don River	508,117	1,081,946	321,875	1,356,004	398,312
Proserpine River	284,542	539,710	174,183	837,962	205,680
O'Connell River	478,097	894,975	260,937	1,223,297	279,585
Pioneer River	692,342	1,388,687	249,530	1,158,768	383,506
Plane Creek	309,931	761,503	75,052	351,879	299,502
Styx River	155,384	420,353	218,115	109,376	225,782
Shoalwater Creek	129,487	350,294	181,763	91,147	188,152
Water Park Creek	97,115	262,721	136,322	68,360	141,114
Fitzroy River	2,852,307	6,170,044	954,533	1,339,964	2,533,631
Calliope River	152,965	406,321	141,438	2,682	80,255
Boyne River	38,691	102,775	35,775	678	20,300
Baffle Creek	215,446	486,235	1,081,646	930	47,143
Kolan River	52,455	190,476	325,578	4,958	5,304
Burnett River	230,755	536,242	849,051	202,436	332,366
Burrum River	79,112	387,027	715,449	63,972	70,928
Mary River	981,183	499,295	1,630,741	658,014	472,580
Sum of basins	43,099,046	46,684,083	53,479,101	94,323,378	30,911,889

4. Modelling and mapping marine water quality

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

4.1 Satellite remote sensing of wet season 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, including frequency maps predicting the areas affected by the combined primary and secondary water types combined (Figure 4-1) or the three wet season water types individually (Figure 4-2) from December 2019 to April 2020.

4.1.1 Areas affected

The extent and frequency of the occurrence of combined primary and secondary water types 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 (e.g. Devlin et al., 2013, 2015), with coastal areas experiencing the highest frequency of primary water types and mid-shelf and offshore areas less frequently exposed to primary waters (Figure 4-2).

Frequency of occurrence: The frequencies of occurrence of the combined primary and secondary water types measured across the Tully, Burdekin and Pioneer transects in 2019–20 (Figure 4-1f) were below the frequencies extracted from the typical wet-year composite and above the frequencies extracted from the typical dry-year composite. In the Tully transect, the frequencies of occurrence were similar to (open coastal) or below (mid-shelf) the long-term average and the representative coral recovery period. In the Burdekin and Pioneer transects, the frequencies of occurrence were slightly above or similar to the long-term average and the representative coral recovery period in the open coastal waterbodies.

Reef area exposed: In 2019–20: only 3% of the Reef was exposed to primary waters, 23% of the Reef was exposed to secondary waters and 70% of the Reef was exposed to tertiary waters.

The area exposed to primary waters was similar to both the long-term and coral recovery percentages and only the inshore Reef waters were exposed (24% of the inshore waterbody area).

However, the area exposed to secondary waters was unexpectedly large and similar to the statistics for a ‘wet’ year (23% of the Reef). This result is related to anomalously large secondary areas measured in the mid-shelf waterbody: 41% of the mid-shelf waterbody area was exposed to secondary waters which is similar to the area of mid-shelf waterbody typically exposed during wet years (39% of the mid-shelf waterbody). These anomalous areas were measured more particularly in the Fitzroy and Burnett-Mary regions (see Regional sections and Appendix C-6, these regions are currently not fully assessed as part of the MMP) and in the Cape York region. Without considering these three regions, the mid-shelf area exposed to primary and secondary wet season water types combined was slightly under the long-term area (18% in 2019–20 versus 20% in the long-term assessment of the Wet Tropics, Burdekin and Mackay-Whitsunday total mid-shelf areas).

Table 4-1: Areas (km²) (and percentages, %) of the Reef lagoon (total 348,839 km²) and division by waterbodies (WB: Ins = inshore, Mid = mid-shelf and Off = offshore) affected by the primary and secondary wet season water types combined, and the three wet season water types individually during the current wet season and for a range of reference periods

		Area of Reef affected in km² and %									
		2019–20 wet season		**Long-term average**		**Average of coral recovery period: 2012–2017**		**Typical Wet-year composite**		**Typical Dry-year composite**	
Water type	**WB**	**km²**	**% Reef (% WB)**	**km²**	**% Reef (% WB)**	**km²**	**% Reef (% WB)**	**km²**	**% Reef (% WB)**	**km²**	**% Reef (% WB)**
Combined primary + secondary (CC1–	**Reef**	**82,052**	**24%**	**60,768**	**17%**	**58,870**	**17%**	**87,660**	**25%**	**42,366**	**12%**
	Ins	39,625	11% (96%)	39,906	11%	39,911	11% (97%)	40,573	12% (98%)	35,497	10% (86%)
	Mid	33,941	10% (41%)	18,045	5%	16,296	5% (22%)	35,290	10% (43%)	6,291	2% (8%)
	Off	8,486	2% (4%)	2,818	1%	2,664	1% (1%)	11,797	3% (5%)	577	0%
Primary	**Reef**	**9,926**	**3%**	**10,381**	**3%**	**10,140**	**3%**	**19,501**	**6%**	**7,127**	**2%**
	Ins	9,921	3% (24%)	10,381	3% (25 %)	10,136	3% (25%)	17,099	5% (41%)	7,127	2% (17%)
	Mid	4	0%	-	0%	4	0%	2,402	1% (3%)	-	0%
	Off	-	0%	-	0%	-	0%	-	0%	-	0%
Secondary	**Reef**	**79,668**	**23%**	**56,797**	**16%**	**55,074**	**16%**	**81,921**	**23%**	**39,742**	**11%**
	Ins	37,861	11% (92%)	38,416	11% (93%)	38,325	11% (93%)	39,548	11% (96%)	33,652	10% (82%)
	Mid	33,466 *	10% (41%)	15,647	4% (19%)	14,387	4% (18%)	31,592	9% (39%)	5,513	2% (7%)
	Off	8,342	2% (4%)	2,734	1% (1%)	2,363	1% (1%)	10,782	3% (5%)	577	0%
Tertiary	**Reef**	**243,711**	**70%**	**165,460**	**47%**	**165,582**	**47%**	**195,072**	**56%**	**136,990**	**39%**
	Ins	22,660	6% (55%)	26,506	8% (64%)	25,711	7% (62%)	27,233	8% (66%)	25,591	7% (62%)
	Mid	82,075	24% (100%)	70,255	20% (86%)	71,728	21% (87%)	76,350	22% (93%)	54,679	16% (67%)
	Off	138,976 *	40% (62%)	68,700	20% (31%)	68,143	20% (31%)	91,489	26% (41%)	56,721	16% (25%)

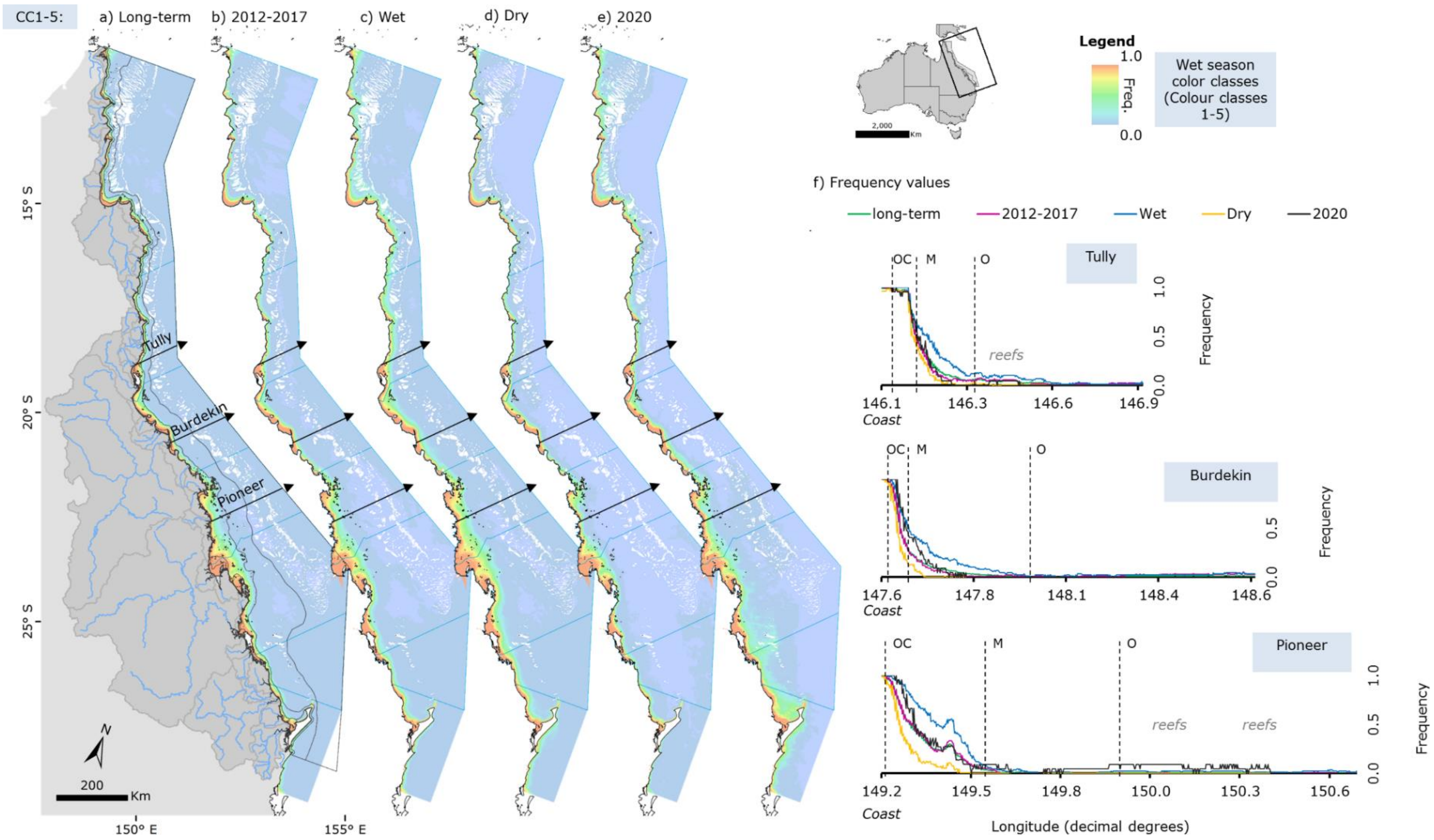

Figure 4-1: Map showing the frequency of primary (CC1–4) and secondary (CC5) water types combined in the a) long-term (16 wet seasons since 2003–04) b) representative coral recovery period (2011–12 to 2016–17, 6 wet seasons or 132 weeks), c) typical wet-year composite and d) typical dry-year wet season composites and e) 2019–20 wet season (22 weeks). Except for the coral recovery period, reference maps (long-term, Wet and Dry frequency maps) are updated every 4 years (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. The highest frequency is shown in orange and the lowest frequency is shown in blue. f) 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.

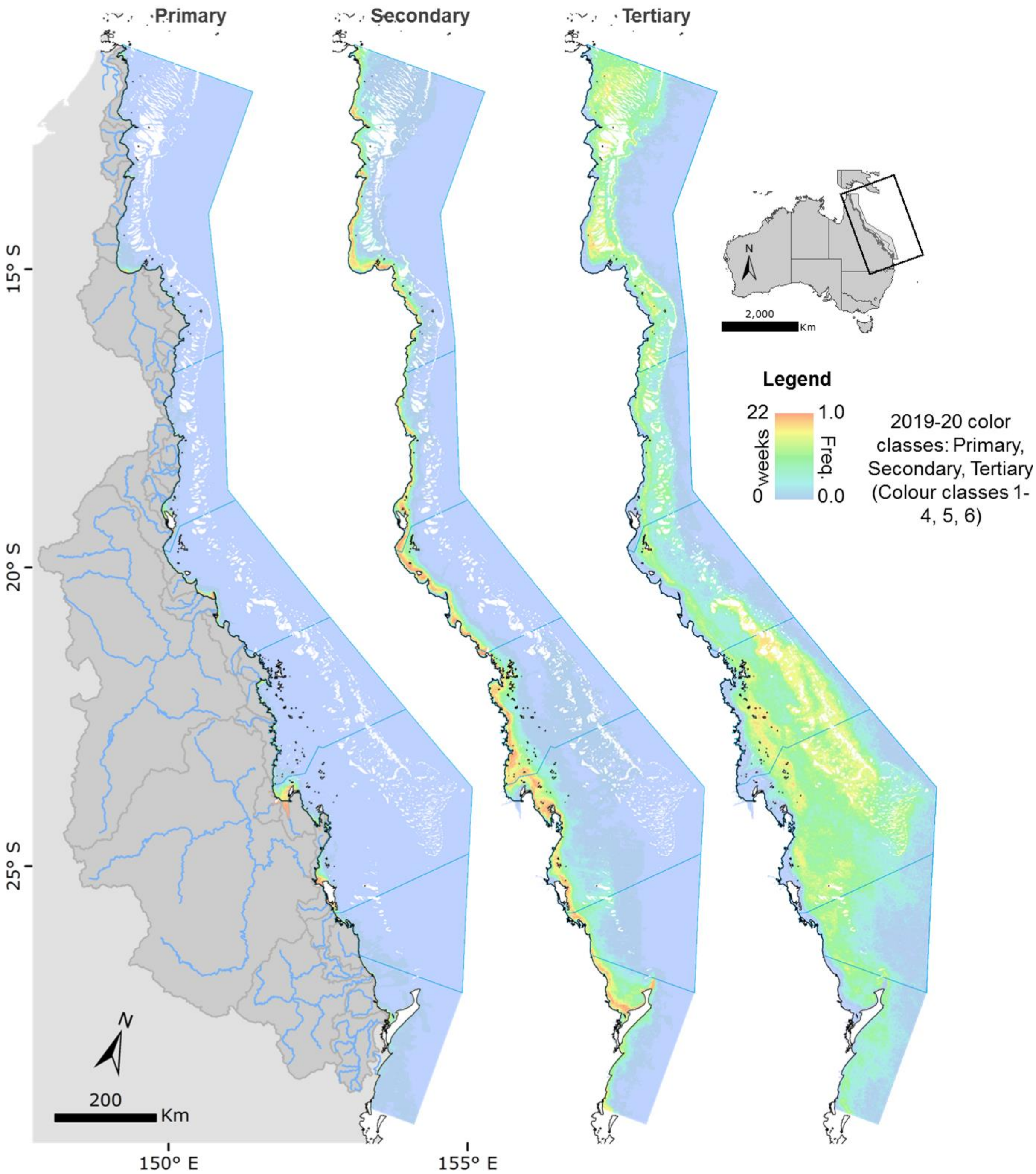

Figure 4-2: Map showing the frequency of primary, secondary and tertiary wet season water types in the 2019–20 wet season (22 weeks). The highest frequency is shown in orange and the lowest frequency is shown in blue. These maps are used in the exposure assessment to represent the spatial likelihood of exposure of each of the wet season water types in 2019–20.

The extended area of secondary waters is hypothesised to be driven by a combination of environmental and image quality factors; but is yet to be fully qualified. There were several MODIS true colour images contaminated by sun glint this wet season, and bad quality images (stripe noise) more particularly in the Cape York and the southern Reef regions (Figure 4-3a). While the most corrupted images where removed from this year satellite database (section 2.6.2), residual noise was still present on some images. Furthermore, it is difficult to separate direct riverine plume influence from sediment resuspension in some satellite images (see for example, Figure 4-3c-e). Sometimes turbid inshore secondary and tertiary waters (riverine inputs and/or wind resuspension) mix with mid-shelf secondary and tertiary waters (resuspension and/or upwelling productivity and/or bottom influence) and this creates large secondary or tertiary areas that cannot be separated. This is particularly common in the Cape York, Fitzroy and Burnett-Mary regions where coral reefs are closer to the coast and is expected to be less pronounced in the wettest wet seasons where this phenomenon is masked by the dominant riverine colour signature. Extra cleaning steps were applied to improve the satellite outputs (Section 2.6.2), but the factors described above are still likely to have influenced the anomalously large secondary areas measured in the Cape York, Fitzroy and Burnett-Mary regions.

Nevertheless, the extent of the secondary waters also often aligned with discharge events (see Regional Reporting in Sections 4.3 to 4.8) and it is likely that the higher frequency of secondary waters (in comparison to the long-term and/or dry season patterns) observed inshore in the Wet Tropics, Burdekin and Mackay-Whitsunday is partially real. It could be related to the characteristics of the 2019–20 wet season, with discharge periods relatively small but discrete, and with potentially less cloud cover, more coverage of data but also less turbidity and more light for algal growth seen in secondary waters. Some MODIS images showed influence from Torres Strait waters during the monsoon season, which may also explain the presence of secondary waters in the northern tip of Cape York on some weekly composites (Figure 4-3 and Figure 4-16: weeks 12-13).

Similarly the Reef area exposed to tertiary waters was unexpectedly large (70% 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 tertiary areas measured in the offshore Reef: 40% of the offshore waterbody area was exposed to tertiary waters which is greater than the offshore area typically exposed during wet years (26% of the mid-shelf waterbody) (extent illustrated in Figure 4-2). This result is not fully understood but could be an indication of other factors such as temperature or outer shelf nutrient upwelling (see for example, Figure 4-3d). This will be further investigated as we switch to Sentinel-3 satellite images and Forel Ule colour scale in the future (e.g., Petus et al., 2019). Tertiary waters are associated with low land-sourced contaminant concentrations and a low magnitude score in the Reef exposure assessment (Figure 4-4 and Figure 4-6). While tertiary areas were larger than usual, this did not result in increasing the potential risk offshore: 99% of the offshore areas were classified as no/very low potential risk in the 2020-21 risk assessment (Figure 4-6).

Furthermore, the 2019–20 wet season was a period of unusually intense bushfires in many parts of Australia, and more particularly in New South Wales and Victoria. Those large fires have impacted on the quality and colour of the atmosphere and large smoke clouds were visible on some MODIS satellite images off New South Wales and Victoria. It is likely that this may have had an impact on the global Reef atmospheric quality and thus on the colour classification of the MODIS images, more particularly in the southern Reef regions.

It is difficult to separate those different signals in the satellite observations and the hypotheses above are not validated, but thought to be reasonable. Some of the exposure assessment results for this wet season should however be taken with caution due to the above uncertainties. The remote sensing methods were originally developed for mapping turbid riverine plumes in the Wet Tropics, Burdekin and Mackay-Whitsunday regions and the above observations reaffirm the need for further understanding of the remote sensing outputs in the Cape York, Fitzroy and Burnett-Mary regions, and more generally in the mid-shelf and offshore areas. This will be investigated in the next years and as the program switches to Sentinel-3 satellite data and the Forel-Ule colour scale (21 colour classes instead of 6 currently used in the wet season colour scale).

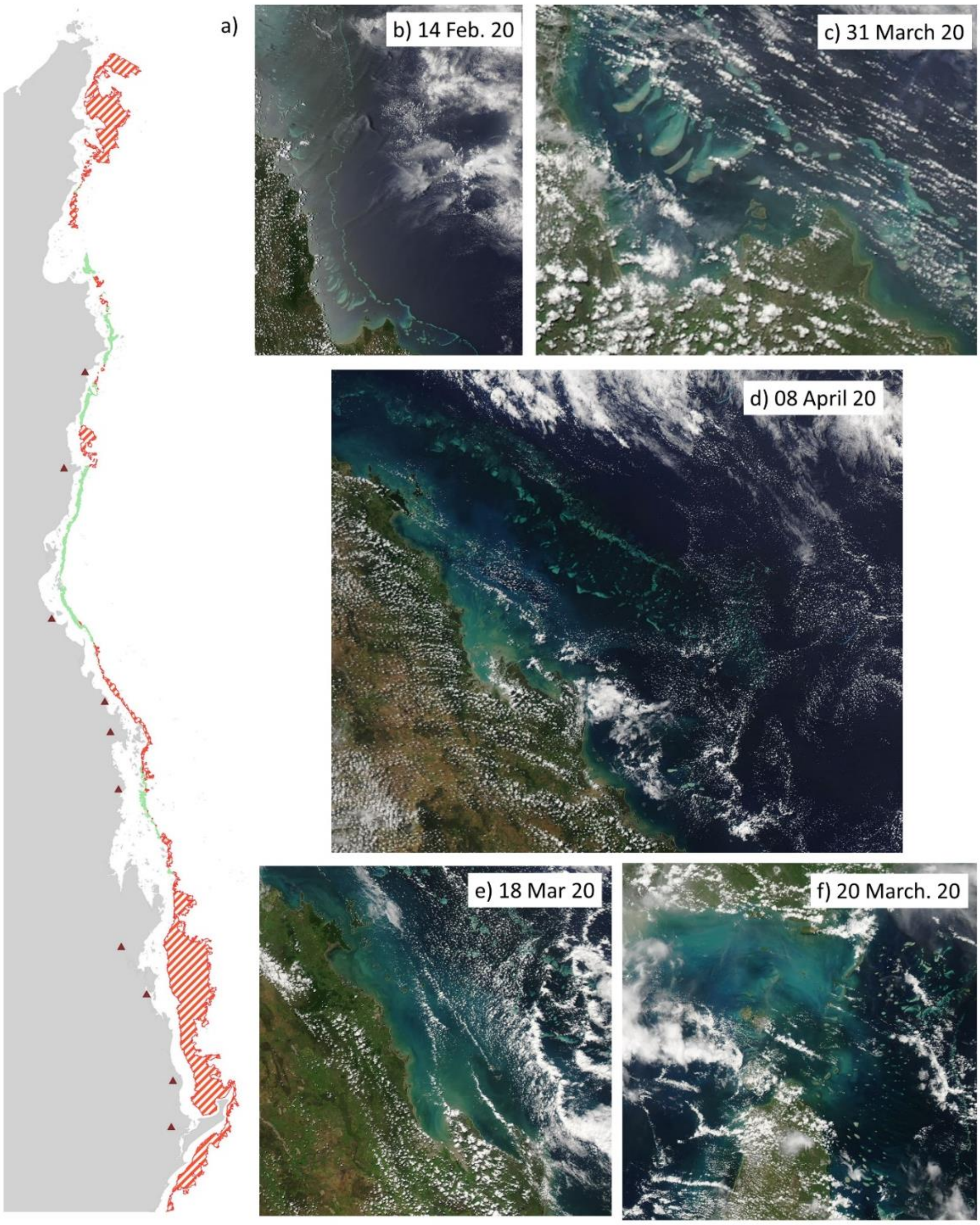

Figure 4-3: a) Difference map illustrating anomalously large CC1–5 extent in 2019–20 (red stripes) against long-term trends. Triangles on the coast represent major towns. MODIS-Aqua true colour images show: b) the influence of sun glint, c–e) mixed riverine plume and sediment resuspension inshore and around reefs following higher riverine discharge and/or stronger wind in c) Cape York (see Figure 4-17: weeks 17–18) and d–e) the southern Reef regions. The image in f) illustrates the intrusion of Torres Strait waters to the northern tip of Cape York.

4.1.2 Composition of water types

Boxplots of long-term water quality parameters in the wet season water types and six colour classes are shown in Figure 4-4 and Figure 4-5, respectively. Detailed summaries of water quality parameters for the long-term period (16 wet seasons) and reporting year are provided in Appendix C. Long-term water quality values are now 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 remain valid as a representative period, and to improve its accuracy as more field data are collected every wet seasons. The last update 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 water quality concentrations are presented rather than the seasonal mean concentrations in each colour class that were reported before 2018-19 which were considered to be potentially biased by the wet season sampling effort. The latter figures are still presented in Appendix C for consistency.

Boxplots of water quality concentrations for every water type followed published patterns (e.g., Devlin et al., 2015; Petus et al., 2019) with TSS, Chl-*a*, CDOM, DIN, DIP, PP and PN decreasing from the primary water type (colour classes 1–4) to the tertiary water type (colour class 6). High TSS, Chl-a and CDOM concentrations are at levels expected to decrease light availability (e.g. Petus et al., 2018) and the Secchi depth was logically lowest in the primary water types and increased from the primary to the tertiary water types (Figure 4-4).The primary water type had the larger interquartile range for all parameters, illustrating a greater variability in water quality concentrations measured in the most turbid water type.

While Devlin et al. (2012) reported higher Chl-*a* concentrations in secondary than in primary water types, the long-term wet season was characterised by higher mean Chl-*a* concentrations in the primary water type (1.61 ± 2.37µg L^{-1}) than in the secondary water type (0.80 ± 0.84 µg L^{-1}). However, when distinguishing individual colour classes (Figure 4-5c) Chl-*a* concentrations were higher in colour class 3 (2.28 ± 2.98 µg L^{-1}) than in colour classes 1 (2.20 ± 3.41 µg L^{-1}) and 2 (1.48 ± 1.12 µg L^{-1}). Thus, the sub-classification into colour classes may better describe fine-scale coastal processes and supports the findings of Devlin et al. (2013) that Chl-*a* concentrations peak in transition zones between the primary and secondary water types. This peak is hypothesised to be driven by factors that control phytoplankton production including light attenuation, nutrient inputs, and salinity (Carstensen et al., 2015). Mean long-term water quality concentrations decreased exponentially across the six colour classes and, except for DIN and DIP, mean long-term concentrations were two (PN and CDOM) to three (TSS and PP) times higher in CC1 than in CC2 or CC3 (Figure 4-5 and see Appendix C-4 for the concentration values).The number of samples collected in CC1 (n=117) and CC2 (n= 104) was however limited in comparison to, for example CC5 (n=926, Appendix C-4). It would be interesting to collect extra samples inshore in the future to further characterise concentrations in the more turbid regions of flood plumes.

Mean long-term concentrations of water quality parameters showed similar patterns between focus regions (Figure 4-6), with maximum concentrations measured in the primary water type and minimum concentrations in the tertiary water type (Figure B-4 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 (Section 4.1.3) are calculated using the mean long-term water quality concentrations across the whole of the Reef (Figure 4-6).

Mean water quality concentrations for TSS, Chl-a, PP and PN were compared against Reef-wide wet season GVs (Figure 4-6). Long-term mean Secchi depths (<7 m in all water types) did not meet the annual mean value (10 m), although the ecological significance of this is not clear. The following patterns were identified for the three water types:

- Primary: the long-term mean TSS, Chl-*a*, PP, and PN concentrations were above the Reef-wide wet season GVs (Figure 4-6). However, it is important to note that water quality parameters in primary waters are highly variable (Figure 4-4)
- Secondary: the long-term mean TSS, Chl-*a* concentrations were above, and the PP and PN concentrations slightly above, the Reef-wide wet season GVs
- Tertiary: the long-term mean TSS concentration was above the wet season GV. Concentrations of Chl-*a*, PP, and PN were below Reef-wide wet season GVs.

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 4-6). 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 water type (refer Section 4.1.3).

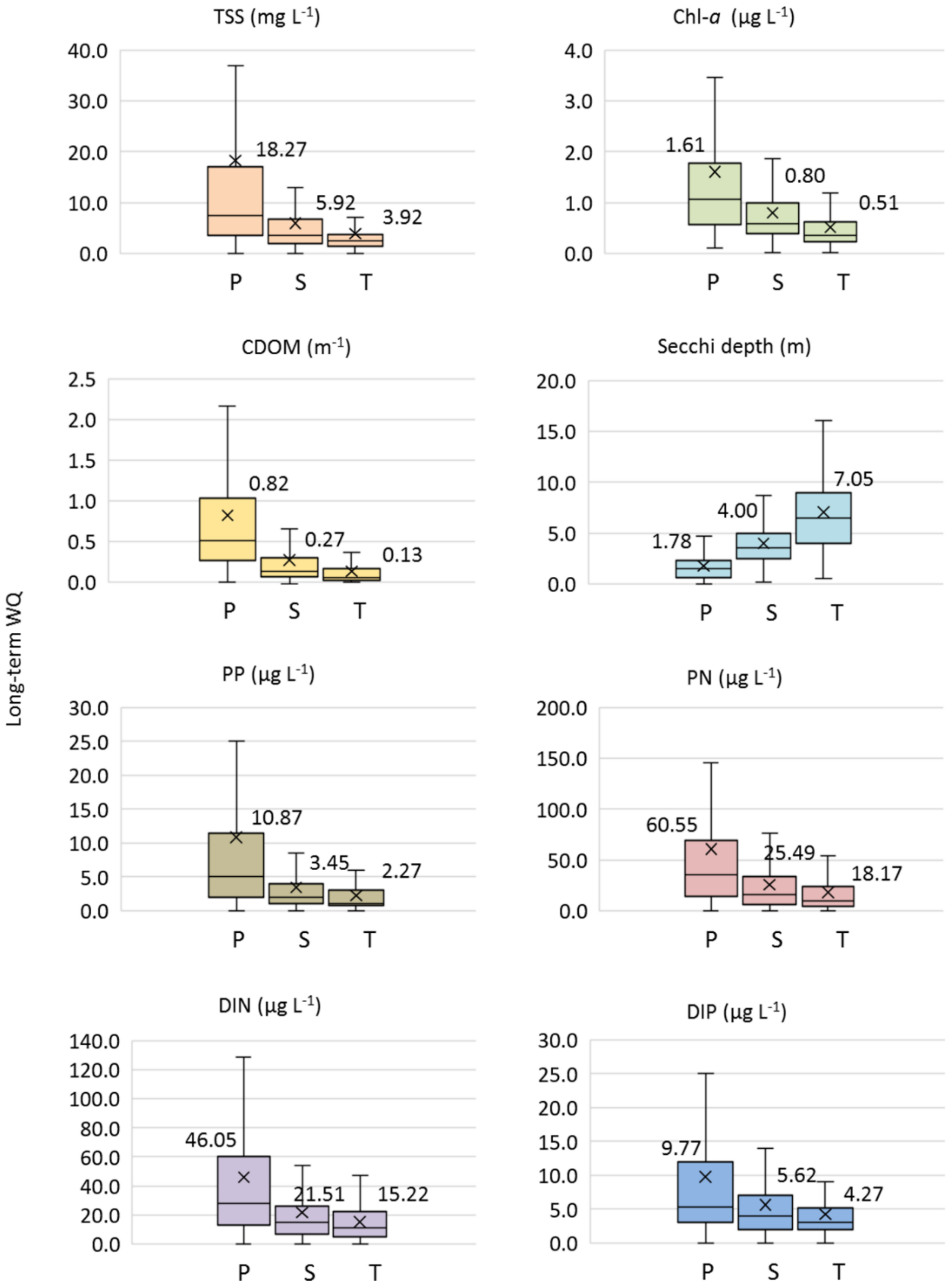

Figure 4-4: Long term water quality (WQ) concentration and Secchi disk depth boxplots for each wet season water type (P = primary, S = secondary, T = tertiary). The mean is plotted as a cross and its numerical value is indicated. The interquartile range is delimited by the box and the median by the line 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 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).

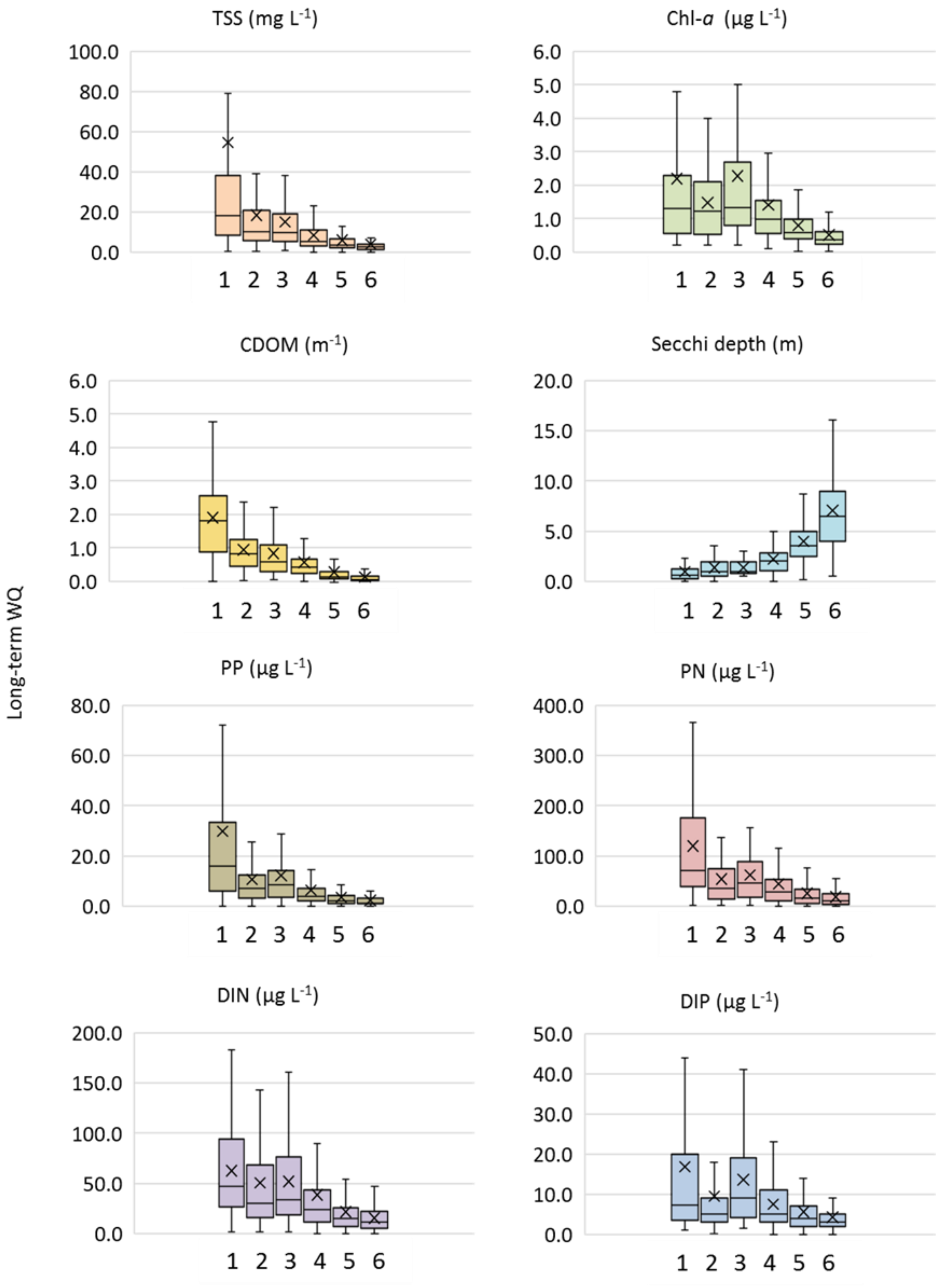

Figure 4-5: Long-term water quality (WQ) concentration and Secchi disk depth boxplots for each wet season colour class.The mean is plotted as a cross and its numerical value is indicated. The interquartile range is delimited by the box and the median by the line inside the box. Whiskers indicate variability 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).

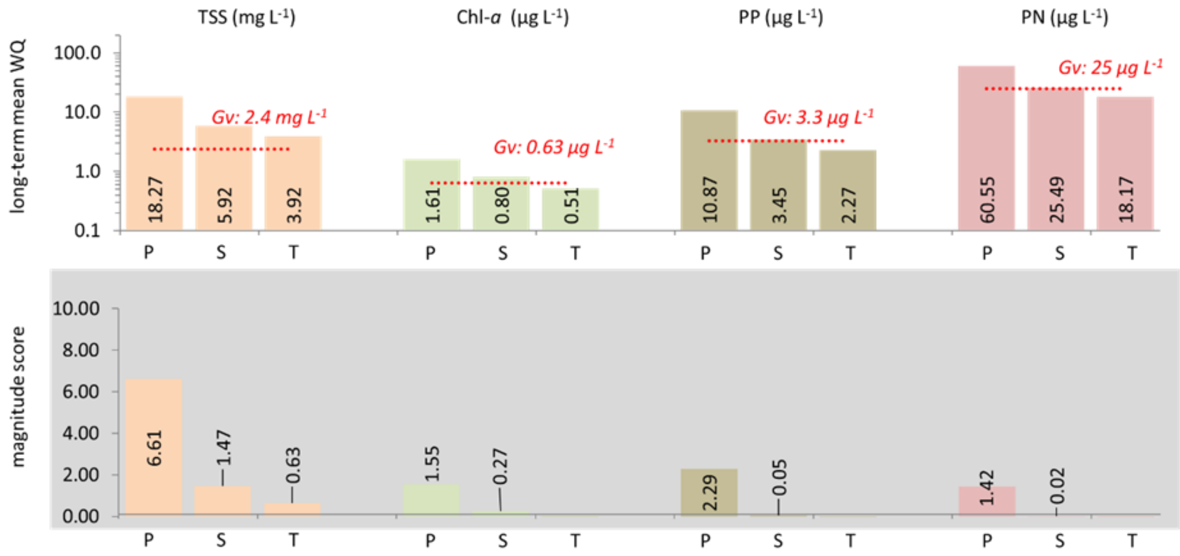

Figure 4-6: (top) Mean long-term water quality concentrations and (bottom) magnitude score across the three wet season water types. Red lines show the Reef-wide wet season GVs (Appendix D Table D-3). Magnitude scores are calculated as the proportional exceedance of the guideline: $magnitude_{water\ type} = ([Poll.]_{water\ type} - GV)/GV$ and Poll. = TSS, Chl-a, PP or PN. Negative Magnitude score are scored as zero. Mean long-term water quality concentrations and Magnitude score are re-calculated every 4 years as additional field data is collected (and/or in the case of extremely wet year or specific event patterns). 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 wet season water types.

The exposure categories are not validated against ecological health data and at this stage 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 2019–20 was spatially limited relative to the scale of the Reef with 85% exposed to no or very low potential risk (Table 4-2 and Figure 4-7). This result is similar to the long-term patterns (87% of the Reef). 15% of the Reef was exposed to combined potential risk categories II–IV. However, only 1% of the Reef was in the highest exposure category (IV) and only 1% of the Reef was in category III (Table 4-2). These patterns were very similar to the long-term patterns (Table 4-2). Patterns were also similar across marine regions, with more than 80% of each regions classified as no / very low risk and less than 2% classified as category III or category IV, respectively (Figure 4-8b).

Table 4-2: Areas (km^2) and percentages (%) of the Reef lagoon, coral reefs and surveyed seagrass affected by different risk categories of exposure during the 2019–20 wet season and the long-term. The last three rows show the differences between % affected in 2019–20 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	2020	296,548	43,510	4,809	3,972	52,291
			LT	304,664	35,767	4,853	3,555	44,175
	%	*100%*	2020	85%	12%	1%	1%	15%
			LT	87%	10%	1%	1%	13%
Coral reefs	area	24,149	2020	20,897	3,839	120	59	4,017
			LT	23,147	861	98	43	1,002
	%	*100%*	2020	84%	15%	<1%	<1%	16%
			LT	96%	4%	<1%	<1%	4%
Surveyed seagrass	area	4,640	2020	828	2,458	589	784	3,832
			LT	875	2,387	691	687	3,765
	%	*100%*	2020	18%	53%	13%	17%	82%
			LT	19%	51%	15%	15%	81%
Difference (2019 – Long Term average)	*Surface area*			-2%	2%	<1%	< 1%	2%
	Coral Reef			-12%	11%	<1%	< 1%	12%
	Surveyed seagrass			-1%	2%	-2%	2%	1%

Reef waterbodies: Only the inshore Reef waters (including macro-tidal enclosed coastal, enclosed coastal, macro-tidal open coastal and open coastal waterbodies combined) were exposed to the highest categories of potential risk (III and IV, Figure 4 8a). Inshore Reef waters were however largely exposed to the lowest category of potential risk only (II: 67 %) and only 12% and 10% of the inshore waters where exposed to the potential risk category III and IV. Approximately 77% (<3,600 km^2) of the Reef seagrass occur in the inshore waters, but only 4% (< 900 km^2) of the Reef corals (Appendix C-6). The mid-shelf and offshore waterbodies were largely classified (80% of the mid-shelf and 99% of the offshore waters) as no / very low potential risk (Figure 4-8a).

Similar cross-shore patterns were observed across Reef marine regions (Figure 4-8c) and all regions were largely classified as no or very low potential risk. Mid-shelf waterbodies in the Cape York and Burnett-Mary regions had the greatest exposure to potential risk category II (34 % of the Cape York and the Burnett-Mary mid-shelf waters). The Mackay-Whitsunday region inshore waterbody had the smaller exposure to risk categories III and IV (9 % of the Mackay-Whitsunday inshore waters). In the other Reef regions, 20 to 30 % of the inshore waterbodies were exposed to risk categories III and IV. Differences across regions are further described in the Regional Reporting (Section 4.3 to 4.8).

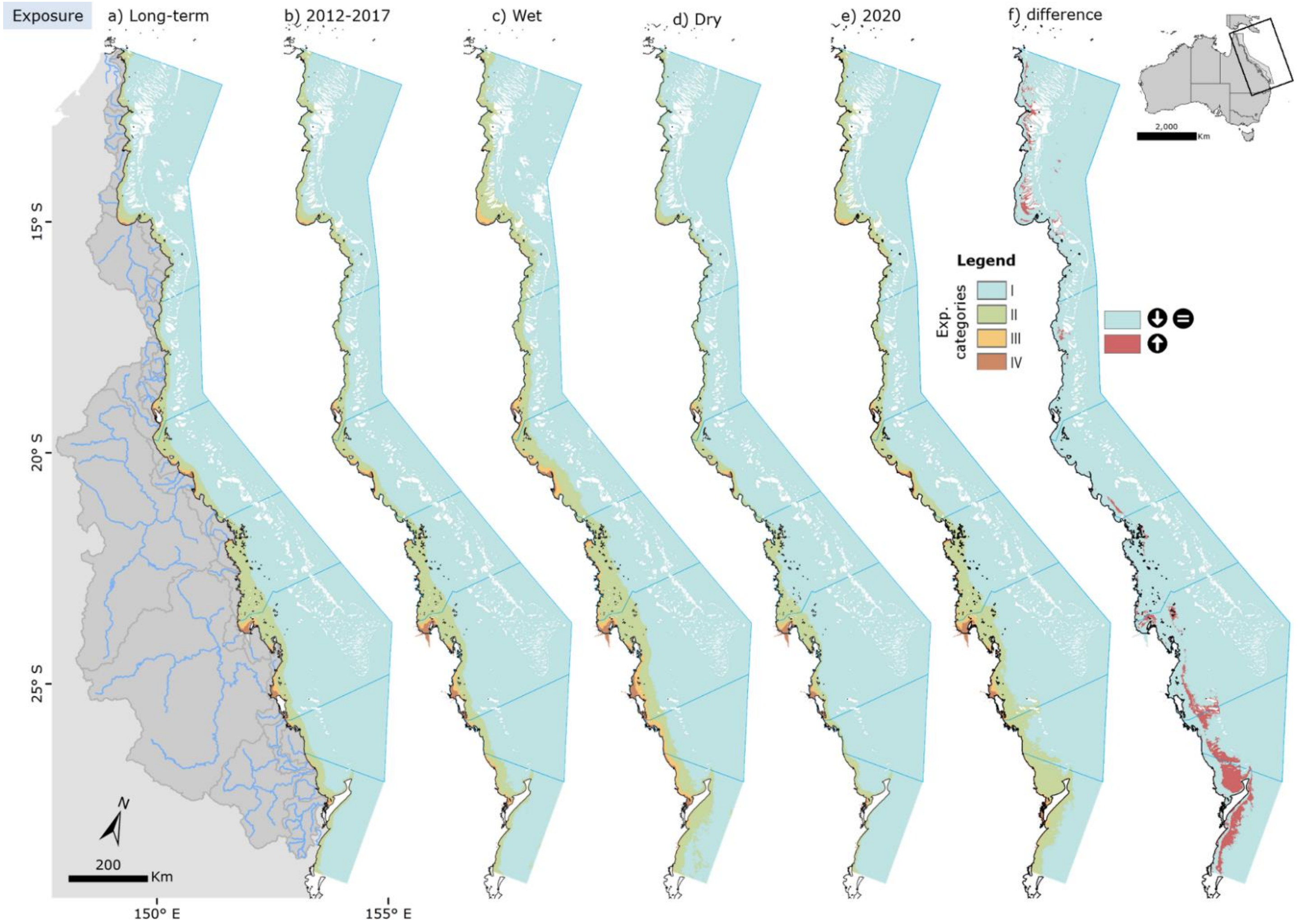

Figure 4-7: Map showing the reclassified surface exposure in the a) long-term, b) representative coral recovery period (2012–2017, 132 weeks), c) typical wet-year and d) typical dry-year wet season composites and e) 2019–20 wet seasons (22 weeks). Except for the coral recovery period, reference maps (long-term, Wet and Dry frequency maps) are updated every 4 years (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 (16 wet seasons). Relative potential risk categories range from I: no to low risk to IV: highest risk. f) Difference map showing areas with an increase in risk category in 2019–20 (in red, ⬆) against long-term trends (calculated as (e) 2020 minus (a) long-term).

Figure 4-8: Percentage of the a) Reef waterbodies, b) Reef regions and c) regional Reef waterbodies and Reef d) seagrass and e) coral habitats affected by different risk categories of exposure during the 2019–20 wet season.

Reef habitats (coral reefs and seagrasses): In 2019–20, it was estimated that:

- 16% of coral reefs were exposed to combined potential risk categories II–IV (Table 4-2). However, less than 1% were in the highest exposure categories IV and III and only inshore coral reef habitats were exposed (Figure 4-7e). The total inshore coral reef area affected by the highest exposure categories was 21% (7% to cat. IV and 14% to cat. III). Midshelf and offshore coral reefs were only exposed to the lowest risk category II or to no potential risk.
- 82% of seagrasses were exposed to combined potential risk categories II–IV. 17% were in the highest exposure category (IV) and 13% were in category III and only inshore seagrass habitats were exposed (Figure 4-7d). The total inshore seagrass area affected by the highest exposure categories was 38% (22% to cat. IV and 16% to cat. III). Mid-shelf and offshore seagrasses 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 (< 1% of the coral reefs, Table 4-2). There was however an increase in area exposed to the lowest potential risk category (II: + 11%). Most of this increase was in the Cape York, Fitzroy and Burnett-Mary regions (see Regional results in Section 4.3 to 4.7) (II: + 11%). As discussed in Section 4.1.1, this is most likely linked to the data confidence issues in these regions (unexpectedly large secondary areas in the mid-shelf waters).
- The seagrass areas exposed to combined potential risk categories II–IV in 2019–20 were similar to the long-term (+2%).

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

An improved understanding of dispersal of river-derived DIN, fine sediment and PN has been developed using the eReefs marine models. The process involves dispersing modelled end-of-catchment loads in individual river plumes, and then the dispersal from each river plume is summed to represent the total fine sediment, DIN, or PN dispersed in that year. For all pollutants, the ‘anthropogenic’ influence was predicted by calculating the difference between a pre-development load scenario and the 2019–20 loading. A time series from 2003 to 2020 is also presented. In the years marked with asterisks, eReefs simulations were not available, so a multi-annual average tracer was used to disperse loads in these years. While the estimates have lower reliability relative to the years where tracer maps were available, they are still considered more robust than methods used in previous reports.

4.2.1 River-derived DIN dispersal

2020 water year

The estimated wet season river-derived DIN loading in the Reef lagoon for the 2020 water year is shown in Figure 4-9 (left panel), with a relatively low area of influence. Only small differences were shown between the 2019–20, pre-development and anthropogenic loading scenarios, with an area of limited anthropogenic DIN loading in the Wet Tropics region.

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

Trends in annual river-derived DIN loading to the Reef 2003–2020

The model-predicted river-derived DIN loading provides an estimate of the dispersion of end-of-catchment DIN loads in Reef waters and the resulting maps highlight spatial and temporal variation in DIN loading. The time series from 2003 to 2020 (Figure 4-10) showed distinct inter-annual variability, driven by river flow and pollutant loads. The areas of influence in 2019–20 were comparable to other years with river discharge below the long-term median (e.g. 2014–15).

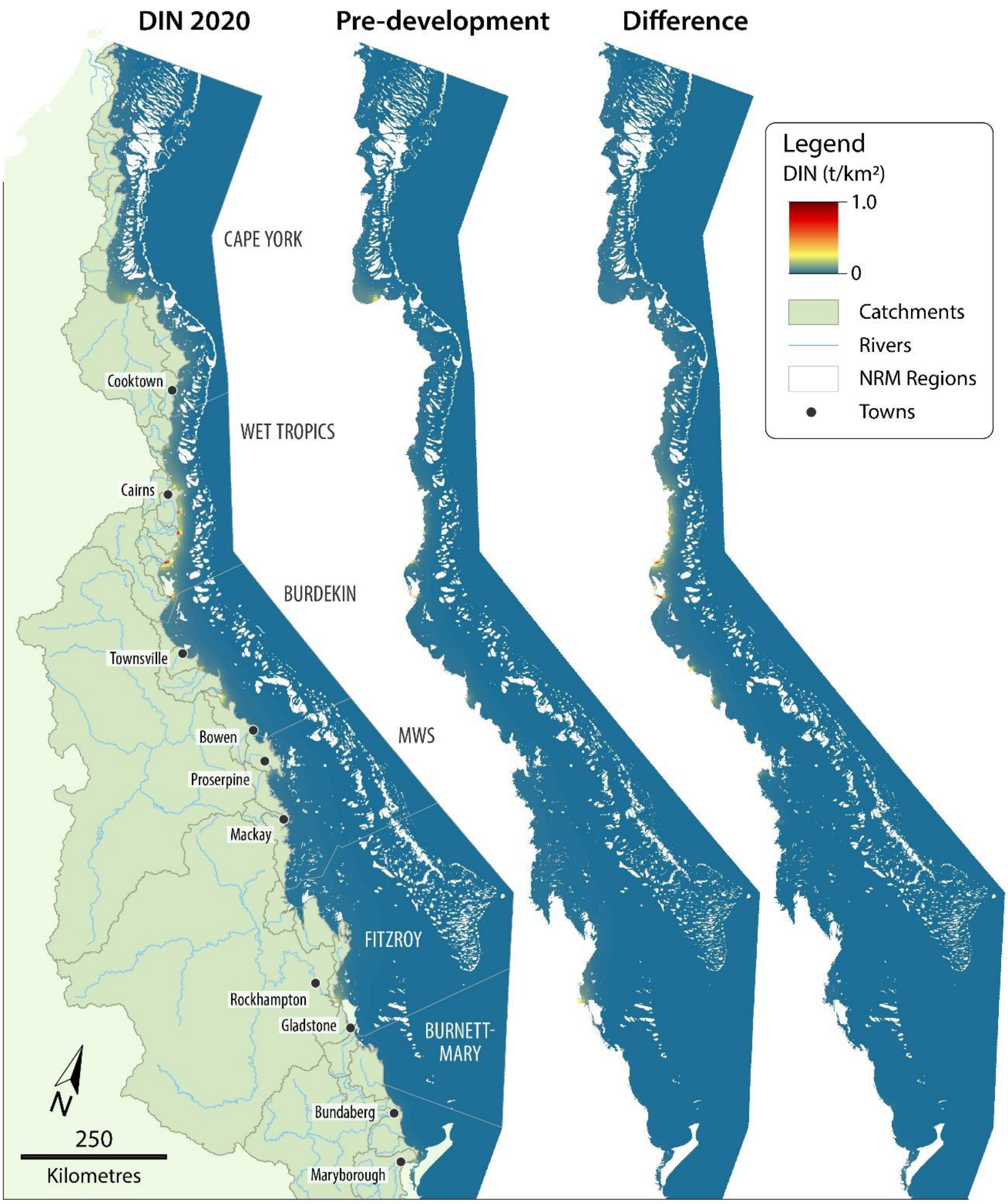

Figure 4-9: River-derived DIN loading (tonnes km^{-2}, relative scale) in the Reef lagoon, modelled for the (left panel) 2020 water year (1 October to 30 September), (centre panel) pre-development loads, and (right panel) difference between the DIN loading for pre-development and 2019 estimates.

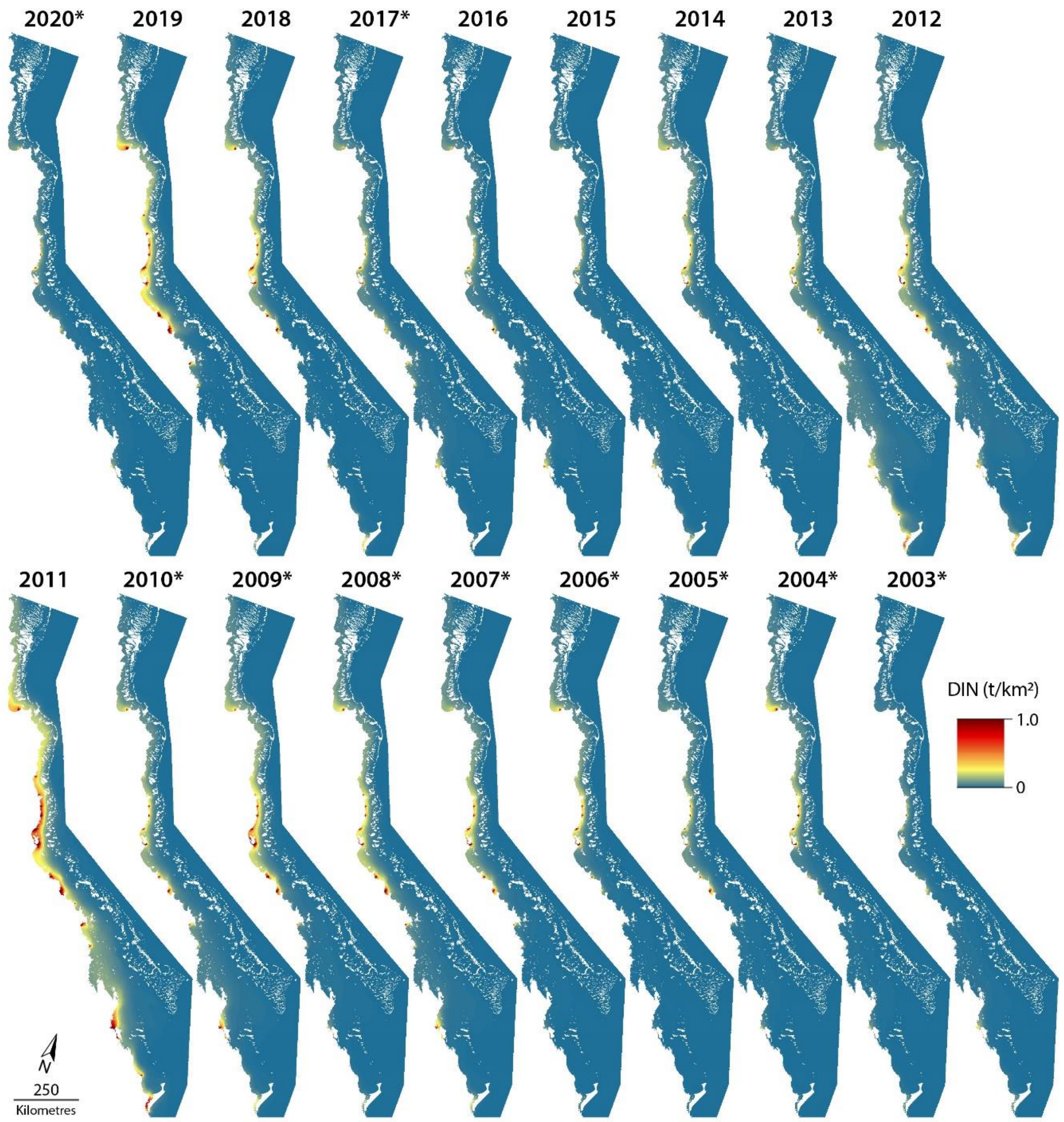

Figure 4-10: River-derived DIN loading (tonnes km^{-2}, relative scale) over the Reef lagoon for the 2003 to 2020 water years (1 October to 30 September). The years marked with asterisks are modelled using a multiannual average tracer.

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

The regions presenting higher DIN loading have remained relatively constant over the years, with higher loading typically observed in the Wet Tropics, Burdekin, and Mackay-Whitsunday NRM regions. The greatest incidence of high DIN loading occurred in the Wet Tropics region in all years (although this is less obvious in 2019–20) and, within the Wet Tropics, the areas of greatest values were correlated with large river discharge events in 2009, 2011, 2018 and 2019. High loading was also observed in each region during different years. For example, high values in the Burdekin region in 2005, each year between 2008 and 2012, 2018 and 2019 (Figure 4-10).

4.2.2 River-derived TSS dispersal

2020 water year

The estimated wet season river-derived TSS loading for the 2019 water year is shown in Figure 4-11 (left panel), with a limited area of influence. Only small differences were shown between the 2019–20, pre-development and anthropogenic loading scenarios, with an area of limited anthropogenic in the Burdekin region.

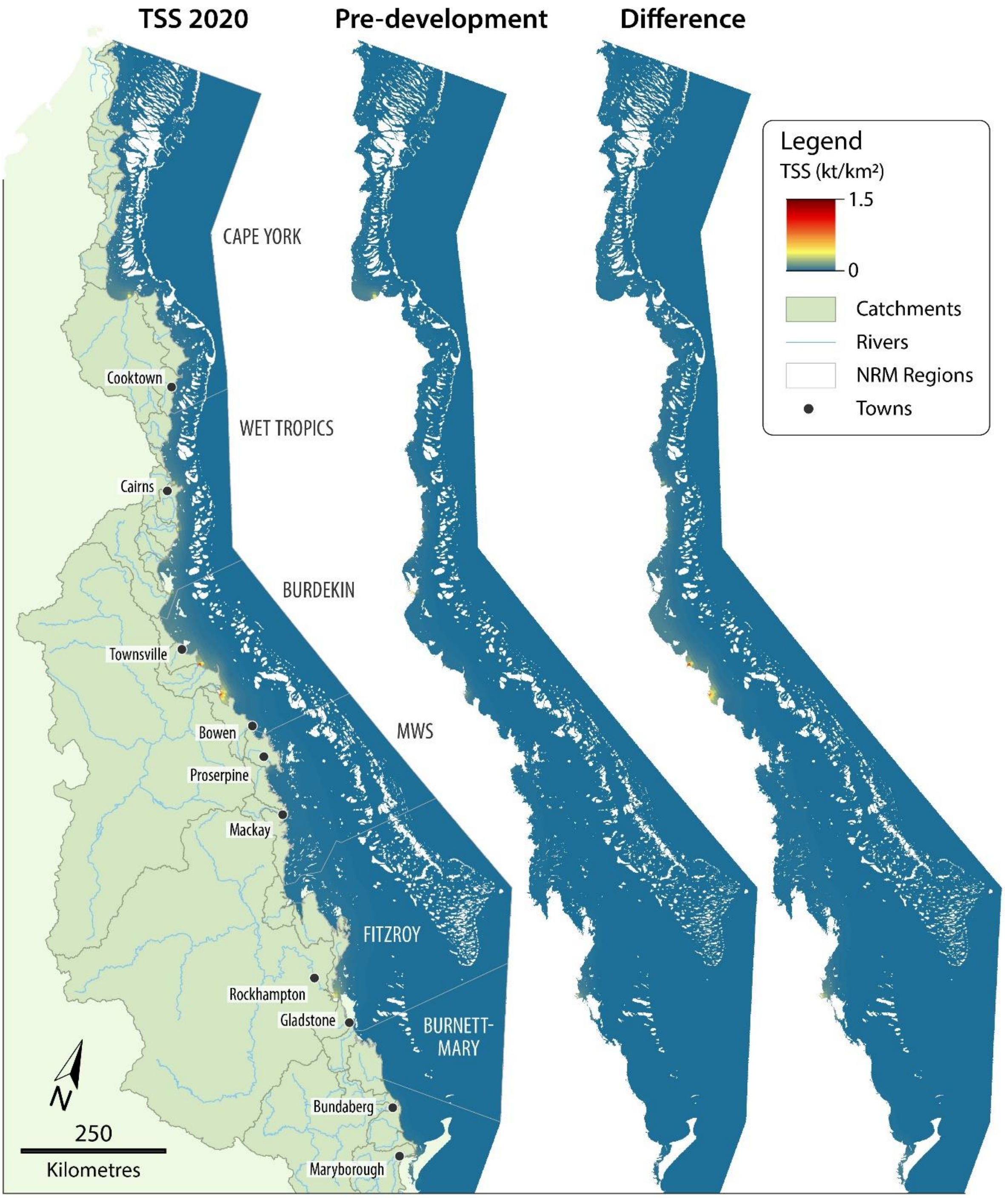

Figure 4-11: TSS (kilotonnes km^{-2}, relative scale) in the Reef lagoon, modelled for the (left panel) 2020 water year (1 October to 30 September), (centre panel) pre-development loads, and (right panel) difference between the TSS loading for pre-development and 2020 estimates.

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

Trends in annual river-derived TSS loading to the Reef 2003–20

The time-series from 2003 to 2020 (Figure 4-12) showed distinct inter-annual differences, driven by river flow and pollutant loads. The areas of influence in 2019–20 were comparable to other years with below long-term median river discharge (e.g. 2006, 2014 and 2015).

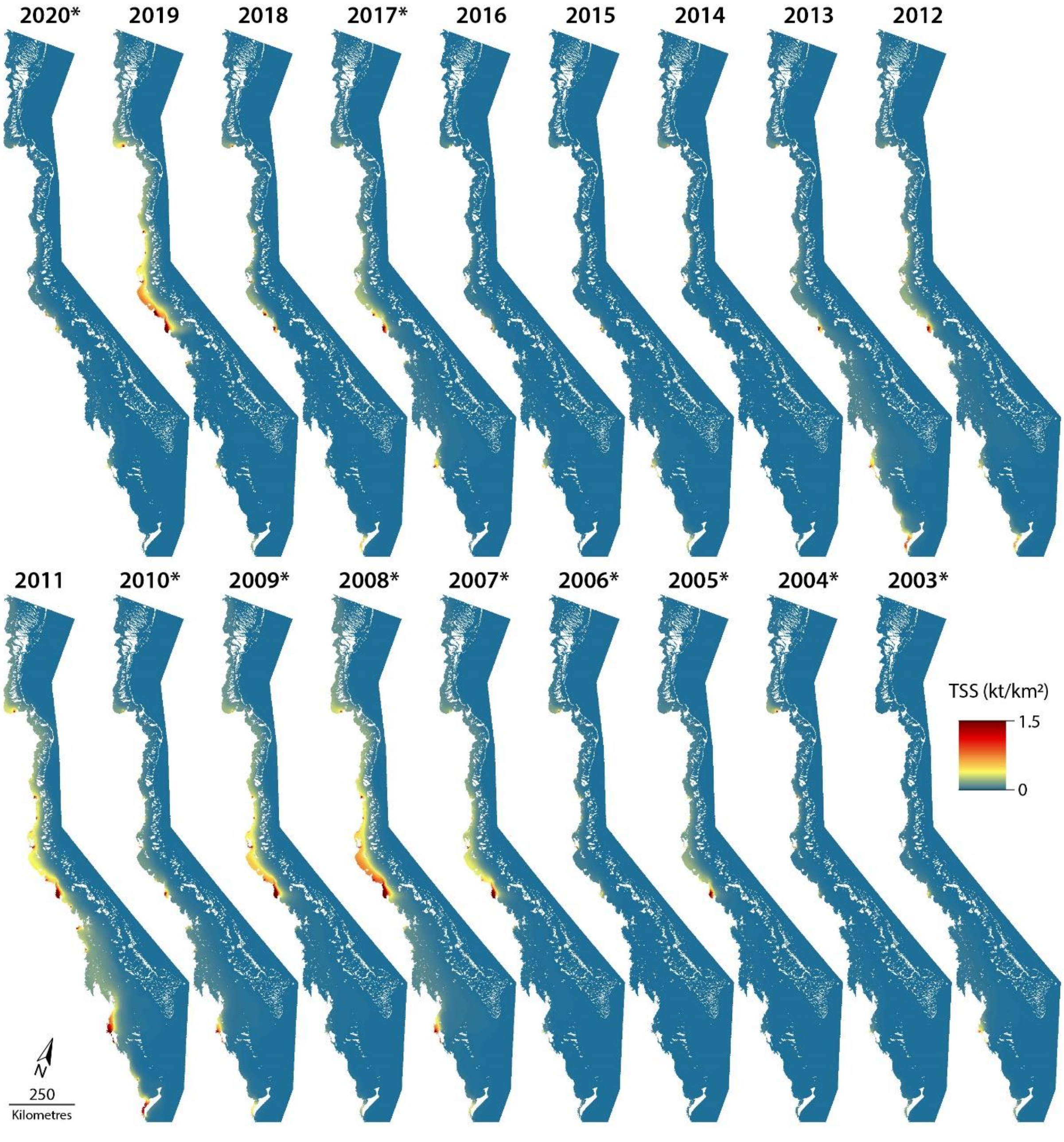

Figure 4-12: TSS loading (kilotonnes per km^2, relative scale) over the Reef lagoon for the 2005 to 2020 water years (1 October to 30 September). The years marked with asterisks are modelled using a multiannual average tracer.

The greatest extent was observed in 2011 linked to heavy rain associated with cyclone Tasha and the subsequent influence of severe cyclone Yasi. The regions with the highest TSS loading were typically the Burdekin, and to a lesser extent, the Fitzroy. The greatest frequency of the high river-derived TSS loading occurred in the Burdekin region and was correlated with large river discharge events (e.g. in 2005, 2007–2009, 2011–2012, 2017 and 2019). High loading was also observed in each region in different years (Figure 4-12).

4.2.3 River-derived PN dispersal

2020 water year

The estimated wet season river-derived PN loading for the 2019 water year is shown in Figure 4-13 (left panel) and showed similar patterns to both the DIN and TSS loading maps, with limited influence of PN loading along most of the Reef coast.

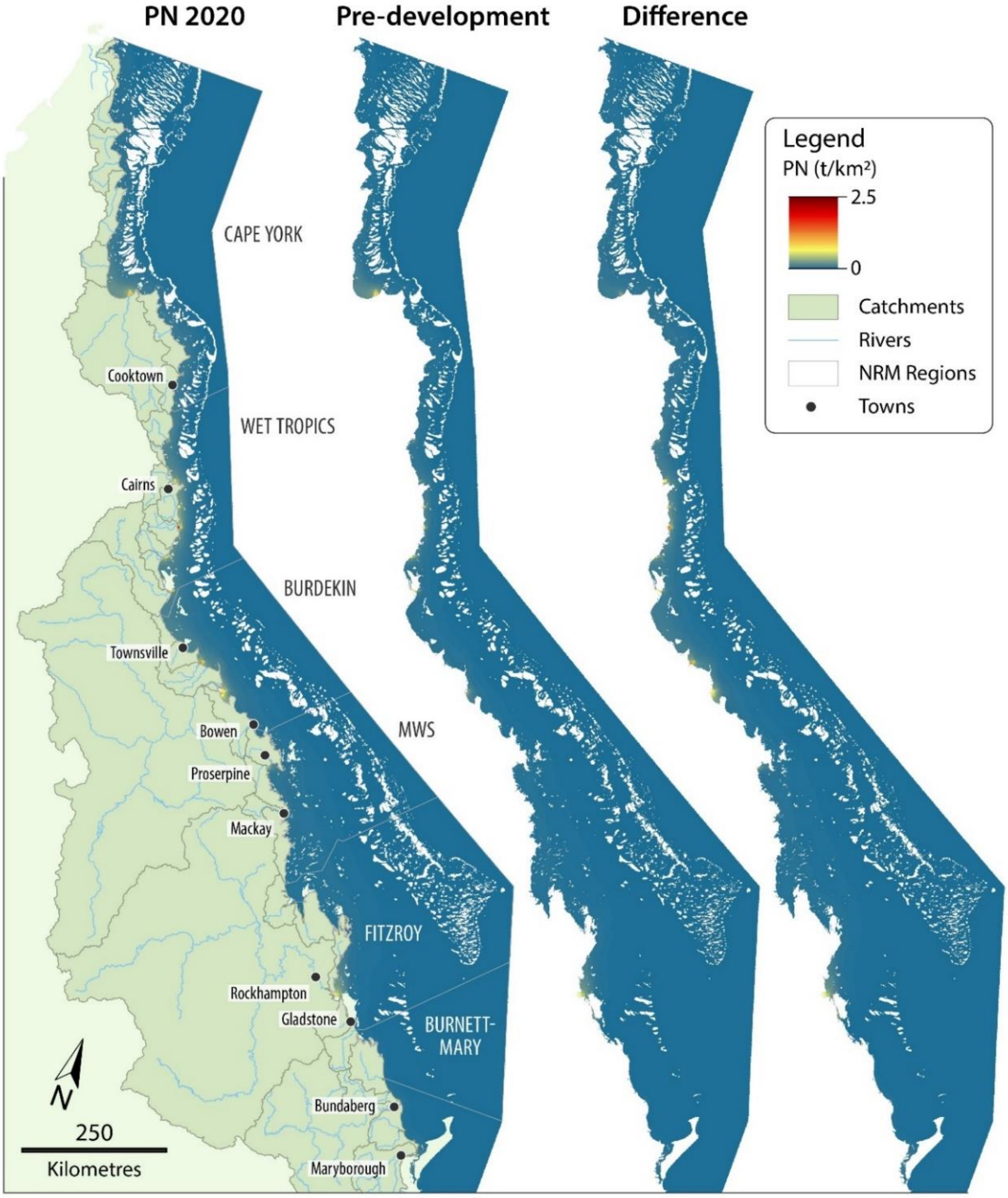

Figure 4-13: River-derived PN loading (tonnes km^{-2}, relative scale) in the Reef lagoon, modelled for the (left panel) 2020 water year (1 October to 30 September), (centre panel) pre-development loads, and (right panel) difference between the PN loading for pre-development and 2020 estimates.

The 'anthropogenic' influence map (Figure 4-13 right panel) was similar to the 2019–20 output, suggesting limited anthropogenic influence in this period as expected given the relatively low end of catchment loads in 2019–20. The same issues exist for PN in the Normanby basin as described for DIN and TSS above, giving this result low certainty.

Trends in annual river-derived PN loading to the Reef 2003–2020

The times series from 2003 to 2020 for PN loading (Figure 4-14) also showed distinct inter-annual differences, driven by river flow and pollutant loads. The greatest extent of the higher model-predicted PN loading was observed in 2008, 2009, 2011 (covering almost the entire Reef), 2013, 2017 and 2019. The areas with the highest PN loading in these years were typically in the Burdekin region.

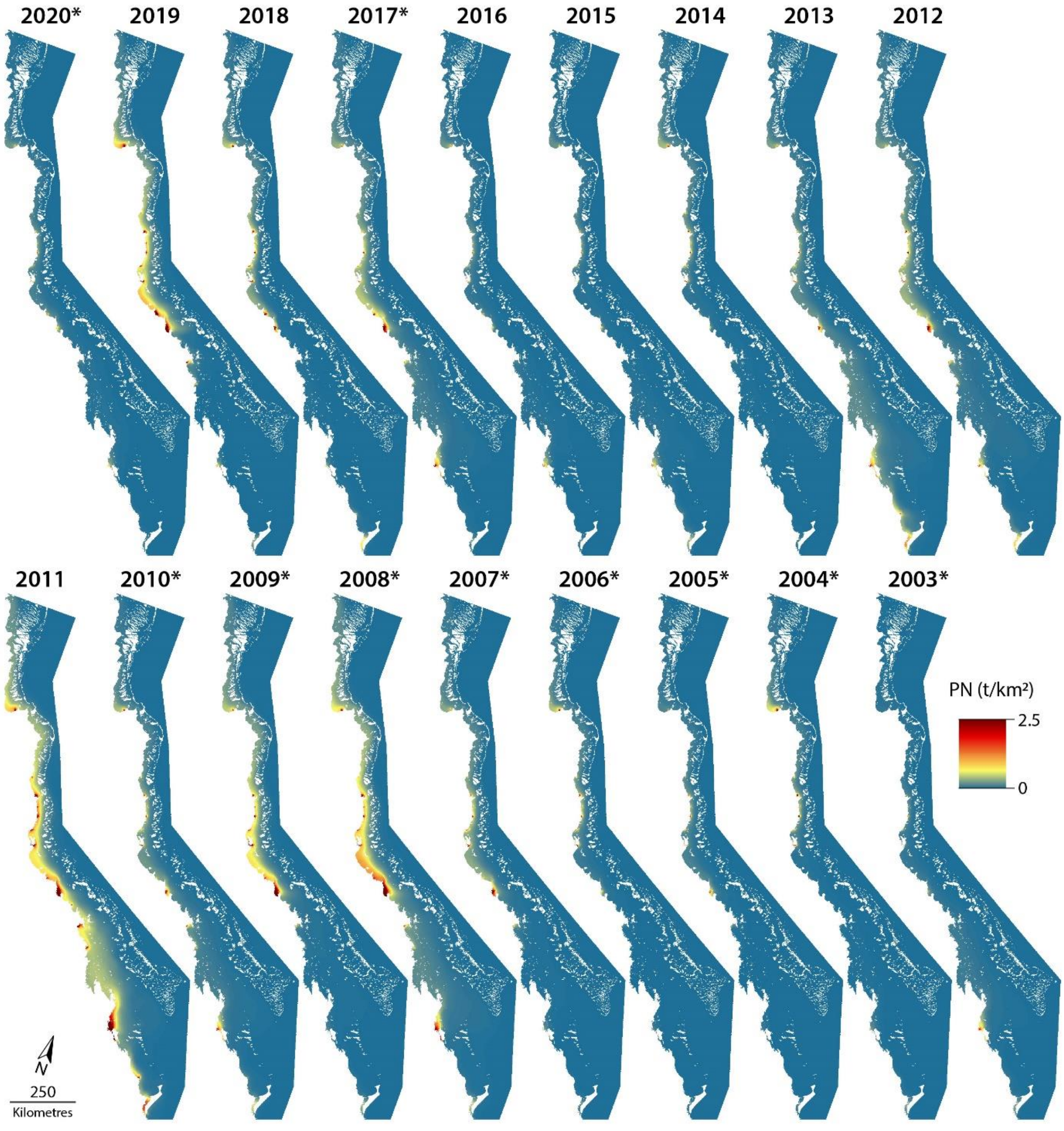

Figure 4-14: River-derived PN loading (tonnes km^{-2}, relative scale) over the Reef lagoon for the 2003 to 2020 water years (1 October to 30 September). The years marked with asterisks are modelled using a multi-annual average tracer.

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

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

4.3.1 Cape York region

The cumulative exposure of coastal waters to wet season discharge from several Cape York rivers (Normanby, Annan, and Endeavour) was estimated using a passive tracer in the eReefs hydrodynamic model. Results from tracer modelling will show smaller spatial extents of river influence than satellite imagery. Tracers represent river discharge and results are integrated over the entire water column, whereas satellite imagery monitors surface colour (the effect of river plumes), which persists longer and for greater distances than the discharge itself.

River gauge data for the Normanby River showed that its 2019–20 discharge was less than its long-term median discharge (Table 3-1). As a result, the three-dimensional extent of Normanby River discharge in 2019–20 was substantially less than the 2018–19 wet season. Moderate exposure to river discharge was confined to enclosed coastal waters of Princess Charlotte Bay during the 2019–20 wet season (Figure 4-15), with exposures exceeding 16 near the Normanby mouth. Open coastal waters of Princess Charlotte Bay had cumulative exposures ~0–8. The mid-shelf water body was exposed to low levels of Normanby River discharge with exposures <2. Extent of exposure (distance that plumes travelled) was higher compared to other rivers modelled, which is a function of local bathymetry, river size, and hydrodynamic conditions. Tracers >1% concentration travelled ~40 km northwest and ~17 km northeast of the Normanby mouth.

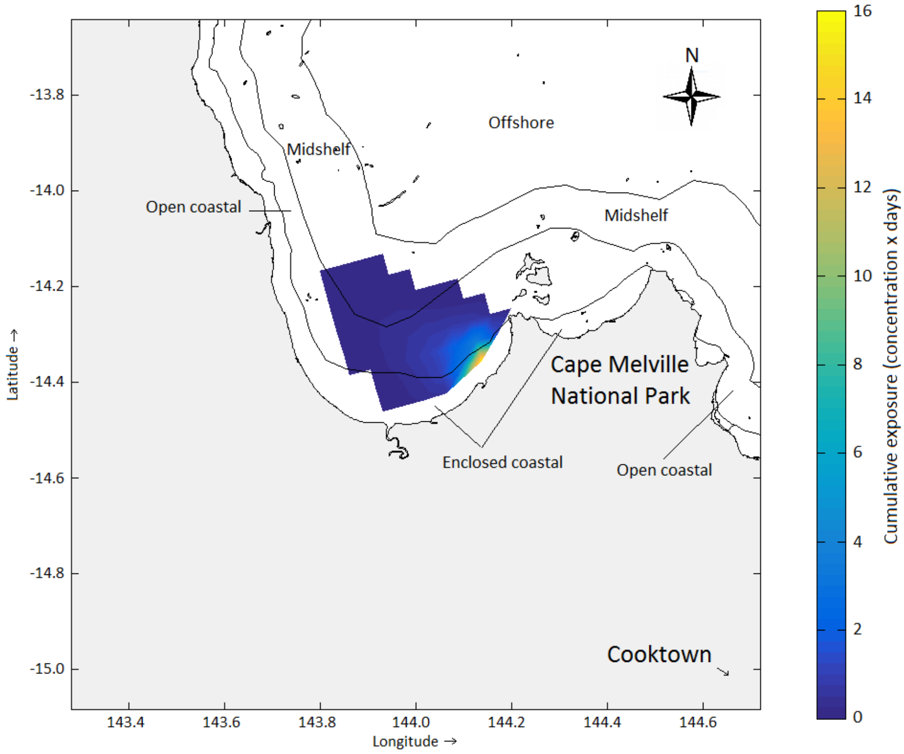

Figure 4-15: Cumulative exposure index for the Normanby River from October 2019 to May 2020. The colour bar indicates the calculated three-dimensional cumulative exposure, defined as the concentration of river water (%) * days of exposure (d). Only concentrations of river water >1% are included in these maps. The colour bar is capped at 20 concentration days.

River gauge data for the Endeavour River showed that its 2019–20 discharge was roughly half its long-term median discharge (Table 3-1). Due to this low amount of discharge, tracer concentrations did not reach 1% over an area large enough to be shown in these maps. While Endeavour River discharge did enter the Reef lagoon this year, its cumulative exposure in coastal waters was negligible.

As described for the Reef, a number of remote sensing products were generated to represent wet season water quality conditions in the Cape York region. These maps are presented in a panel of weekly characteristics throughout the 22-week wet season period (Figure 4-16 and Figure 4-17) and in Figure 4-18, which presents: the frequency of the combined primary and secondary water types; the frequency of primary, secondary and tertiary wet season water types individually; the exposure maps in the long-term and 2019–20 wet season; and a difference map showing areas exposed to an increased risk in 2020. Details in the panels include river discharge, wind speed and direction, weekly maps of wet season colour classes, and the location and timing of *in situ* data collected by the CYWMP.

The MODIS monitoring products (when not obstructed by cloud cover) clearly illustrated wet season surface water movements in the Cape York region, as well as the influence of river discharge including changes in water colour from nutrient and sediment inputs and resuspension (Figure 4-16 and Figure 4-17). Discharge in the Cape York region was less than 1.5 times the long term median (Section 3.2.2) and no major flood events influenced Cape York during the 2019–20 wet season. Minor flood plumes were captured with MODIS satellite imagery off the Normanby River in February and in early March 2020 and off the Stewart, Lockhart and Pascoe rivers in early to mid-March. Primary flood waters had minimal impact on mid-shelf reefs in Princess Charlotte Bay and the Northern Cape York. Secondary waters extended further offshore from mid-March and occasionally reached the mid-shelf reefs. No large primary plume was captured in the southern region of Cape York, but secondary waters extended further offshore from mid-March and reached the mid-shelf reefs in the last week of April. The large secondary area mapped offshore on week 11 (9-15 February 2020) in the northern Cape York area is likely due to the data issues described in Section 4.1.

Sampling of the Cape York flood plumes occurred during and after the small flood events and across all colour classes (1 to 6) except for colour class 3. A full description of water quality patterns and flood plumes is available in Section 5.1 of this report.

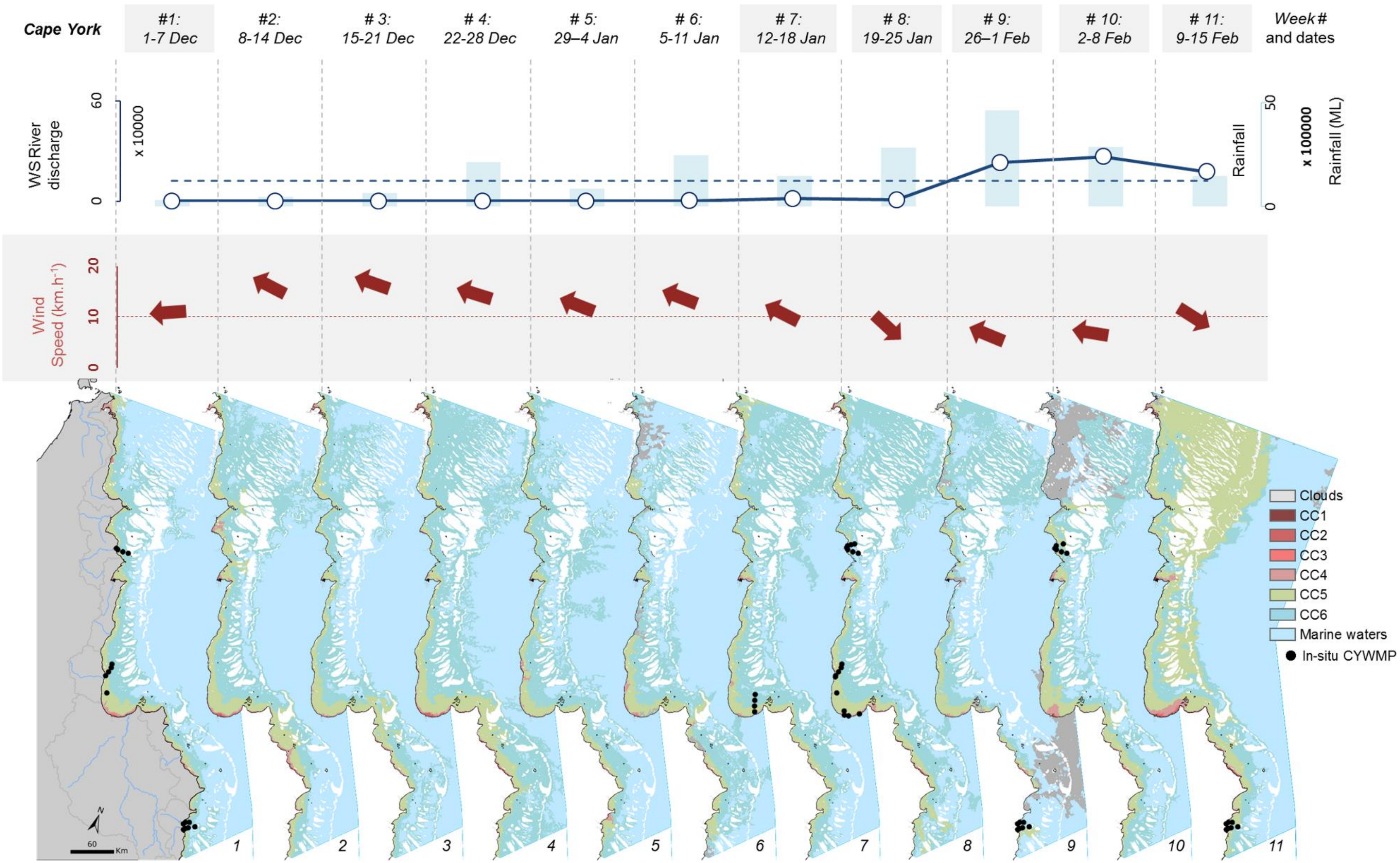

Figure 4-16: Panel of water quality and environmental characteristics in the Cape York region throughout the 2019–20 wet season period: weeks 1 to 11. Includes: 2019–20 weekly river discharge (ML d^{-1}) and rainfall (ML); mean wind speed (km h^{-1}) and direction; and wet season water type maps showing the location of the *in situ* data collected by CYWMP. The mean long-term weekly river discharge is indicated by a dotted blue line. Weekly river discharges are the sum of discharge (ML) from the Pascoe, Stewart, Normanby and Endeavour Rivers.

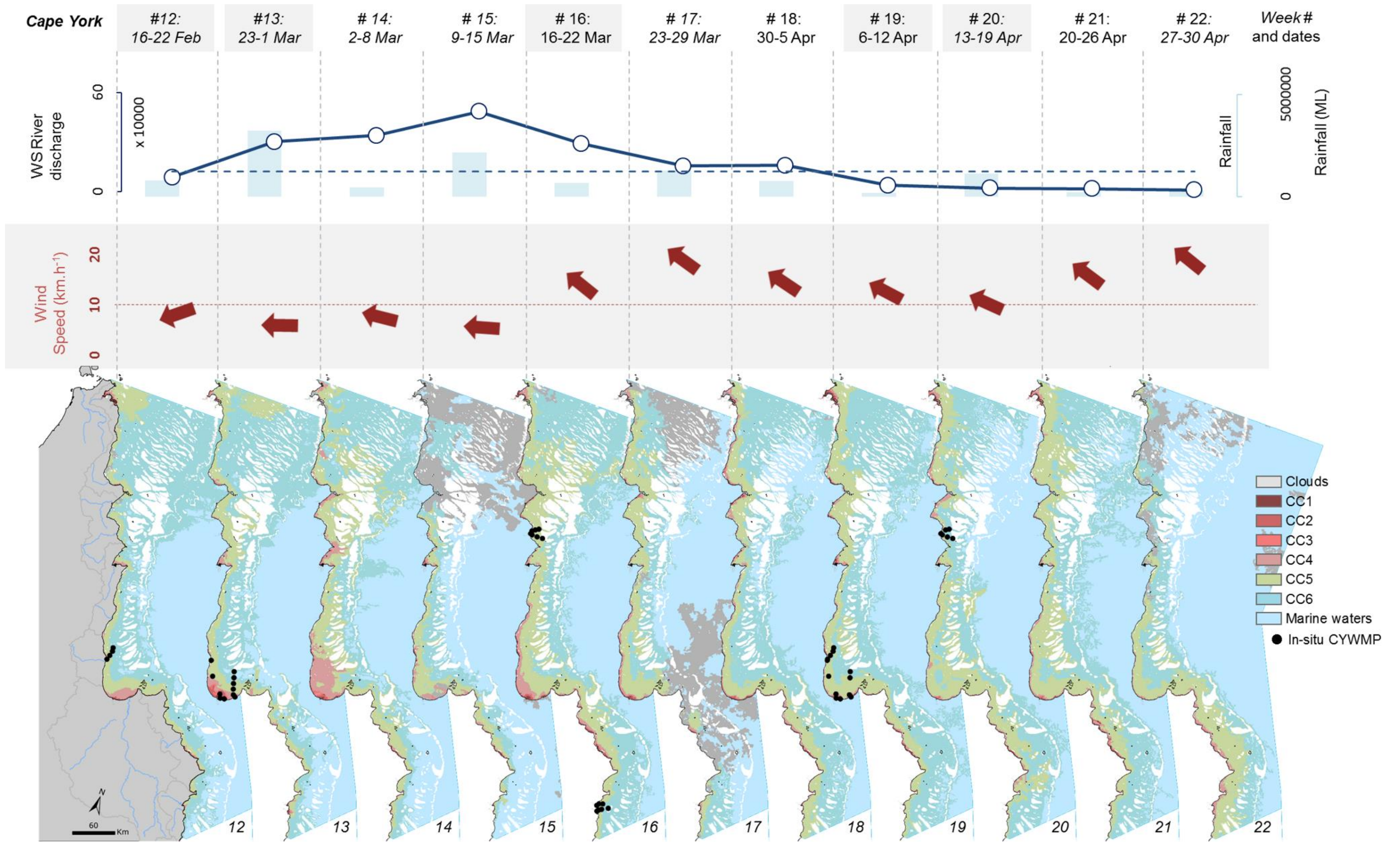

Figure 4-17: Panel of water quality and environmental characteristics in the Cape York region throughout the 2019–20 wet season period: weeks 12 to 22. Includes: 2019–20 weekly river discharge (ML d^{-1}) and rainfall (ML); mean wind speed (km h^{-1}) and direction; and wet season water type maps showing the location of the *in situ* data collected by CYWMP. The mean long-term weekly river discharge is indicated by a dotted blue line. Weekly river discharges are the sum of discharge (ML) from the Pascoe, Stewart, Normanby and Endeavour Rivers.

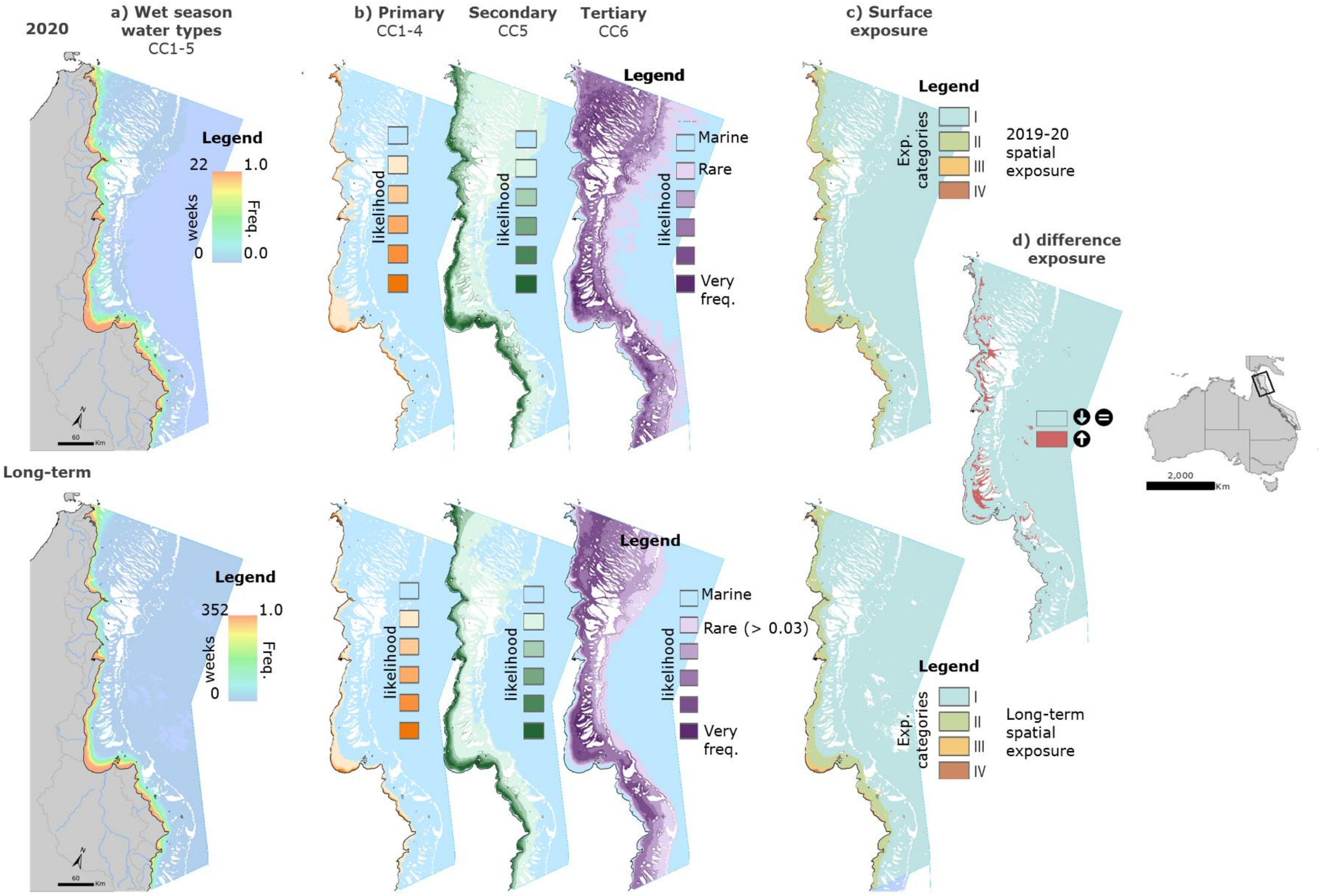

Figure 4-18: Long-term and current year remote sensing results for the Cape York region showing the a) frequency of combined primary and secondary water types; b) the frequency of primary, secondary and tertiary wet season water types regrouped into five likelihood categories [<0.2 (Rare), 0.2–0.4, 0.4–0.6, 0.6–0.8 and 0.8–1 (very frequent)]; c) exposure in the long-term (bottom) and 2019–20 wet season (top); and d) a difference map showing any areas with an increase in risk category in 2020 (in red, ⬆) against long-term trends [calculated as (c, top) exposure in 2020 minus (c, bottom) long-term].

Table 4-3 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 wet season 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 detectable but low water quality concentrations and therefore low risk of any detrimental ecological effect. Areas exposed to category I are presented in Table 4-3, but not described below. 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 2019–20, it was estimated that:

- Cape York region: 85% of Cape York was not exposed to a potential risk, similar to long-term patterns (89%, Table 4-3). 15% of the Cape York region was exposed to combined potential risk categories II–IV. However, only 1% of the Cape York region was in the highest exposure category (IV) and only 1% was in category III.
- Cape York waterbodies: only the inshore Cape York waters were exposed to the highest categories of potential risk (III and IV). The area exposed was however spatially limited and corresponded to 17% (cat. III) and 7% (cat. IV) of the total Cape York inshore area (Figure 4-8c). The mid-shelf and offshore Cape York waterbodies were largely exposed to no / very low risk (66% and 97% of the Cape York mid-shelf and offshore waterbodies).
- Cape York habitats:
    - 30% of coral reefs in the Cape York region were exposed to a potential risk (combined potential risk categories II–IV). However, less than 1% of corals were in the highest exposure category (IV) and in category III and they were all inshore reefs (Figure 4-19 b). Only 3% (< 900 km^2) of the Cape York corals reefs occur in the inshore waters (Appendix C-6). The coral area exposed to higher potential risk corresponded to 14% (cat. III) and 5 % (cat. IV) of the total inshore coral reef area in Cape York. Mid-shelf reefs were exposed to the lower risk category II or to no / very low risk (66% and 34% of the total mid-shelf coral reef area in Cape York). 81% of the Cape York offshore reefs were classified as no / very low risk.
    - 72% of seagrasses in the Cape York region were exposed to combined potential risk categories II–IV (Table 4-3), 8% of seagrasses were in the highest exposure category (IV) and 13% were in category III, and they were all inshore seagrasses (Figure 4-19 a). 67% (~ 300 km^2) of the Cape York seagrass occur in the inshore waters (Appendix C-6). The seagrass area exposed to higher potential risk corresponded to 19% (cat. III) and 12 % (cat. IV) of the total inshore seagrass area in Cape York. Mid-shelf and Offshore seagrasses were largely classified as no / very low risk (> 70% of the Cape York mid-shelf and offshore seagrasses).
    - The coral areas exposed to highest potential risk categories III and IV were similar to the long-term patterns (1% of the coral reefs), There was however an increase in the coral area exposed to the lowest potential risk category (II: + 24%).This is likely to be linked to the suspiciously large secondary areas measured in the mid-shelf Cape York waters (section 4.1.1), including remaining noise in the data around week 11.
    - The seagrass areas exposed to combined potential risk categories II–IV in 2019–20 were similar to the long-term (+1%).

Table 4-3: Areas (km^2) and percentages (%) of the Cape York region, coral reefs, and surveyed seagrass affected by different categories of exposure during the 2019–20 wet season and the long-term. The last three rows show the differences between % affected in 2019–20 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.

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	2020	81,575	12,768	1,361	612	14,741
			LT	86,044	8,649	1,125	498	10,272
	%	*100%*	2020	85%	13%	1%	1%	15%
			LT	89%	9%	1%	1%	11%
Coral reefs	area	10,375	2020	7,281	3,036	41	16	3,094
			LT	9,837	496	34	8	538
	%	*100%*	2020	70%	29%	0%	0%	30%
			LT	95%	5%	<1%	<1%	5%
Surveyed seagrass	area	2,655	2020	741	1,356	337	222	1,915
			LT	777	1,371	319	189	1,878
	%	*100%*	2020	28%	51%	13%	8%	72%
			LT	29%	52%	12%	7%	71%
Difference (2019 – Long Term average)	*Surface area*			-4%	4%	<1%	< 1%	4%
	Coral Reef			-25%	24%	<1%	< 1%	25%
	Surveyed seagrass			-1%	-1%	1%	1%	1%

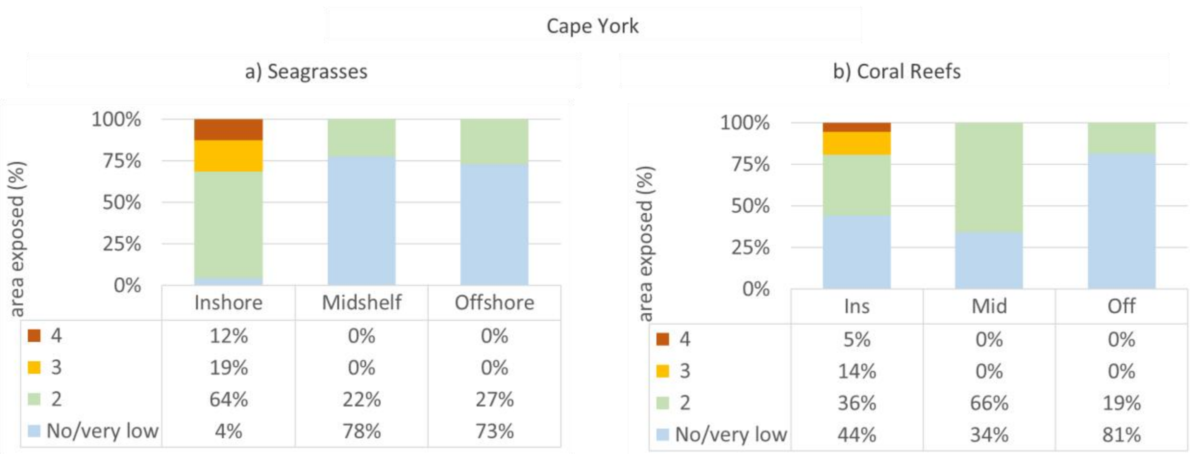

Figure 4-19: Percentage of the Cape York region a) seagrass and b) coral reef habitats affected by different risk categories of exposure during the 2019–20 wet season.

4.3.2 Wet Tropics region

The three-dimensional cumulative exposure of coastal waters to wet season discharge from several Wet Tropics rivers (Barron, Russell-Mulgrave, and Tully) was estimated using a passive tracer in the eReefs hydrodynamic model. Results from tracer modelling will show smaller extents of river influence than satellite imagery. Tracers represent river discharge and results are integrated over the entire water column, whereas satellite imagery monitors surface colour (the effect of river plumes), which persists longer and for greater distances than the discharge itself.

River gauge data for the Barron River showed that 2019–20 discharge was roughly half its long-term median discharge (Table 3-1). Due to this low discharge, tracer concentrations were less than 1% over an area large enough to be visible on these maps. While Barron River discharge did enter the Reef lagoon this year, its cumulative exposure in coastal waters was negligible.

River gauge data for the Russell-Mulgrave River showed that its 2019–20 discharge was below its long-term median discharge (Table 3-1). As a result, the three-dimensional extent of Russell-Mulgrave River discharge in 2019–20 was less than the 2018–19 wet season (Figure 4-20). Low exposure to river discharge occurred in enclosed coastal waters near the river mouth, where exposures were ~3. Open coastal waters near the Russell-Mulgrave (e.g., High Island) had low exposures ~1–2.5 during the 2019–20 wet season. Exposure to river discharge in the mid-shelf water body may have occurred; however, model resolution (e.g., grid cell size) is not sufficient to capture this very low level of exposure. Extent of exposure was far less than 2018–19, and tracers >1% concentration travelled ~15 km north and south of the Russell-Mulgrave River mouth.

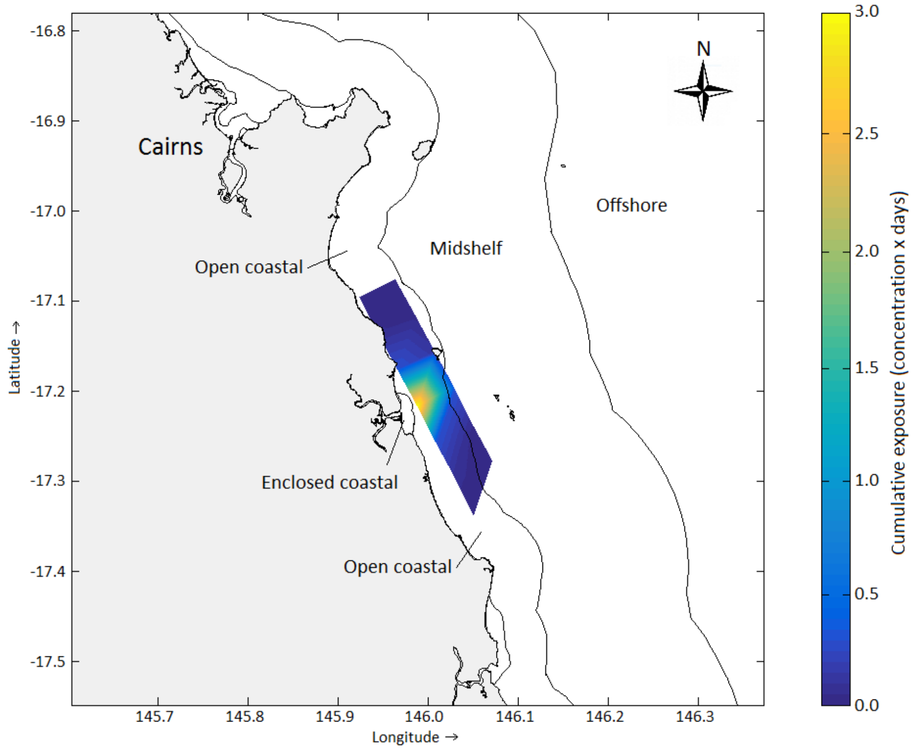

Figure 4-20: Cumulative exposure index for the Russell-Mulgrave River from October 2019 to May 2020. The colour bar indicates the calculated three-dimensional cumulative exposure, defined as the concentration of river water (%) * days of exposure (d). Only concentrations of river water >1% are included in these maps. The colour bar is capped at 3 concentration days.

River gauge data for the Tully River showed that its 2019–20 discharge was below the long-term median discharge (Table 3-1). As a result, the three-dimensional extent of Tully River discharge in 2019–20 was far less than the 2018–19 wet season (Figure 4-21). Minor exposure to river discharge occurred in enclosed coastal waters near the river mouth, where exposures were ~2. Open coastal waters in close proximity to the Tully River mouth had minor exposures ~0–1 during the 2019–20 wet season. Extent of exposure was far less than the 2018–19 wet season, and tracers >1% concentration travelled <10 km east of the river mouth.

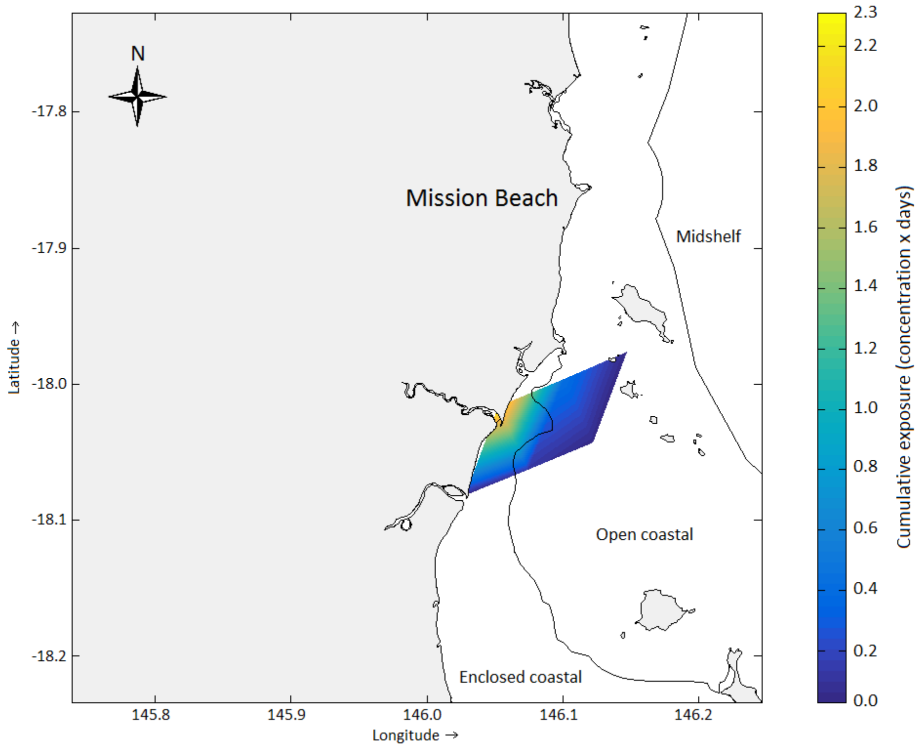

Figure 4-21: Cumulative exposure index for the Tully River from October 2019 to May 2020. The colour bar indicates the calculated three-dimensional cumulative exposure, defined as the concentration of river water (%) * days of exposure (d). Only concentrations of river water >1% are included in these maps. The colour bar is capped at 2.3 concentration days.

As described for the Reef, a number of remote sensing products were generated to represent wet season water quality conditions in the Wet Tropics region. These maps are presented in a panel of weekly characteristics throughout the 22-week wet season period (Figure 4-22 and Figure 4-23) and in Figure 4-24, which presents: the frequency of the combined primary and secondary water types; the frequency of primary, secondary and tertiary wet season water types individually; the exposure maps in the long-term and 2019–20 wet season; and a difference map showing areas exposed to an increased risk in 2020. Details in the panels include river discharge, wind speed and direction, weekly maps of wet season colour classes, and the location and timing of *in situ* data collection.

The MODIS monitoring products (when not obstructed by cloud cover) clearly illustrated wet season surface water movements in the Wet Tropics region, as well as the influence of river discharge including changes in water colour from nutrient and sediment inputs and resuspension (Figure 4-22 and Figure 4-23). Discharge in the Wet Tropics region was less than 1.5 times the long term median (Section 3.2.2) and no major flood events influenced the Wet Tropics during the 2019–20 wet season.

Weekly composites of the Wet Tropics region showed that primary waters were confined to the Wet Tropics river mouths and in the enclosed coastal waters most of the wet season. Tully primary waters (CC1–4) reached the open coastal waters and Dunk Island in week 14 (2 to 8 March) potentially linked to greater rainfall in week 13 but generally, primary flood waters had minimal impact on the open coastal and mid-shelf regions and ecosystems of the Wet Tropics in 2019–20. Secondary waters extended further offshore from mid-March and reached the mid-shelf region. This was also the period of greatest discharge in the region. Off the Barron River, Green Island reefs were occasionally exposed to secondary waters in April (weeks 16, 20 and 22). Patchy primary areas off the Daintree Rivers in week 20 are misclassified pixels (noise).

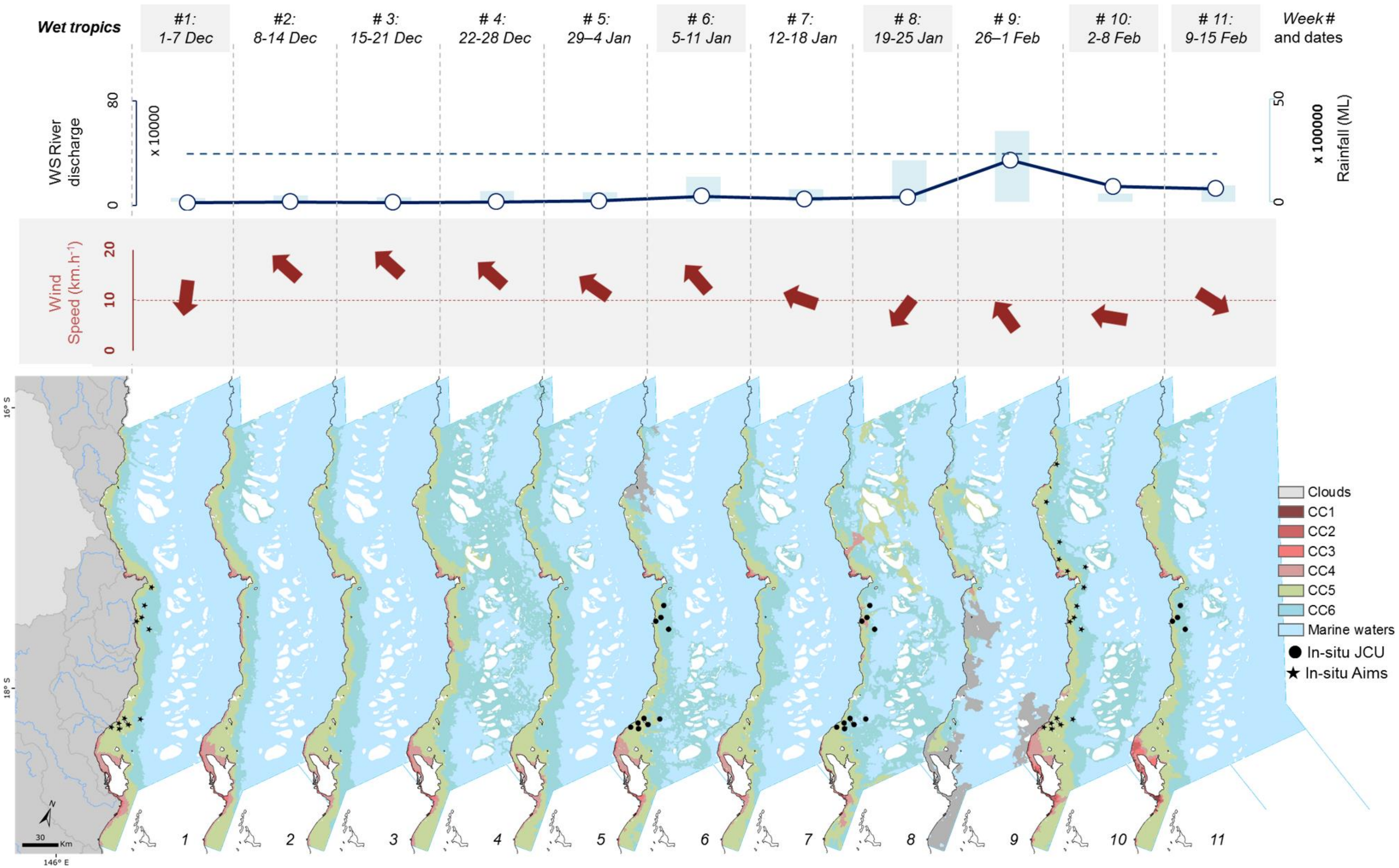

Figure 4-22: Panel of water quality and environmental characteristics in the Wet Tropics region throughout the 2019–20 wet season period: weeks 1 to 11. Includes: 2019–20 weekly river discharge (ML d^{-1}) and rainfall (ML); mean wind speed (km h^{-1}) and direction; and wet season water type maps showing the location of the *in situ* data collected by JCU and AIMS. The mean long-term weekly river discharge is indicated by a dotted blue line. Weekly river discharges are the sum of discharge (ML) from the Barron, Daintree, Herbert, Mossman, Mulgrave, Murray, North Johnstone, Russell, South Johnstone and Tully Rivers.

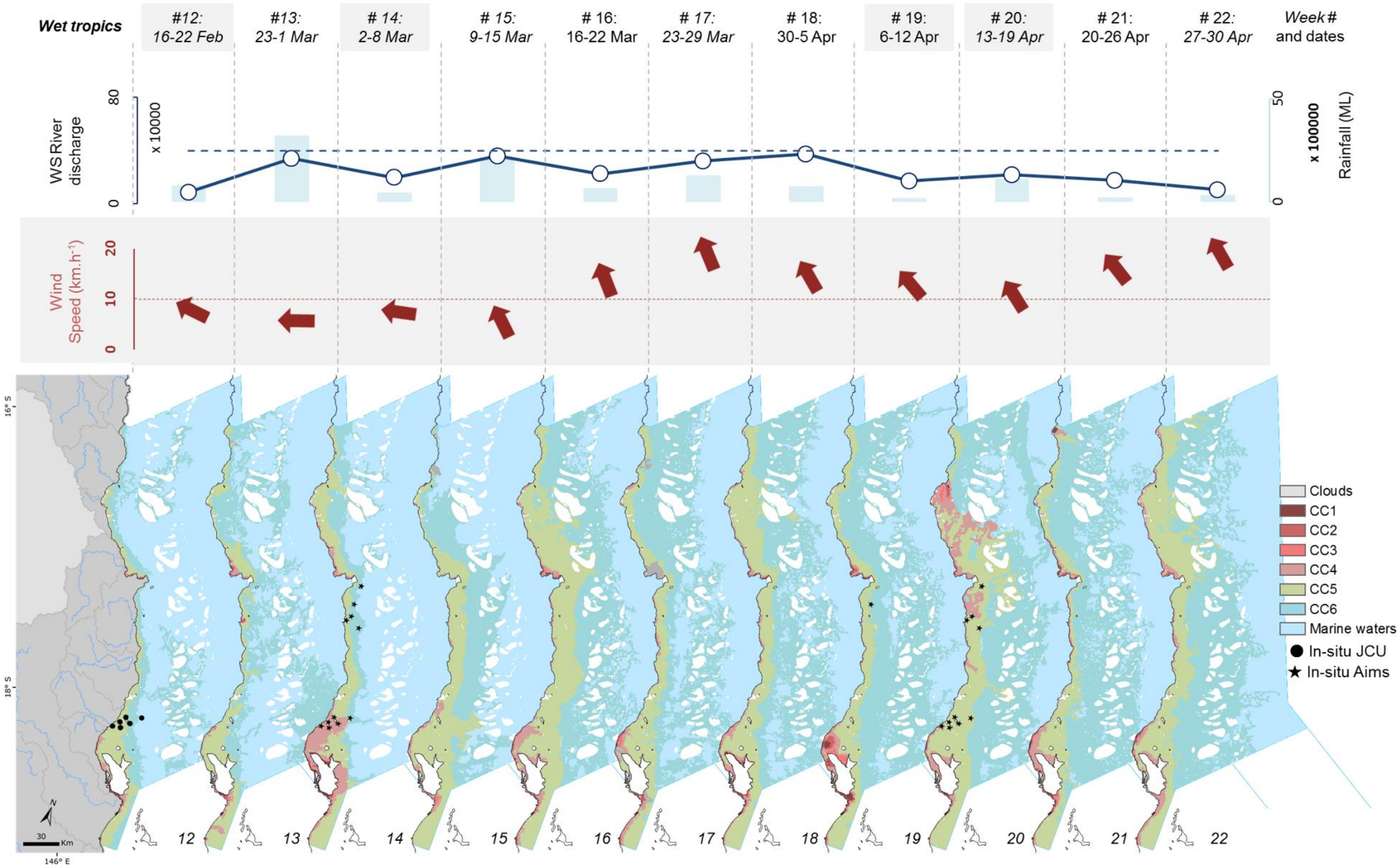

Figure 4-23: Panel of water quality and environmental characteristics in the Wet Tropics region throughout the 2019–20 wet season period: weeks 12 to 22. Includes: 2019–20 weekly river discharge (ML d-1) and rainfall (ML); mean wind speed (km h^{-1}) and direction; and wet season water type maps showing the location of the *in situ* data collected by JCU and AIMS. The mean long-term weekly river discharge is indicated by a dotted blue line. Weekly river discharges are the sum of discharge (ML) from the Barron, Daintree, Herbert, Mossman, Mulgrave, Murray, North Johnstone, Russell, South Johnstone and Tully Rivers.

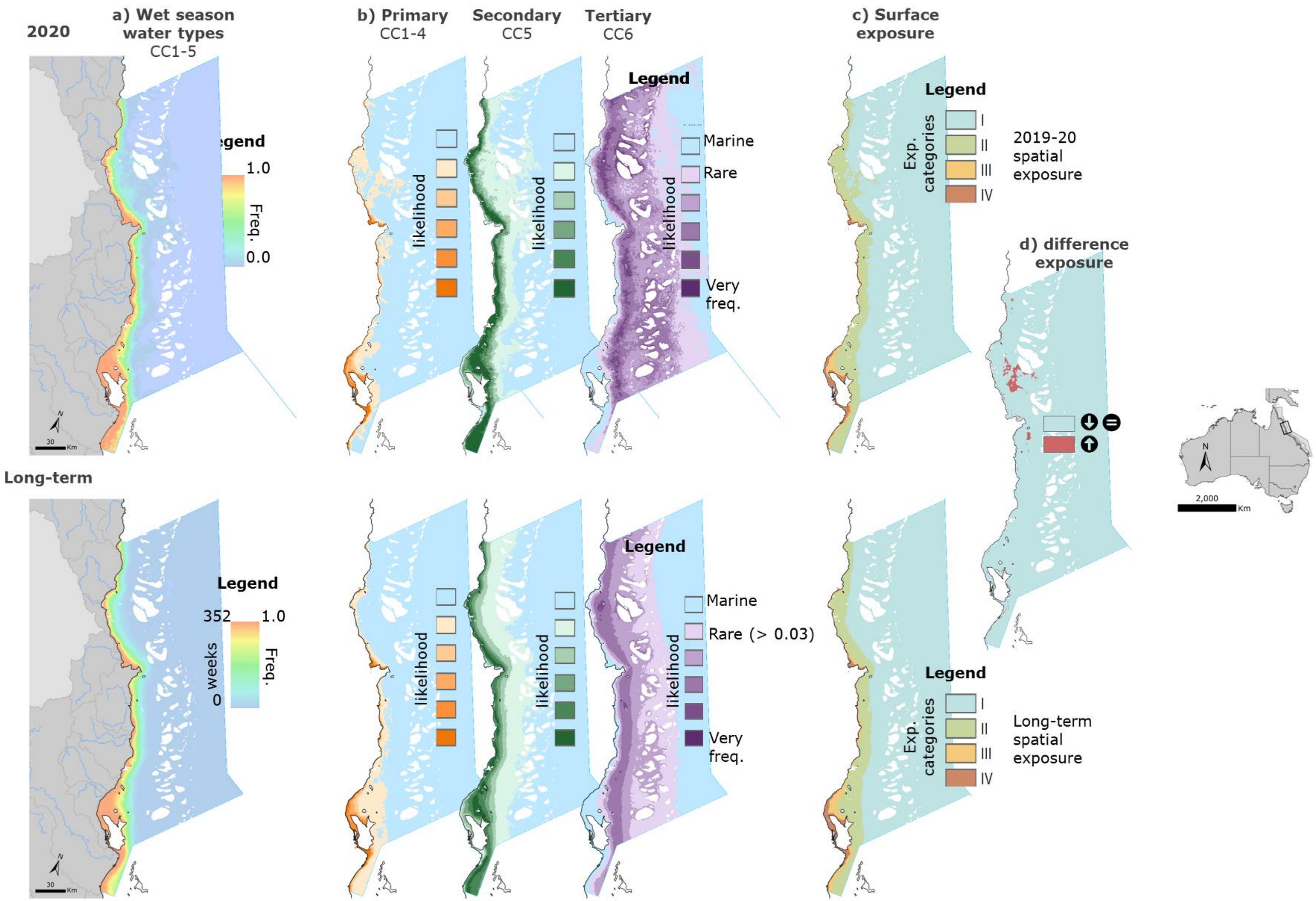

Figure 4-24: Long-term and current year remote sensing results for the Wet Tropics region showing the a) frequency of combined primary and secondary water types; b) the frequency of primary, secondary and tertiary wet season water types regrouped into five likelihood categories [<0.2 (Rare), 0.2–0.4, 0.4–0.6, 0.6–0.8 and 0.8–1 (very frequent)]; c) exposure in the long-term (bottom) and 2019–20 wet season (top); and d) a difference map showing any areas with an increase in risk category in 2020 (in red, ➊) against long-term trends [calculated as (c, top) exposure in 2020 minus (c, bottom) long-term].

Table 4-4 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 seagrass and coral reef ecosystems. Category I (No or Very low risk) represents waters with detectable but low water quality concentrations and therefore low risk of any detrimental ecological effect. Areas exposed to category I are presented in Table 4-4, but not described below. 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 2019–20, it was estimated that:

- Wet-Tropics wide: 86% of the Wet Tropics region was not exposed to a potential risk, similar to long-term patterns (84%, Table 4-4). 14% of the Wet Tropics region was exposed to combined potential risk categories II–IV. However, only 1% of the region was in the highest exposure category (IV) and only 2% was in category III.
- Wet Tropics waterbodies: only the inshore Wet Tropics waters were exposed to the highest categories of potential risk (III and IV). The area exposed was however spatially limited and corresponded to 14% (cat. III) and 11% (cat. IV) of the total Wet Tropics inshore area (Figure 4-8c). The mid-shelf and offshore Wet Tropics waterbodies were largely exposed to no/very low risk (80% and 100% of the Wet Tropics mid-shelf and offshore waterbodies).

- Wet Tropics habitats:
    - 2% of coral reefs in the Wet Tropics region were exposed to a potential risk (combined potential risk categories II–IV). However, less than 1% of coral were in the highest exposure category (IV) and in the category III and they were all inshore reefs (Figure 4-25b). Only 3% (~ 80 km^2) of the Wet Tropics corals occur in the inshore waters (Appendix C-6). The coral area exposed to higher potential risk corresponded to 11% (cat. III) and 3% (cat. IV) of the total inshore reef area in the Wet Tropics. Mid-shelf and offshore reefs were largely exposed to no potential risk (95% and 100% of the total mid-shelf reef area in the Wet Tropics).
    - 94% of seagrasses in the Wet Tropics region were exposed to combined potential risk categories II–IV. 45% of seagrasses were in the highest exposure category (IV) and 25% were in category III, and they were all inshore seagrasses (Figure 4-25a). 98% (~230 km^2) of the Wet Tropics seagrass occur in the inshore waters (Appendix C-6). The seagrass area exposed to higher potential risk corresponded to 26% (cat. III) and 46% (cat. IV) of the total inshore seagrass area in the Wet Tropics. Mid-shelf seagrasses were largely classified as no / very low risk (74% of the Wet Tropics mid-shelf seagrasses).
    - The coral and seagrass areas in the Wet Tropics region exposed to combined potential risk categories II–IV in 2019–20 were similar to the average long-term areas (changes < 1%).

Table 4-4: Areas (km2) and percentages (%) of the Wet Tropics region, coral reefs, and surveyed seagrass affected by different risk categories of exposure during the 2019–20 wet season and the long-term. The last three rows show the differences between % affected in 2018–19 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.

Wet Tropics		Total		Potential Risk category: No / Very low I	Lowest II	III	Highest IV	Total area exposed II-IV
Surface area	area	31,976		27,340	3,680	533	422	4,635
			LT	26,928	3,919	710	419	5,048
	%	100%	2020	86%	12%	2%	1%	14%
			LT	84%	12%	2%	1%	16%
Coral reefs	area	2,425	2020	2,379	36	9	2	47
			LT	2,380	34	10	2	46
	%	100%	2020	98%	1%	<1%	<1%	2%
			LT	98%	1%	<1%	<1%	2%
Surveyed seagrass	area	232	2020	14	54	58	106	218
			LT	14	40	79	99	219
	%	100%	2020	6%	23%	25%	45%	94%
			LT	6%	17%	34%	43%	94%
Difference (2019 – Long term average)	*Surface area*			2%	<1%	<1%	< 1%	-2%
	Coral Reef			<1%	<1%	<1%	< 1%	< 1%
	Surveyed seagrass			<1%	6%	-9%	2%	< 1%

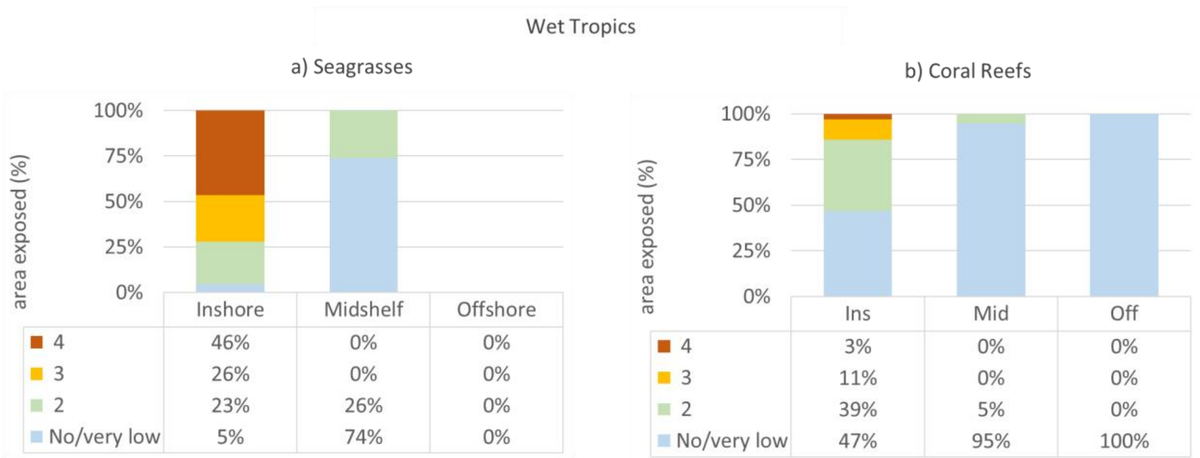

Figure 4-25: Percentage of the Wet Tropics region a) seagrass and b) coral reef habitats affected by different risk categories of exposure during the 2019–20 wet season.

4.3.3 Burdekin region

The cumulative exposure of coastal waters to wet season discharge from the Burdekin River was estimated using a passive tracer in the eReefs hydrodynamic model. Results from tracer modelling will show smaller extents of river influence than satellite imagery. Tracers represent river discharge and results are integrated over the entire water column, whereas satellite imagery monitors surface colour (the effect of river plumes), which persists longer and for greater distances than the discharge itself.

River gauge data for the Burdekin River showed that its 2019–20 discharge was roughly half its long-term median discharge (Table 3-1). As a result, the three-dimensional extent of Burdekin River discharge in 2019–20 was far less than the 2018–19 wet season (Figure 4-26). Moderate exposure to river discharge occurred in enclosed coastal waters near the Burdekin mouth where exposures were ~13. Open coastal waters from Cape Upstart to Cape Cleveland had minor exposures ~0–3 and Burdekin exposure in mid-shelf waters was negligible. Extent of exposure was far less than the 2018–19 wet season, and tracers >1% concentration travelled <20 km from the river mouth.

As described for the Reef, a number of remote sensing products were generated to represent wet season water quality conditions in the Burdekin region. These maps are presented in a panel of weekly characteristics throughout the 22-week wet season period (Figure 4-27 and Figure 4-28) and in Figure 4-29, which presents: the frequency of the combined primary and secondary water types; the frequency of primary, secondary and tertiary wet season water types individually; the exposure maps in the long-term and 2019–20 wet season; and a difference map showing areas exposed to an increased risk in 2020. Details in the panels include river discharge, wind speed and direction, weekly maps of wet season colour classes, and the location and timing of *in situ* data collection.

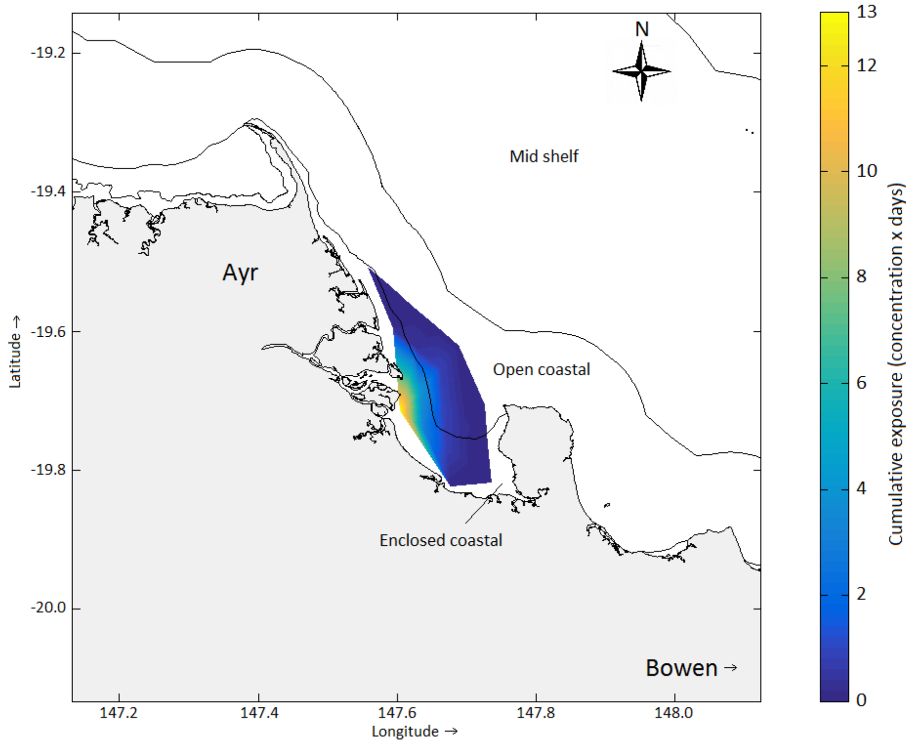

Figure 4-26: Cumulative exposure index for the Burdekin River from October 2019 to May 2020. The colour bar indicates the calculated three-dimensional cumulative exposure, defined as the concentration of river water (%) * days of exposure (d). Only concentrations of river water >1% are included in these maps. The colour bar is capped at 13 concentration days.

The MODIS monitoring products (when not obstructed by cloud cover as in week 9) clearly illustrated wet season surface water movements in the Burdekin region, as well as the influence of river discharge including changes in water colour from nutrient and sediment inputs and resuspension (Figure 4-27 and Figure 4-28). Discharge in the Burdekin region was less than 1.5 times the long-term median (Section 3.2.2) and no major flood events influenced the Burdekin region during the 2019–20 wet season.

Weekly composites of the Burdekin region showed that primary waters were confined next to the Burdekin river mouth and in the enclosed coastal waters most of the wet season. Burdekin primary waters (CC4) reached the open coastal waters in week 14 following a small discharge event (week 13) but, generally, primary flood waters had minimal impact on the open coastal and mid-shelf regions and ecosystems of the Burdekin region in 2019–20. Secondary waters extended further offshore from mid-March and reached the boundary between the open coastal and mid-shelf region, which could also be linked to the elevated discharge in week 13-15 (23 February to 15 March).

Table 4-5 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 wet season 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 detectable but low water quality concentrations and therefore low risk of any detrimental ecological effect. Areas exposed to category I are presented in Table 4-5, but not described below. 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 2019–20, it was estimated that:

- Burdekin-wide: 87% of Burdekin region was not exposed to a potential risk, similar to long-term patterns (86%, Table 4-5). 13% of the Burdekin region was exposed to combined potential risk categories II–IV. However, only 1% of the region was in the highest exposure category (IV) and 1% was in category III.
- Burdekin waterbodies: only the inshore Burdekin waters were exposed to the highest categories of potential risk (III and IV). The area exposed was however spatially limited and corresponded to 11% (cat. III) and 12% (cat. IV) of the total Burdekin inshore area (Figure 4-8c). The mid-shelf and offshore Burdekin waterbodies were largely exposed to no / very low risk (94% and 100% of the Burdekin mid-shelf and offshore waterbodies).
- Burdekin habitats:
    - 1% of coral reefs in the Burdekin region were exposed to combined potential risk categories II–IV. However, less than 1% of corals were in the highest exposure categories IV and III. Only 1% (< 40 km^2) of the Burdekin corals occur in the inshore waters (Appendix C-6). The coral area exposed to higher potential risk corresponded to 13% (cat. III) and 4 % (cat. IV) of the total inshore coral reef area in the Burdekin region. Mid-shelf and offshore coral reefs were largely exposed to no / very low risk (87% and 100% of the total mid-shelf reef area in the Burdekin region).
    - 98% of seagrasses in the Burdekin region were exposed to combined potential risk categories II–IV. 24% of seagrasses were in the highest exposure category (IV) and 12% were in category III, and they were all inshore seagrasses (Figure 4-30a). 99% (~700 km^2) of the Burdekin seagrasses occur in the inshore waters (Appendix C-6). The seagrass area exposed to higher potential risk corresponded to 12% (cat. III) and 24 % (cat. IV) of the total inshore seagrass area in the Burdekin region. Mid-shelf seagrasses were largely exposed to the lower category of risk (II, 94% of the Burdekin mid-shelf seagrasses).
    - The coral and seagrass areas in the Burdekin region exposed to combined potential risk categories II–IV in 2019–20 were both similar to the average long-term areas (< 1% and +5 %, respectively).

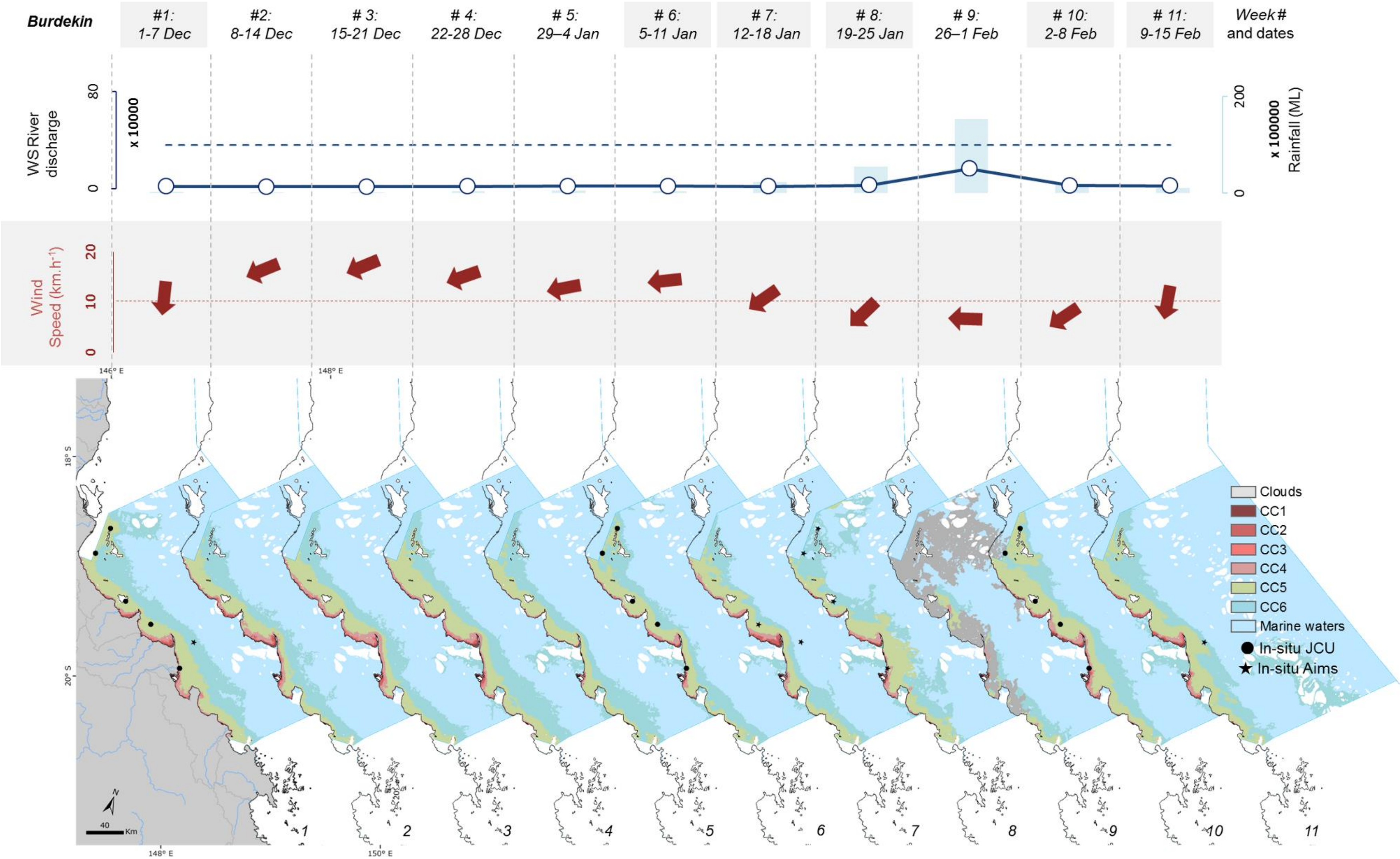

Figure 4-27: Panel of water quality and environmental characteristics in the Burdekin region throughout the 2019–20 wet season period: weeks 1 to 11. Includes: 2019–20 weekly river discharge (ML d^{-1}) and rainfall (ML); mean wind speed (km h^{-1}) and direction; and wet season water type maps showing the location of the *in situ* data collected by JCU and AIMS. The mean long-term weekly river discharge is indicated by a dotted blue line. Weekly river discharges are the sum of discharge (ML) from the Black, Ross, Haughton, Burdekin and Don rivers.

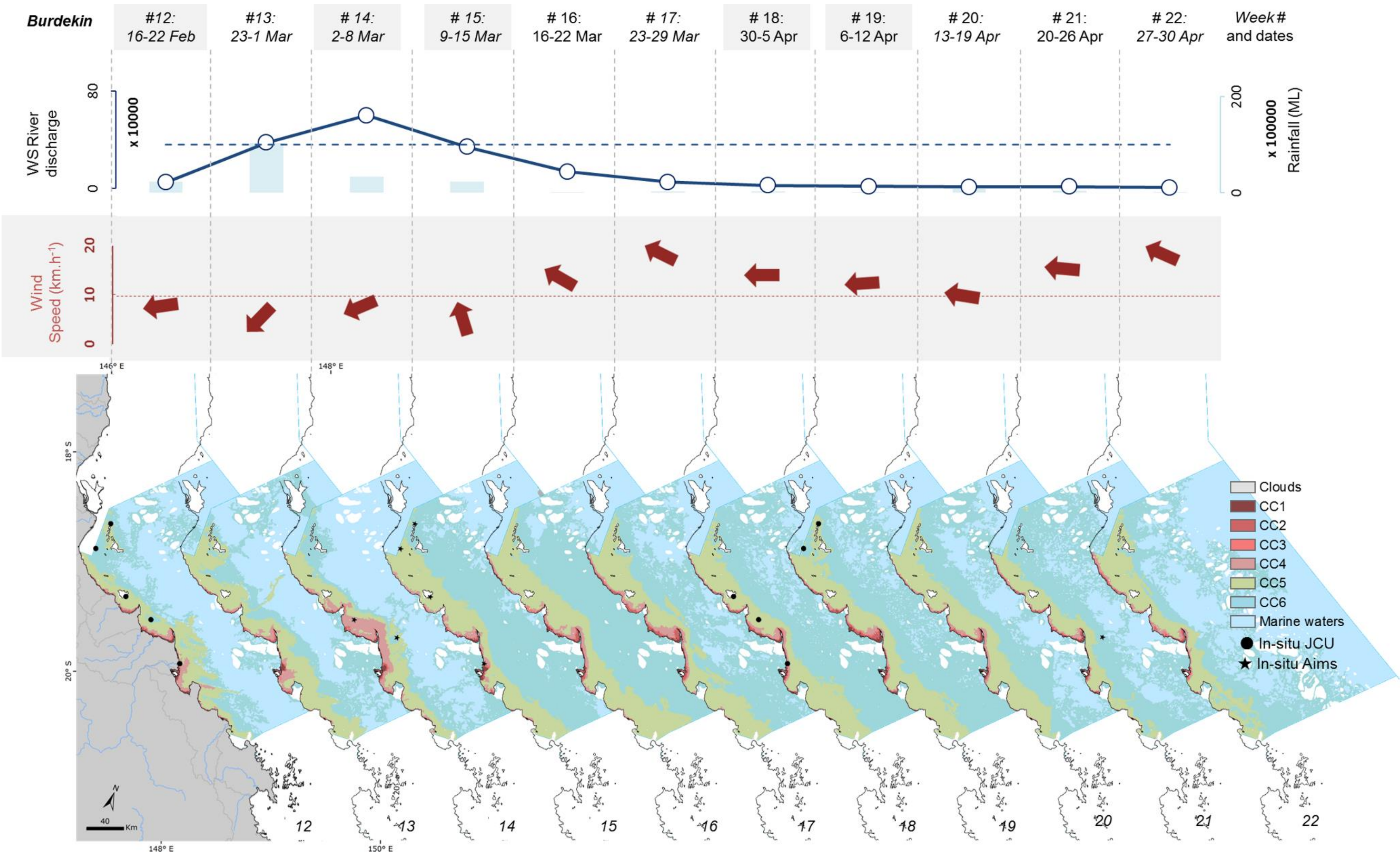

Figure 4-28: Panel of water quality and environmental characteristics in the Burdekin region throughout the 2019–20 wet season period: weeks 12 to 22. Includes: 2019–20 weekly river discharge (ML d^{-1}) and rainfall (ML); mean wind speed (km h^{-1}) and direction; and wet season water type maps showing the location of the *in situ* data collected by JCU and AIMS. The mean long-term weekly river discharge is indicated by a dotted blue line. Weekly river discharges are the sum of discharge (ML) from the Black, Ross, Haughton, Burdekin and Don rivers.

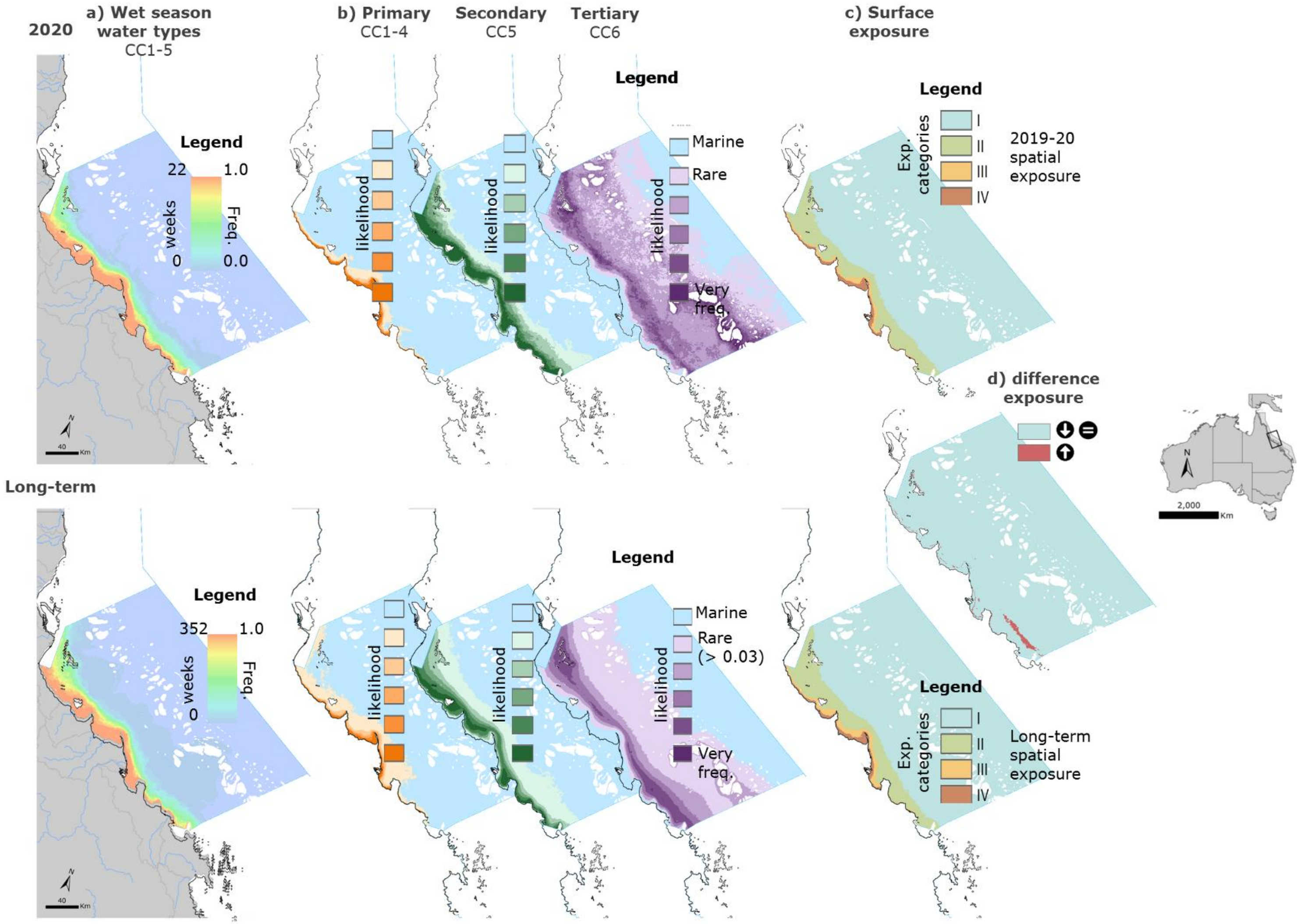

Figure 4-29: Long-term and current year remote sensing results for the Burdekin region showing the a) frequency of combined primary and secondary water types; b) the frequency of primary, secondary and tertiary wet season water types regrouped into five likelihood categories [<0.2 (Rare), 0.2–0.4, 0.4–0.6, 0.6–0.8 and 0.8–1 (very frequent)]; c) exposure in the long-term (bottom) and 2019–20 wet season (top); and d) a difference map showing any areas with an increase in risk category in 2020 (in red, 🡅) against long-term trends [calculated as (c, top) exposure in 2020 minus (c, bottom) long-term].

Table 4-5: Areas (km²) and percentages (%) of the Burdekin region, coral reefs, and surveyed seagrass affected by different risk categories of exposure during the 2019–20 wet season and the long-term (2003–2018). The last three rows show the differences between % affected in 2020 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.

Burdekin		Total		Potential Risk category				Total area exposed II-IV
				No / very low	Lowest		Highest	
				I	II	III	IV	
Surface area	area	47,009	2020	41,099	4,642	611	658	5,910
			LT	40,627	4,867	914	602	6,382
	%	100%	2020	87%	10%	1%	1%	13%
			LT	86%	10%	2%	1%	14%
Coral reefs	area	2,966	2020	2,919	42	4	1	47
			LT	2,916	36	13	1	50
	%	100%	2020	98%	1%	<1%	<1%	1%
			LT	98%	1%	<1%	<1%	2%
Surveyed seagrass	area	708	2020	15	440	86	167	693
			LT	32	346	184	146	676
	%	100%	2020	2%	62%	12%	24%	98%
			LT	5%	49%	26%	21%	95%
Difference (2019 – Long Term average)	*Surface area*			1%	<1%	-1%	<1%	-1%
	Coral Reef			<1%	<1%	<1%	< 1%	< 1%
	Surveyed seagrass			-3%	13%	-14%	3%	5%

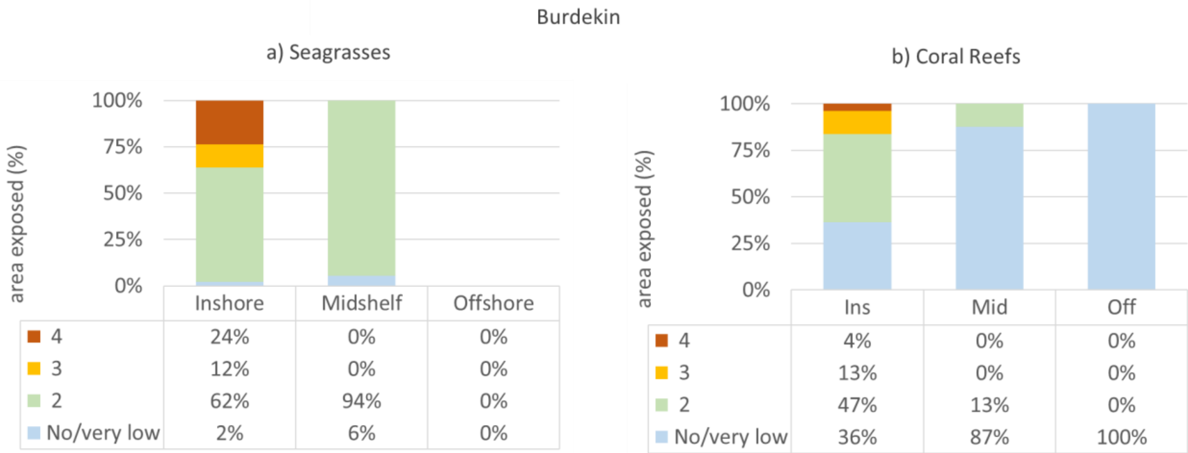

Figure 4-30: Percentage of the Burdekin region a) seagrass and b) coral reef habitats affected by different risk categories of exposure during the 2019–20 wet season.

4.3.4 Mackay-Whitsunday region

The cumulative exposure of coastal waters to wet season discharge from the O'Connell River was estimated using a passive tracer in the eReefs hydrodynamic model. Results from tracer modelling will show smaller extents of river influence than satellite imagery. Tracers represent river discharge and results are integrated over the entire water column, whereas satellite imagery monitors surface colour (the effect of river plumes), which persists longer and for greater distances than the discharge itself.

River gauge data for the O'Connell River showed that its 2019–20 discharge was less than its long-term median discharge (Table 3-1). Due to this low amount of discharge, tracer concentrations did not reach 1% over an area large enough to be shown in these maps. While O'Connell River discharge did enter the Reef lagoon this year, its cumulative exposure in coastal waters was negligible.

As described for the Reef, a number of remote sensing products were generated to represent wet season water quality conditions in the Mackay-Whitsunday region. These maps are presented in a panel of weekly characteristics throughout the 22-week wet season period (Figure 4-31 and Figure 4-32) and in Figure 4-33, which presents: the frequency of the combined primary and secondary water types; the frequency of primary, secondary and tertiary wet season water types individually; the exposure maps in the long-term and 2019–20 wet season; and a difference map showing areas exposed to an increased risk in 2020. Details in the panels include river discharge, wind speed and direction, weekly maps of wet season colour classes, and the location and timing of *in situ* data collection.

The MODIS monitoring products (when not obstructed by cloud cover) clearly illustrated wet season surface water movements in the Mackay-Whitsunday region, as well as the influence of river discharge including changes in water colour from nutrient and sediment inputs and resuspension (Figure 4-31 and Figure 4-32). Discharge in the Mackay-Whitsunday region was less than 1.5 times the long-term median (Section 3.2.2) and no major flood events influenced the region during the 2019–20 wet season.

Weekly composites of the Mackay-Whitsunday region showed that primary waters were confined to the river mouths and in the enclosed coastal waters most of the wet season. Primary waters (CC4) reached the open coastal waters in week 14 but, generally, primary flood waters had minimal impact on the open coastal and mid-shelf regions and ecosystems of the Mackay-Whitsunday region in 2019–20. Secondary waters extended largely into the open coastal region from early March and reached the mid-shelf region in week 16 (16–22 March). This does not appear to be linked to any discharge events and is most likely explained by the issues identified in Section 4.1.

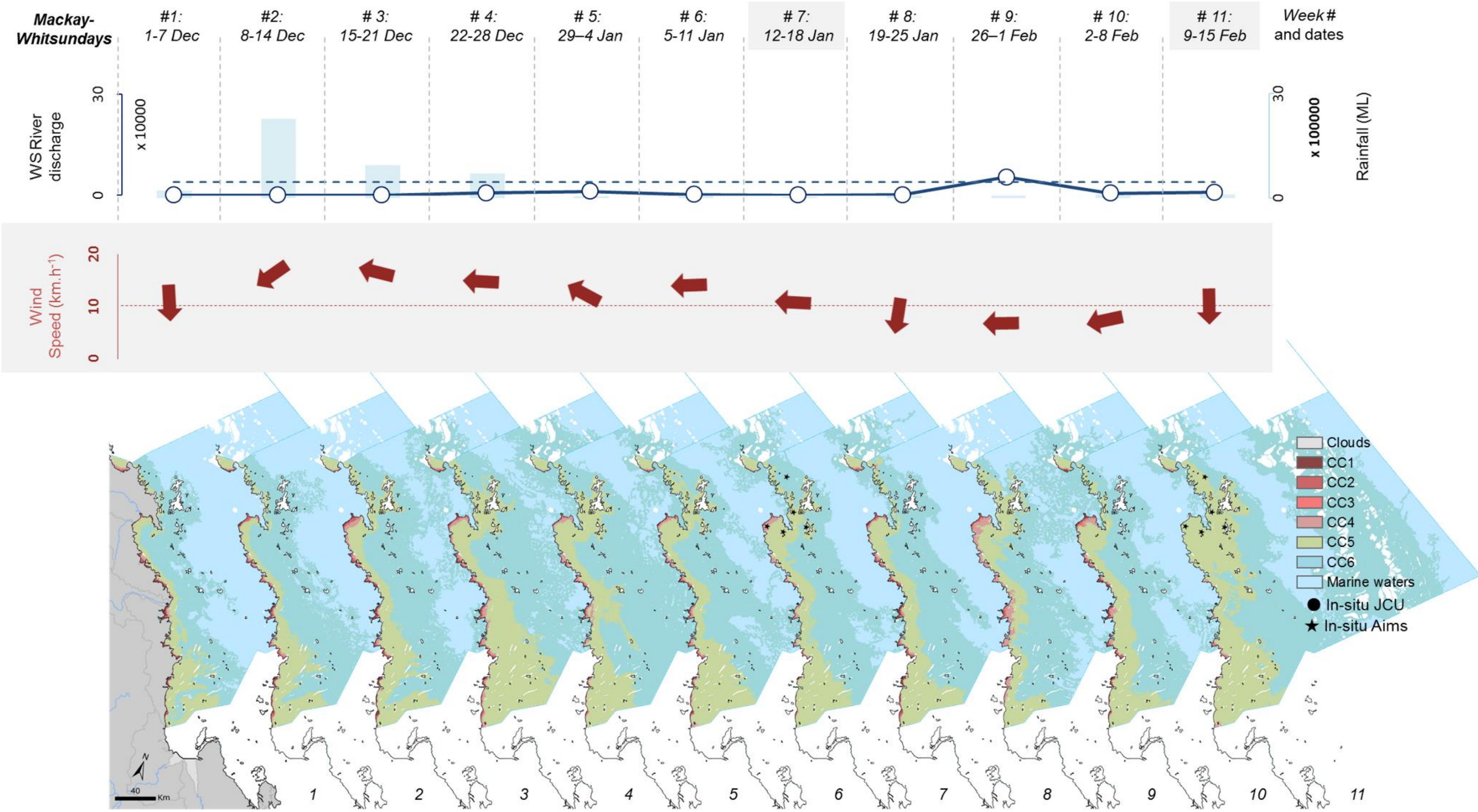

Figure 4-31: Panel of water quality and environmental characteristics in the Mackay-Whitsunday region throughout the 2019–20 wet season period: weeks 1 to 11. Includes: 2019–20 weekly river discharge (ML d^{-1}) and rainfall (ML); mean wind speed (km h^{-1}) and direction; and wet season water type maps showing the location of the *in situ* data collected by AIMS. The mean long-term weekly river discharge is indicated by a dotted blue line. Weekly river discharges are the sum of discharge (ML) from the O'Connell, Pioneer and Sandy Creek Rivers.

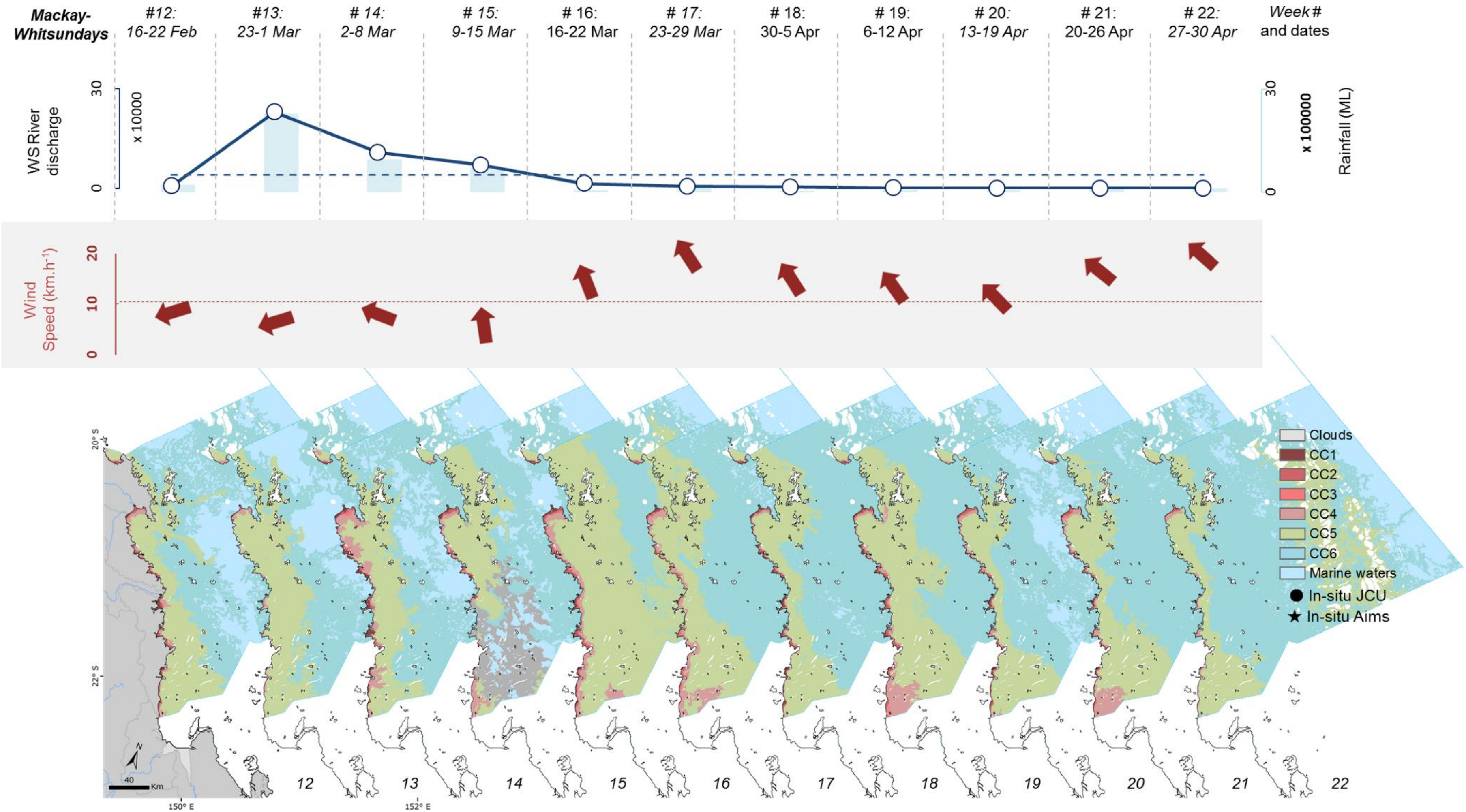

Figure 4-32: Panel of water quality and environmental characteristics in the Mackay-Whitsunday region throughout the 2019–20 wet season period: weeks 12 to 22. Includes: weekly river discharge (ML d-1) and rainfall (ML); mean wind speed (km h-1) and direction; and wet season water type maps showing the location of the *in situ* data collected by AIMS. The mean long-term weekly river discharge is indicated by a dotted blue line. Weekly river discharges are the sum of discharge (ML) from the O'Connell, Pioneer, and Sandy Creek Rivers.

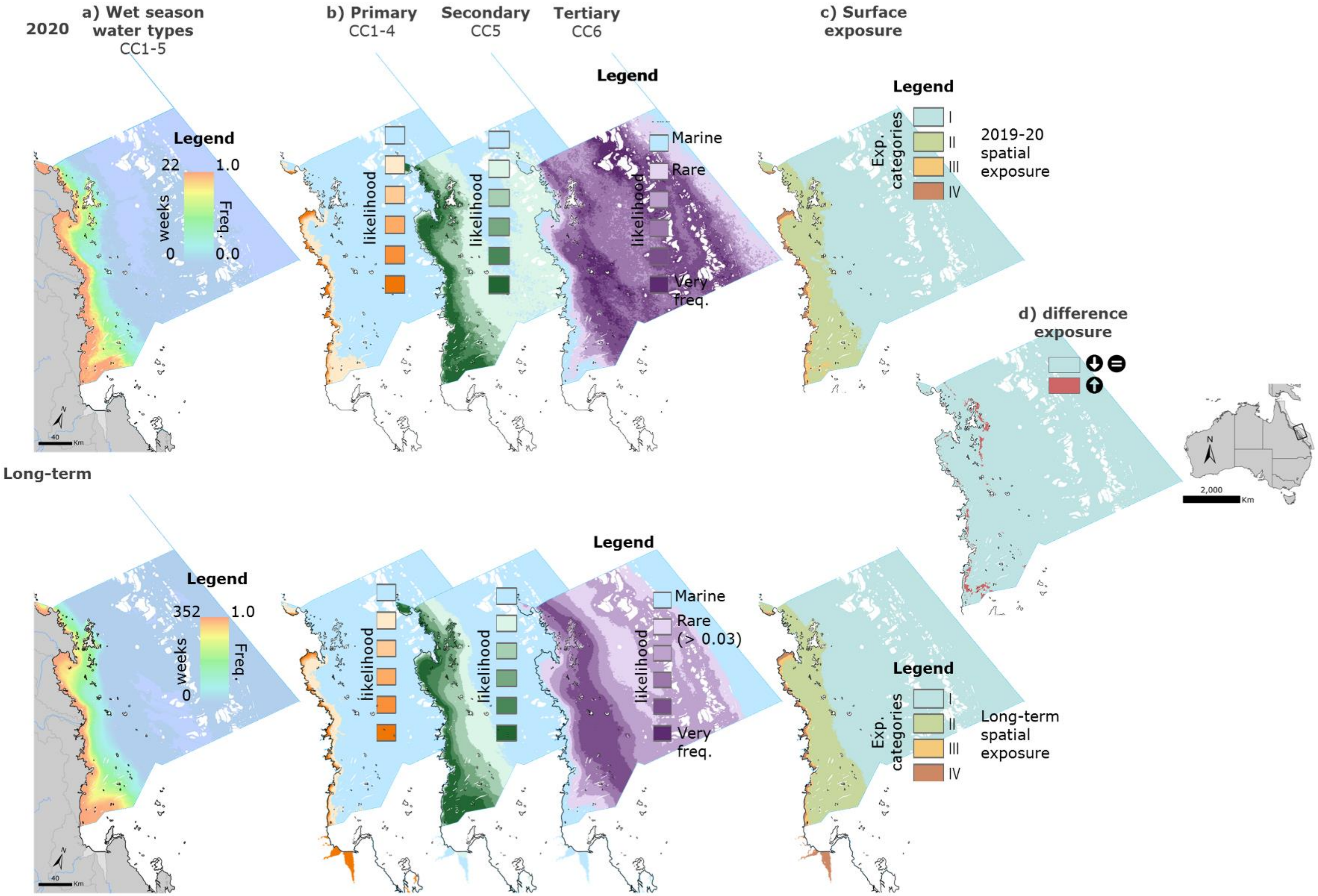

Figure 4-33: Long-term and current year remote sensing results for the Mackay-Whitsunday region showing the a) frequency of combined primary and secondary water types; b) the frequency of primary, secondary and tertiary wet season water types regrouped into five likelihood categories [<0.2 (Rare), 0.2–0.4, 0.4–0.6, 0.6–0.8 and 0.8–1 (very frequent)]; c) exposure in the long-term (bottom) and 2019–20 wet season (top); and d) a difference map showing areas with an increase in risk category in 2020 (in red, ⬆) against long-term trends [calculated as (c, top) exposure in 2020 minus (c, bottom) long-term].

Table 4-6 presents the areas (km²) and percentage (%) of Mackay-Whitsunday region, coral reef, and seagrass areas affected by different categories of exposure (or potential risk) based on satellite-derived wet season 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 detectable but low water quality concentrations and therefore low risk of any detrimental ecological effect. Areas exposed to category I are presented in Table 4-6, but not described below. 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 4-6: Areas (km²) and percentages (%) of the Mackay-Whitsunday region, coral reefs, and surveyed seagrass affected by different risk categories of exposure during the 2019–20 wet season and the long-term. The last three rows show the differences between % affected in 2020 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.

Mackay-Whitsunday		**Total**		**Potential Risk category** No / very low	Lowest		Highest	**Total area exposed II-IV**
				I	**II**	**III**	**IV**	
Surface area	area	48,957	2020	39,049	8,765	660	483	9,908
			LT	38,701	9,320	515	419	10,255
	%	*100%*	2020	80%	18%	1%	1%	20%
			LT	79%	19%	1%	1%	21%
Coral reefs	area	3,216	2020	3,004	180	26	6	213
			LT	3,004	194	16	2	212
	%	*100%*	2020	93%	6%	1%	<1%	7%
			LT	93%	6%	<1%	<1%	7%
Surveyed seagrass	area	307	2020	20	158	47	83	288
			LT	19	169	42	77	288
	%	*100%*	2020	6%	51%	15%	27%	94%
			LT	6%	55%	14%	25%	94%
Difference (2019 – Long Term average)	*Surface area*			1%	-1%	<1%	< 1%	-1%
	Coral Reef			<1%	<1%	<1%	< 1%	< 1%
	Surveyed seagrass			<1%	-4%	1%	2%	<1%

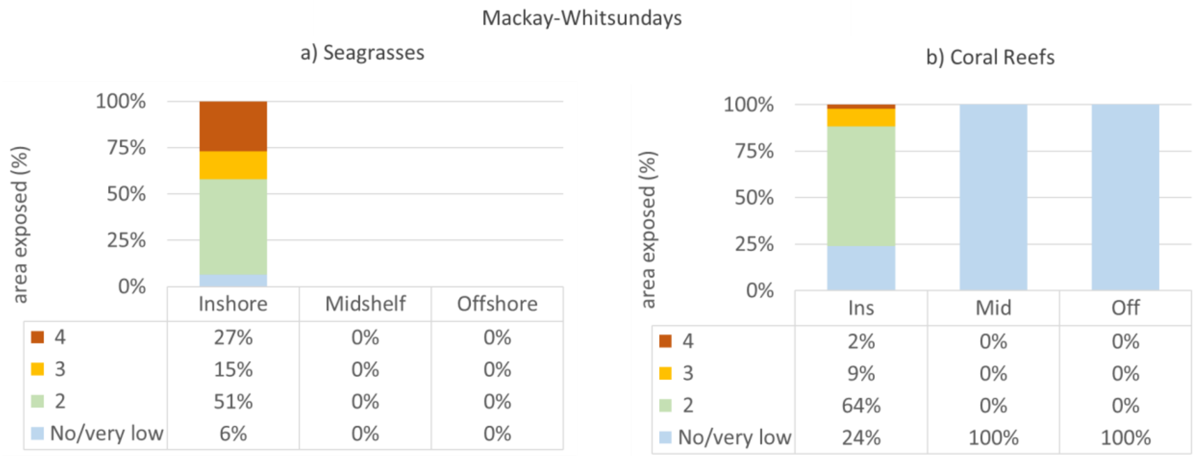

Figure 4-34: Percentage of the Mackay-Whitsunday region a) seagrass and b) coral reef habitats affected by different risk categories of exposure during the 2019–20 wet season.

In 2019–20, it was estimated that:

- Mackay-Whitsunday wide: 80% of the Mackay-Whitsunday region was not exposed to a potential risk, similar to long-term patterns (79%, Table 4-6). 20% of the Mackay-Whitsunday region was exposed to combined potential risk categories II–IV. However, only 1% of the region was in the highest exposure category (IV) and 1% in category III.
- Mackay-Whitsunday waterbodies: only the inshore Mackay-Whitsunday waters were exposed to the highest categories of potential risk (III and IV). The area exposed was however spatially limited and corresponded to 5% (cat. III) and 4% (cat. IV) of the total Mackay-Whitsunday inshore area (Figure 4-8c). The mid-shelf and offshore Mackay-Whitsunday waterbodies were not exposed to potential risk.

- Mackay-Whitsunday habitats:
    - 7% of coral reefs in the Mackay-Whitsunday region were exposed to combined potential risk categories II–IV. However, less than 1% of coral were in the highest exposure category (IV) and 1 % in category III, and they were all inshore reefs (Figure 4-34b). 9% (< 300 km^2) of the Mackay-Whitsunday corals occur in the inshore waters (Appendix C-6). The coral area exposed to higher potential risk corresponded to 9% (cat. III) and 2% (cat. IV) of the total inshore reef area in the Mackay-Whitsunday region. Mid-shelf and offshore reefs were not exposed to a potential risk.
    - There are only inshore seagrasses in the Mackay-Whitsunday region (Appendix C-6). 94% of seagrasses in the Mackay-Whitsunday region were exposed to combined potential risk categories II–IV. 27% of seagrasses were in the highest exposure category (IV) and 15% were in category III,
    - The coral and seagrass areas in the Mackay-Whitsunday region exposed to combined potential risk categories II–IV in 2018-19 were very similar to the long-term areas (<1% changes).

4.3.5 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, for the second year, the results of the assessment of potential risk are presented below as they are relevant context for the coral reef and seagrass data in these regions. It should be noted that exposure maps have a higher degree of uncertainty in these 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 detectable but low water quality concentrations and therefore low risk of any detrimental ecological effect. Area exposed to category I are presented in Table 4-7 but not described. 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 2019–20 was less than 1.5 times the long-term median, and there were no large flood plumes captured in satellite imagery in the Fitzroy region during the wet season. Weekly composites of the Fitzroy region showed that primary waters were confined in the enclosed coastal waters next to the Fitzroy and Calliope River mouths in the first half of the wet season. Primary waters reached the open coastal waters north of Curtis Island from mid-February but generally, primary flood waters had limited impact on the open coastal and mid-shelf regions and ecosystems of the Fitzroy region in 2019–20. Secondary waters extended largely into the open coastal region from mid-February and reached the mid-shelf region in weeks 15–16 (9–22 March).

Table 4-7 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 2019–20, it was estimated that:

- Fitzroy-wide: 86% of the Fitzroy region was not exposed to a potential risk, similar to long-term patterns (88%, Table 4-7). 14% of the Fitzroy region was exposed to combined potential risk categories II–IV. However, only 2% of the region was in the highest exposure category (IV) and 2% in category III.
- Fitzroy waterbodies: only the inshore Fitzroy waters were exposed to the highest categories of potential risk (III and IV). The area exposed was however spatially limited and corresponded to 14% (cat. III) and 15% (cat. IV) of the total Fitzroy inshore area (Figure 4-8c). The mid-shelf and offshore Fitzroy waterbodies were largely exposed to no / very low risk (90% and 100% of the Fitzroy mid-shelf and offshore waterbodies).
- Fitzroy habitats:
    - 10% of coral reefs in the Fitzroy region were exposed to combined potential risk categories II–IV. However, less than 1% of coral were in both the highest exposure category (IV) and category III, and they were all inshore reefs (Figure 4-35b). Only 4% (< 200 km^2) of the Fitzroy corals occur in the inshore waters (Appendix C-6). The coral area exposed to higher potential risk corresponded to 21% (cat. III) and 17 % (cat. IV) of the total inshore coral reef area in the Fitzroy. Mid-shelf reefs were largely exposed to lower risk category II (77% of the total mid-shelf coral reef area in the Fitzroy region). 100% of the Fitzroy region offshore reefs were classified as no / very low risk.
    - 96% of seagrasses in the Fitzroy region were exposed to combined potential risk categories II–IV. 32% of seagrasses were in the highest exposure category (IV) and 9% were in category III, and they were all inshore seagrasses (Figure 4-35a). 81% (< 400 km^2) of the Fitzroy seagrasses occur in the inshore waters (Appendix C-6). The seagrass area exposed to higher potential risk corresponded to 11% (cat. III) and 40% (cat. IV) of the total inshore seagrass area in the Fitzroy region. 100% of the mid-shelf seagrasses were exposed to the lower category of risk (II).
    - The coral areas exposed to highest potential risk categories III and IV were similar to the long-term patterns (<1% of the coral reefs), There was however an increase in area exposed to the lowest potential risk category (II: + 7%).This likely to be linked to the suspiciously large secondary areas measured in the mid-shelf Fitzroy waters (section 4.1.1). The seagrass areas in the Fitzroy region exposed to combined potential risk categories II–IV in 2019–20 were similar to the average long-term areas.

Table 4-7: Areas (km²) and percentages (%) of the Fitzroy region, coral reefs, and surveyed seagrass affected by different risk categories of exposure during the 2019–20 wet season and the long-term. The last three rows show the differences between % affected in 2019–20 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	2020	74,404	9,357	1,471	1,638	12,466
			LT	76,616	7,457	1,322	1,475	10,253
	%	*100%*	2020	86%	11%	2%	2%	14%
			LT	88%	9%	2%	2%	12%
Coral reefs	area	4,881	2020	4,385	429	37	30	495
			LT	4,729	100	22	30	152
	%	*100%*	2020	90%	9%	1%	1%	10%
			LT	97%	2%	<1%	<1%	3%
Surveyed seagrass	area	478	2020	21	261	42	153	457
			LT	20	286	34	137	457
	%	*100%*	2020	4%	55%	9%	32%	96%
			LT	4%	60%	7%	29%	96%
Difference (2019 – Long term average)	*Surface area*			-2%	2%	<1%	<1%	2%
	Coral Reef			-7%	7%	<1%	<1%	7%
	Surveyed seagrass			<1%	-5%	2%	3%	<1%

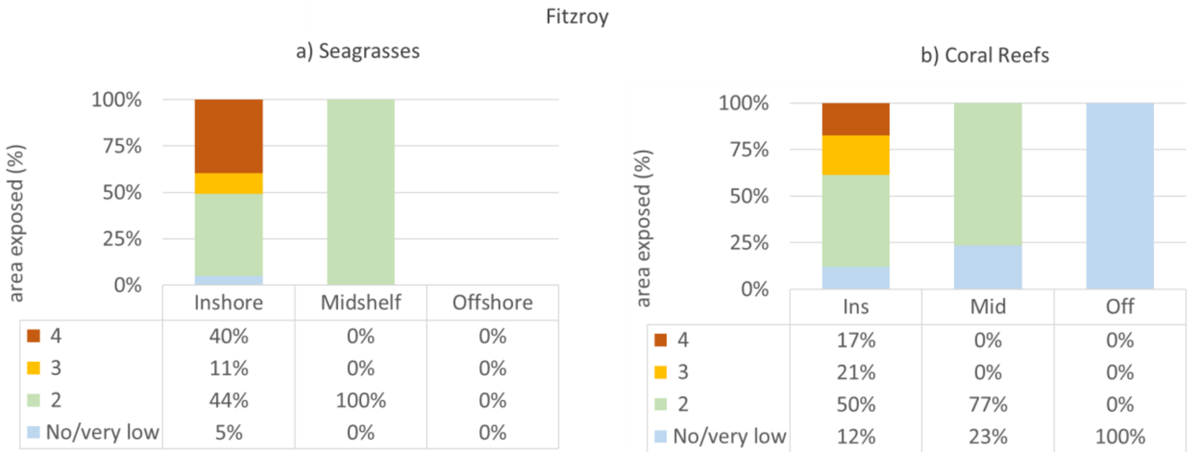

Figure 4-35: Percentage of the Fitzroy region a) seagrass and b) coral reef habitats affected by different risk categories of exposure during the 2019–20 wet season.

Burnett-Mary

The river discharge from the Burnett-Mary region in 2019–20 was less than 1.5 times the long-term median, and there were no large flood plumes captured in satellite imagery in the Burnett-Mary region during the wet season. Primary waters were largely confined in enclosed coastal waters off Hummock Hill Island, and occasionally in the open coastal waters along the southern Burnett-Mary coast during the wet season; but this may also be linked to resuspension of sediments in the shallow waters. Primary waters reached the open coastal waters in mid-March (week 15) but generally, primary waters had limited impact on the open coastal and mid-shelf regions of the Burnett-Mary region in 2019–20. Secondary waters extended into the mid-shelf region from mid-February.

Table 4-8 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 2019–20, it was estimated that:

- Burnett-Mary wide: 88% of the Burnett-Mary region was not exposed to a potential risk, which was under long-term patterns (95%, Table 4-8). 12% of the Burnett-Mary region was exposed to combined potential risk categories II–IV, with less than 1% in both the highest exposure category (IV) and category III.
- Burnett-Mary waterbodies: only the inshore Burnett-Mary waters were exposed to the highest categories of potential risk (III and IV). The area exposed was however spatially limited and corresponded to 15% (cat. III) and 13% (cat. IV) of the total Burnett-Mary inshore area (Figure 4-8c). The mid-shelf and offshore Burnett-Mary waterbodies were largely exposed to no / very low risk (66% and 100% of the Burnett-Mary mid-shelf and offshore waterbodies).
- Burnett-Mary habitats:
  - 40% of coral reefs in the Burnett-Mary region were exposed to combined potential risk categories II–IV, However less than 1% of coral exposed to the highest risk categories III and IV and there were all inshore reefs. Only 2% (< 10 km^2) of the Mackay-Whitsunday corals occur in the inshore waters (Appendix C-6). The coral area exposed to higher potential risk corresponded to 20% (cat. III) and 9 % (cat. IV) of the total inshore coral reef area in the Burnett-Mary region. Mid-shelf coral reefs were exposed to lower risk category II or to no / very low risk (40% and 60% of the total mid-shelf reef area in the Burnett-Mary region). There are no offshore reef in the Burnett-Mary region.
  - 97% of seagrasses in the Burnett-Mary region were exposed to combined potential risk categories II–IV. However, 17% of seagrasses were in the highest exposure category (IV) and 7% were in category III and they were all inshore seagrasses (Figure 4-36a). 71% (< 200 km^2) of the Mackay-Whitsunday corals occur in the inshore waters (Appendix C-6). The seagrass area exposed to higher potential corresponded to 10% (cat. III) and 23% (cat. IV) of the total inshore seagrass area in the Burnett-Mary region. 100% of the Mid-shelf seagrasses in the Burnett-Mary region were exposed to the lowest category of risk.
  - The coral and seagrass areas in the Burnett-Mary region exposed to combined potential risk categories II–IV in 2019–20 were 40% and 44% higher than the average long-term areas, respectively. These increases were mainly related to an increase in coral and seagrass area exposed to the lowest potential risk category (II: + 40 and 37 %) which may be linked to the extended areas of secondary waters in mid-shelf waters discussed in 4.1.1

Table 4-8: Areas (km^2) and percentages (%) of the Burnett-Mary region, coral reefs, and surveyed seagrass affected by different risk categories of exposure during the 2019–20 wet season and the long-term. The last three rows show the differences between % affected in 2019–20 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 I	Lowest II	III	Highest IV	Total area exposed II-IV
Surface area	area	37,713	2020	33,082	4,298	174	160	4,631
			LT	35,748	1,556	267	142	1,965
	%	*100%*	2020	88%	11%	<1%	<1%	12%
			LT	95%	4%	<1%	<1%	5%
Coral reefs	area	285	2020	170	113	1	1	114
			LT	281	0	3	0	4
	%	*100%*	2020	60%	40%	0%	0%	40%
			LT	99%	0%	<1%	0%	<1%
Surveyed seagrass	area	259	2020	9	189	18	43	251
			LT	9	170	39	42	251
	%	*100%*	2020	3%	73%	7%	17%	97%
			LT	3%	36%	8%	9%	53%
Difference (2019 – Long term average)	*Surface area*			-7%	7%	< 1%	< 1%	7%
	Coral Reef			-39%	40%	< 1%	< 1%	40%
	Surveyed seagrass			< 1%	37%	-1%	8%	44%

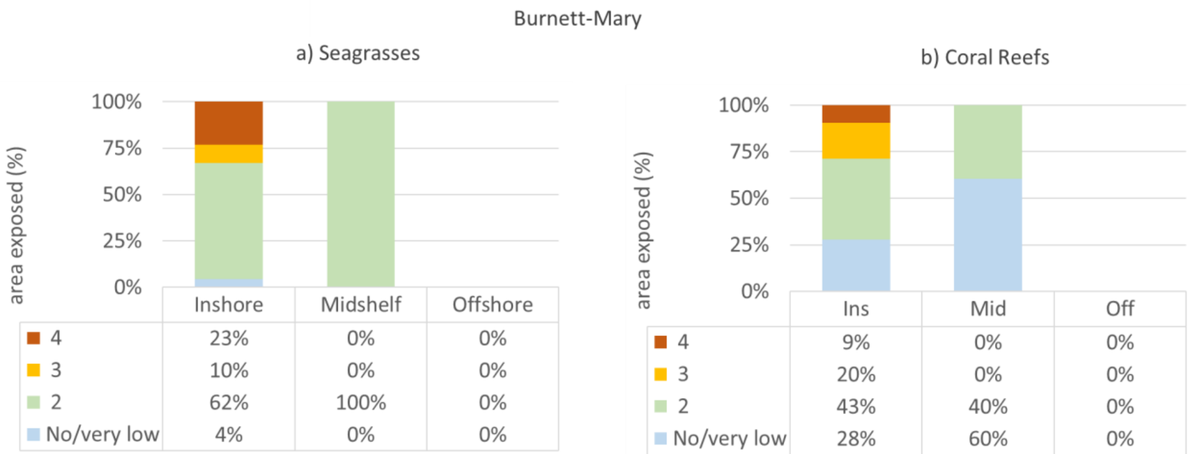

Figure 4-36: Percentage of the Burnett-Mary region a) seagrass and b) coral reef habitats affected by different risk categories of exposure during the 2019–20 wet season.

4.4 Modelling and mapping summary and discussion

Tracer simulations (eReefs hydrodynamic model)

Simulations of three-dimensional tracer dispersal showed open coastal waters had generally minor influence from river discharge this year. Discharge from the Normanby and Russell-Mulgrave rivers reached mid-shelf waters although river-derived material was very dilute in the mid-shelf water body.

River discharge generally travelled in a northerly direction along the coastline and had a far smaller spatial 'footprint' than the 2018–19 wet season. Three-dimensional river water influence greater than 1% generally extended 10–40 km from river mouths; the greatest distance of tracer travel was observed for the Normanby River (compared to 2018-19 for example where discharge reached >200km north of the river mouth in the Burdekin region).

Water type frequency maps (MODIS data)

Maps showed a well-documented inshore-to-offshore spatial pattern, with the highest frequency of the primary water type (typically enriched in sediment and dissolved organic matter, brownish turbid waters) in the inshore waterbody. Mid-shelf waterbodies were most frequently exposed to the secondary water type and offshore waterbodies were most frequently exposed to the tertiary water type (typically detectable water quality concentrations but with a low risk of any detrimental ecological effect). Only 3% of the Reef (inshore waters only) was exposed to primary waters, which was similar to long-term and coral recovery patterns. It is important to note that there was a higher uncertainty in the mapping of secondary water extent this year, particularly in the mid-shelf waters of Cape York and the Fitzroy and Burnett-Mary regions. Similarly, the offshore reef was exposed to anomalously large tertiary waters. This is hypothesised to be linked to several image quality and environmental factors including some image noise (glint, stripes), the influence of wind resuspended sediments inshore and around reefs, as well as the degraded atmospheric conditions linked to the widespread bushfire season. Generally though, the patterns were similar to long-term patterns.

Exposure maps (MODIS and field water quality data)

Tertiary waters are associated with low land-sourced contaminant concentrations) and a low magnitude score in the Reef exposure assessment. While tertiary areas in 2019–20 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 2019–20 was spatially limited and similar to the long-term patterns. Eighty five percent of the Reef was exposed to no or very low potential risk and only 2% of the Reef was in the highest exposure categories IV and III. Cross-shore, the mid-shelf and offshore waterbodies were largely classified as no or very low potential risk (80% and 99% respectively), but 12% and 10% of the inshore waters were exposed to the highest potential risk categories III and IV.

Only inshore Reef habitats were exposed to the highest exposure categories III and IV. 77% of the Reef seagrass occur in the inshore waters, but only 4% of the Reef corals. 21% the total inshore reef area (only 1% of the total coral reef area of the Reef) and 38% of the total inshore seagrass area (~ 30% of the total seagrass area in the Reef) were exposed to the highest risk categories III and IV. This is a relatively small proportion, but the inshore water encompasses habitat of high ecological importance. Mid-shelf and offshore coral reefs were only exposed to the lowest risk category II or to no potential risk. The suspiciously large secondary areas measured in the Cape York, Fitzroy and Burnett-Mary regions resulted in an increase in coral areas exposed to the lowest potential risk category II in those regions, which must be considered with caution. However, the habitat areas exposed to a potential risk (combined risk categories II, III and IV) were largely similar to the long-term patterns in all other regions Regional exposure results are summarised in Section 7.

The panels showing the pressures combined with the wet season water types and frequency maps for each NRM region highlight the need to distinguish the influence of river discharge, as opposed to other processes such as resuspension, in driving water quality as well as the need to keep integrating spatial and temporal information obtained from the wet season water type maps with the *in situ* water quality measurements. This was particularly evident in this year's results when the extent of the secondary water type was greater than usual for a relatively dry wet season. Refinement would require establishment of a metric specific to river plumes, distinct from overall wet season conditions.

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 wet season water types and exposure history; therefore, the highest risk of an ecological response could be during large events when primary/secondary water types extend into otherwise low exposure (more offshore) areas.
- Reporting the areas of coral reefs and seagrass in the highest potential exposure categories cannot be assessed in terms of ecological relevance at this stage and is included as a comparative measure between regions and between years.
- One-week exposures are reported for which the ecological consequence is not presently known.
- The degree of validation with *in situ* data varies between regions, with limited current water quality data in the Fitzroy and Burnett-Mary regions.

Further discussion of the results in the context of possible limitations is in Section 6

River-derived DIN, TSS and PN loading maps

The estimated wet season river-derived DIN, TSS and PN loading in the Reef lagoon for the 2020 water year showed a relatively low area of influence for all parameters. Only small differences were shown between the 2019–20, pre-development and anthropogenic loading scenarios, with an area of limited anthropogenic DIN loading in the Wet Tropics region and anthropogenic TSS loading in the Burdekin region. For all parameters, the areas of influence in 2019–20 were comparable to other years with river discharge below the long-term median.

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

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

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

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

5. Focus region water quality and Water Quality Index

The following sections provide detailed analysis of key water quality variables in focus regions in the context of local environmental drivers, specifically focused on 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 (with the exception of Cape York, where data are presented differently as some aspects of monitoring in this region are still under development):

- 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 2020
- 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:

- Figure C-1: Time-series of chlorophyll and turbidity measured by moored FLNTUSB instruments
- Figure C-2: Time-series of temperature and salinity measured by moored Sea-Bird Electronics instruments
- Table C-1: Cape York: Summary statistics for each water quality variable from each monitoring location, September 2019 to October 2020
- Table C-2: Wet Tropics, Burdekin and Mackay-Whitsunday: Summary statistics for each water quality variable from each monitoring location, Sept 2019 to Oct 2020
- Table C-3: Annual summaries of moored FLNTUSB turbidity measurements for each monitoring location, including percentage exceedances of GVs
- Table C-4 to Table C-8: Summary of water quality data (collected as part of the JCU event-based sampling) across the wet season 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-nine 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 due to strong winds (>25 km.h^{-1}) preventing access during the winter months.

As the 2019–20 water year is only the fourth year of sampling for the Cape York region, 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). 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.

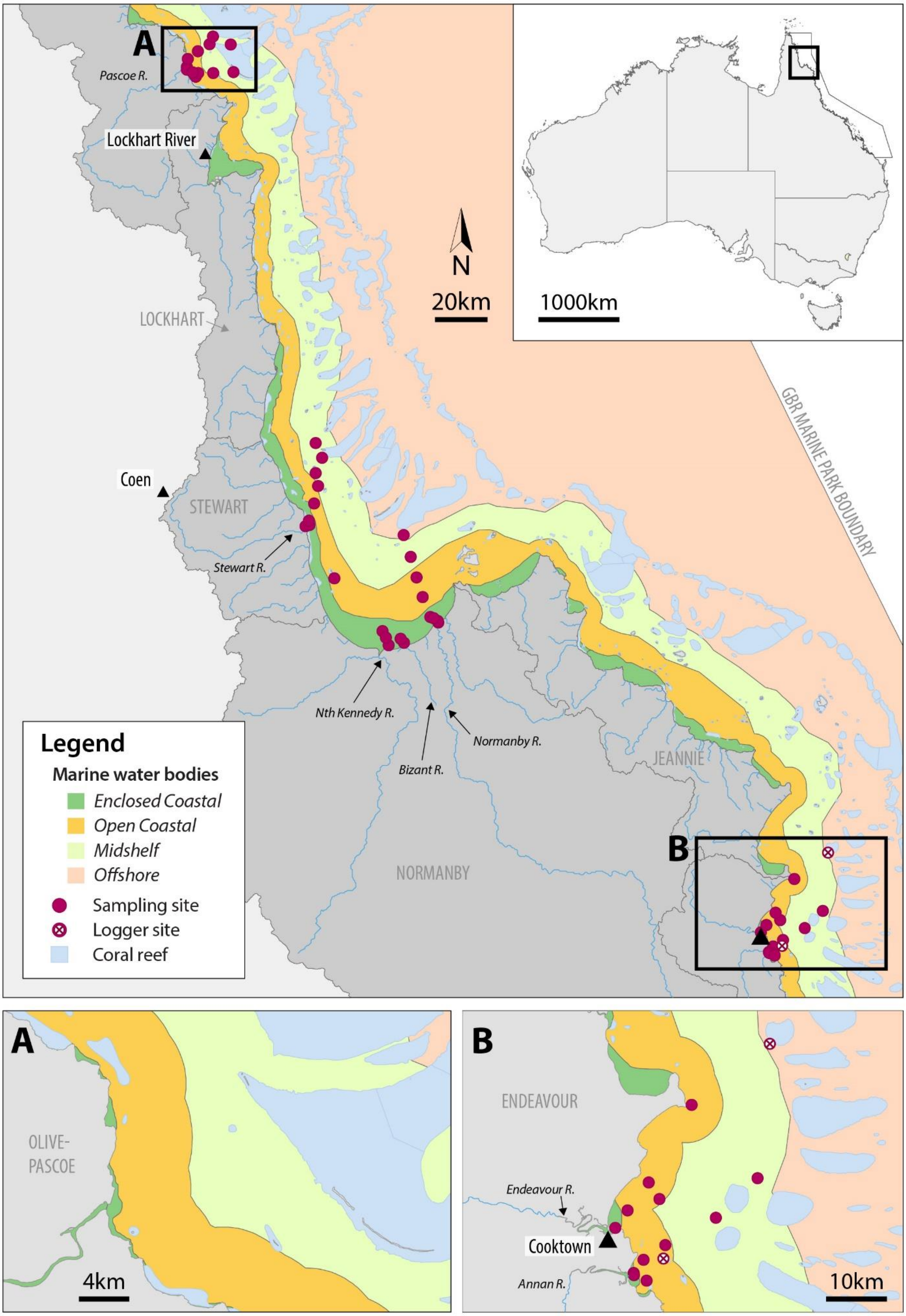

Figure 5-1: Water quality sampling sites in the Cape York region shown with water body boundaries.

5.1.1 Pascoe

The Pascoe focus region is influenced primarily by discharge from the Pascoe and Olive Rivers. During the first year of sampling (2016–17), five sampling sites (PRN1 to PRN5) were located along a transect from the mouth of the Pascoe River north to open coastal waters, and two additional sites were located to the south: PRS01 (south of the river mouth) and PRBB located at Middle Reef (locally known as Blue Bells). Due to the observation of floodwaters flowing to the southeast during 2017–18 and subsequent wet seasons, additional sites (PRS2.5 and PRS5) were added along the southern transect (Figure 5-2). Site PRN5 (located to the north of Eel Reef) is now only sampled during major flood events that reach Eel Reef.

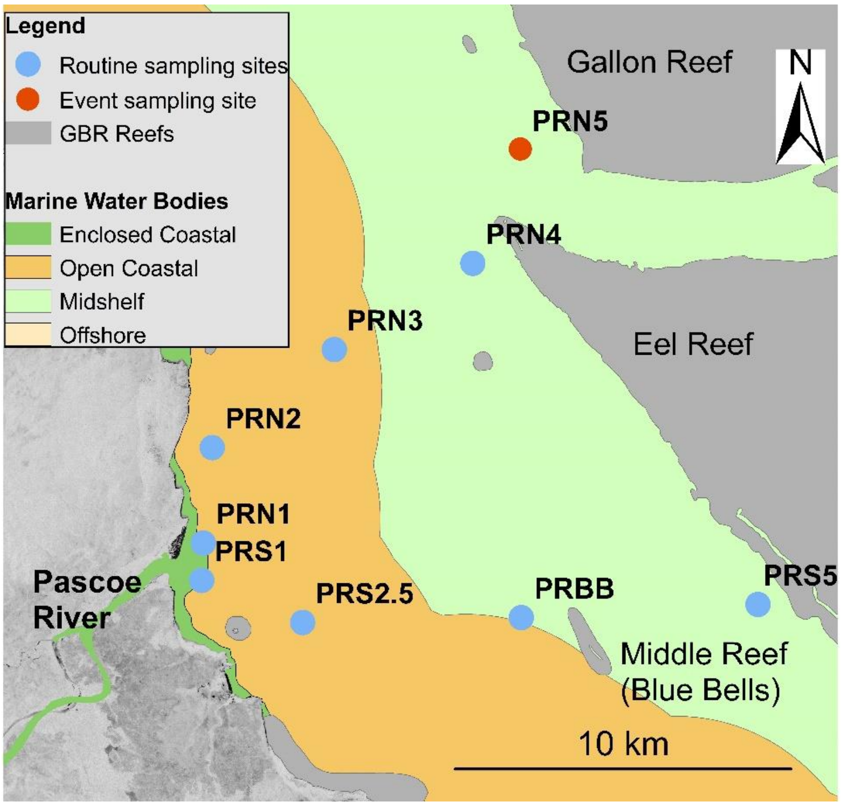

Figure 5-2: Water quality sampling sites in the Pascoe River transect with water body boundaries.

The Pascoe River transect was sampled five times under ambient wet season conditions from December 2019–April 2020 (Figure 5-3) with a total of 51 surface and subsurface samples collected. No targeted flood monitoring was conducted, however regular sampling conducted in February and March 2020 occurred during periods of significant freshwater influence in the enclosed coastal and open coastal water bodies (refer also Figure 4-17). Peak daily discharge for the wet season (58 GL) occurred at the Garraway gauge (located 42 km upstream from the mouth) on 13 March 2020 and transect sampling occurred on 16 March 2020.

Estimated annual discharge for the Olive-Pascoe basin was 3,200 GL for the 2019–20 water year, which is close to the long term median annual discharge (Figure 5-4).

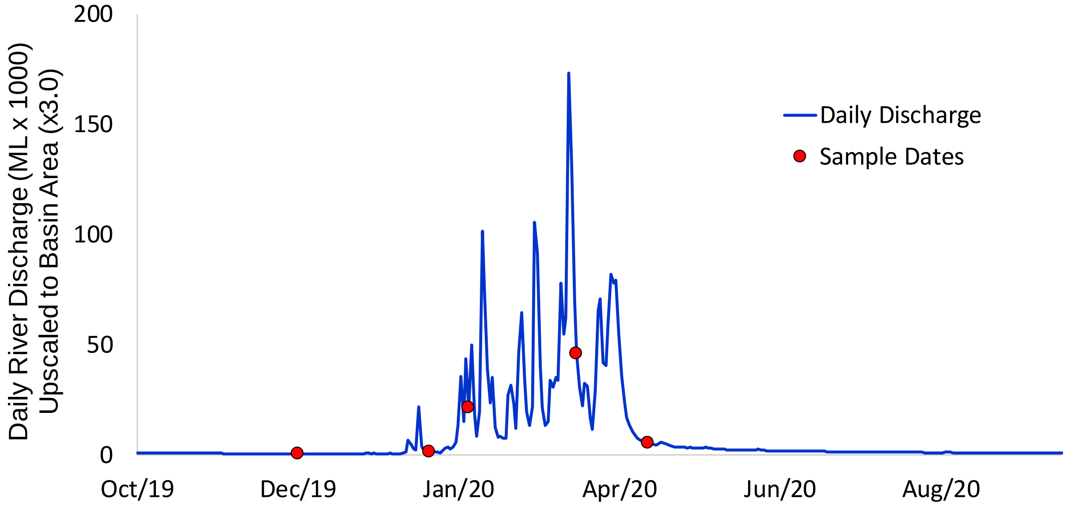

Figure 5-3: Daily discharge for the Pascoe River (gauge 102102A) for the 2019–20 water year. Red dots represent sampling dates.

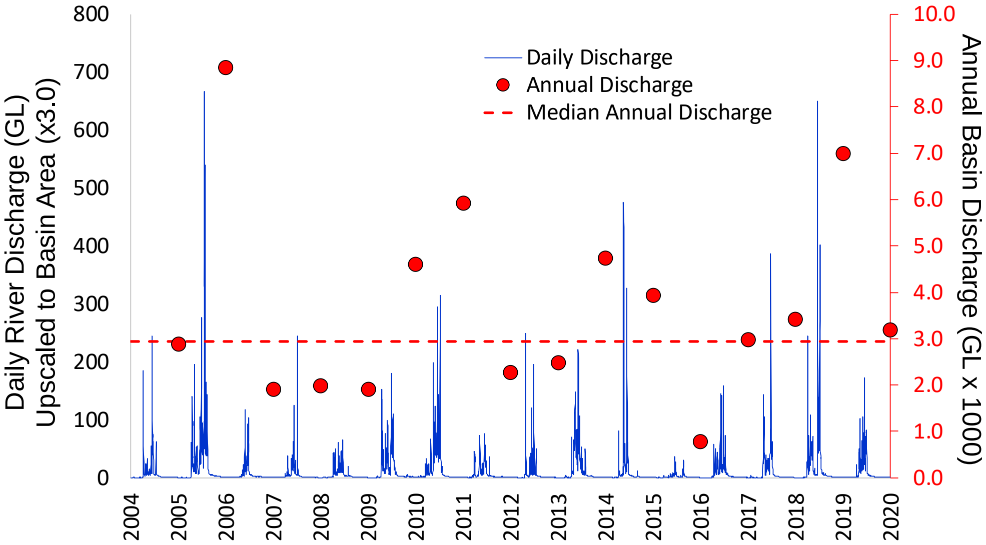

Figure 5-4: Long-term discharge for the Pascoe River (gauge 102102A). Daily (blue) and water year (October to September, red symbols) discharge volumes shown. Red dashed line represents long-term median of the combined annual discharge.

The total discharge and modelled loads estimated for the 2019–20 water year from the Pascoe catchment (upscaled from the Garraway gauge) are shown in Figure 5-5. The discharge and loads calculated for the 2019–20 water year from the Pascoe catchment (not including the Olive catchment) were just above the median. Over the 14-year period from 2006-07:

- discharge has varied from 425 GL (2015–16) to 3,770 GL (2018–19)
- modelled TSS loads ranged from 20 kt (2015–16) to 194 kt (2018–19)
- modelled DIN loads ranged from 28 t (2015–16) to 275 t (2018–19)
- modelled PN loads ranged from 59 t (2015–16) to 1,068 t (2018–19).

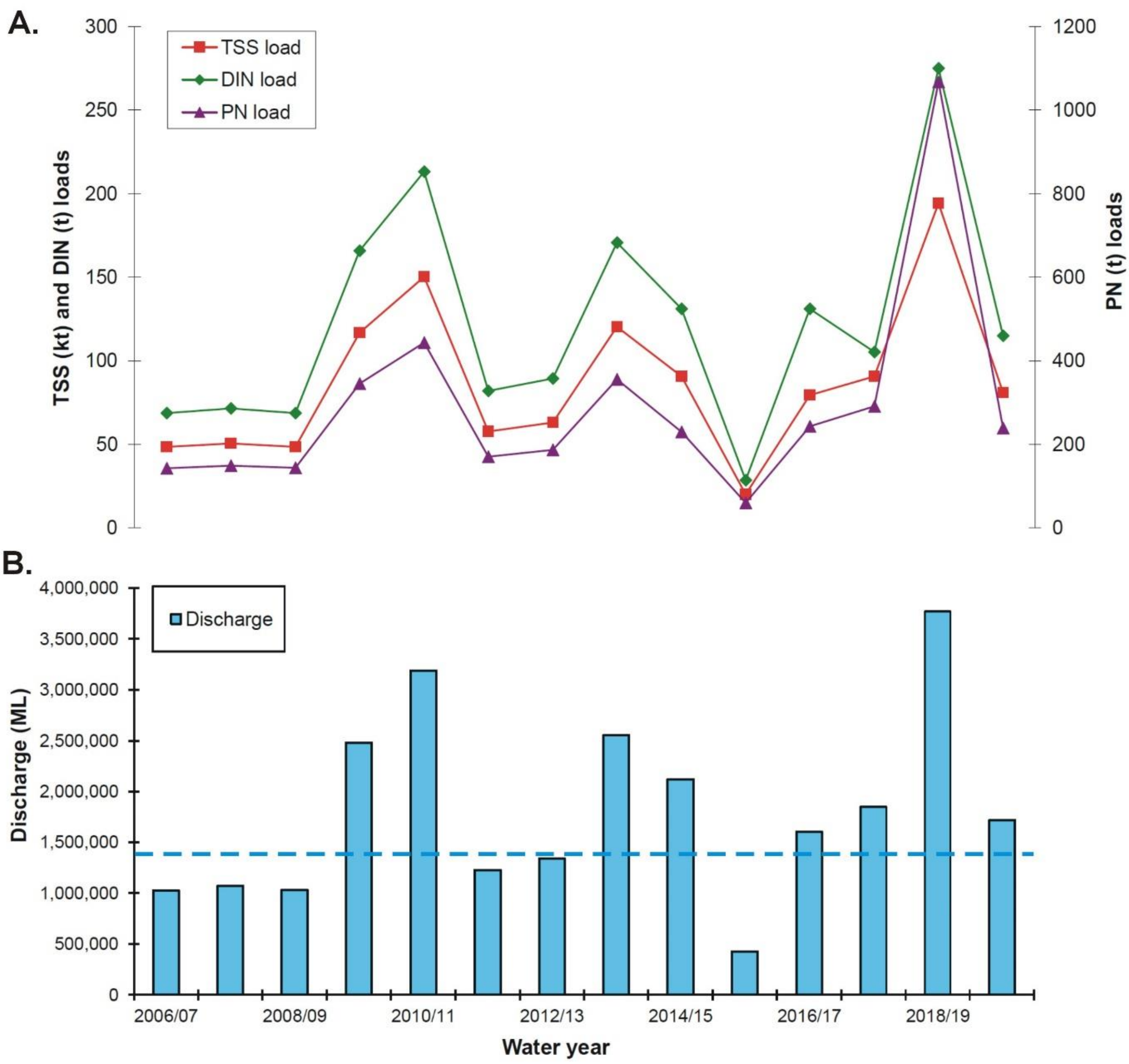

Figure 5-5: Modelled loads of (A) TSS, DIN and PN and (B) discharge for the Pascoe catchment (note Pascoe catchment only, does not include the Olive catchment) from 2006 to 2020. The loads reported here are a combination of 'best estimates' based on 'up-scaled' discharge data from gauging stations and monitoring data for 2014–15, 2016–17, 2017–18 and 2018–19 and an average of the annual mean concentrations for these four 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

There was some freshwater influence in the Pascoe River transect (salinity ranging from 1.2 to 17.0) in the enclosed coastal water body during the February, March and April sampling, resulting in elevated TSS and nutrient concentrations (particularly DIN). Peak daily discharge for the 2019–20 wet season (58 GL) occurred at the Garraway gauge (located 42 km upstream from the mouth) on 13 March 2020. During scheduled sampling on 16 March, the visible flood plume extended just beyond site PRS02 approximately 3.5 km from the river mouth. TSS within the plume ranged from 10 to 15 mg L^{-1} at the time of sampling. NO_x within the plume was also notably elevated (76.9 µg L^{-1}) above ambient concentrations.

Low salinity and higher concentrations close to the river mouth are common along the Pascoe transect in the wet season and therefore most of these data remain characterised as "ambient" for statistical analysis. However, the low salinity samples (<20) noted as being collected within visible flood plumes were excluded from comparisons with the relevant GVs. All sample results are plotted against distance from the river mouth in Figure 5-6.

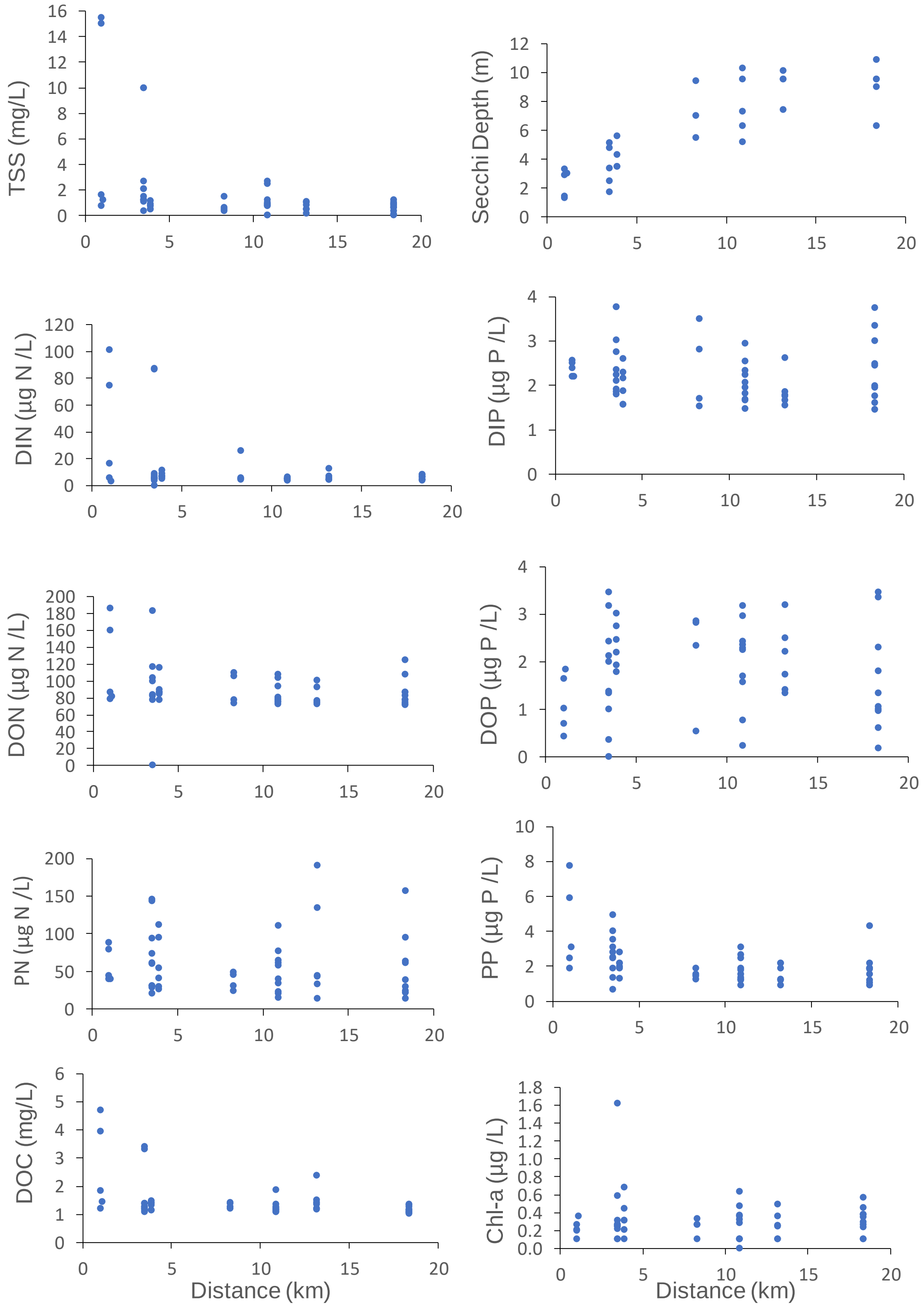

Figure 5-6: Water quality concentrations (surface and subsurface samples) and Secchi depth over distance (km) from river mouth for the Pascoe River focus region (all 2019–20 samples).

Comparison of the 2019–20 ambient results with previous years and the GVs (see Appendix C Table C-1) highlights that:

- Ambient TSS concentrations met the annual (wet and dry season results combined) and wet season GVs in all water bodies.
- Secchi depths generally met the relevant GVs with the exception of the mid-shelf water body, where mean Secchi depth (8.6 m) was less than the GV (≥10 m).
- Median wet season NH_3 and NO_X concentrations in the enclosed coastal water body exceeded the GVs. High DIN concentrations were driven by freshwater discharge in the enclosed coastal water body.
- In the open coastal water body, NO_x, PO_4 and PN all exceeded the wet season GVs. Maximum concentrations occurred during periods of maximum river discharge; however even with low salinity samples excluded from the statistics, median concentrations for these parameters remained well above the GVs.
- In the mid-shelf water body, median wet season concentrations of NH_3, NO_x, PO_4 and PN were all more than double the annual GV. There are no wet season GVs for this water body, and the comparison of wet season data only against annual guidelines is likely to contribute to the GV exceedances.
- Uncertainties associated with the analytical results for NH_3, NO_x, and PO_4 are likely to contribute to GV exceedances for these parameters in all water bodies (GBRMPA, 2020).

5.1.2 Stewart

The Stewart focus region is influenced primarily by discharge from the Stewart River, however 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.

Five sampling sites for the Stewart River are located in a transect from the river mouth to mid-shelf waters, representing a gradient in water quality (Figure 5-7). The transect (surface and subsurface) was sampled five times (over 8 days) between October 2019 and April 2020 (Figure 5-8). Schedule sampling in March 2020 did not occur due to COVID-19 travel restrictions. There were no major flood events in the Stewart River over the 2019–20 wet season, however there was some freshwater influence on coastal waters during the February 2020 sampling.

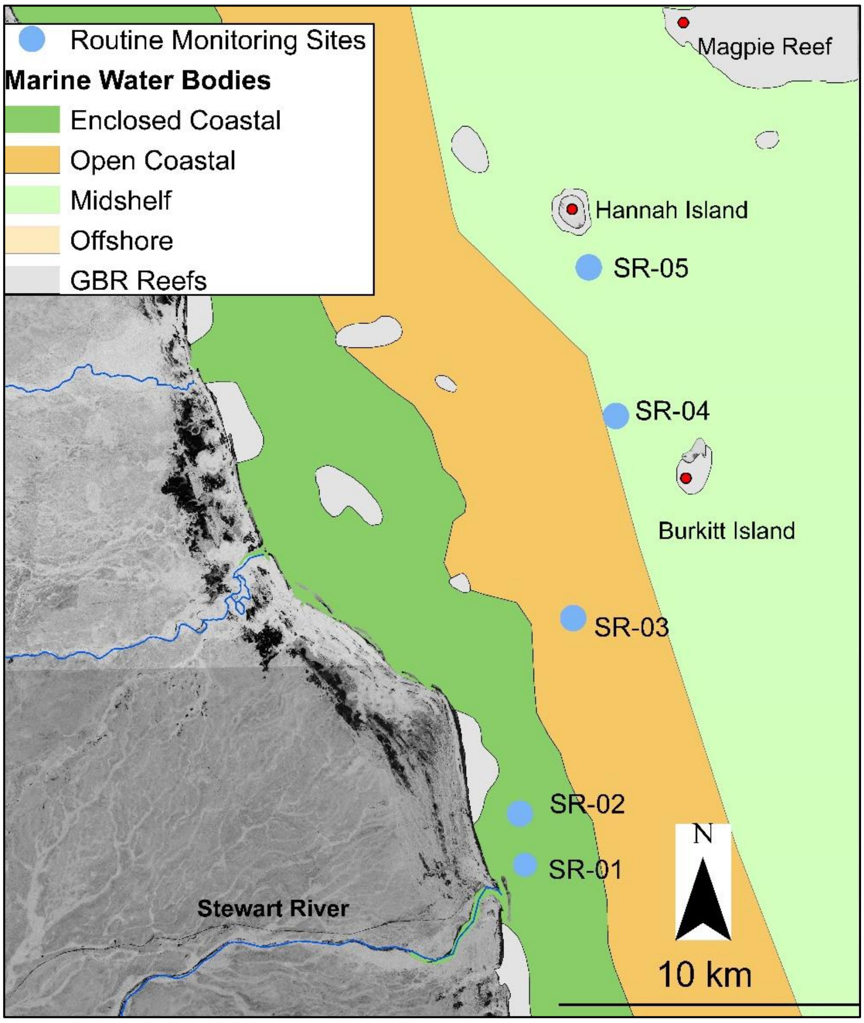

Figure 5-7: Water quality sampling sites in the Stewart River transect with water body boundaries.

The total annual discharge for 2019–20 water year is estimated at 580 GL based on the measurements from the Upper Stewart River gauge 104001A (Figure 5-9) corrected for catchment area. This is slightly less than the long-term median annual discharge and one-fifth the discharge from the previous water year (Table 3-1).

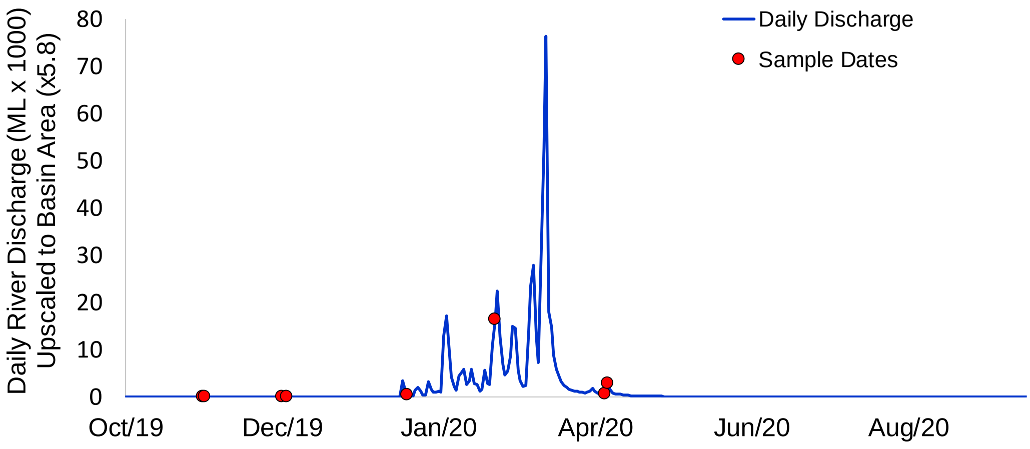

Figure 5-8: Daily discharge and sampling dates for the Stewart River (gauge 104001A) for the 2019–20 wet season.

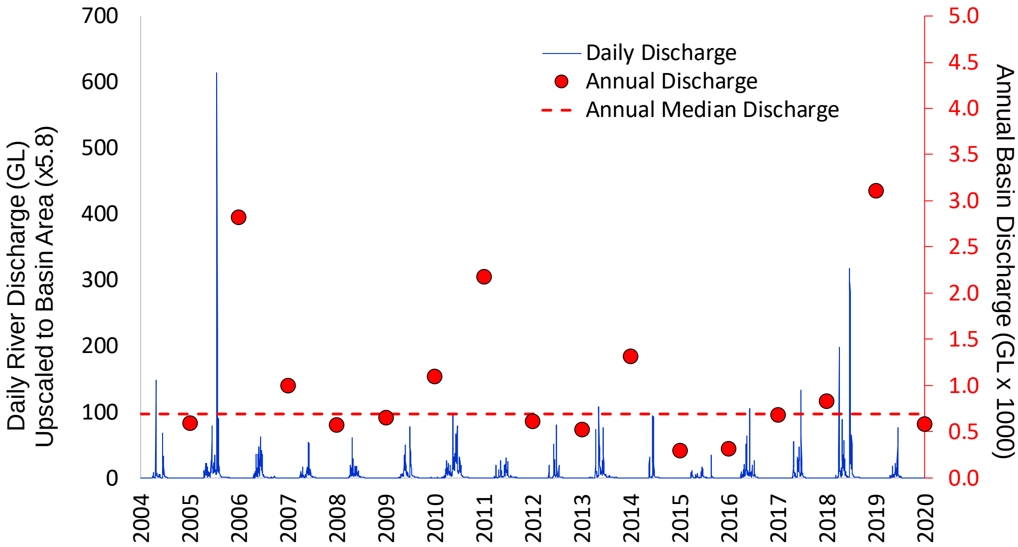

Figure 5-9: Long-term discharge for the Stewart River (gauge 104001A). Daily (blue) and water year (October to September, red circles) discharge volumes shown. Red dashed line represents long-term median annual discharge.

The combined discharge and modelled loads estimated for the 2019–20 water year from the Stewart Basin are shown in Figure 5-10. The discharge and loads calculated for the 2019–20 water year from the Stewart Basin were the second lowest estimated over the previous decade. Over the 14-year period from 2006-07:

- discharge has varied from 299 GL (2014–15) to 3,109 GL (2018–19)
- TSS loads ranged from 6 kt (2014–15) to 62 kt (2018–19)
- DIN loads ranged from 15 t (2014–15) to 155 t (2010–11)
- PN loads ranged from 18 t (2015–16) to 187 t (2018–19).

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

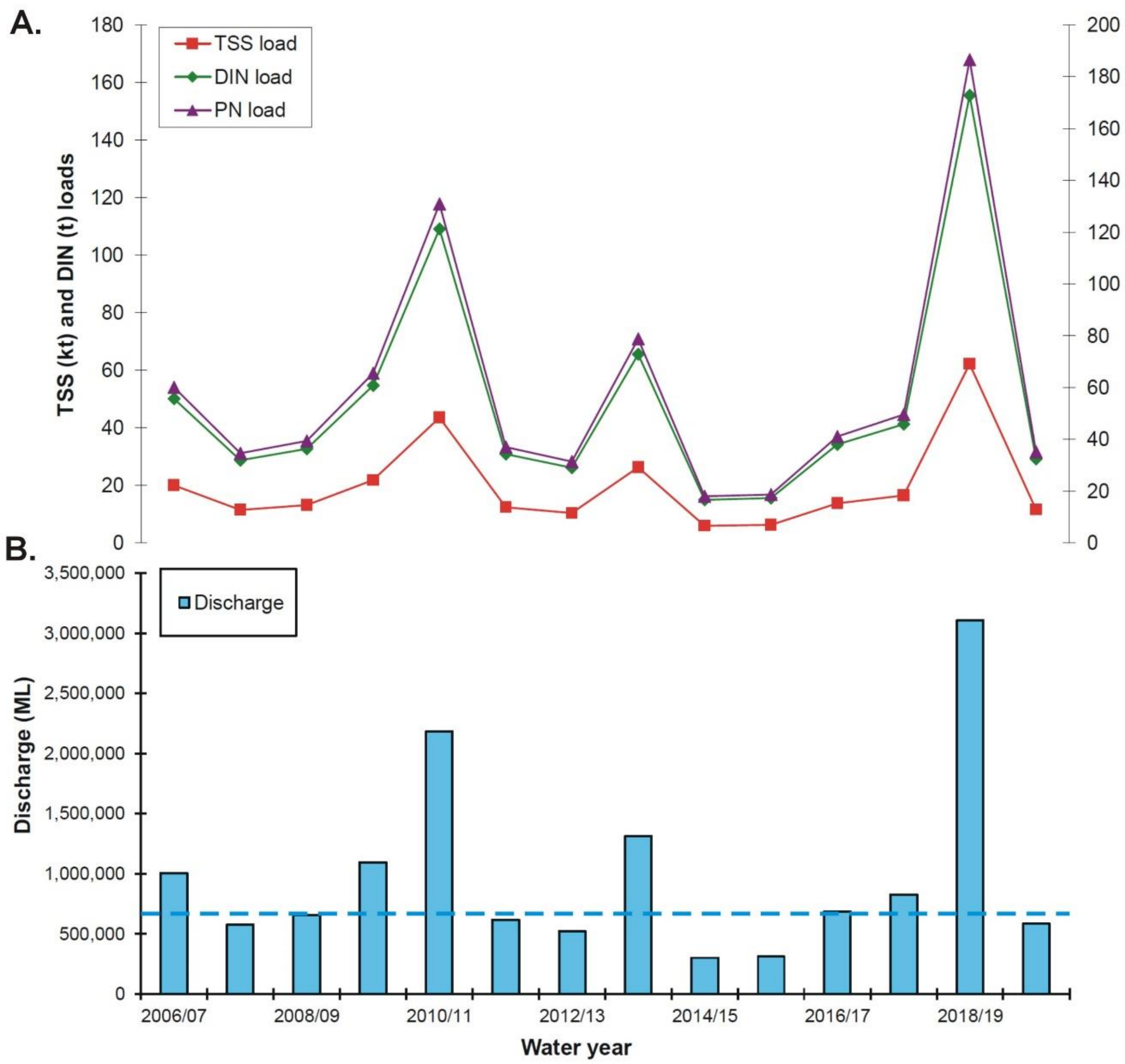

Figure 5-10. Loads of (A) TSS, DIN and PN, and (B) discharge for the Stewart Basin from 2006 to 2020. The loads reported here are based on the annual mean concentration reported in the Source Catchments modelling data and applied to each water year. Dotted line represents the long-term median for basin discharge. Note the different scales on the two y-axes.

Ambient water quality

The ambient and event sampling results for the Stewart River transect are plotted against the distance from the river mouth in Figure 5-11.

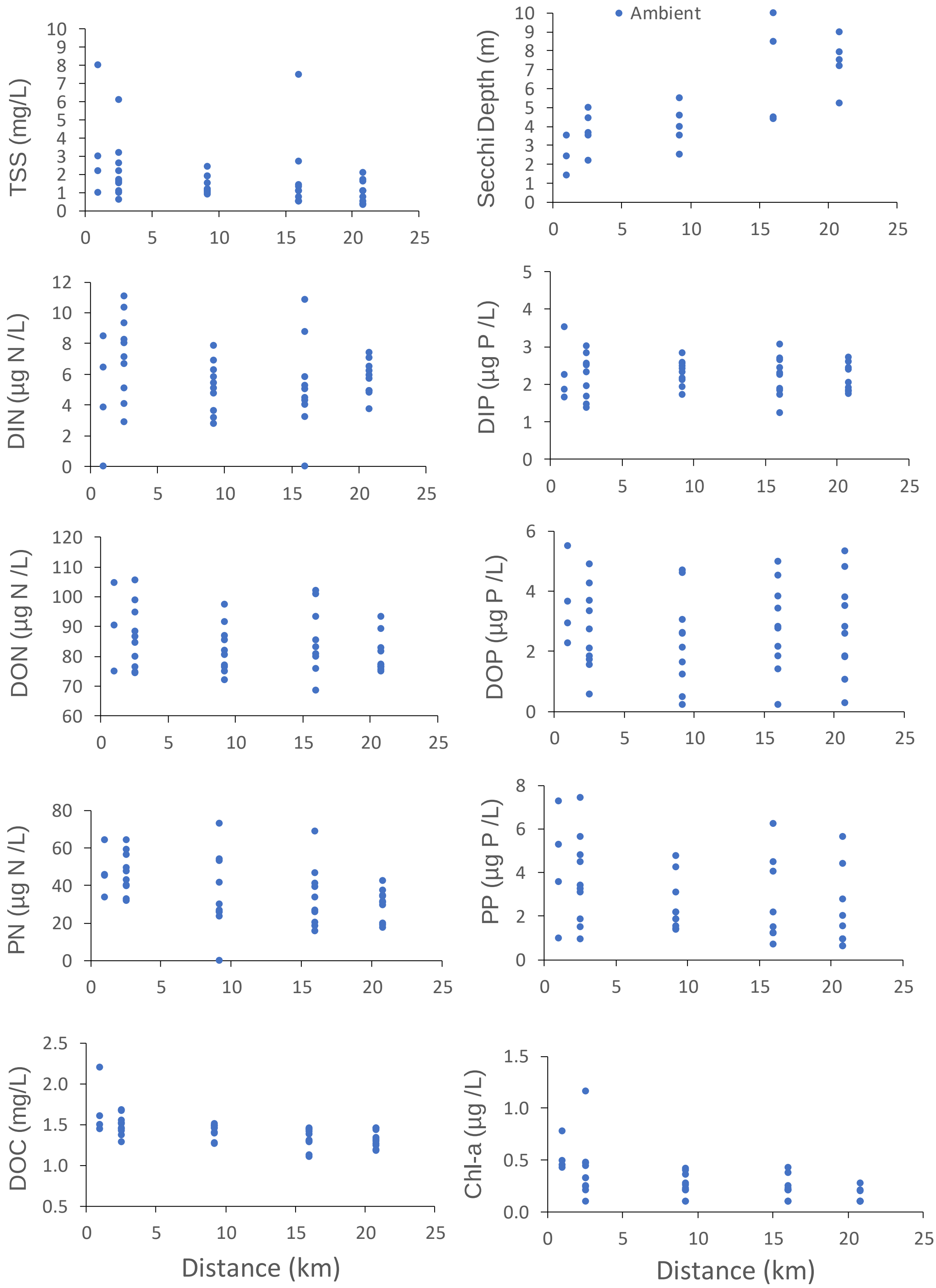

Figure 5-11: Water quality concentrations (surface and subsurface samples) and Secchi depth over distance (km) from river mouth for the Stewart River focus region, during ambient (blue circles) conditions. The Water Quality Index has not been calculated for Cape York due to the lack of long-term data.

Comparison of the 2019–20 ambient results with previous years and the water quality GVs (noting that the small number of sampling trips may not be representative of dry season conditions) (see Appendix C Table C-1) highlights that:

- Secchi depth increased from an annual (primarily wet season) mean of 3.3 m in the enclosed coastal waters to 7.4 m in the mid-shelf water body. This was an improvement from the previous high rainfall water year.
- Mean annual TSS concentrations in the enclosed coastal, open coastal and mid-shelf water bodies respectively (2.6, 1.6 and 1.1 respectively) were lower than the means for the 2018–19 water year (8.2, 2.7, and 2.1 mg L^{-1} respectively). Wet season TSS concentrations were within the GVs for all water bodies.
- NH_3 and NO_x wet season concentrations exceeded the relevant GVs for the enclosed coastal water body. Median NH_3, NO_X and PO_4 concentrations also exceeded the wet season GVs in the open coastal water body. As previously noted, laboratory inaccuracies may have contributed to these exceedances (GBRMPA, 2020).
- Chl-*a* concentrations were within the GVs for all water bodies. Mean annual concentrations in all water bodies were significantly lower in 2019–20 than during the previous (above-average rainfall) water year and were similar to the 2017–18 average rainfall year.

Event water quality

The largest Stewart River 2019–20 flood event occurred in mid-March, producing approximately half of the annual river discharge over ten days. No samples were collected due to COVID-19 travel restrictions. Based on satellite images and the relatively small magnitude of the event (estimated event discharge 300 GL), flood water from this event is likely to have had minimal influence on reefs beyond the open coastal water body.

5.1.3 Normanby

The Normanby focus region is influenced by discharge from the Normanby, Laura, Kennedy, Hann, Mossman, Morehead and Annie Rivers, plus three distributaries—the North Kennedy, Normanby and Bizant. Six of ten sampling sites for the Normanby focus region are located along a transect from the Normanby River mouth to open coastal waters and Corbett Reef (Figure 5-12). Two sample sites are located near the Kennedy River and one near the Bizant River mouth in the enclosed coastal water body. Site CI01 is located near the Cliff Isles ('Marrpa' in traditional Lama Lama language).

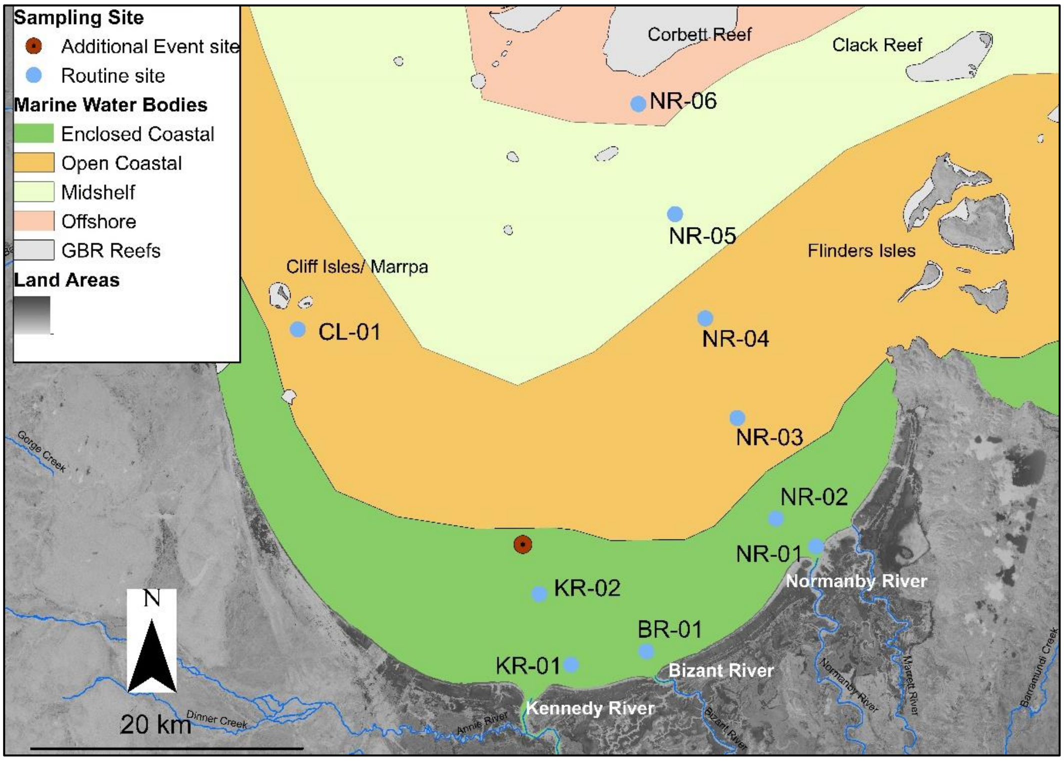

Figure 5-12: Water quality sampling sites in the Normanby Basin focus area with water body boundaries.

A total of 60 surface and sub-surface samples were collected over five sampling periods from November 2019 to March 2020 (Figure 5-13). Most sites were sampled four times, however Cliff Isles (CI-01) was sampled 5 times and NR-06 in the offshore zone was sampled twice. Scheduled sampling was not conducted in March 2020 due to COVID-19 travel restrictions. Sub-surface samples were collected at sites where water depths were greater than 3 m.

Estimated discharge from the Normanby Basin for the 2019–20 water year (2793 GL) was below the long-term median and less than one quarter the 2018–19 annual discharge (Table 3-1, Figure 5-14). Total discharge for the whole of the Normanby Basin cannot be accurately calculated as there is no gauge on the Kennedy River or at the mouth of any of the three Normanby Basin distributaries, and so has been estimated using the method described in Table 2-3.

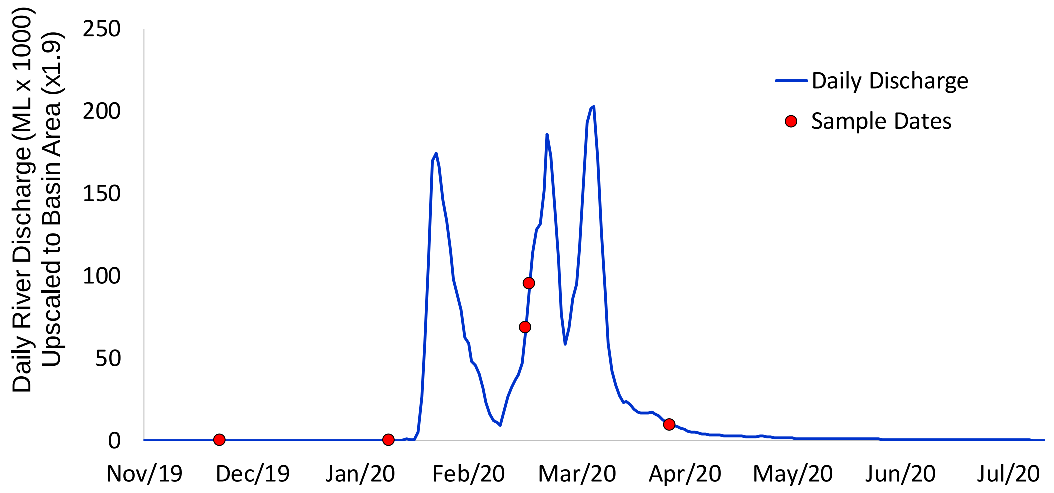

Figure 5-13: Daily discharge and sampling dates for the Normanby River (gauge 105107A) for the 2019–20 wet season. Note there is a 2 to 3-day travel time between the gauge and coastal waters, therefore February event samples were collected earlier in the rising flood stage than shown on the hydrograph.

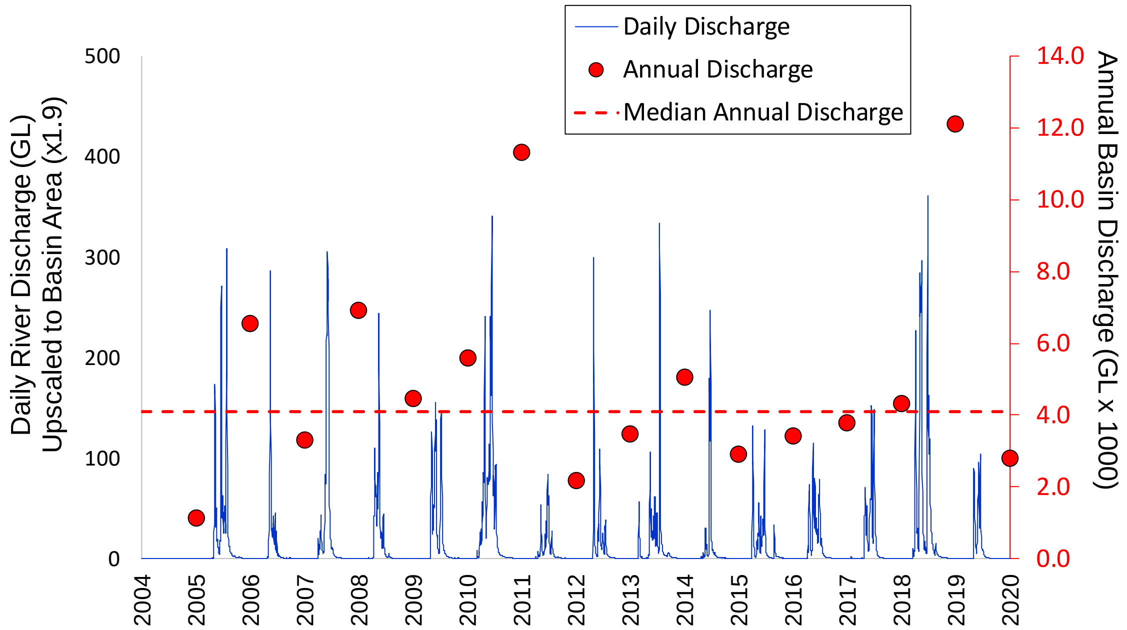

Figure 5-14: Long-term discharge for the Normanby River at gauge 105107A (Kalpowar Crossing). Daily (blue) and water year (October to September, red symbols) discharge volumes shown. Method for estimation is described in Table 2-3.

The discharge and modelled load estimates (Source Catchments) for the 2019–20 water year from the Normanby Basin were the second lowest calculated for the past decade. Over the 14-year period from 2006–07:

- discharge has varied from 2,182 GL (2011–12) to 12,102 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)
- PN loads ranged from 124 t (2009–10) to 2,470 t (2018–19).

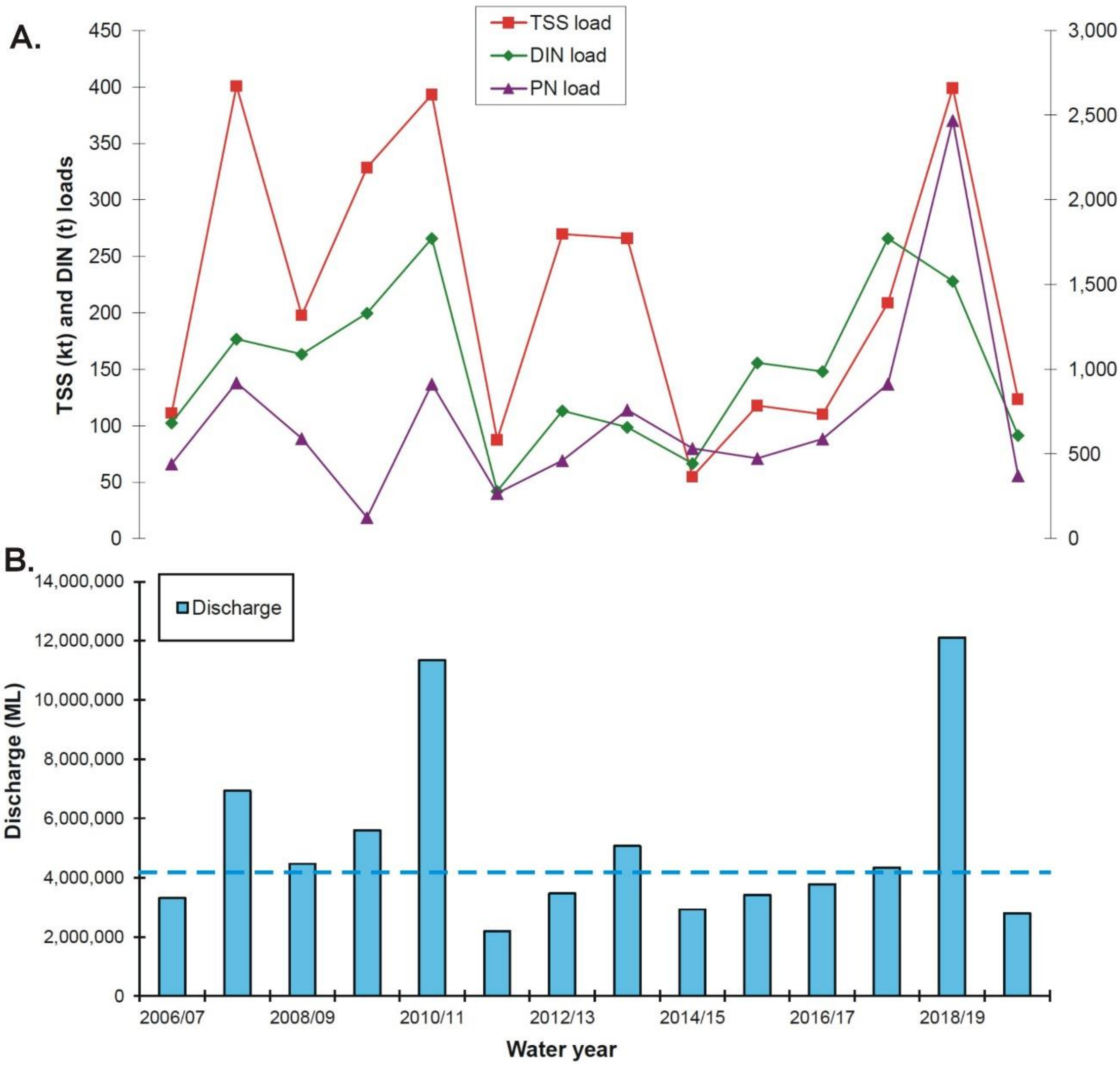

Figure 5-15: Modelled loads of (A) total suspended solids, dissolved inorganic (DIN) and particulate nitrogen (PN) and (B) discharge for the Normanby Basin. The loads reported here are a combination of 'best estimates' based on 'up-scaled' discharge and monitoring data from the Normanby River at Kalpowar 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 four sampling events (five at CI-01) during the wet season, including one that coincided with a flood event (Figure 5-13). Both ambient and event water quality results are plotted against distance from the closest river mouth (Normanby, Bizant, or Kennedy) in Figure 5-17. Ambient results only are compared against the GV for each water body in Appendix C Table C-1.

Comparison of the 2019–20 ambient results with previous years and the GVs (see Appendix C Table C-1) highlights that:

- High TSS in the enclosed coastal water body occurred during both dry and wet season conditions (median 11 and 12 mg L^{-1}, respectively), exceeding the wet season 50th percentile GV (6 mg L^{-1}). TSS also exceeded the wet season 20th and 80th percentile GVs (not the median) in the open coastal water body but was below GVs in mid-shelf waters (Figure 5-17, Appendix C Table C-1).
- Secchi depth did not meet the wet season or annual GVs for the enclosed coastal, open coastal or mid-shelf water body (mean 1.0, 3.6 and 7.0 m, respectively).

- Median NO_x and PO_4 concentrations (2.9 and 2.6 µg L^{-1}, respectively) in the enclosed coastal water body exceeded the wet season guidelines. NH_3, NO_x and PO_4 exceeded the annual and wet season GVs in open coastal waters..
- PN concentrations were more than double the wet season 20-50-80th percentile GVs for open coastal waters.
- Chl-*a* concentrations remained below guidelines at all locations, in contrast to the previous year when mean and median concentrations were above the GVs in all water bodies. This difference is likely due to the much higher river discharge over the 2018–19 wet season compared to 2019–20.

Event water quality

Minimal flooding occurred in this focus region over the 2019–20 wet season compared to previous wet seasons, however there were three periods of elevated discharge and freshwater influence at Princess Charlotte Bay (Figure 5-14). Sampling occurred early in the rising stage of one of the events (25 and 26 February, Figure 5-13). While low salinity was measured in the enclosed coastal waters adjacent to the Normanby, Bizant and Kennedy estuaries, the plume was most evident along the Kennedy transect sampled on 26 February 2020, and rainfall records showed that the majority of rain occurred in the Hann sub-basin (Kennedy River distributary). Samples were collected along the Kennedy transect from the turbid primary plume waters (salinity 6, TSS 34 mg L^{-1},) through the greenish secondary plume in the open coastal water body (salinity 20, TSS 3.4 mg L^{-1}) and beyond the plume to the turquoise waters at Cliff Isles (CI01, salinity 32, TSS 1.6 mg L^{-1}). All parameters followed a similar pattern to TSS, with decreasing concentrations with distance from the river mouth (Figure 5-17). The exception was Chl-*a*, which increased to 1.55 µg L^{-1} at KR-02 (Figure 5-12) where TSS fell below 15 µg L^{-1}. These flood plume concentrations were relatively low compared to flood event samples from Princess Charlotte Bay collected during previous years (Gruber et al., 2020; Howley et al., 2018). It is difficult to estimate total river discharge associated with this event due to the lack of gauging on the Kennedy River.

Based on the analytical results and the extent of the flood plume (Figure 5-16), the floodwater was likely to have had minimal influence on coral reefs in Princess Charlotte Bay. Fringing coastal seagrass meadows were inundated with relatively high TSS, however high TSS concentrations are common in the Princess Charlotte Bay enclosed coastal water body.

Figure 5-16: Satellite image of Kennedy River flood plume on 26 February 2020. Source: NASA MODIS Aqua.

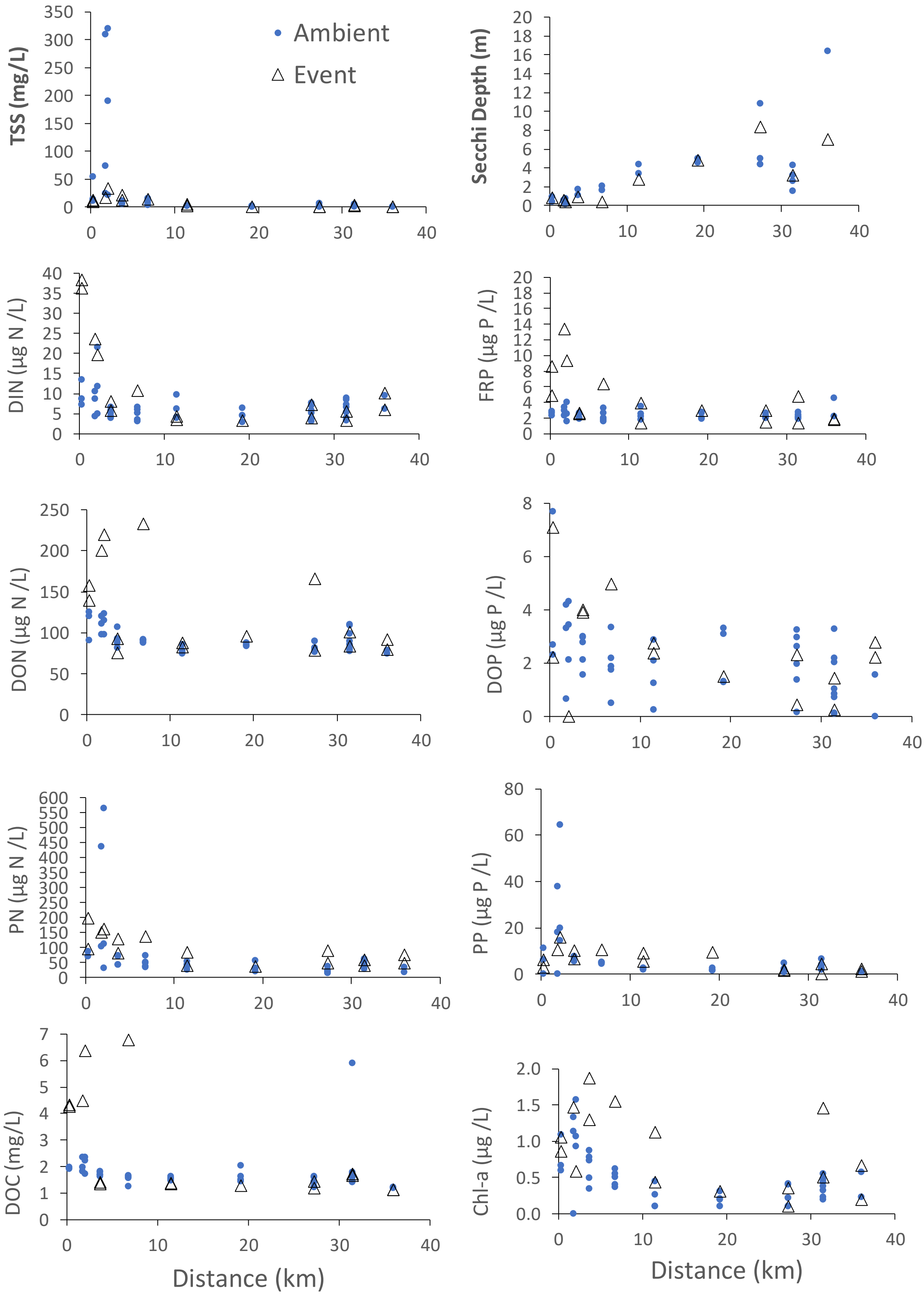

Figure 5-17: Water quality concentrations (surface and subsurface) and Secchi depth over distance (km) from river mouth for the Normanby focus region, all 2019–20 ambient (blue circles) and event (black triangles) sampling dates.

5.1.4 Annan-Endeavour

The Annan-Endeavour focus area is influenced primarily by discharge from the Endeavour and Annan Rivers. Seven sampling sites are located along transects from the two river mouths to mid-shelf waters, representing a gradient in water quality (Figure 5-18).

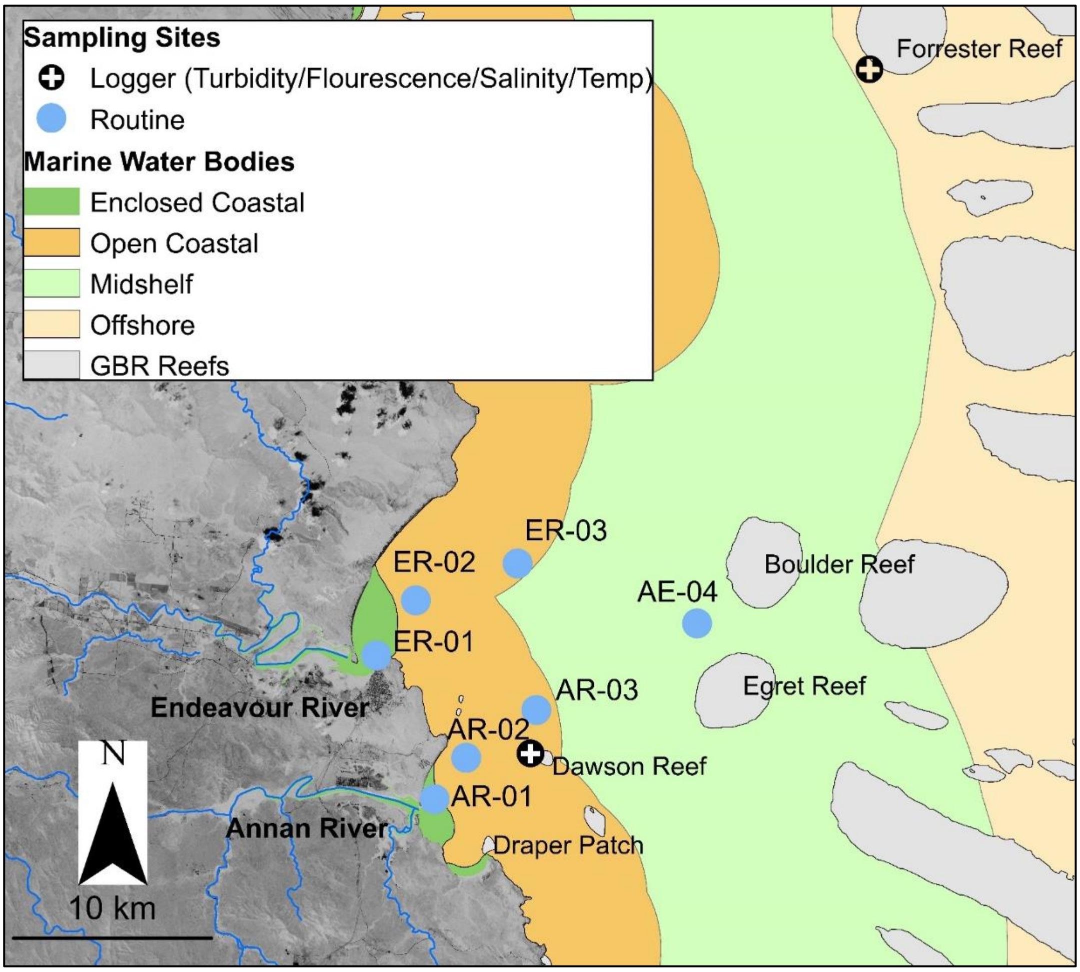

Figure 5-18: Water quality sampling sites in the Cape York region shown with water body boundaries.

A total of 67 surface and subsurface samples were collected from the Annan and Endeavour transect over nine days (including two consecutive days) during ambient conditions (between October 2019–March 2020). An additional six event samples were collected along the Annan River transect on 30 January 2020 (Figure 5-19). In addition to manual sampling, dataloggers monitored 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 5-18).

The estimated total discharge from the Endeavour Basin for the 2019–20 water year (773 GL) is well below the long-term median discharge and the lowest annual discharge in more than a decade (Table 3-1, Figure 5-20 and Figure 5-21). The combined discharge and modelled loads estimated for the 2019–20 water year from the Endeavour Basin are shown in Figure 5-21. Over the 14-year period from 2006–07:

- discharge has varied from 773 GL (2019–20) to 3,847 GL (2018–19)
- TSS loads have ranged from 39 kt (2019–20) to 192 kt (2018–19)
- DIN loads from 39 t (2019–20) to 192 t (2018–19)
- PN loads from 60 t (2019–20) to 308 t (2018–19).

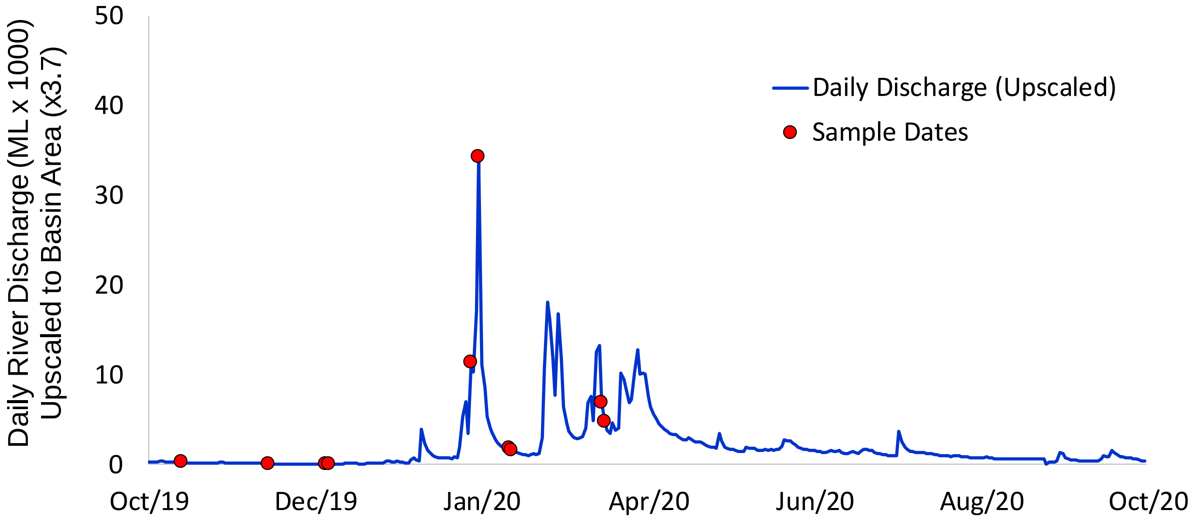

Figure 5-19: Daily discharge and sampling dates for the Endeavour Basin, combined (upscaled) values from the Annan River (gauge 107003A) and Endeavour River gauge (107001B) for the 2019–20 wet season.

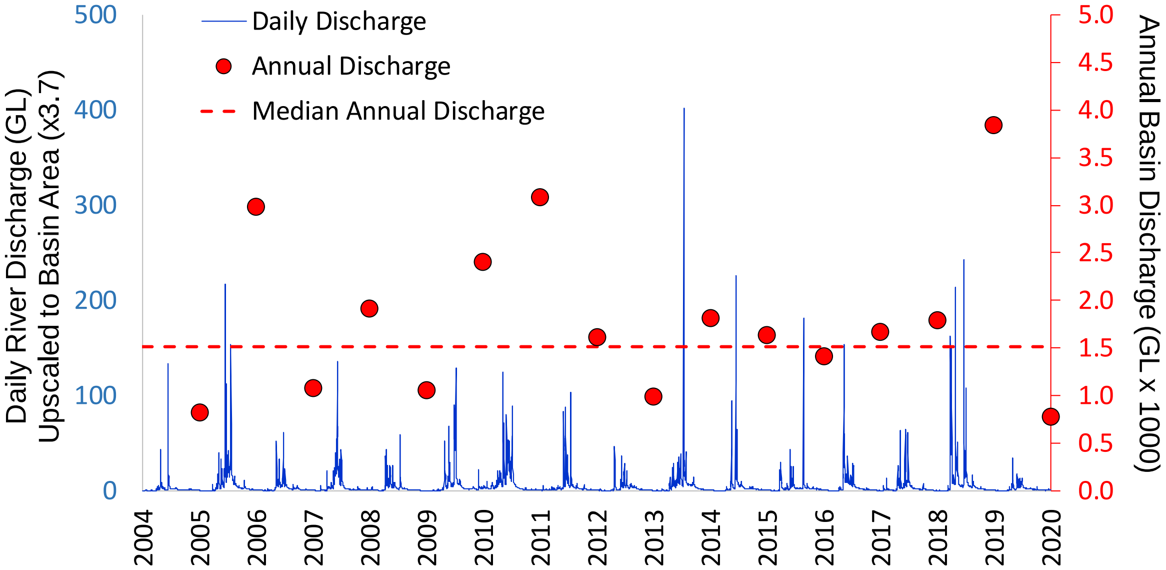

Figure 5-20: Long-term discharge for the Endeavour Basin, combined values from the Annan River (gauge 107003A) and Endeavour River (gauge 107001B). Daily (blue) and water year (October to September, red symbols) discharge volumes shown. Red dashed line represents long-term median of the combined annual discharge. Method for estimation is described in Table 2-3.

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

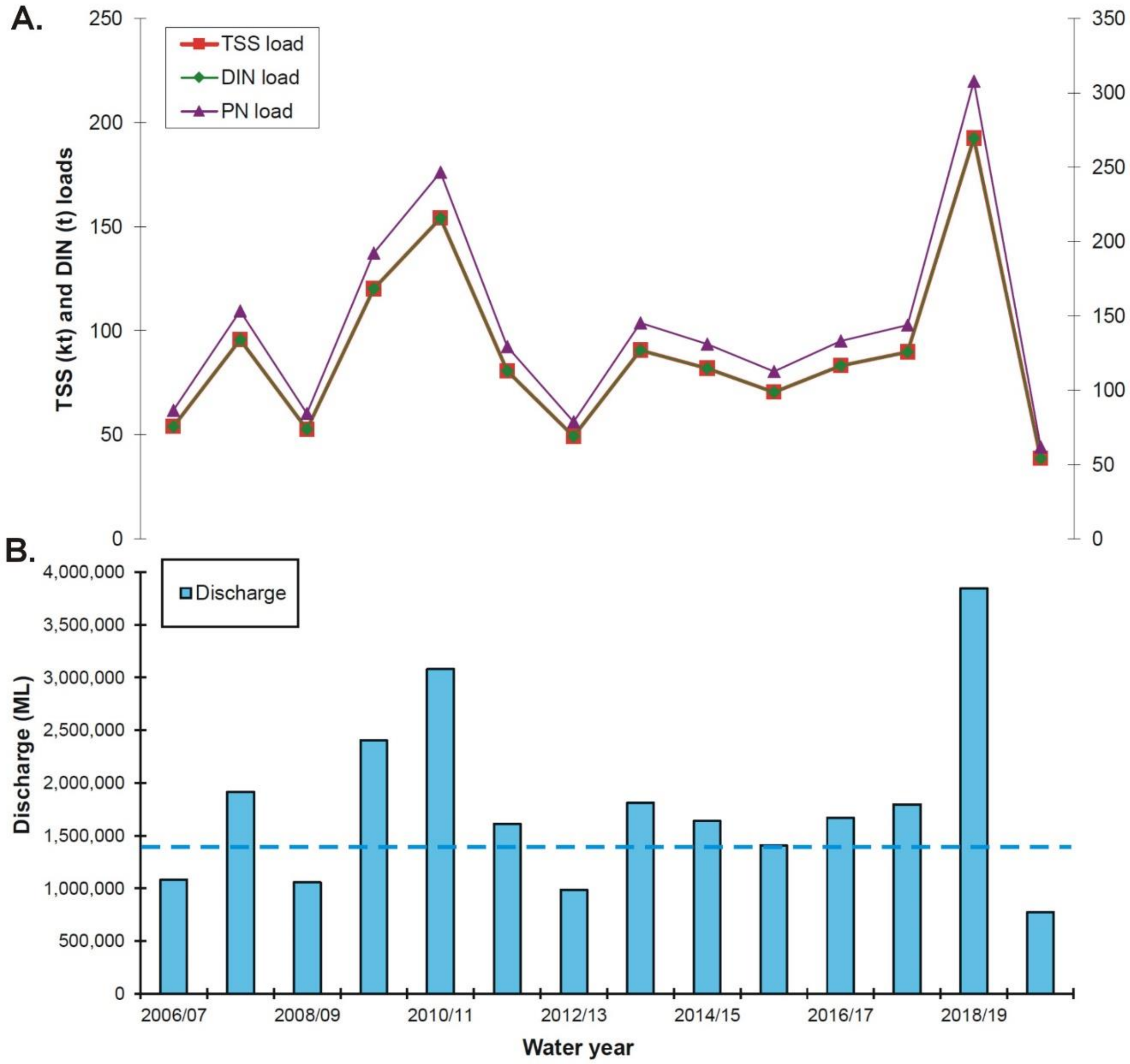

Figure 5-21. Loads of (A) total suspended solids, dissolved inorganic (DIN) and particulate nitrogen (PN) and (B) discharge for the Endeavour Basin from 2006 to 2020. The loads reported here are based on the annual mean concentration reported in the Source Catchments modelling data and applied to each water year. Dotted line represents the long-term median for basin discharge. 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 5-22). Ambient mean, median, 20th and 80th percentile values for each parameter are compared against the draft Eastern Cape York regional guidelines for the enclosed coastal (sites ER-01 and AR-01), open coastal (ER02, ER03, AR02, and AR03) and mid-shelf (AE04) water bodies in Appendix C Table C-1 .

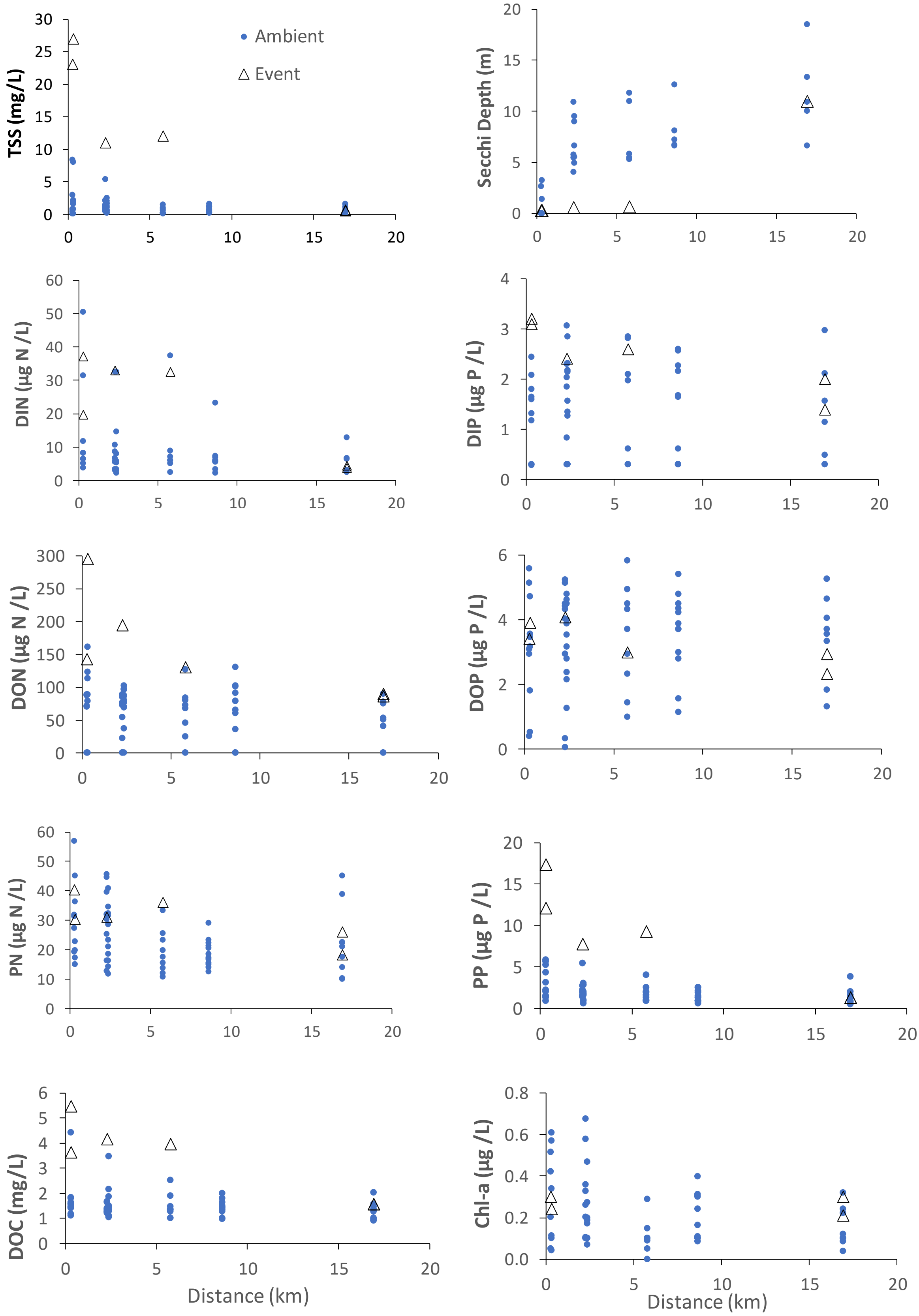

Figure 5-22: Water quality concentrations (surface and subsurface samples) and Secchi depth over distance from river mouth (km) for the Endeavour Basin focus region during ambient (blue circles) and event (black triangles) conditions (2019–20 water year).

Comparison of the 2019–20 ambient results with previous years and the water quality GVs (Appendix C Table C-1) highlights that:

- In the enclosed coastal waters, NH_3, NO_x and Secchi depth exceeded the wet season GVs (Appendix C Table C-1).
- In the open coastal waters, median or mean NO_x, PN and PO_4 exceeded the GVs during both the dry season and wet season and mean Secchi depth did not meet the annual GV.
- Median NH_3, NO_x and PN in mid-shelf waters exceeded the annual GVs.
- There is some uncertainty around the accuracy of NO_x, NH_3 and PO_4 results, which is likely to have contributed to these exceedances (Great Barrier Reef Marine Park Authority, 2020).
- Median datalogger turbidity values and Chl-*a* concentrations at Dawson and Forrester reefs meet the relevant GVs. The median turbidity at Dawson (0.73 NTU) was less than half that measured in the previous wet season (2.1 mg L^{-1}). Chl-*a* at Dawson Reef (0.22 µg L^{-1}) was also lower than the previous wet season median of 0.35 µg/L.

Event water quality

Minor flooding occurred in the Annan River from 23 January 2020, peaking on 30 January. This below-average magnitude event was the largest event of the wet season and generated an estimated total discharge of 130 GL. Flood sampling showed that turbid plume waters inundated reefs in the open coastal waters including Dawson and Cowlishaw Reefs

Manual sampling just after the peak of the event on 31 January 2020 measured:

- a TSS maxima of 23 and 27 mg L^{-1} near the mouths of the Annan and Endeavour rivers respectively
- TSS of 12 and 15 mg L^{-1} (surface and subsurface) near Dawson Reef in open coastal waters
- Chl-*a* concentrations around 0.3 µg L^{-1} in the enclosed coastal and open coastal water bodies during flood sampling. At Dawson Reef, the datalogger showed a Chl-*a* wet season maximum of 1.8 µg L^{-1} on 30 January associated with the flood event.

Sampling immediately after the event (10 and 11 February) showed that TSS levels had returned to ambient conditions, with TSS <2 mg L^{-1} and Chl-*a* remaining low (≤0.3 µg L^{-1}).

The datalogger results (Figure 5-23) showed that the below average water discharge from the Annan-Endeavour rivers resulted in less catchment to reef connectivity than was observed during previous years. However, there were several turbidity peaks above 5 to 10 NTU at Dawson Reef associated with periods of increased discharge and turbidity (>350 NTU) in the Annan estuary in late January and February 2020. Chl-*a* also peaked during these events, with concentrations of 1.8 µg L^{-1} and 1.0 µg L^{-1} on 30 January and 25 February. At Forrester Reef, only minor periods of elevated turbidity (2 to 6 NTU) and Chl-*a* were recorded and these were associated with flood events or high winds. Peak Chl-*a* fluorescence (1.3 µg L^{-1}) was measured at Forrester Reef on 15 March, associated with a minor flood event in the Endeavour Basin (turbidity 238 NTU in the Endeavour River 13 March). The values measured at Dawson and Forrester Reef represent sub-surface concentrations (2 to 3 m below the surface) and are likely to be significantly higher at the surface (Gruber et al., 2020).

Figure 5-23: 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 2019–20 wet season. Estuary turbidity (EXO2) data provided by CYWMP and CSIRO. Dotted lines show wet season GVs.

5.2 Wet Tropics region

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

5.2.1 Barron Daintree

This focus region contains the six sites of the 'Cairns Transect', which are sampled three times a year (Figure 5-24). 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.

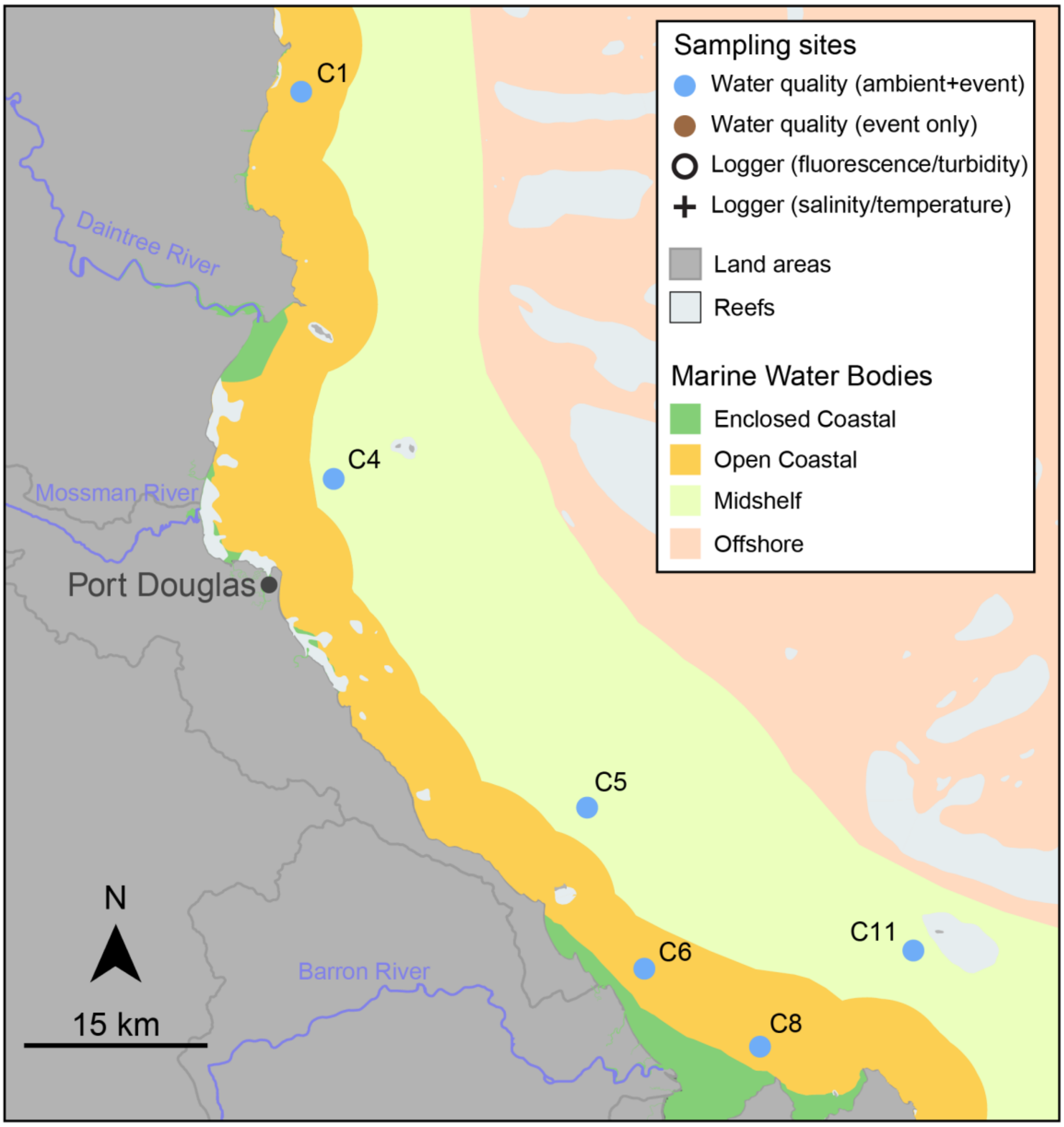

Figure 5-24: Sampling sites in the Barron Daintree focus region shown with water body boundaries.

The total discharge during the 2019–20 water year was well below the long-term median discharge (Figure 5-25), and was the smallest on record since the start of the MMP.

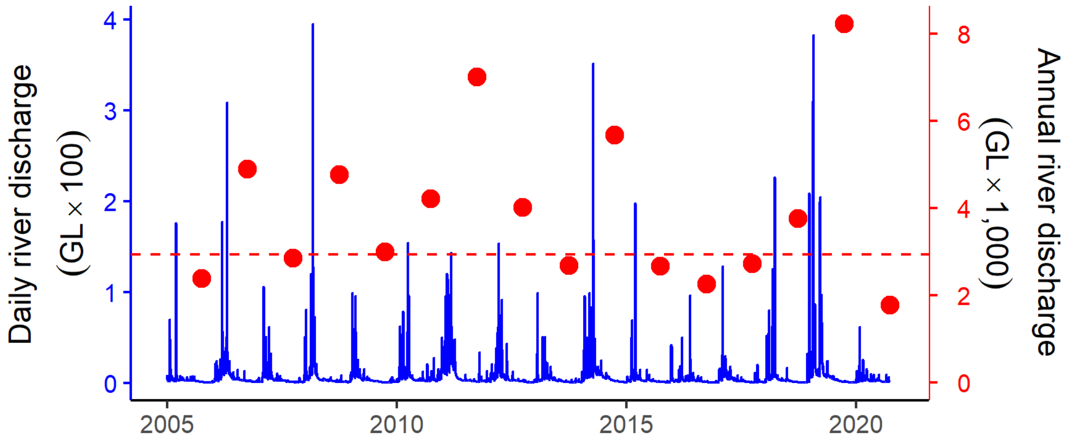

Figure 5-25: Combined discharge for the Barron (Myola gauge) and Daintree (Bairds gauge) Rivers. Daily (blue) and water year (October to September, red symbols) discharge volumes shown. Red dashed line represents long-term median of the combined annual discharge.

The combined discharge and loads calculated for the 2019–20 water year from the Barron, Daintree, and Mossman Basins were the lowest since the start of the MMP (Figure 5-26). The discharge from the Daintree and Mossman Basins was the lowest over the past decade and discharge from the Barron was the third lowest over the past decade and all were well below the long-term median (Table 3-1). Over the 14-year period from 2006-07:

- discharge has varied from 1,777 GL (2019–20) to 8,174 GL (2018–19)
- TSS loads ranged from 137 kt (2019–20) to 697 kt (2010–11)
- DIN loads ranged from 167 t (2019–20) to 758 t (2018–19)
- PN loads ranged from 411 t (2019–20) to 2,092 t (2010–11).

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).

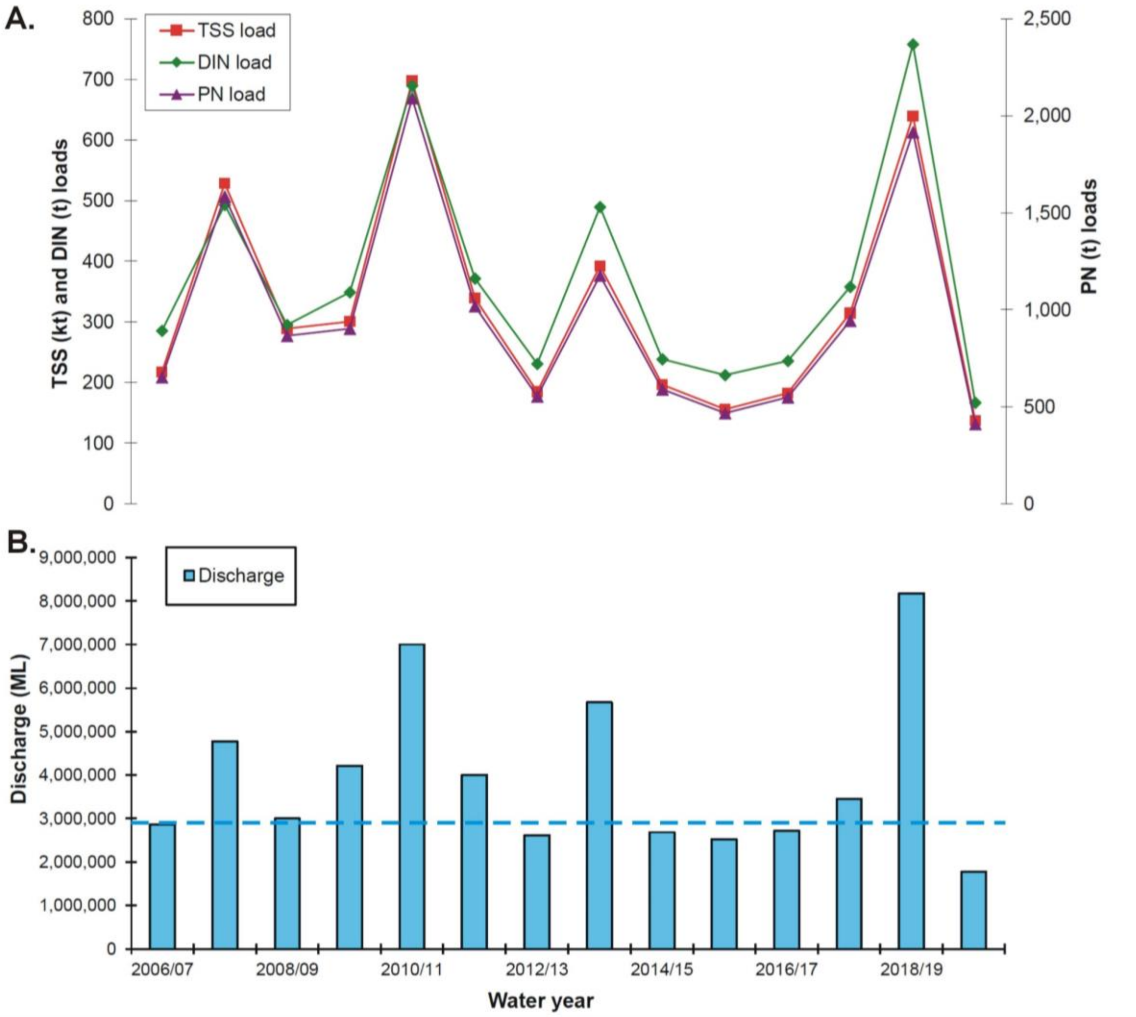

Figure 5-26: Loads of (A) TSS, DIN and PN and (B) discharge for the Barron, Daintree, and Mossman Basins from 2006–2020. The loads reported here are a combination of 'best estimates' for each basin based on 'up-scaled discharge data from gauging stations, monitoring data (Barron River), the DIN model 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 5-27. 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 5-27). Site-specific statistics and comparison to GVs for all variables are available in Appendix C Table C-2. Mean concentrations of Chl-*a* and TSS have generally fluctuated around GVs (Great Barrier Reef Marine Park Authority, 2010) since the inception of the MMP. Analysis of trends shows that from 2015–2020, mean concentrations of both Chl-*a* and TSS have decreased and are now both below (meeting) water quality GVs. Mean concentrations of PO_4 have been relatively stable since the start of the MMP, whereas mean NO_x concentrations have generally increased since 2005. Analysis of trends shows that from 2015–2020, mean concentrations of PO_4 have declined and are currently below (meeting) GVs, while NO_x has not significantly changed and continues to be well above (exceeding) GVs.

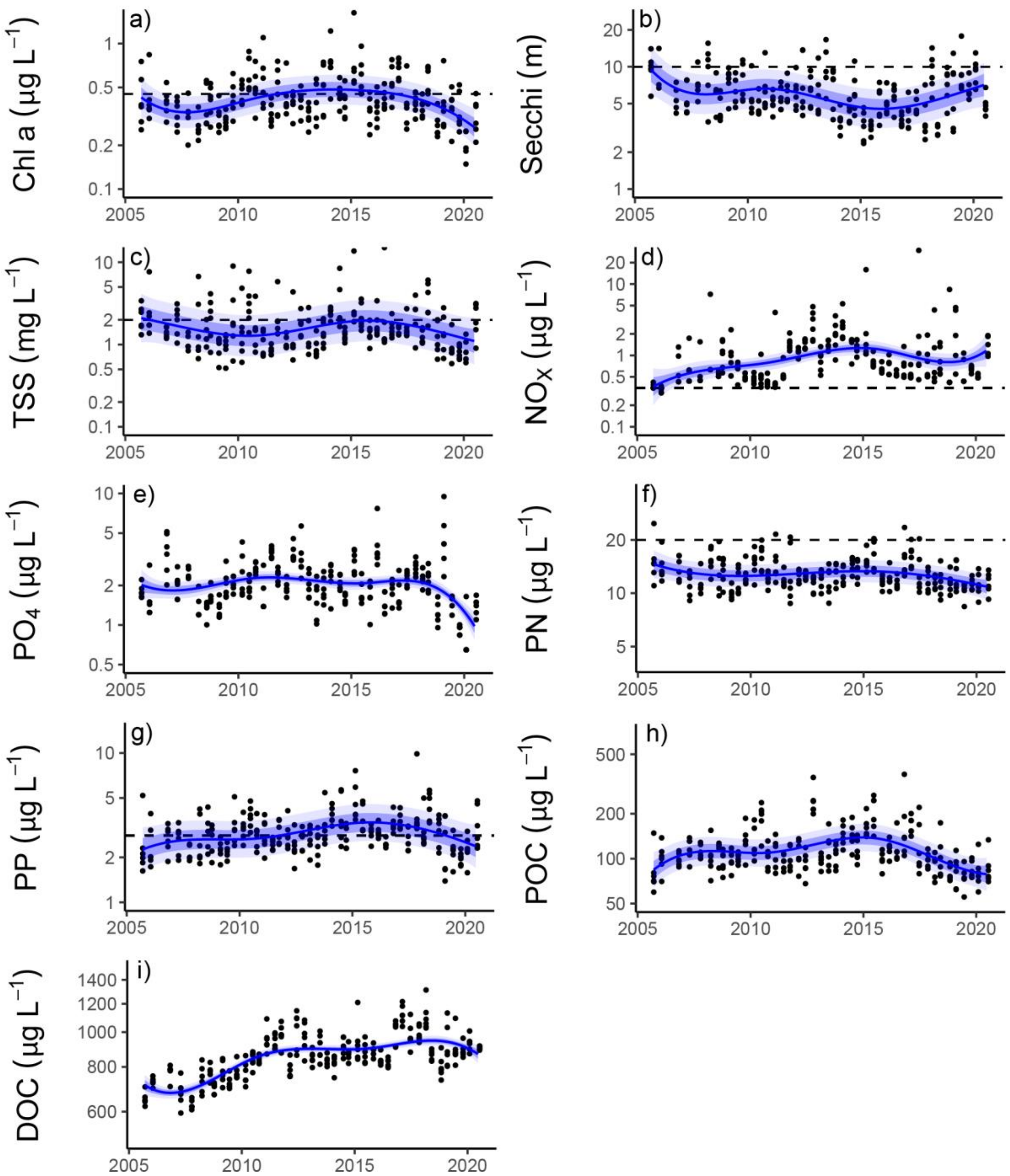

Figure 5-27: Temporal trends in water quality variables for the Barron Daintree focus region: a) chlorophyll *a* (Chl-*a*), b) Secchi depth, c) total suspended solids (TSS), d) nitrate/nitrite (NO_x), e) phosphate (PO_4), f) particulate nitrogen (PN), g) particulate phosphorus (PP), h) particulate organic 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 guidelines.

Mean Secchi depth declined (i.e. water clarity worsened) in previous years (up until 2016), but analysis of trends shows that from 2015–2020, Secchi depth has increased (e.g., water clarity has improved) although it remains below (exceeding) the GV.

Mean concentrations of PN and PP have been relatively stable since the inception of the MMP. Analysis of trends shows that from 2015–2020, mean concentrations of PN have not significantly changed and remain below (meeting) GVs, while mean concentrations of PP have decreased but remain above (exceeding) GVs.

Mean concentrations of POC have varied since 2005, and analysis of trends shows that from 2015–2020, POC has decreased. Mean concentrations of DOC have increased dramatically since the inception of the MMP although trend analysis indicates they remained stable from 2015–2020.

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). For the Barron Daintree focus region (the Cairns Transect sites), no additional sites were added in 2015 and sampling is still conducted three times per year, unlike all other focus regions. The Methods section and Appendix B contain details of the calculations for both indices.

The long-term WQ Index has generally scored water quality as 'good' since 2005 with two years of 'moderate' in 2016–17 and 2017–18 water years. The long-term trend has been a small (i.e., changing by a single grade) but gradual decline in water quality from 2005–2018. Water quality appears to be trending towards improvement in the last two years, although further data is needed before this can be confirmed (Figure 5-28a).

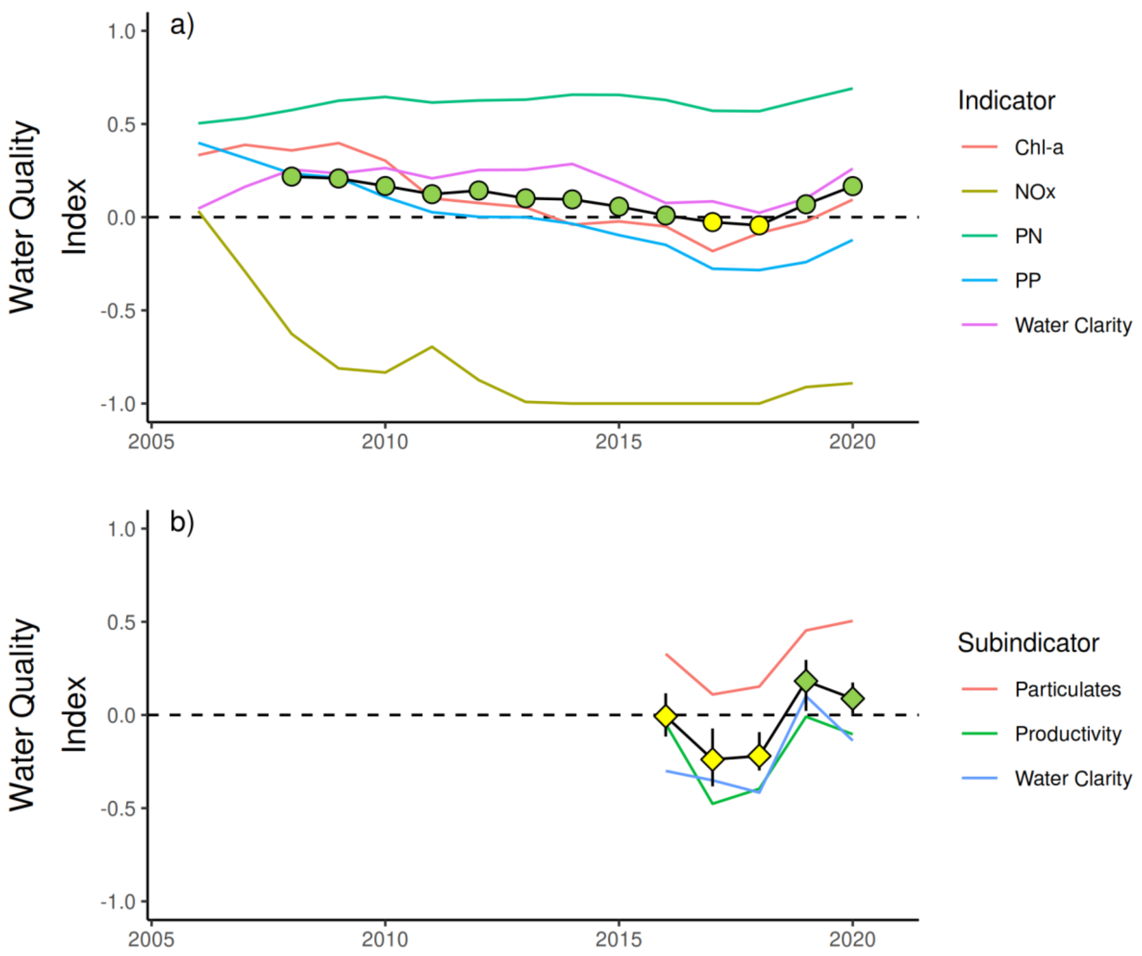

Figure 5-28: The Water Quality Index (WQ Index) for the Barron Daintree focus region. The WQ Index uses two formulations to communicate: a) long-term trend (based on pre-2015 sampling design) and b) the annual condition (based on post-2015 sampling design). WQ Index colour coding: ● / ◆– 'very good'; ● / ◆ – '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.

The annual condition WQ Index scored water quality as 'moderate' during the 2015–18 water years and 'good' during the last two water years (Figure 5-28b). 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 well below average in this focus region this year, which likely contributed to a '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.

Event water quality

No event sampling was conducted in the Barron Daintree focus area in 2019–20.

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., 2017a). 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 C-1). The monitoring sites are located in a transect from the river mouth to mid-shelf waters, representing a gradient in water quality. Five sites are located 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 5-29).

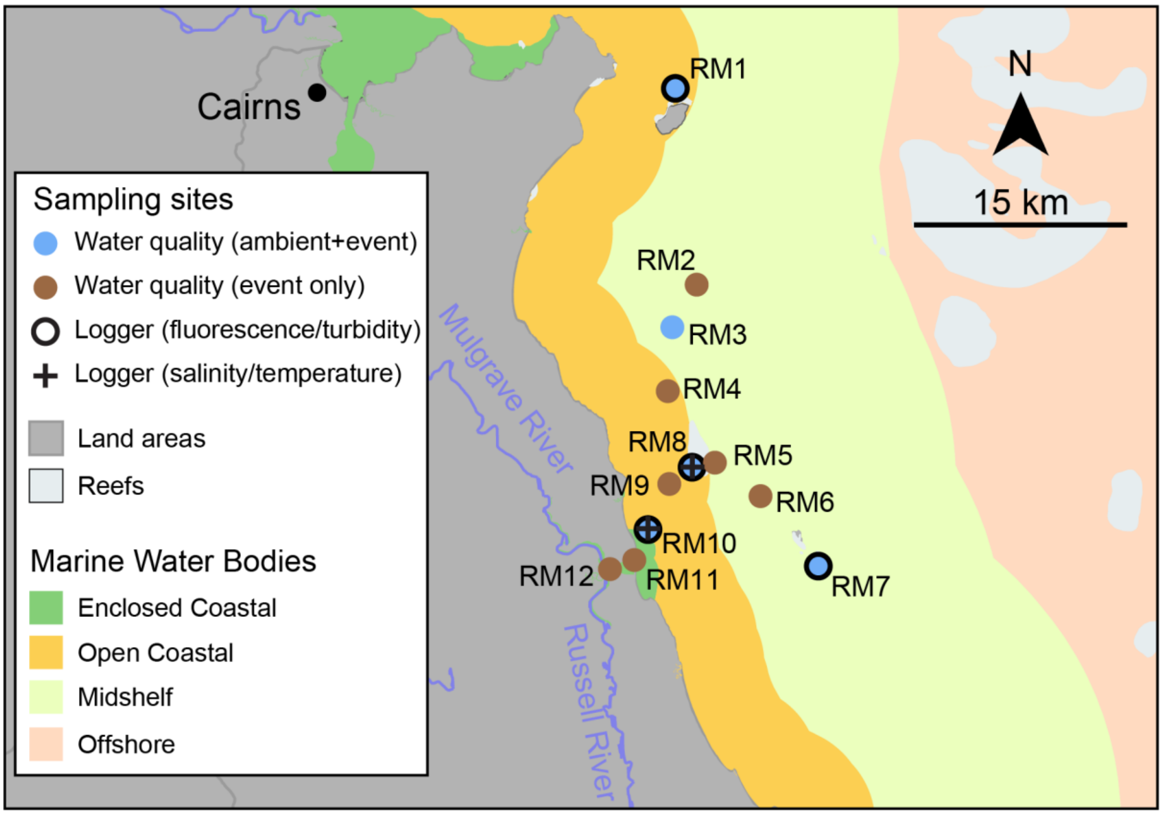

Figure 5-29: Sampling sites in the Russell-Mulgrave focus region, shown with the water body boundaries.

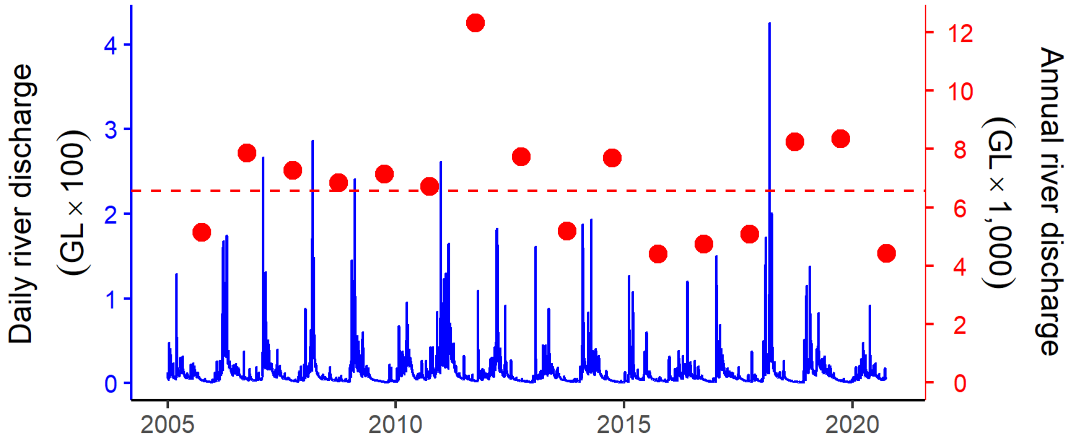

Figure 5-30: Combined discharge for the North and South Johnstone (Tung Oil and Central Mill gauges, respectively), Russell (Bucklands gauge) and Mulgrave (Peets Bridge gauge) Rivers. Daily (blue) and water year (October to September, red symbols) discharge is shown. Red dashed line represents the long-term median of the combined annual discharge.

The combined discharge volume of the Russell-Mulgrave and Johnstone Rivers was well below the long-term median over the 2019–20 water year and was similar to the annual discharge from the 2014–15 water year (Figure 5-30).

The combined discharge and loads calculated for the 2019–20 water year from the Russell-Mulgrave and Johnstone Basins were in the lower range to that recorded over the past decade (Figure 5-31).

Discharge, TSS, PN and DIN loads were amongst the lowest estimated since the 2006–07 water year. Over the 14-year period:

- discharge has varied from 4,372 GL (2014–15) to 12,335 GL (2010–11)
- TSS loads ranged from 309 kt (2014–15) to 911 kt (2010–11)
- DIN loads ranged from 744 t (2014–15) to 2,145 t (2010–11)
- PN loads ranged from 1,290 t (2014–15) to 3,783 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, although the latter basins contribute higher values (particularly DIN) during the high discharge years such as in 2008–09 and 2010–11 water years

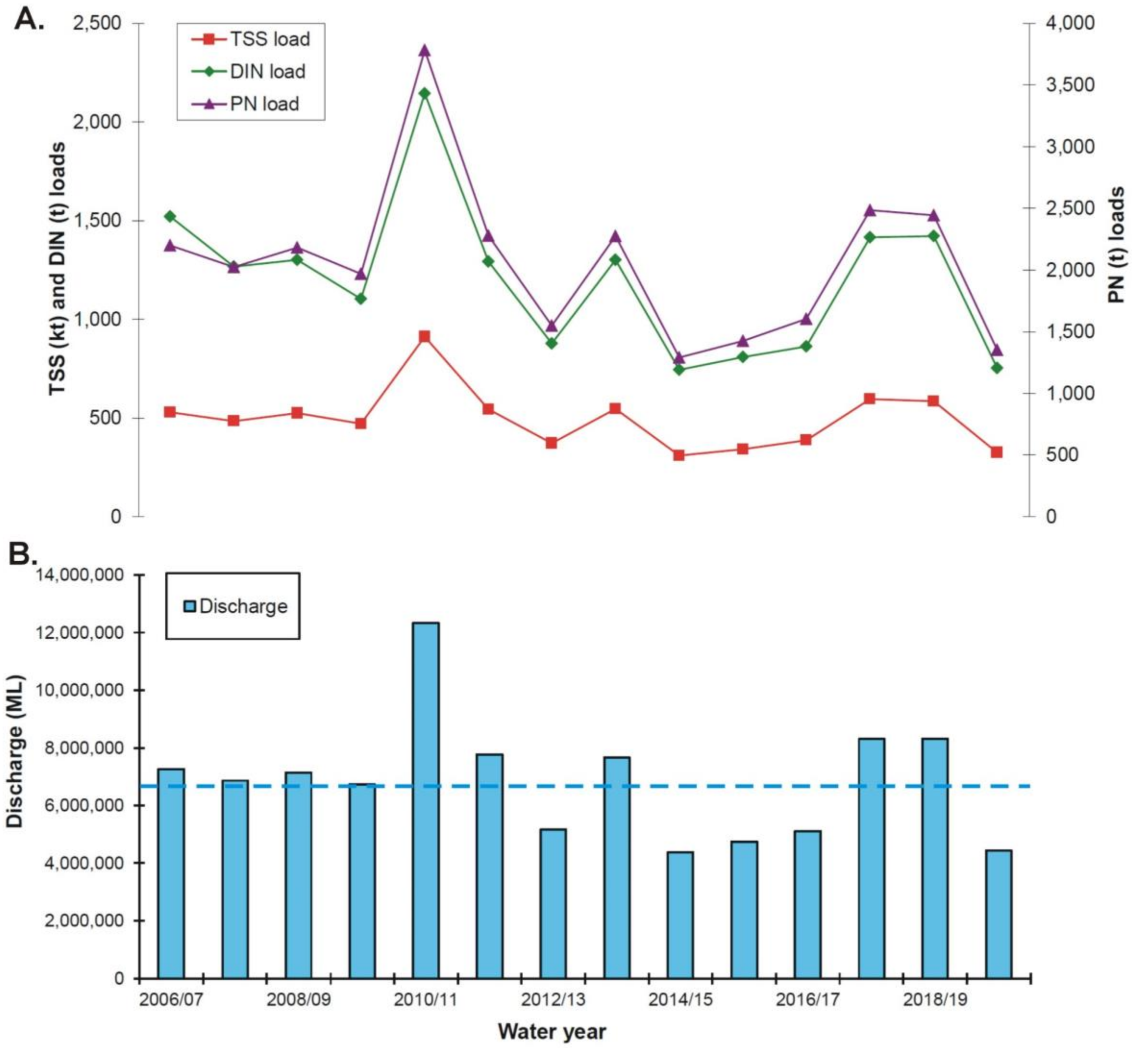

Figure 5-31: Loads of (A) TSS, DIN and PN and (B) discharge for the Russell, Mulgrave and Johnstone Basins from 2006 to 2020. The loads reported here are a combination of 'best estimates' for each basin based on 'up-scaled discharge data from gauging stations, monitoring data (Johnstone River), the DIN 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 (river mouth = 0 km) had high concentrations of NO_x (during the wet season) and particulate nutrients (PN and PP), which declined with distance away from the river mouth, reaching low levels in mid-shelf waters (Figure 5-32, 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.

Seasonal differences were not as prominent as in previous years, which was likely due to below-average river discharge during the 2019–20 water year. Seasonal differences in water quality were present for some variables. Ambient monitoring during the wet season showed greater values of NO_x than during the dry season, especially at sites close to the river mouth. Concentrations of Chl-*a* and PP were similar between wet and dry seasons, while TSS displayed higher concentrations during the dry season than the wet (Figure 5-32). This can happen in years of low river discharge, as the dry season has higher average wind speeds than the wet season, which leads to increased wind-driven resuspension. Secchi depths were overall greater (water clarity was higher) during the wet season than the dry. There was likely little influence of river discharge on mid-shelf waters during the 2019–20 water year, which was demonstrated by wet and dry season values converging in mid-shelf waters (e.g., NO_x and TSS).

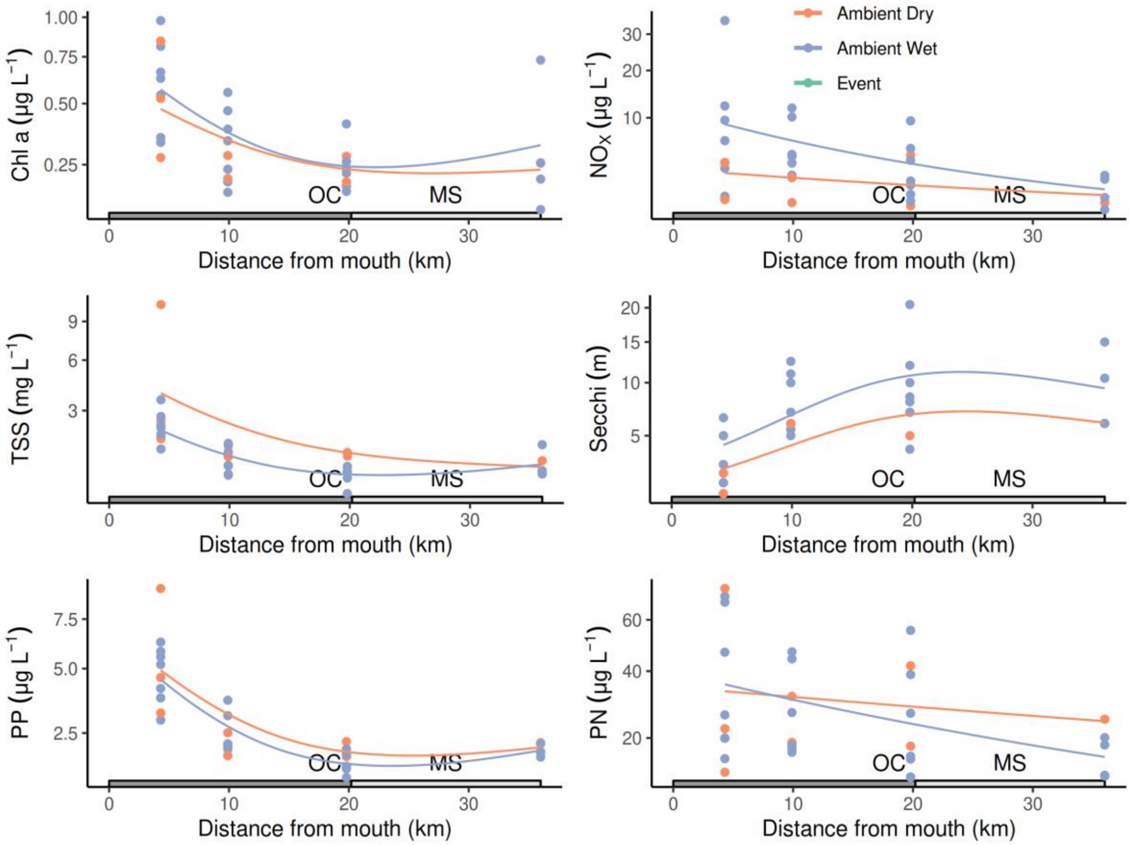

Figure 5-32: Water quality variables measured during ambient and event sampling in 2019–20 along the Russell-Mulgrave focus region transect. Chlorophyll *a* (Chl-*a*), nitrate/nitrite (NO_x), total suspended solids (TSS), Secchi depth, particulate nitrogen (PN), and particulate phosphorus (PP) are shown 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 (e.g., not during peak flood events) of the dry and wet seasons are presented in Figure 5-33. 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 5-33). Site-specific statistics and comparison to GVs for all variables are available in Appendix C Table C-2. Mean concentrations of Chl-*a* and TSS have generally fluctuated around GVs (Great Barrier Reef Marine Park Authority, 2010) since the start of the MMP. Analysis of trends shows that from 2015–2020, mean concentrations of both Chl-*a* and TSS have decreased and are now both below (meeting) water quality GVs at most sites.

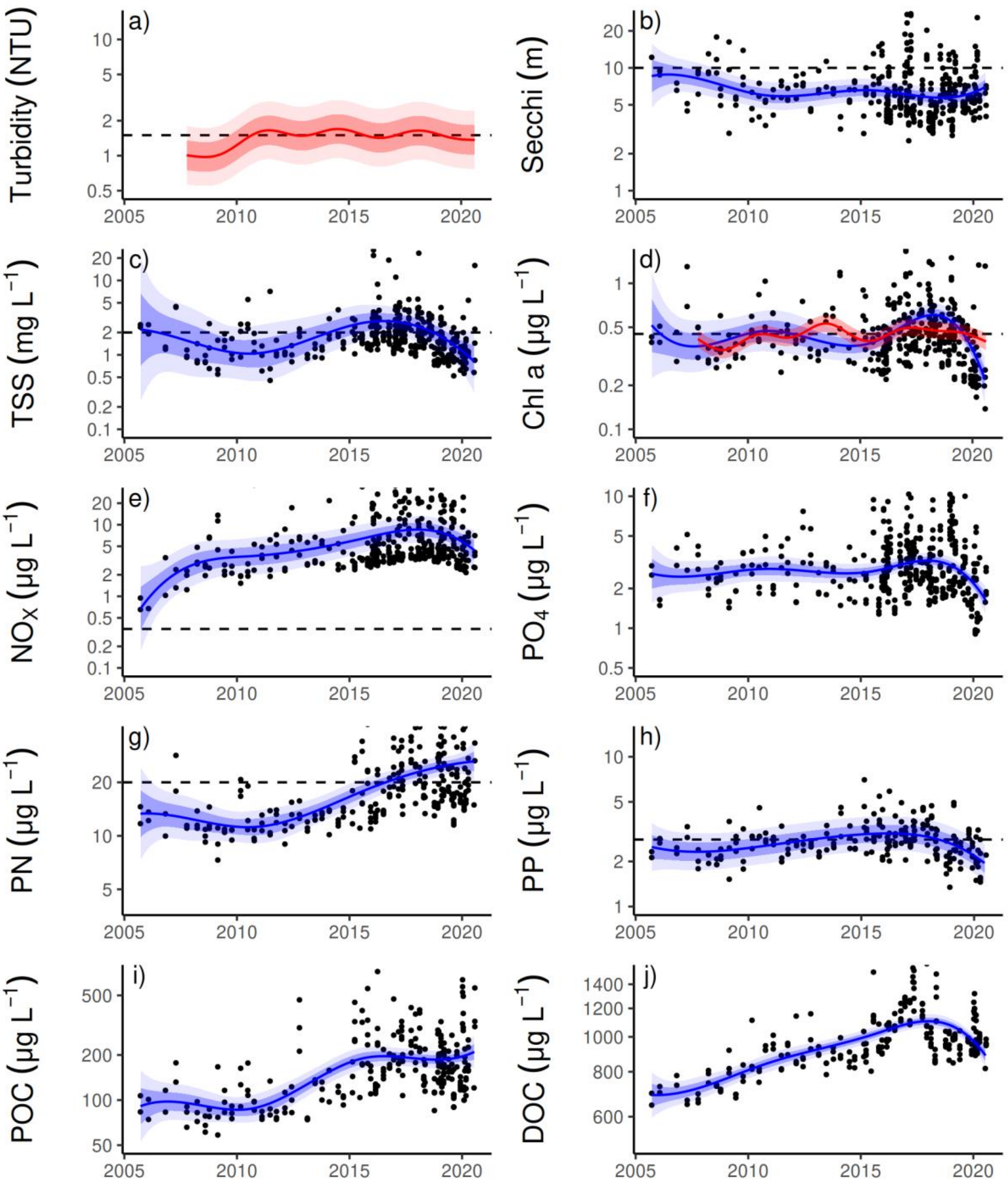

Figure 5-33: Temporal trends in water quality variables for the Russell-Mulgrave focus region: a) turbidity, b) Secchi depth, c) total suspended solids (TSS), d) chlorophyll a (Chl-*a*), e) nitrate/nitrite (NO_x), f) phosphate (PO_4), g) particulate nitrogen (PN), h) particulate phosphorus (PP), i) particulate 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.

Mean concentrations of PO_4 have been relatively stable since the inception of the MMP, and analysis of trends shows that from 2015–2020 concentrations have declined and are currently below (meeting) GVs at most sites. Mean concentrations of NO_x have generally increased since 2005 and analysis of trends shows that from 2015–2020 concentrations have remained stable and are currently well above (exceeding) GVs. Mean Secchi depth declined (i.e. water clarity worsened) since the inception of the MMP, but analysis of trends shows that from 2015–2020, Secchi depth has remained stable and below (exceeding) the GV.

Mean concentrations of PN and PP have varied around the GV since the inception of the MMP. Analysis of trends shows that from 2015–2020, mean concentrations of PN have increased and continue to be above (exceeding) GVs at most sites, while mean concentrations of PP have decreased and are currently below (meeting) GVs at most sites. Mean concentrations of POC and DOC dramatically increased since monitoring began in 2005, although this trend has been reversing in recent years. Analysis of trends shows that from 2015–2020, POC has remained stable, while DOC has decreased.

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 indices.

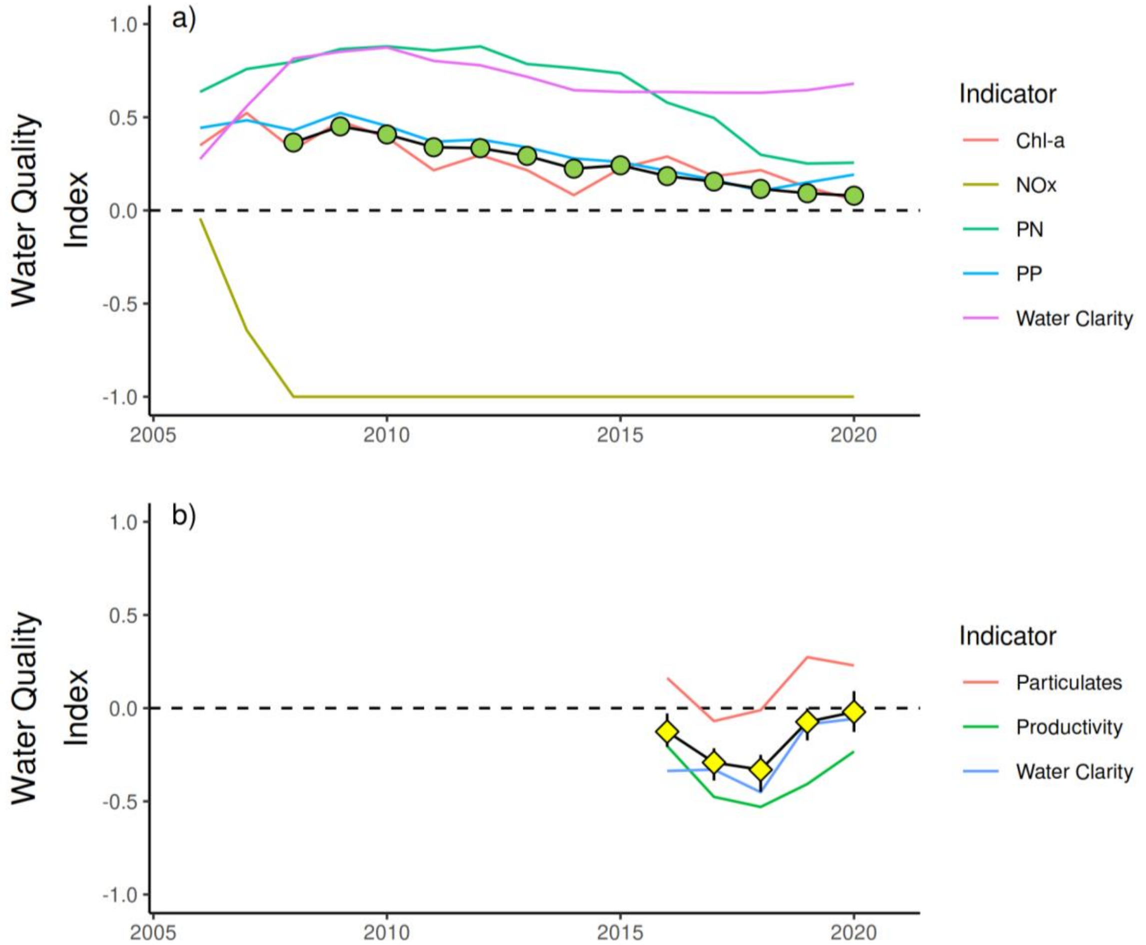

Figure 5-34: The Water Quality Index (WQ Index) for the Russell-Mulgrave focus region. The WQ Index uses two formulations to communicate: a) long-term trend (based on pre-2015 sampling design) and b) the annual condition (based on post-2015 sampling design). WQ Index colour coding: ● / ◆– 'very good'; ● / ◆ – '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 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 water quality since 2009 (Figure 5-34a). This downward trend has generally been driven by trends in PN, PP, and Chl-*a* indicators.

The annual condition WQ Index scored water quality as 'moderate' for the last five years (Figure 5-34b), and the score for the 2019–20 water year was higher than previous years (although still within the 'moderate' grade range). 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 below average in this focus region this year, which likely contributed to an improved annual condition 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.

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 Appendix C Table C-1. The monitoring sites are located in a transect from the river to mid-shelf waters, representing a gradient in water quality. Seven sites are located in the open coastal water body, one site is located in the mid-shelf water body, one site is in mid-estuarine waters, and two sites are in lower estuarine waters (Figure 5-35).

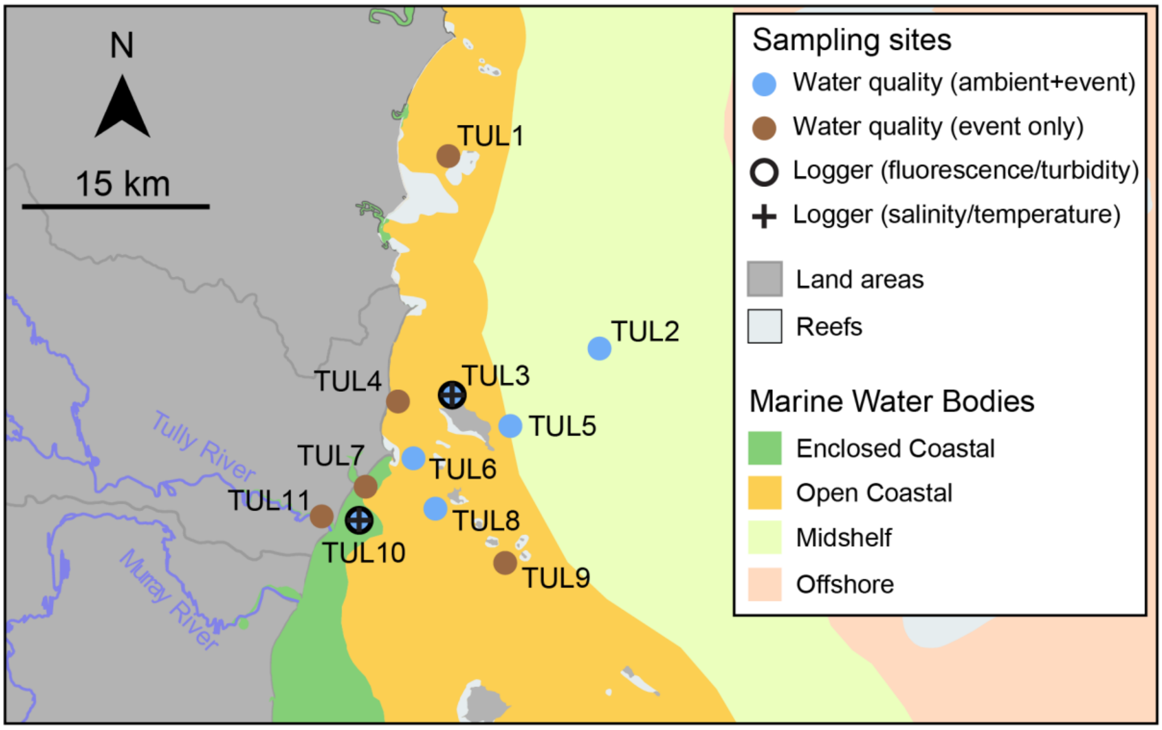

Figure 5-35: Sampling sites in the Tully focus area, shown with the water body boundaries.

The total discharge for the Tully, Murray and Herbert Rivers in 2019–20 was the second lowest over the past decade and well below the long-term median (Figure 5-36). The total discharge for this focus region over the 2019–20 water year (1 October 2018–September 2019) was nearly half of the long-term median (Table 3-1).

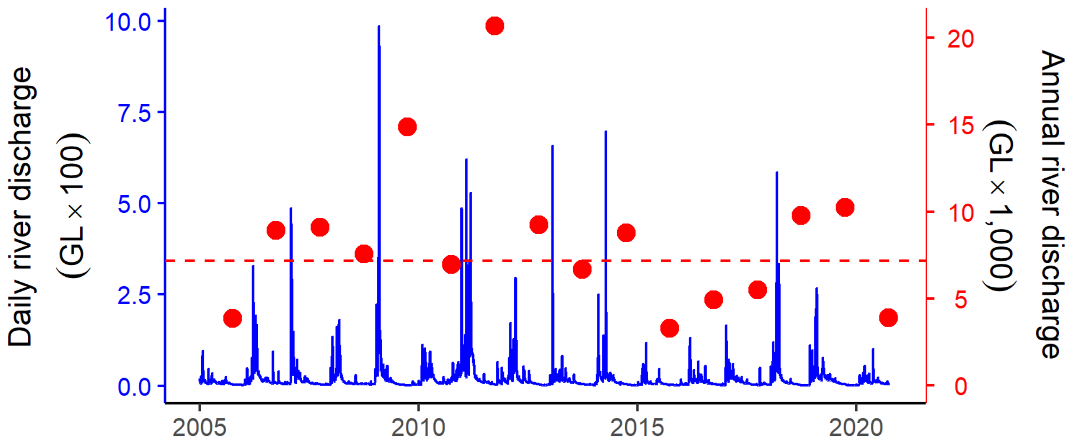

Figure 5-36: Combined discharge for Tully (Euramo gauge) and Herbert (Ingham gauge) Rivers. Daily (blue) and water year (October to September, red) discharge is shown. Red dashed line represents the long-term median of the combined annual discharge. Please note as this is the combined discharge, high flows in one river will not necessarily be visible in the graph.

The combined discharge and loads calculated for the 2019–20 water year from the Tully, Murray, and Herbert Basins were the second lowest recorded over the past decade (Figure 5-37). Over the 14-year period:

- discharge has varied from 3,647 GL (2014–15) to 20,738 GL (2010–11)
- TSS loads ranged from 188 kt (2014–15) to 1,530 kt (2010–11)
- DIN loads ranged from 1,022 t (2014–15) to 5,214 t (2010–11)
- PN loads ranged from 653 t (2014–15) to 4,330 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.

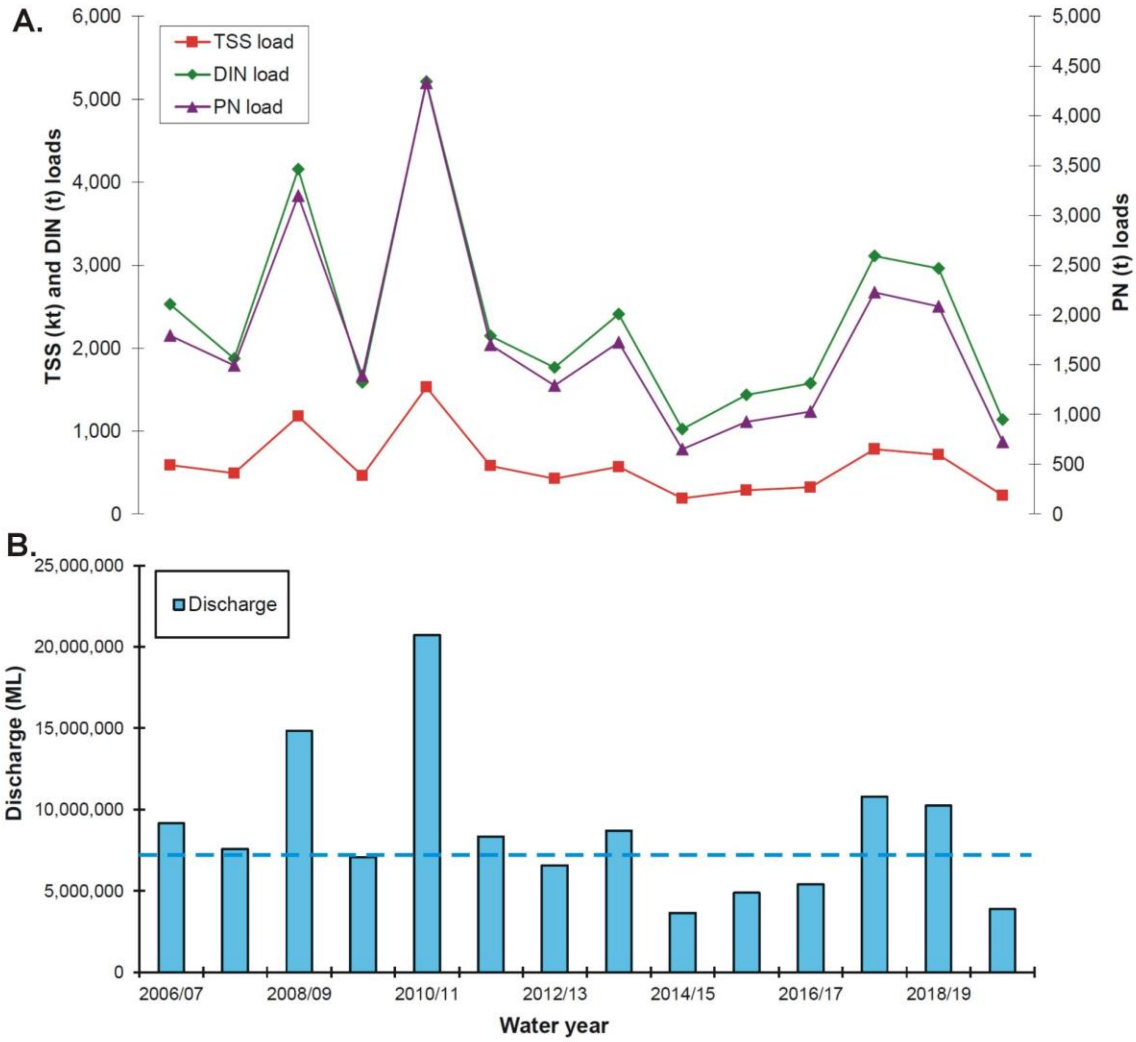

Figure 5-37: Loads of (A) TSS, DIN and PN and (B) discharge for the Tully, Murray, and Herbert Basins from 2006–07 to 2019–20. The loads reported here are a combination of 'best estimates' for each basin based on 'up-scaled discharge data from gauging stations, monitoring data (Tully and Herbert Rivers), 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 (river mouth = 0 km) had high concentrations of particulate nutrients (PN and PP), which declined with distance away from the river mouth, reaching low levels in mid-shelf waters (Figure 5-38, Appendix C Table C-2). 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 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 were variable along the transect and did not show clear patterns.

Seasonal differences were not as prominent as in previous years, which was likely due to below-average river discharge during the 2019–20 water year. Seasonal differences in water quality were present for some variables. Ambient monitoring during the wet season showed greater values of PN and PP than during the dry season. Concentrations of NO_x, Chl-*a*, and TSS were similar between wet and dry seasons (Figure 5-38). Secchi depths were overall greater (water clarity was higher) during the wet season than the dry.

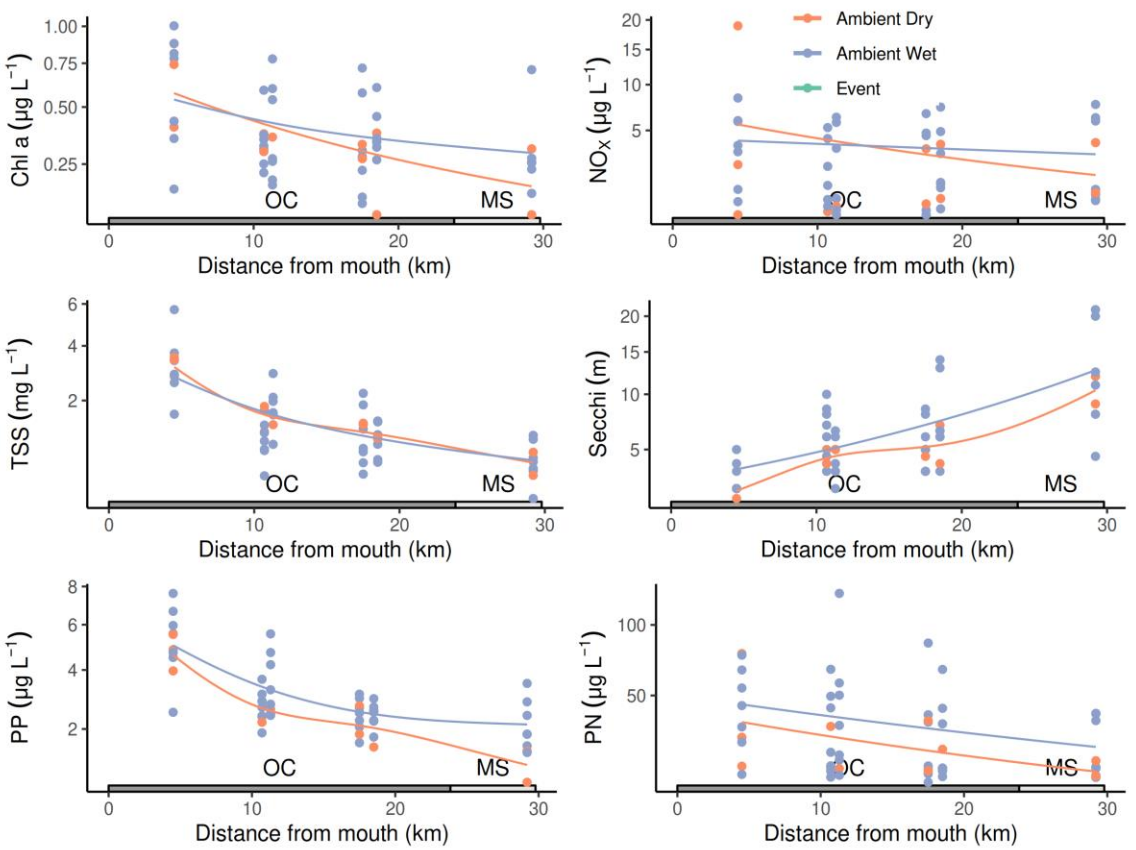

Figure 5-38: Water quality variables measured during ambient and event sampling in 2019–20 along the Tully focus region transect. Chlorophyll *a* (Chl-*a*), nitrate/nitrite (NO_x), total suspended solids (TSS), Secchi depth, particulate nitrogen (PN), and particulate phosphorus (PP) are shown with distance 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 (e.g. not during peak flood events) of the dry and wet seasons are presented in Figure 5-39. 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 5-39). Site-specific statistics and comparison to GVs for all variables are available in Appendix C (Table C-2). Mean concentrations of Chl-*a* and TSS have generally fluctuated around GVs (Great Barrier Reef Marine Park Authority, 2010) since the inception of the MMP. Analysis of trends shows that from 2015–2020, mean concentrations of both Chl-*a* and TSS have decreased and are now both below (meeting) water quality GVs at all sites.

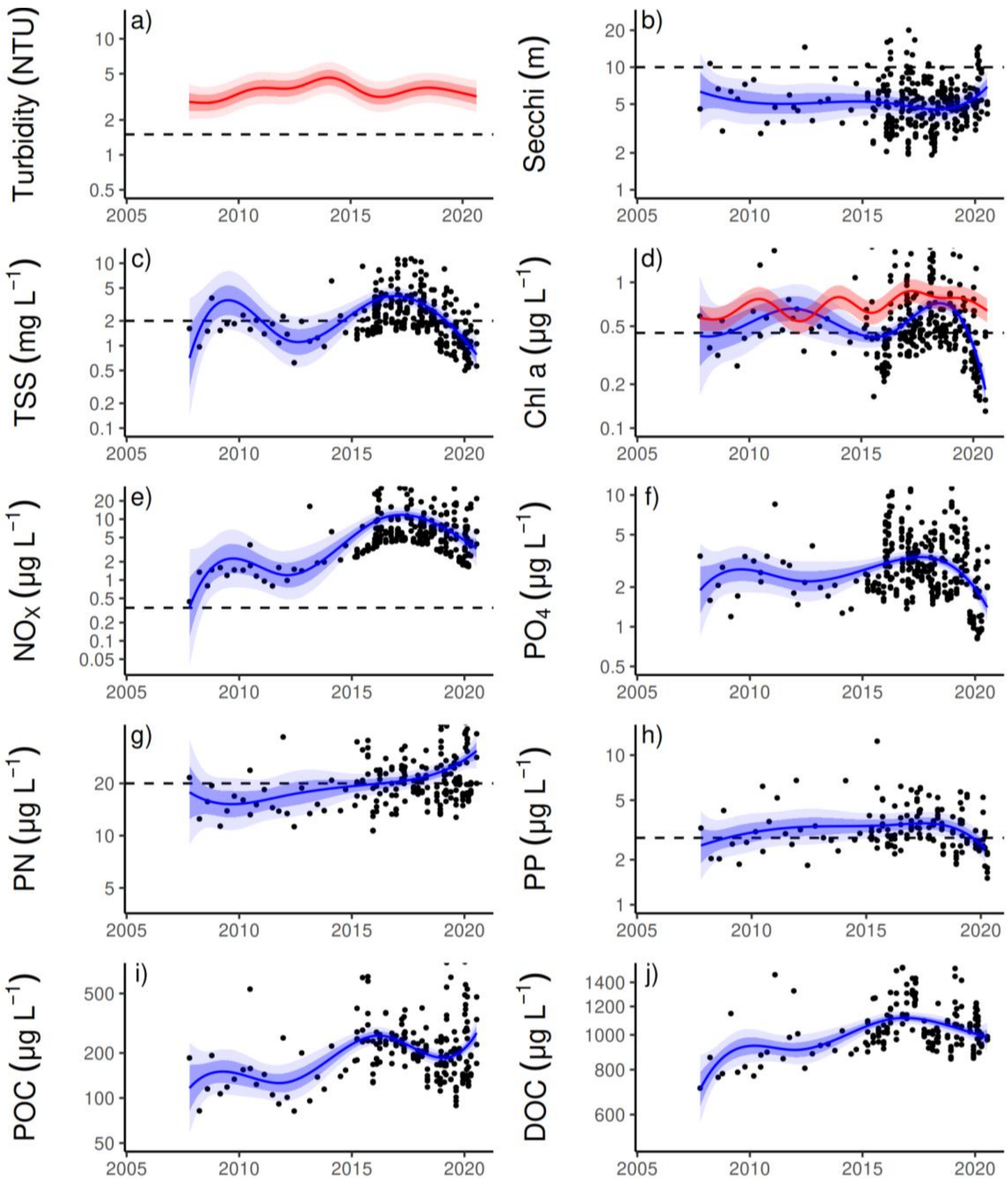

Figure 5-39: Temporal trends in water quality variables for the Tully focus region: a) turbidity, b) Secchi depth, c) total suspended solids (TSS), d) chlorophyll a (Chl-*a*), e) nitrate/nitrite (NO_x), f) phosphate (PO_4), g) particulate nitrogen (PN), h) particulate phosphorus (PP), i) particulate 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 PO_4 have been relatively stable since the inception of the MMP, and analysis of trends shows that from 2015–2020 concentrations have declined and are currently below (meeting) GVs at all sites. Mean concentrations of NO_x have generally increased since 2008 and analysis of trends shows that from 2015–2020 concentrations have slightly decreased but remain well above (exceeding) GVs.

Mean Secchi depth has been relatively stable since the inception of the MMP, and analysis of trends shows that from 2015–2020, Secchi depth has slightly increased (water clarity improved) although it currently remains below (exceeding) the GV.

Mean concentrations of PN and PP have been relatively stable and close to GVs since the inception of the MMP. Analysis of trends shows that from 2015–2020, mean concentrations of PN have increased and continue to be above (exceeding) GVs, while mean concentrations of PP have also declined slightly and are currently below (meeting) GVs. Mean concentrations of POC and DOC generally increased since 2008. Analysis of trends shows that from 2015–2020, both POC and DOC have 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 indices.

The long-term WQ Index has scored water quality as 'moderate' or 'poor' since 2010 (Figure 5-40a). The long-term trend has varied since the inception of the MMP but has shown a small (e.g., change by a single grade) decline over the time-series. This downward trend has generally been driven by trends in water clarity, PN, PP, and Chl-*a* indicators.

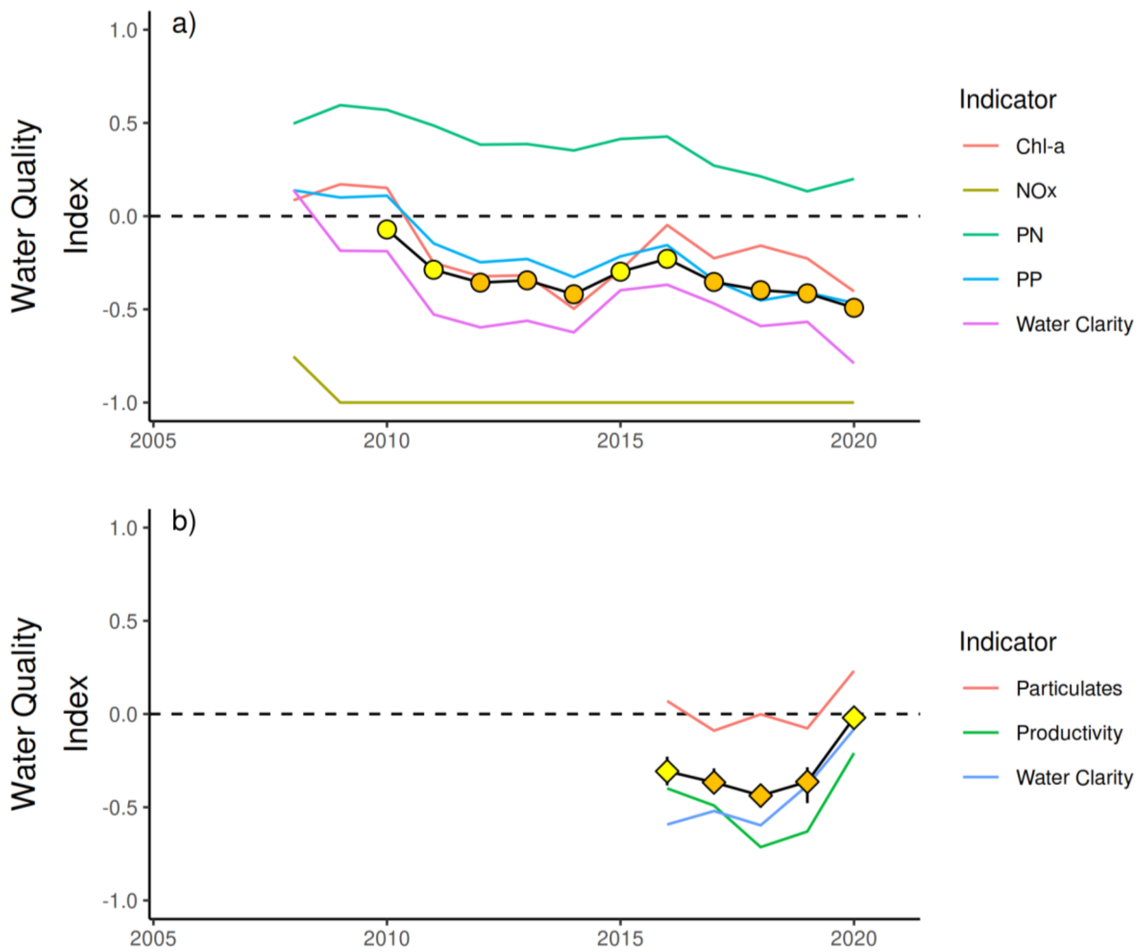

Figure 5-40: The Water Quality Index (WQ Index) for the Tully focus region. The WQ Index uses two formulations to communicate: a) long-term trend (based on pre-2015 sampling design) and b) the annual condition (based on post-2015 sampling design). WQ Index colour coding: ● / ◆– 'very good'; ● / ◆ – 'good'; ● / ◆ – '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’ for the previous three years and ‘moderate’ for the 2019–20 water year (Figure 5-40b). The score for the 2019–20 water year was much higher than previous years. 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 below average in this focus region this year, which likely contributed to an improved annual condition 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.

Pesticide monitoring results

Two sites were monitored in the wet season in the region: at Dunk and High Islands. The results are included in Appendix C-7. No exceedances of individual pesticide guideline values were detected.

Continuing the trend of previous monitoring years, the predominant pesticides detected were the PSII herbicides diuron, atrazine, and hexazinone. The concentrations of all pesticides detected were very low concentrations (<5 ng/L), and are unlikely to cause effects on marine species. The risk of exposure to the mixture of pesticides met the very low risk category: protective of ≥99% of species (i.e., ≤1% of species are affected) at both sites in all months in the wet season.

Previous reports of pesticide monitoring have been independently published and are available here.

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 sampled in this focus region up to nine times per year, with six sites sampled during both the dry and wet seasons and nine additional sites sampled during major flood events (Table C-1). The monitoring sites are located in a transect from the river to mouth in a north-easterly direction, representing a gradient in water quality. Eight sites are located in the open coastal water body, two sites are located in the mid-shelf water body, and five sites are in enclosed coastal waters (Figure 5-41).

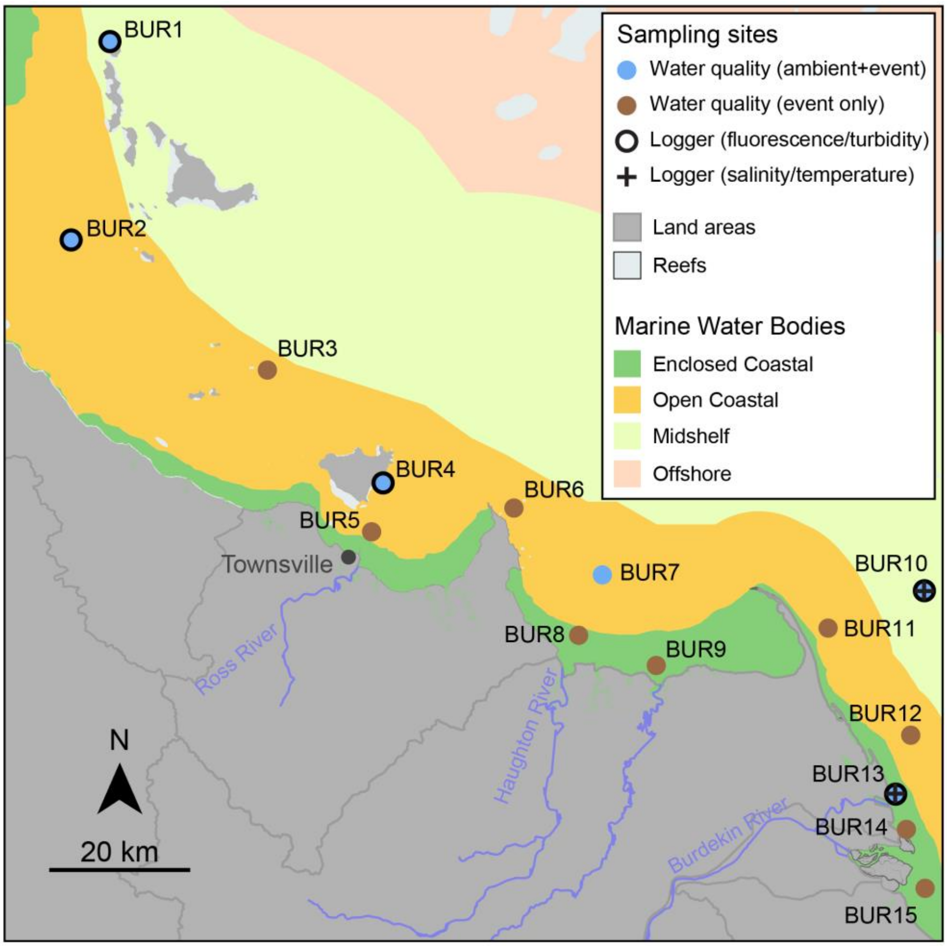

Figure 5-41: Sampling sites in the Burdekin focus area, shown with the water body boundaries.

The total discharge for the Burdekin region in 2019–20 was below the long-term median (Figure 5-42). The annual discharge was nearly half the long-term median (Table 3-1). The combined discharge and loads calculated for the 2019–20 water year from the Burdekin and Haughton Basins were in the lower range over the past decade (Figure 5-43). Over the 14-year period:

- discharge has varied from 998 GL (2014–15) to 36,811 GL (2010–11)
- TSS loads ranged from 285 kt (2013–14) to 15,011 kt (2007–08)
- DIN loads ranged from 205 t (2014–15) to 3,031 t (2018–19)
- PN loads ranged from 487 t (2013–14) to 21,773 t (2007–08).

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

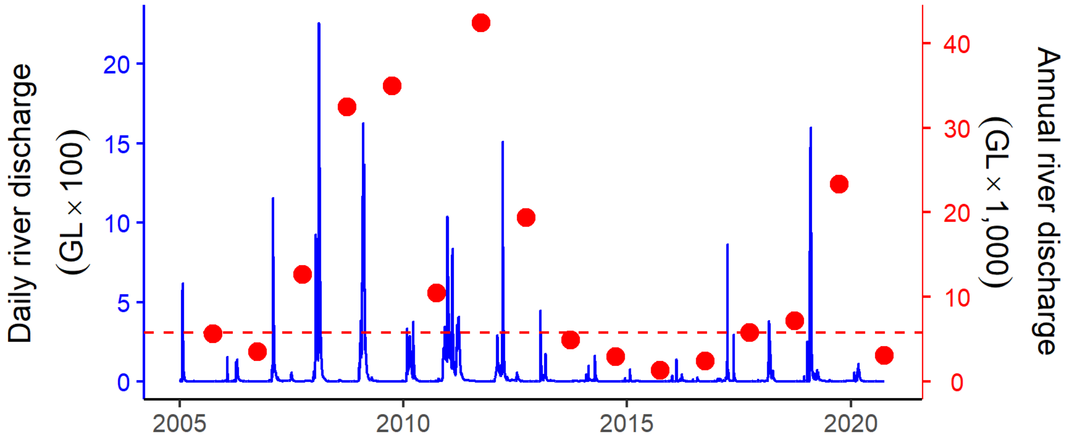

Figure 5-42: Total discharge for the Burdekin region (Table 2-3). Daily (blue) and water year (October to September, red) discharge is shown. Red dashed line represents the long-term median annual discharge.

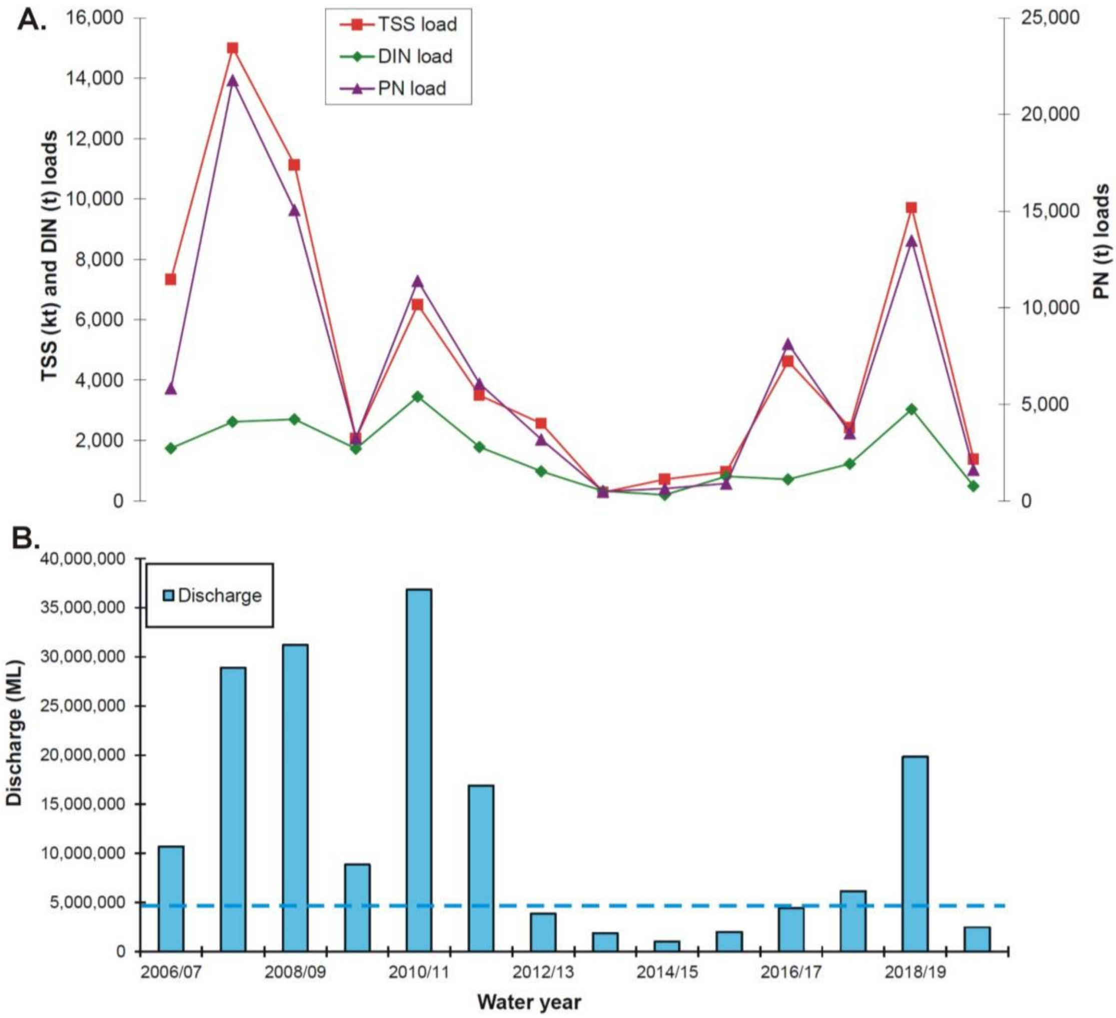

Figure 5-43: Loads of (A) TSS, DIN and PN and (B) discharge for the Burdekin and Haughton Basins from 2006–07 to 2019–20. The loads reported here are a combination of 'best estimates' for each basin based on 'up-scaled discharge data from gauging stations, monitoring data (Burdekin River), and annual 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 (river mouth = 0 km) had high concentrations of TSS, Chl-*a* (wet season only), and particulate nutrients (PN and PP), which declined with distance away from the river mouth (Figure 5-44, Appendix C Table C-2). Secchi depths were low at sites near the river mouth (water clarity was poor) and increased (water clarity improved) with distance from the river mouth. Concentrations of NO_x were variable along the transect and did not show clear patterns.

Seasonal differences were not as prominent as in previous years, which was likely due to below-average river discharge during the 2019–20 water year. Seasonal differences in water quality were present for some variables, although it is important to note that only one instance of dry season sampling is represented in this dataset. Ambient monitoring during the wet season showed greater values of Chl-*a* (near the river mouth), NO_x, and PN than during the dry season (Figure 5-44). Concentrations of PP were similar between wet and dry seasons, while concentrations of TSS were greater during the dry season than the wet. Secchi depths were overall greater (water clarity was higher) during the wet season than the dry.

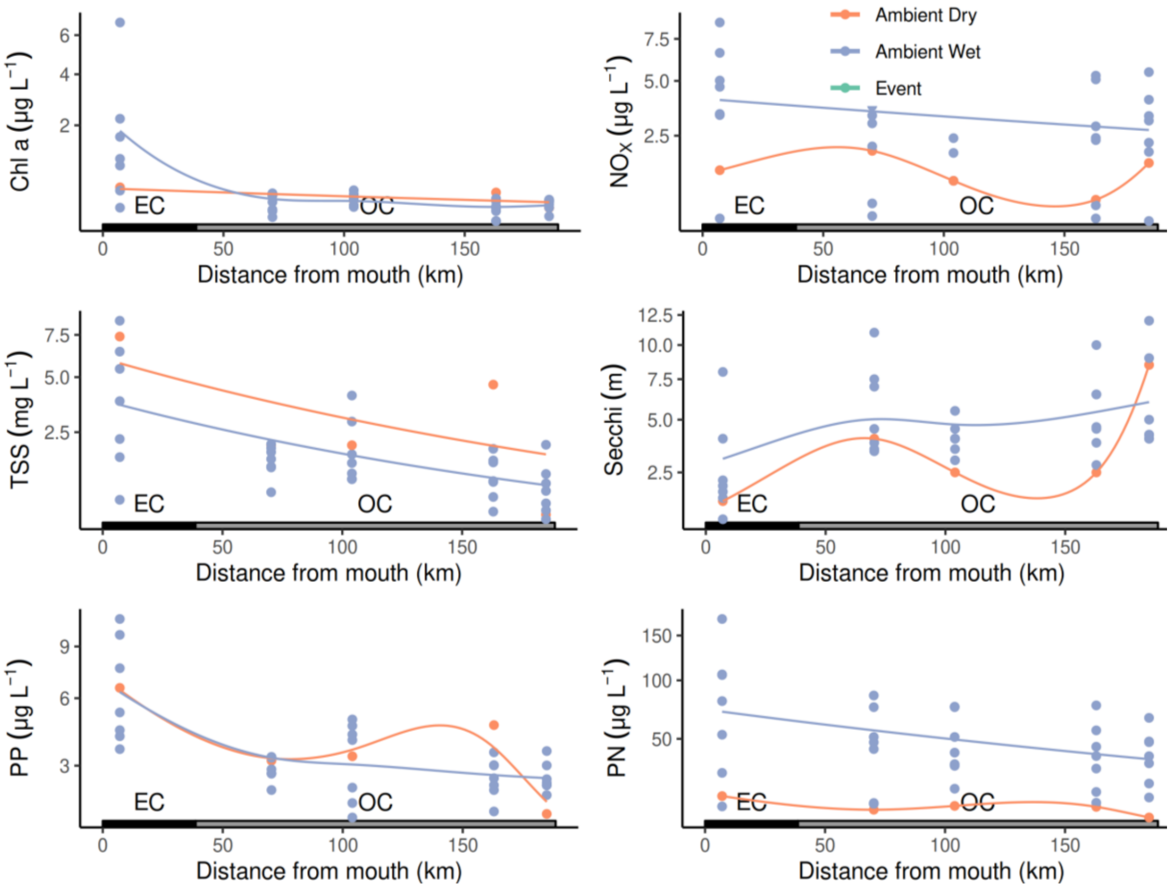

Figure 5-44: Water quality variables measured during ambient and event sampling in 2019–20 along the Burdekin focus region transect. Chlorophyll *a* (Chl-*a*), nitrate/nitrite (NO_x), total suspended solids (TSS), Secchi depth, particulate nitrogen (PN), and particulate phosphorus (PP) are shown with 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 5-45. 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.

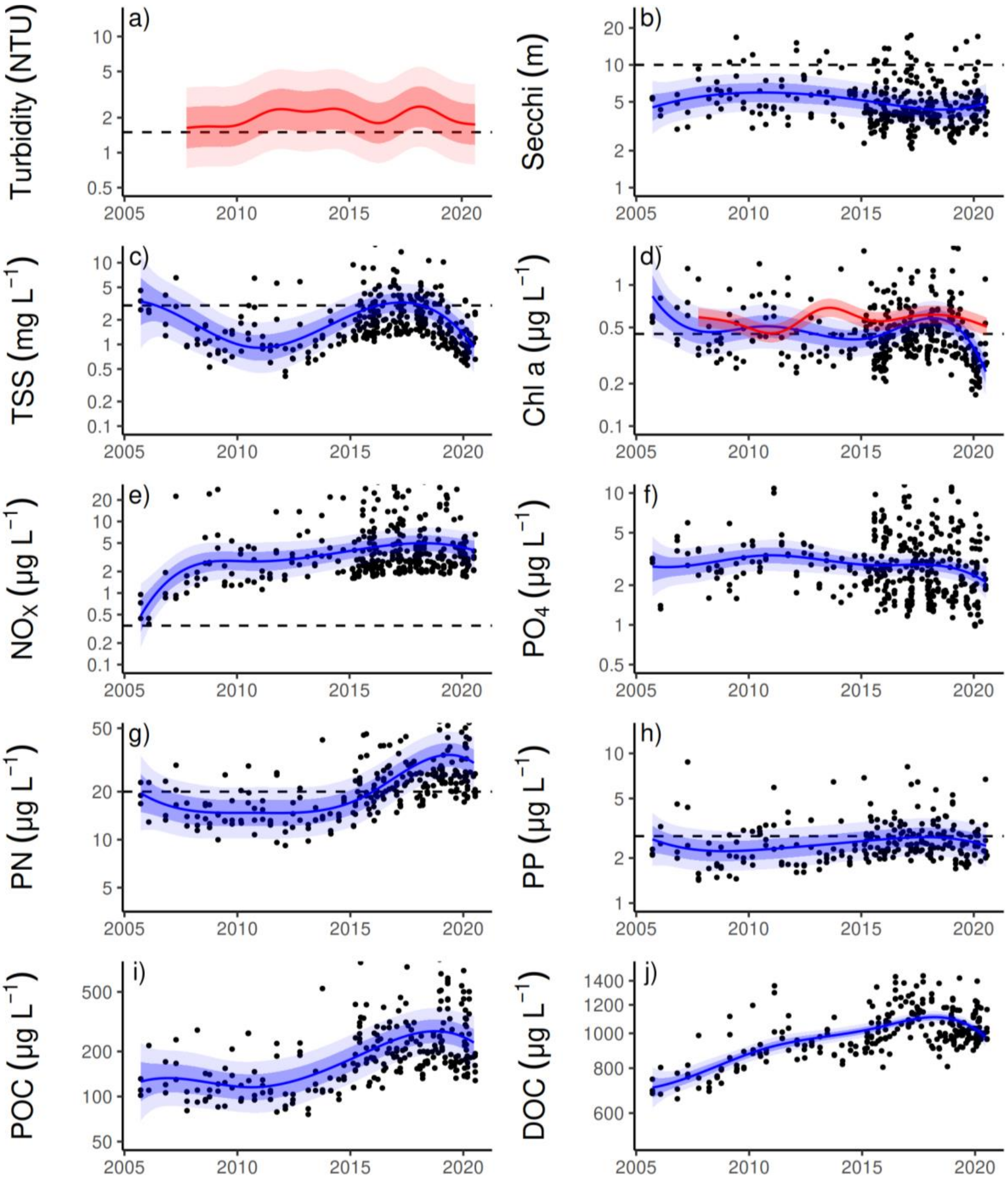

Figure 5-45: Temporal trends in water quality variables for the Burdekin focus region: a) turbidity, b) Secchi depth, c) total suspended solids (TSS), d) chlorophyll a (Chl-*a*), e) nitrate/nitrite (NO_x), f) phosphate (PO_4), g) particulate nitrogen (PN), h) particulate phosphorus (PP), i) particulate 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.

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 indices.

The long-term WQ Index has scored water quality as ‘good’ or ‘moderate’ since 2008 (Figure 5-46a). The long-term trend has shown a small (e.g., 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.

The annual condition WQ Index scored water quality as ‘good’ for the 2019–20 water year whereas it has been ‘moderate’ for the previous four years.(Figure 5-46b). 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 below average in this focus region this year, which likely contributed to an improved annual condition 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.

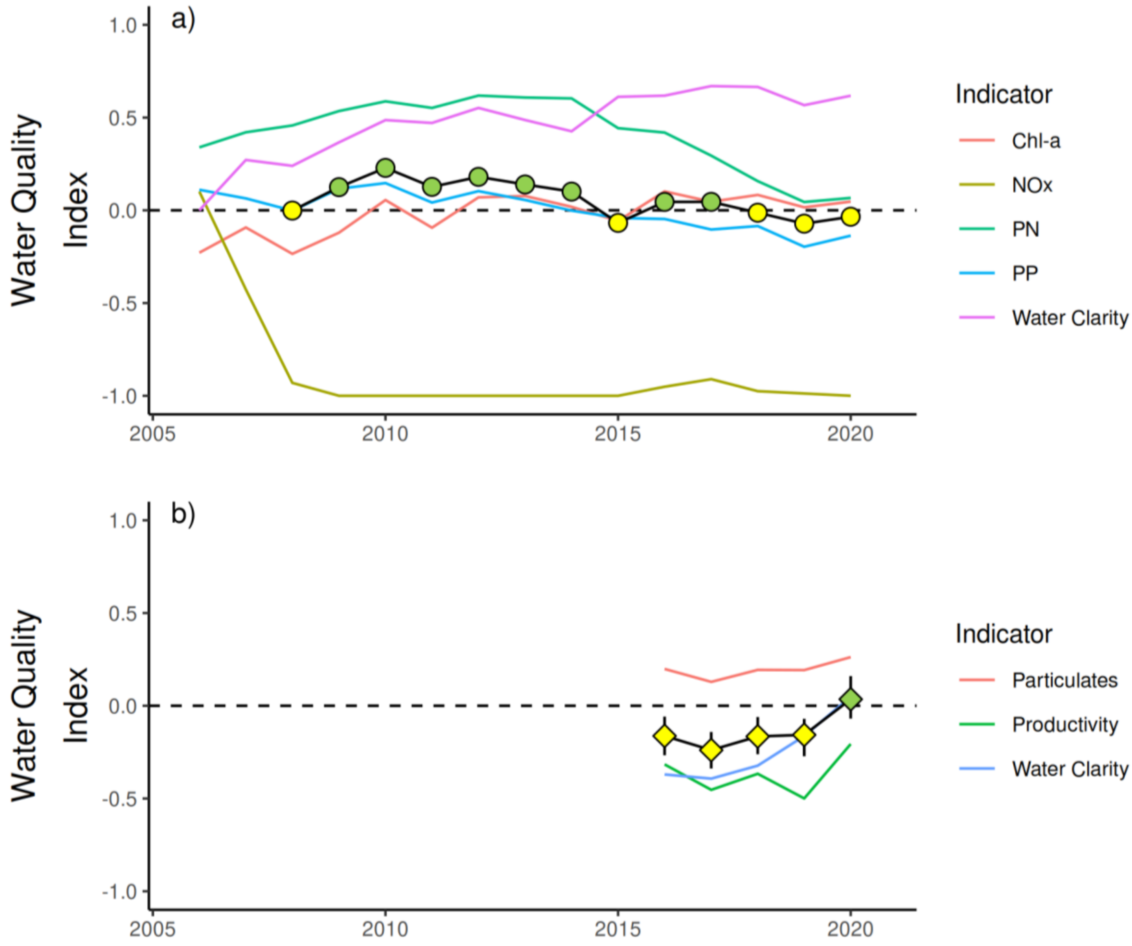

Figure 5-46: The Water Quality Index (WQ Index) for the Burdekin focus region. The WQ Index uses two formulations to communicate: a) long-term trend (based on pre-2015 sampling design) and b) the annual condition (based on post-2015 sampling design). WQ Index colour coding: ● / ◆– ‘very good’; ● / ◆ – ‘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.

5.4 Mackay-Whitsunday region

The Mackay-Whitsunday region comprises four major river basins, the Proserpine, O'Connell, Pioneer, and Plane Basins. The region is also potentially influenced by runoff from the 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 are sampled in this focus region up to five times per year, with eight sites sampled during both the dry and wet seasons and three additional sites sampled during major flood events (Table C-1). The sites are located in a transect from the O'Connell River mouth to open coastal waters, representing a gradient in water quality. Ten sites are located in the open coastal water body and one site is in enclosed coastal waters (Figure 5-47).

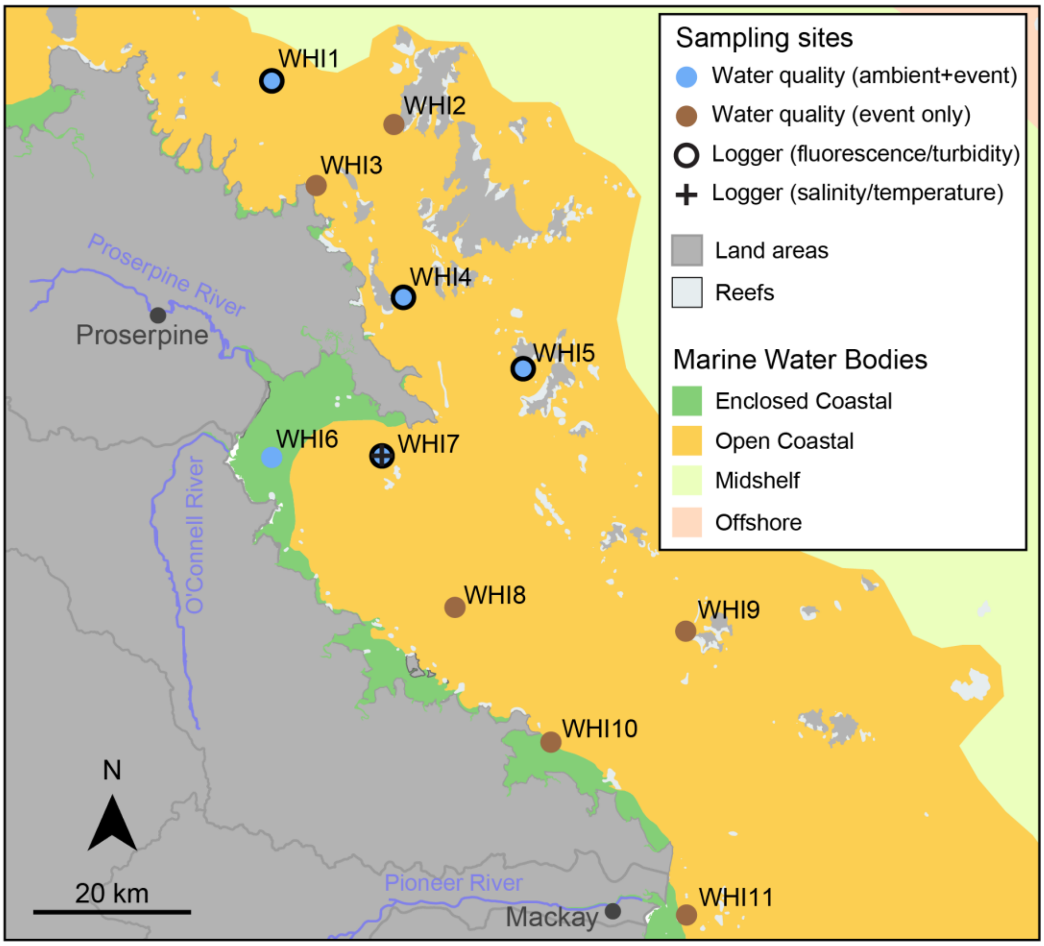

Figure 5-47: Sampling sites in the Mackay-Whitsunday focus area, shown with the water body boundaries.

Annual discharge for the Mackay-Whitsunday region was below long-term median levels (Figure 5-48) and was similar to discharge during the 2015–16 water year. Annual discharge from the Proserpine and Plane Basins were just below the long-term median while the O'Connell and Pioneer Rivers were well below the long-term median (Table 3-1).

The combined discharge and loads calculated for the 2019–20 water year from the Proserpine, O'Connell, Pioneer and Plane Basins (Figure 5-49, Figure 5-51) were similar to that measured in the 2015–16 and were among the lowest recorded over the past decade. Over the 14-year period:

- discharge has varied from 337 GL (2014–15) to 8,675 GL (2010–11)
- TSS loads ranged from 29 kt (2014–15) to 1,436 kt (2010–11)
- DIN loads ranged from 85 t (2014–15) to 2,158 t (2010–11)
- PN loads ranged from 122 t (2014–15) to 4,782 t (2010–11).

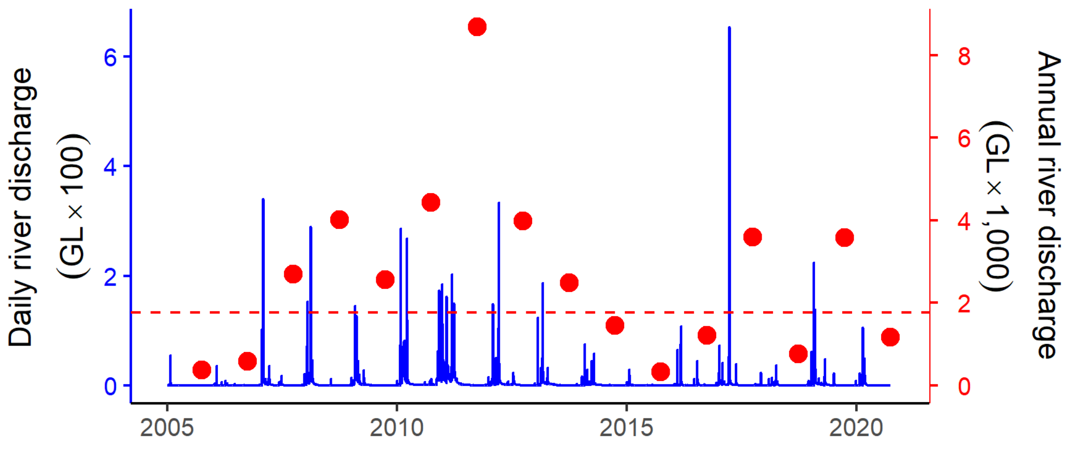

Figure 5-48: Combined discharge for the Mackay-Whitsunday focus region. Daily (blue) and water year (October to September, red) discharge is shown. Red dashed line represents the long-term median of the combined annual discharges. See Table 2-3 for a list of flow gauge data used. Please note as this is the combined discharge, high flows in one river will not necessarily be visible in the graph.

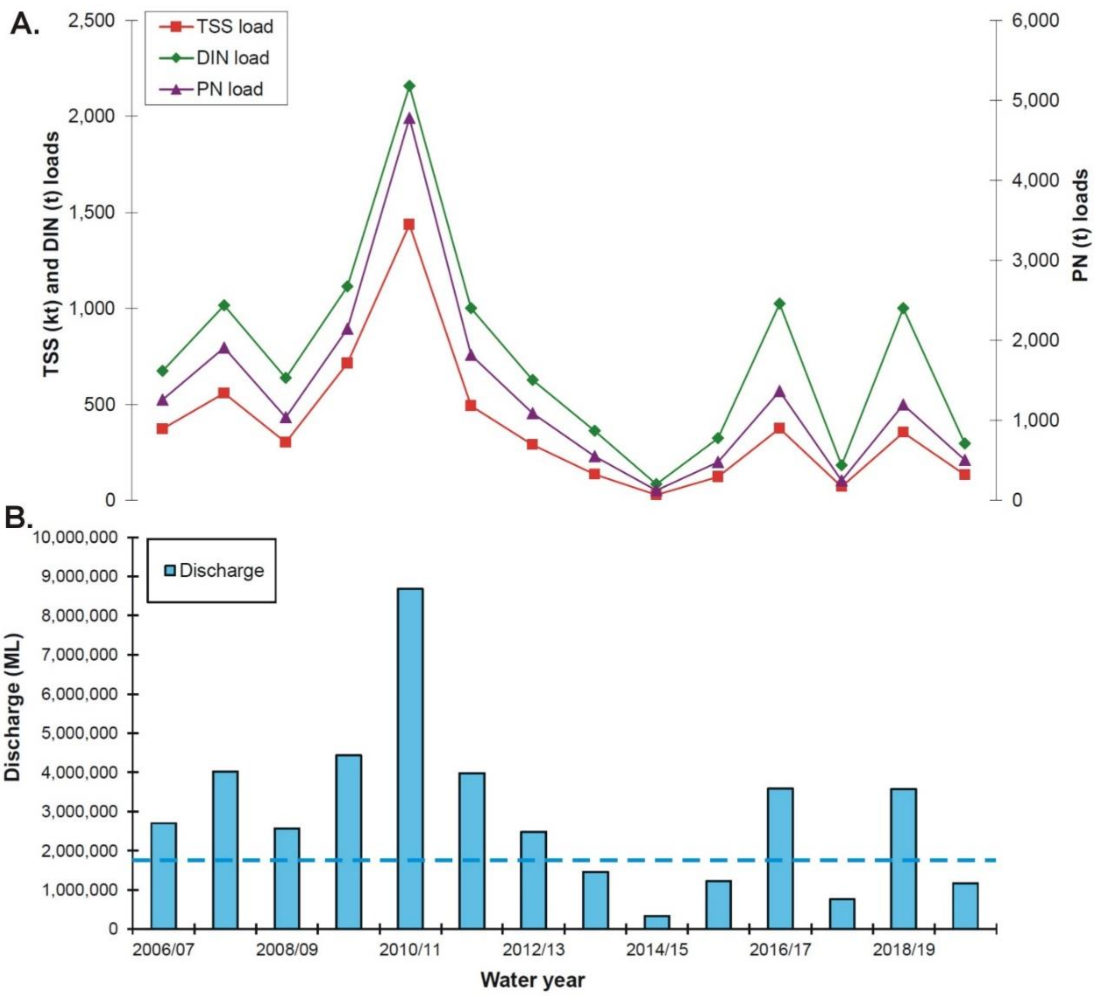

Figure 5-49: Loads of (A) TSS, DIN and PN and (B) discharge for the Proserpine, O'Connell, Pioneer, and Plane Basins from 2006–07 to 2019–20. The loads reported here are a combination of 'best estimates' for each basin based on 'up-scaled discharge data from gauging stations, monitoring data (O'Connell and Pioneer Rivers and Sandy Creek), and annual mean concentrations and discharge from monitoring data or Source Catchments modelling data. Dotted line represents the long-term median for basin discharge. Note the different scales on the two y-axes.

Ambient water quality and the in situ Water Quality Index

Water quality showed trends along the sampling transect (O'Connell mouth to open coastal waters). The site located in the enclosed coastal water body (river mouth = 0 km) had high concentrations of NO_x (dry season only), TSS (dry season only), Chl-*a*, and particulate nutrients (PN and PP), which declined with distance away from the river mouth (Figure 5-50, Table E-2). Secchi depths were low at sites near the river mouth (water clarity was poor) and increased (water clarity improved) with distance from the river mouth. Concentrations of TSS, NO_x, and Secchi depth were highly variable in this focus region, which is likely related to its large tidal range and physical oceanographic characteristics.

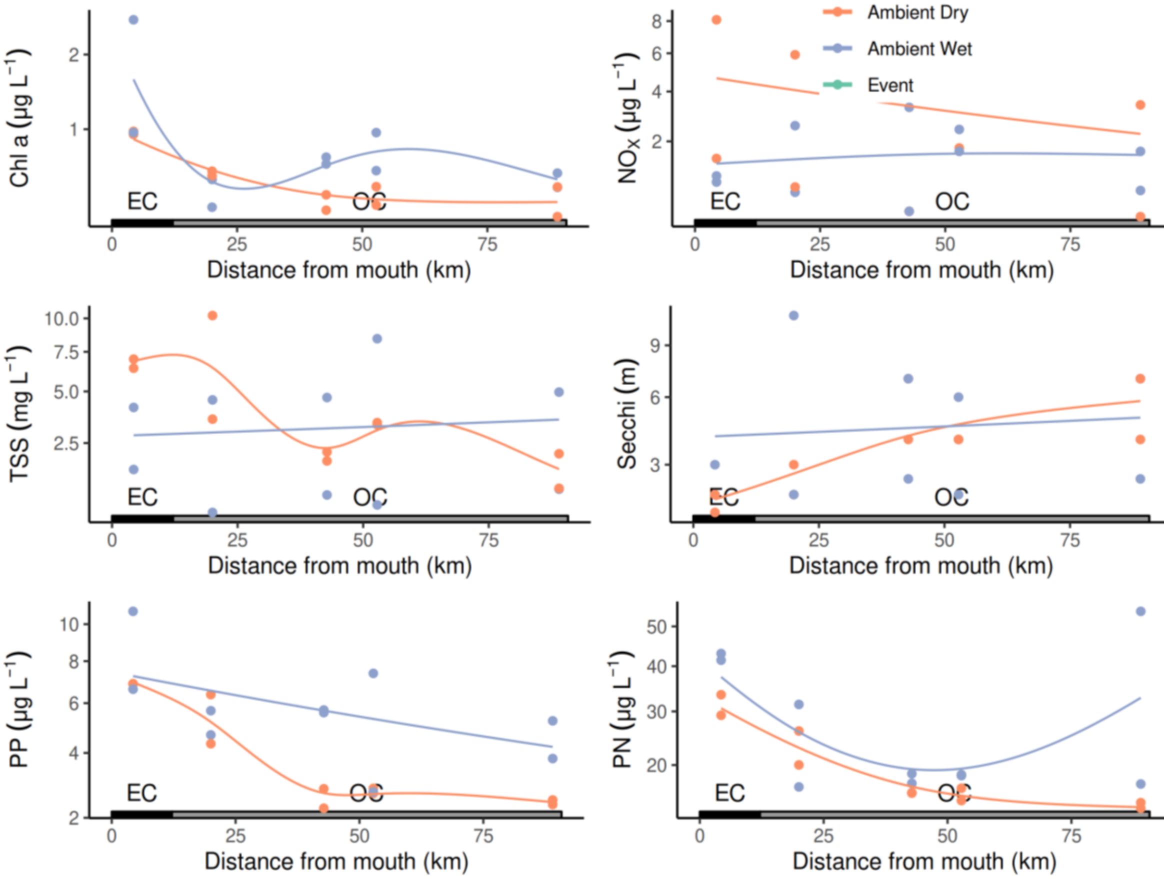

Figure 5-50: Water quality variables measured during ambient and event sampling in 2019–20 along the Mackay-Whitsunday focus region transect. Chlorophyll *a* (Chl-*a*), nitrate/nitrite (NO_x), total suspended solids (TSS), Secchi depth, particulate nitrogen (PN), and particulate phosphorus (PP) are shown 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.

Seasonal differences were not as prominent as in previous years, which was likely due to below-average river discharge during the 2019–20 water year. Seasonal differences in water quality were present for some variables. Ambient monitoring during the wet season showed greater values of Chl-*a* (most sites), PN, and PP than during the dry season (Figure 5-50). Concentrations of TSS and Secchi depth were similar (highly variable) between wet and dry seasons, while concentrations of NO_x were greater during the dry season than the wet.

Long-term trends in water quality variables measured during ambient periods (e.g. not during peak flood events) of the dry and wet seasons are presented in Figure 5-51. 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.

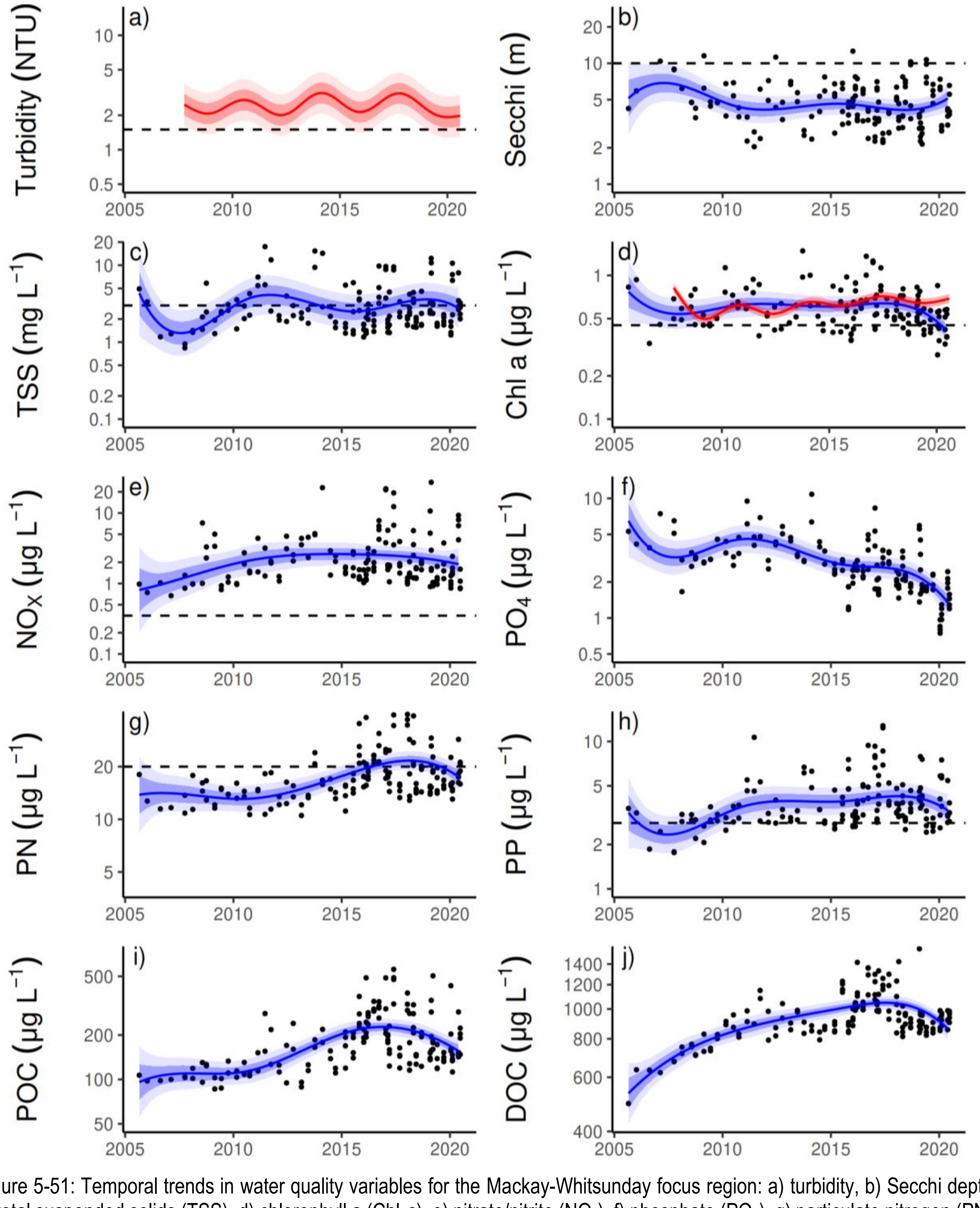

Figure 5-51: Temporal trends in water quality variables for the Mackay-Whitsunday focus region: a) turbidity, b) Secchi depth, c) total suspended solids (TSS), d) chlorophyll a (Chl-*a*), e) nitrate/nitrite (NO_x), f) phosphate (PO_4), g) particulate nitrogen (PN), h) particulate phosphorus (PP), i) 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.

Distinct long-term trends (since 2005) were observed in some water quality variables, while others showed little change (Figure 5-51). Site-specific statistics and comparison to GVs for all variables are available in Appendix C (Table C-2). Mean concentrations of Chl-*a* and TSS have generally fluctuated around GVs (Great Barrier Reef Marine Park Authority, 2010) since the inception of the MMP. Analysis of trends shows that from 2015–2020, mean concentrations of TSS have remained stable, while concentrations of Chl-*a* have declined slightly. Both variables are currently above (exceeding) water quality GVs.

Mean concentrations of PO_4 have markedly declined since the inception of the MMP, and analysis of trends shows that from 2015–2020 concentrations have continued to decline but are currently above (exceeding) GVs. Mean concentrations of NO_x have been relatively stable since 2010 and analysis of trends shows that from 2015–2020 concentrations have remained stable and continue to be well above (exceeding) GVs.

Mean Secchi depth has been relatively stable since 2008, and analysis of trends shows that from 2015–2020, Secchi depths have remained stable and are currently below (exceeding) the GV.

Mean concentrations of PN and PP have varied around the GV since the inception of the MMP. Analysis of trends shows that from 2015–2020, mean concentrations of both PN and PP have remained stable and continue to be above (exceeding) GVs. Mean concentrations of POC and DOC have generally increased since 2005. Analysis of trends shows that from 2015–2020, POC and DOC have decreased slightly.

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 indices.

The long-term WQ Index has scored water quality as ‘moderate’ or ‘poor’ since 2008 (Figure 5-52a). The long-term trend has shown a small (e.g., change by a single grade) decline over the time-series since 2008. This downward trend has generally been driven by trends in water clarity, PN, and PP indicators, especially over the period 2008–2016.

The annual condition WQ Index scored water quality as ‘moderate’ or ‘poor’ for the previous four years and ‘poor’ for the 2019–20 water year (Figure 5-52b). The score for the 2019–20 water year was lower than previous years. 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.

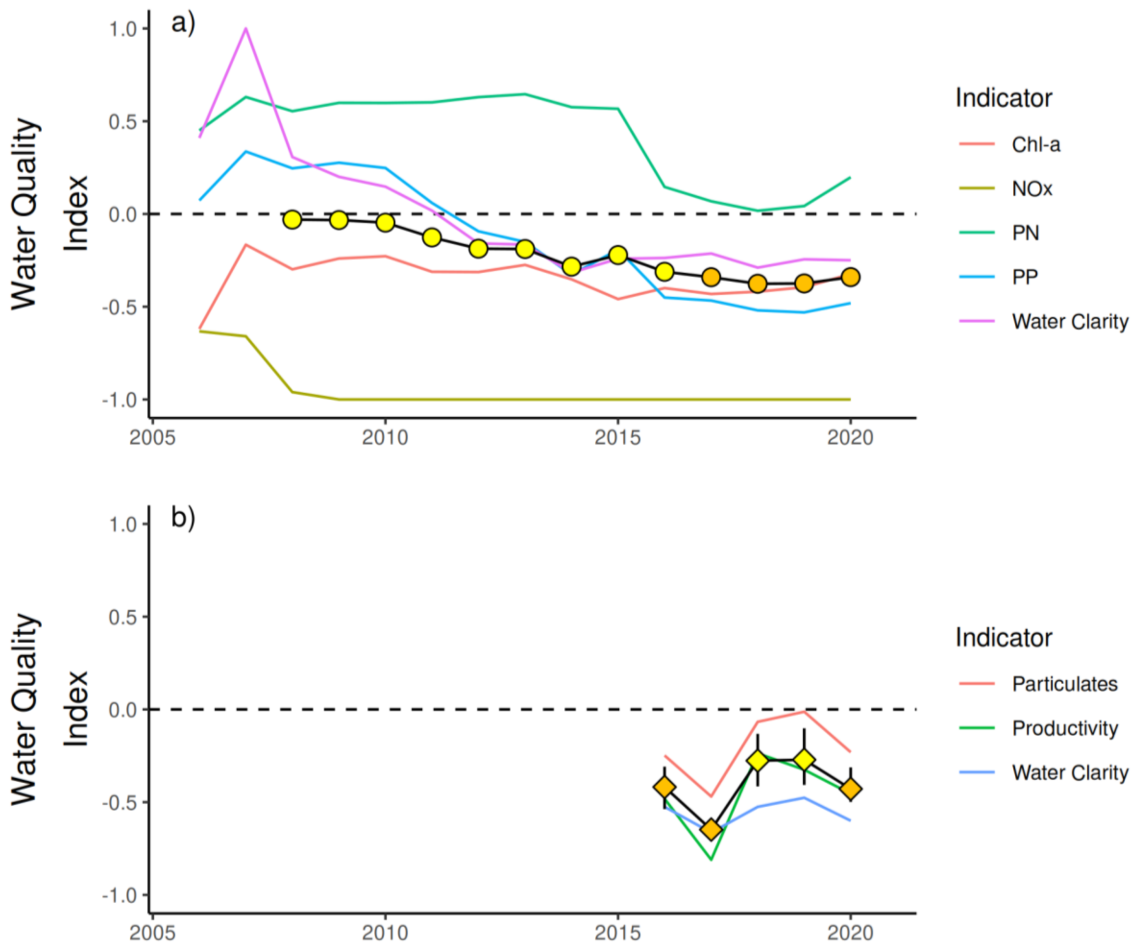

Figure 5-52: The Water Quality Index (WQ Index) for the Mackay-Whitsunday focus region. The WQ Index uses two formulations to communicate: a) long-term trend (based on pre-2015 sampling design) and b) the annual condition (based on post-2015 sampling design). WQ Index colour coding: ● / ◆ – 'very good'; ● / ◆ – '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.

Pesticide monitoring results

Three sites were monitored in the region this reporting year: Flat Top Island, Repulse Bay and Sandy Creek. The results are presented in Appendix C-7. No exceedances of individual pesticide guideline values were detected in this monitoring year.

Continuing the trend of previous monitoring years, the predominant pesticides detected were diuron, atrazine and hexazinone. All detections were below guideline levels derived to be protective of 99% of species. Although some individual samples did reach diuron concentrations that have shown detectable effects on at least one sensitive species around the detected concentration (<95 ng/L versus GV of 430 ng/L: Devilla et al., 2005; Larras et al., 2012).

The risk of exposure to mixtures of pesticides returned two risk categories with samples either meeting the very low risk: protective of ≥99% of species (i.e. ≤1% of species affected), or low risk: protective of 95 to less than 99 per cent of species (i.e. 1% to ≤5% of species affected).

Previous reports of pesticide monitoring have been independently published and are available here.

6. Discussion

6.1 Long-term changes in water quality

Previous work has demonstrated that to detect trends in water quality and distinguish between long-term changes and natural variability, decadal time scales are required (Henson et al., 2016). After more than a decade of continuous sampling, there is evidence that most focus regions have experienced gradual declines in water quality since 2008, although there are early indications that water quality may be improving in at least one focus region, the Barron-Daintree.

In addition, year-to-year and seasonal differences in water quality are a key feature of this monitoring dataset. This is an important point, as it demonstrates that while overall multi-year water quality may be considered 'good' relative to guideline values, inshore ecological communities can experience periods of 'very poor' water quality in relation to episodic events such as river discharge (McKenzie et al., 2020; Petus et al., 2014a, b, 2016; Thompson et al., 2020). Ecological community response to such disturbances is confounded by other factors such as organism sensitivity and resilience; this complexity results in difficulty in directly linking river inputs to ecological community change.

The results for 2019–20 followed typical patterns of water quality in the inshore Reef, which generally show distinct gradients away from river mouths, with elevated levels of most parameters closest to the coast. Seasonal differences in water quality during 2019–20 were not as prominent as in previous years, which was most likely due to river discharge that was well below average in all focus regions. These gradients are influenced over short time periods by flood events and sediment resuspension, and over longer time periods by complex interactions between physical and biogeochemical processes (Schaffelke et al., 2017). Such dynamics are a part of the natural Reef ecosystem, albeit under lower levels of input of river-derived material than at present (Kroon et al., 2012).

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

Our analyses of long-term monitoring data from coastal waters of the Reef suggest that some variables showed no long-term net increases or decreases in concentration, whereas other variables have increased in concentration over time. This analysis is not yet possible in the Cape York focus region which has only been routinely sampled for four years.

In the majority of the Wet Tropics, Burdekin, and Mackay-Whitsunday focus regions:

- TSS:
  - Meeting GVs for the 2019–20 water year
  - Concentrations improving (lower) or stable in recent years (2015–2020)
- Chl-*a*:
  - Meeting GVs for the 2019–20 water year
  - Concentrations improving (lower) in recent years (2015–2020)
- NO_x:
  - Exceeding GVs for the 2019–20 water year
  - Concentrations stable or improving (lower) in recent years (2015–2020)
- PO_4:
  - Meeting GVs for the 2019–20 water year
  - Concentrations improving (lower) in recent years (2015–2020)

- PN:
    - Exceeding GVs for the 2019–20 water year
    - Concentrations stable or worsening (higher) in recent years (2015–2020)
- PP:
    - Exceeding GVs for the 2019–20 water year
    - Concentrations stable or improving (lower) in recent years (2015–2020)
- Secchi depth:
    - Exceeding GVs for the 2019–20 water year
    - Values stable or improving (greater) in recent years (2015–2020)

Previous water quality monitoring reports highlighted the large increases that had occurred in organic carbon concentrations (DOC and POC) since the beginning of the MMP. Monitoring results from the last few years suggest that both POC and DOC are presently stable or declining in all focus regions. The causes and implications of these changes are discussed in previous reports (Gruber et al., 2019) and remain unclear until further process-based experiments can be conducted.

Analysis of the longer term trends of the remote sensing datasets show high variability between monitoring years, driven by a range of factors and in particular, river discharge. The results for the 2019–20 wet season indicated similar conditions to median long term conditions, or in some areas, those characteristic of drier years. The anomalies identified in the extent of the secondary and tertiary water types in some regions highlight the complexity of water quality characteristics in the region, and the need for greater understanding of the potential drivers to that variability.

These complications highlight the importance of maintaining and further developing a range of monitoring, processing and modelling tools, supporting the integrated design of the MMP Inshore Water Quality Program. The results examining flood event and ambient conditions coupled with other research programs within the Reef lagoon provide important insights on water quality in the Reef. For example, remote sensing products highlight the spatial and temporal influence of river plumes during the wet season within the Reef lagoon and help to identify where coastal ecosystems may be at risk from exposure to elevated levels of pollutants (Devlin et al., 2015; Petus et al., 2014a, b, 2016) or chronic reduced light levels (Petus et al., 2019). Recent studies highlight the influence of river discharge and associated constituents on water clarity in the inshore and mid-shelf Reef waters in the months following flood events using satellite photic depth data (Fabricius et al., 2014, 2016) or a combination of *in situ* and satellite-derived data (Petus et al., 2019).

Our capacity to link coastal water quality to end-of-catchment loads and our ability to estimate the potential impacts of flood plumes on reef ecosystems are based on the spatial and temporal extent of available water quality data. Long-term coastal water quality patterns are complex and influenced by many factors including oceanographic forcing, climate change, and the impact of severe storms. As predictive tools, including the eReefs hydrodynamic and biogeochemical models, are further progressed for practical applications such as these, our ability to report on these objectives will continue to improve.

In addition to data needs, there are several key knowledge needs that will help improve our ability to predict and manage linkages between land management and marine water quality. Further research is required on the rates of key biogeochemical processes (in addition to information on concentrations) operating in the coastal ocean, including the production and consumption rates of carbon, nitrogen, and phosphorus species. Recent work suggests that organic nutrient pools may serve as a major nitrogen and phosphorus source for phytoplankton production in the Reef lagoon (Lønborg et al., 2017), and that particulate nitrogen derived from river discharge may be more bioavailable than previously thought (Waterhouse et al., 2018). Further research on organic and particulate nutrient pools is needed to determine how these sources compare with nitrate in supporting phytoplankton production.

Addressing these knowledge needs will provide greater ability to interpret patterns in coastal water quality and greater confidence that management action has delivered improvement in water quality.

6.2 Water quality and effects on marine communities

Water quality comprises the sediment, nutrient, and contaminant concentrations present in a water body. Water quality characteristics have an effect on certain physico-chemical properties such as water clarity (light attenuation) and key ecological processes including rates of primary productivity (especially in phytoplankton) and nutrient cycling. In addition to anthropogenic stressors described in Section 3, the Reef lagoon is influenced by many natural drivers and pressures that affect suspended nutrient and sediment concentrations including: the upwelling of deeper Coral Sea waters onto the continental shelf (Benthuysen et al., 2016; Furnas and Mitchell 1996); resuspension of bottom sediments by wind and waves (Orpin et al., 1999); extreme weather conditions such as cyclones (Dufois et al., 2017); and nitrogen fixation by cyanobacteria (Messer et al., 2017).

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

Thirty-five major rivers drain into the Reef lagoon, and the average annual export of sediments, nutrients, and herbicides from these catchments to the coastal zone has increased more than 5-fold since European settlement (Kroon et al., 2012). River loading has large spatial and temporal variation, with the contribution of individual rivers differing substantially along the coast (Wolff et al., 2018) and during periods of high rainfall (Schroeder et al., 2012; Waterhouse et al., 2017a).

Local environmental conditions, such as water quality, influence the benthic communities including seagrasses and corals found in coastal and inshore waters of the Reef. Collectively, inshore coral reefs differ markedly from those found in clearer, offshore waters (e.g. Done, 1982; Wismer et al., 2009). The premise underpinning the Reef 2050 Plan is that loads of nutrients, sediments and pesticides delivered by rivers contribute to declining Reef ecosystem health (Schaffelke et al., 2017) and suppress ecological resilience. A review of the potential effects of water quality on seagrass and coral communities can be found in the MMP reports specific to ecological monitoring (McKenzie et al., 2021; Thompson et al., 2021). However, the direct link between land-runoff, pollutant loads and Reef ecosystem response remains difficult to measure in the context of the complexities such as regional variation, time lags and the other drivers, activities and pressures noted above. The MMP plays an important role in providing further evidence to improve understanding of these linkages.

The *2017 Scientific Consensus Statement: A synthesis of the science of land-based water quality impacts on the Great Barrier Re*ef concluded that: 'Key Great Barrier Reef ecosystems continue to be in poor condition. This is largely due to the collective impact of land runoff associated with past and ongoing catchment development, coastal development activities, extreme weather events and climate change impacts such as the 2016 and 2017 coral bleaching events...'. Furthermore, 'the decline of marine water quality associated with land-based run-off from the adjacent catchments is a major cause of the current poor state of many of the coastal and marine ecosystems of the Great Barrier Reef. Water quality improvement has an important role in ecosystem resilience' (Waterhouse et al., 2017b). The data presented in this report will contribute to the review and assessment of the evidence for the 2022 iteration of the Scientific Consensus Statement.

6.3 Management response

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

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

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

Sustained improvements in the marine water quality of the inshore Reef have not yet been observed in the MMP water quality program. The complexity of the relationship between land-based runoff and water quality, the influence of inter-annual variability, the progress of changed management practice adoption, and the expected slow response timeframes between land-based changes and marine water quality all contribute to this lack of observed change. Continued water quality monitoring and modelling of the Reef lagoon will be fundamental to detecting and tracking changes in response to management actions and interventions.

7. Conclusions

This section provides major conclusions from water quality monitoring efforts in nine focus areas spanning four NRM regions. Table 7-1 provides a high level summary by NRM region.

Results showed variable responses to the below-average river discharges and end-of-catchment pollutant loads in 2019–20. The river discharges in all focus regions of the Reef (except the Pascoe region) were below the long-term median during the 2019–20 wet season. A number of focus regions had river discharges among the lowest recorded in the last decade.

The main findings for each NRM region are highlighted below and are separated into results from ambient (routine sampling during wet and dry seasons) and event-based (sampling during flood events) monitoring.

7.4 Cape York

As this was only the fourth year of sampling in the Cape York region under the MMP, no long-term trends have been evaluated.

Discharge from rivers in the Cape York focus regions in 2019–20 was below the long-term median discharge for all sub-regions other than the Pascoe River, which was just above median annual discharge. As a result of the relatively low discharge, mean and median concentrations of most parameters were less than those measured during the previous above-average discharge year. Most parameters met the water quality GVs, except for dissolved inorganic nutrient fractions.

Ambient water quality:

Enclosed coastal, open coastal and mid-shelf waters (for those parameters with guidelines):

- NO_x, NH_3 and PO_4 exceeded the GVs for most sub-regions in the enclosed coastal, open coastal and mid-shelf water bodies. Uncertainties associated with the analytical results for dissolved nutrients are likely to contribute to GV exceedances for these analytes.
- PN exceeded the GVs in some sub-regions and water bodies.
- Secchi depth exceeded the enclosed coastal and open coastal GVs for the Annan-Endeavour, Normanby and Stewart River sub-regions. However, monitoring occurred primarily during the wet season and means are compared against annual guidelines.
- In contrast to the previous high discharge year, TSS and Chl-*a* were less than the GV values for almost all sub-regions and waterbodies.

Event water quality

- Due to the below average discharge and lack of major flooding across Cape York, there was very little focussed flood monitoring in the Cape York sub-regions.
- Minor flooding resulted in increased turbidity and Chl-*a* concentrations for short periods at inshore reefs such as Dawson Reef, 6 km from the mouth of the Annan River (measured by *in situ* continuous dataloggers).
- eReefs hydrodynamic model exposure output showed that enclosed coastal and open coastal waters were moderately affected by river discharge from the Normanby River, which also reached mid-shelf sites. Open coastal waters off Cooktown had negligible three-dimensional exposure to discharge from the Annan and Endeavour rivers. River discharge was transported in the northerly direction from the Normanby River mouth.

Table 7-1: Summary of results for some of the primary indicators measured in the MMP Inshore Water Quality program, 2019–20. * Arrows indicate difference relative to long-term patterns: → area exposed in 2020 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**	
Focus area	**Cyclone activity (Category, timing)**	**River discharge (ref to LT median)**	**Area (in %) exposed to a potential risk***	**Area (in %) exposed to the <u>highest</u> potential risk (categories III and IV)#**	**Annual**	**Trend**
GBR wide	Cyclone Gretel (low, March)	<1.5	Reef: 15% → • **Note** ↗ (+11%) in coral area exposed to lowest cat of risk (II), <u>but low confidence</u>[*1]. Related to ↗ in Cape York, Fitzroy and Burnett-Mary regions.	Reef: 2% → <1% → , 30% → →Only <u>inshore</u> Reef waters and habitats	na	na
Cape York	Cyclone Gretel (low, March)	<1.5	CY: 15% → • **Note** ↗ (+24%) in coral area exposed to lowest cat of risk (II), <u>but low confidence</u>[*1]	CY: 2% → <1% → , 21% → → Only <u>inshore</u> CY waters habitats	na	na
Wet Tropics	na	<1.5	WT: 14% →	WT: 3% → <1% → , 70% ↘ → Only <u>inshore WT</u> waters and habitats	Good	**Declined** 2008-2018, improved last 2 years
Burdekin	na	<1.5	B: 13% →	B: 2% → <1% → , 36% ↘ → Only <u>inshore Burd</u> waters and habitats	Good	**Declined** gradually since 2010
Mackay-Whitsunday	na	<1.5	MW: 20% →	MW: 2% → 2% → , 42% → → Only <u>inshore MW</u> waters and habitats	Poor	**Declined** since 2008
Fitzroy	na	<1.5	F: 14% → • **Note** ↗ (+7%) in coral area exposed to lowest cat of risk (II), <u>but low confidence</u>[*1]	F: 4% → 2% → , 41% → → Only <u>inshore Fitz</u> waters and habitats	na	na
Burnett-Mary	na	<1.5	BM: 12% ↗ • **Note** ↗ in BM area (+7%), coral (+40%) and seagrass area (+37%) exposed to lowest cat of risk (II), but <u>low confidence</u>[*1]	BM: <1% → <1% → , 24% ↗ → Only <u>inshore BM</u> waters and habitats	na	na

- 85% of the Cape York region was not exposed to a potential risk, similar to long-term patterns. Approximately 15% of the total area of the Cape York region, including 30% of the region's coral reefs and 72% of the seagrasses were exposed to a potential risk. However, only the inshore Cape York waters, seagrass and coral habitats were exposed to the highest categories of potential risk (III and IV) and areas exposed were similar to the long-term patterns. Mid-shelf and offshore Cape York reefs and seagrasses were exposed to the lower potential risk category II or to no / very low risk. There was an increase in the coral area exposed to the lowest potential risk category (II: + 24%). This result is, however, to be taken with caution and likely to be linked to the increase in areas exposed to secondary waters in the mid-shelf waters of Cape York, discussed in Section 4.1).

7.5 Wet Tropics

Discharge from the Daintree, Mossman, and Barron Basins was the lowest recorded since the start of the MMP and was well below the long-term median. The discharge and loads from the Russell-Mulgrave, Johnstone, Tully, Murray and Herbert Basins were well below long-term medians and were in the lower range of values recorded over the past decade. 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).

Ambient water quality

Enclosed coastal, open coastal, and mid-shelf waters (for those parameters with guidelines):

- Exceeded guidelines: NO_x (all focus regions), Secchi depth (all focus regions), PP (Barron-Daintree region), and PN (Russell-Mulgrave and Tully regions).
- Met (below) guidelines: Chl-*a*, TSS, PO_4, PN (Barron-Daintree region), and PP (Russell-Mulgrave and Tully regions).
- Increases over the period 2015–2020: Secchi depth (Barron-Daintree and Tully regions) and PN (Russell-Mulgrave and Tully regions).
- Stable over the period 2015–2020: NO_x (Barron-Daintree and Russell-Mulgrave regions), PN (Barron-Daintree region), Secchi depth (Russell-Mulgrave region), DOC (Barron-Daintree and Tully regions), and POC (Russell-Mulgrave and Tully regions).
- Declines over the period 2015–2020: Chl-*a*, TSS, PO_4, NO_x (Tully region), PP, POC (Barron-Daintree region), and DOC (Russell-Mulgrave region).
- Water Quality Index scores have shown a long-term trend of decline since 2008 in all focus regions, although the Barron-Daintree scores show early signs of improvement in recent years. For the 2019–20 water year, Water Quality Index scores were 'good' in the Barron Daintree, 'moderate' in the Russell-Mulgrave, and 'moderate' in the Tully focus regions.

Wet season and event water quality

- The eReefs hydrodynamic model output showed that enclosed and open coastal waters had low cumulative exposure to river discharge from the Russell-Mulgrave and Tully Rivers. Open coastal waters had negligible three-dimensional exposure to Barron River discharge. River discharge was mainly transported in northerly and south-easterly directions from all rivers.

- There were no major flood events in the Wet Tropics region during the 2019–20 wet season.
- 86% of the Wet Tropics region was not exposed to a potential risk, similar to long-term patterns. Approximately 14% of the total area of the Wet Tropics region, including 2% of the region's coral reefs and 94% of the seagrasses were exposed to a potential risk. However, only the inshore Wet Tropics waters, seagrass and coral habitats were exposed to the highest categories of potential risk (III and IV). Mid-shelf and offshore Wet Tropics reefs and mid-shelf Wet Tropics seagrasses were largely exposed to no / very low risk. The areas were similar to the long-term average areas (changes <1%).

7.6 Burdekin

The combined discharge and loads calculated for the 2019–20 water year from the Burdekin and Haughton Basins were below long-term median values and were among the lowest recorded over the previous decade.

Ambient water quality

Enclosed coastal, open coastal, and mid-shelf waters (for those parameters with guidelines):

- Exceeded guidelines: NO_x, PO_4, PN, PP, and Secchi depth
- Met (below) guidelines: TSS and Chl-*a*
- Increases over the period 2015–2020: PN.
- Stable over the period 2015–2020: NO_x, PP, Secchi depth, DOC, and POC.
- Declines over the period 2015–2020: Chl-*a*, TSS, and PO_4.
- Water Quality Index scores have shown a long-term trend of decline since 2008. For the 2019–20 water year, Water Quality Index scores were 'good' and had improved since the 2018–19 water year.

Wet season and event water quality

- eReefs hydrodynamic model output showed that open coastal waters from Cape Upstart to Cape Cleveland had minor exposures to river discharge. The extent of three-dimensional exposure to river discharge was low in all directions. Tracers travelled <20 km from the Burdekin River mouth.
- There were no major flood events in the Burdekin region during the 2019–20 wet season.
- 87% of Burdekin region was not exposed to a potential risk, similar to long-term patterns. Approximately 13% of the total area of the Burdekin region, including 1% of the region's coral reefs and 98% of the seagrasses were exposed to a potential risk. However, only the inshore Burdekin waters, seagrass and coral habitats were exposed to the highest categories of potential risk (III and IV). Mid-shelf Burdekin seagrasses were largely exposed to the lowest potential risk category, while mid-shelf and offshore Burdekin reefs were largely exposed to no / very low risk. These areas were similar to the long-term average area (<1%– 5% difference).

7.7 Mackay-Whitsunday

The combined discharge and loads calculated for the 2019–20 water year from the Proserpine, O'Connell, Pioneer and Plane Basins were below long-term median values. Discharge from the O'Connell and Pioneer Basins was well below long-term median values.

Ambient water quality

Enclosed coastal and open coastal waters (for those parameters with guidelines):

- Exceeded guidelines: Chl-*a*, TSS, NO_x, PO_4, PN, PP, and Secchi depth.
- Met (below) guidelines: No variables.
- Increases over the period 2015–2020: No variables.
- Stable over the period 2015–2020: TSS, NO_x, PN, PP, and Secchi depth.
- Declines over the period 2015–2020: Chl-*a*, PO_4, POC, and DOC.
- Water Quality Index scores have shown a long-term trend of decline since 2008. For the 2019–20 water year, Water Quality Index scores were 'poor' and had decreased since the 2018–19 water year.

Wet season and event water quality

- eReefs hydrodynamic model output showed that coastal waters had negligible three-dimensional exposure to O'Connell River discharge this year.
- There were no major flood events in the Mackay-Whitsunday region during the 2019–20 wet season.
- 80% of the Mackay-Whitsunday region was not exposed to a potential risk, similar to long-term patterns. Approximately 20% of the total area of the Mackay-Whitsunday region, including 7% of the region's coral reefs and 94% of the seagrasses were exposed to a potential risk. However, only the inshore Mackay-Whitsunday waters, seagrass and coral habitats were exposed to the highest categories of potential risk (III and IV). Mid-shelf and offshore Mackay-Whitsunday reefs were exposed to no / very low risk. These areas were similar to the long-term average areas (within 1%).

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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 CYWMP during 2019–20. 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. * Not event samples but taken during routine sampling for Russell Mulgrave before that was ceased.

Site Location	Logger Deployment		Ambient sampling at fixed sites (proposed and 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/ CYWMP	Additional surface-sampling/year by JCU/ CYWMP
Cape York					
Normanby-Kennedy transect					* (specific sites TBD)
Kennedy mouth				4 (Sampling 2 depths) (4)	1
Kennedy inshore				4 (Sampling 2 depths) (4)	
Cliff Islands				4 (Sampling 2 depths) (4)	1
Bizant River mouth				4 (Sampling 1 depth) (4)	
Normanby River mouth				4 (Sampling 2 depths) (4)	1
Normanby inshore				4 (Sampling 2 depths) (4)	
NR-03				4 (Sampling 2 depths) (4)	
NR-04				4 (Sampling 2 depths) (4)	
NR-05				4 (Sampling 2 depths) (3)	
Corbett Reef				4 (Sampling 2 depths) (3)	
Additional sites/ event samples					3
Pascoe transect					* (specific sites TBD)
Pascoe mouth north				5 (Sampling 2 depths) (4)	
Pascoe mouth south				5 (Sampling 2 depths) (4)	
PR-N2				5 (Sampling 2 depths) (4)	
PR-N3				5 (Sampling 2 depths) (3)	
PR-N5				5 (Sampling 2 depths) (1)	
PR-N6					1
PR-S2.5				5 (Sampling 2 depths) (4)	
Middle Reef				5 (Sampling 2 depths) (4)	
PR-S5				5 (Sampling 2 depths) (3)	
Additional sites/ event samples					2
Annan and Endeavour transect					* (specific sites TBD)
Annan mouth				5 (Sampling 2 depths) (4)	(3)
Walker Bay				5 (Sampling 2 depths) (4)	(2)
Dawson Reef	√			5 (Sampling 2 depths) (4)	(1)

Site Location	Logger Deployment		Ambient sampling at fixed sites (proposed and 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/ CYWMP	Additional surface-sampling/year by JCU/ CYWMP
Endeavour mouth				5 (Sampling 2 depths) (4)	(3)
Endeavour north shore				5 (Sampling 2 depths) (3)	(3)
Endeavour offshore				5 (Sampling 2 depths) (4)	(2)
Egret and Boulder Reef				5 (Sampling 2 depths) (3)	(2)
Additional sites/ event samples					(10)
Stewart transect					* (specific sites TBD)
Stewart mouth				5 (Sampling 2 depths) (5)	1
SR-02				5 (Sampling 2 depths) (5)	
SR-03				5 (Sampling 2 depths) (5)	
SR-04				5 (Sampling 2 depths) (5)	
Hannah Island				5 (Sampling 2 depths) (4)	
Additional site					2
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					** (Surface sampling only) (2)
RM3			5 (Sampling 2 depths) (5)	5 (Sampling 2 depths) (5)	
RM4					** (Surface sampling only) (1)
High Island East					** (Surface sampling only) (2)
Normanby Island					** (Surface sampling only) (2)
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					** (Surface sampling only) (1)
Russell-Mulgrave River mouth mooring	√	√	5 (Sampling 2 depths) (5)	5 (Sampling 2 depths) (5)	
Russell-Mulgrave River mouth					** (Surface sampling only) (2)

Site Location	Logger Deployment		Ambient sampling at fixed sites (proposed and 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/ CYWMP	Additional surface-sampling/year by JCU/ CYWMP
Russell-Mulgrave junction [River]					** (Surface sampling only) (1)
Tully Focus Area					
King Reef					** (Surface sampling only)
East Clump Point			5 (Sampling 2 depths) (5)	5 (Sampling 2 depths) (5)	
Dunk Island North	√	√	5 (Sampling 2 depths) (5)	5 (Sampling 2 depths) (5)	
South Mission Beach					** (Surface sampling only) (2)
Dunk Island South East			5 (Sampling 2 depths) (5)	5 (Sampling 2 depths) (5)	
Between Tam O'Shanter and Timana			5 (Sampling 2 depths) (5)	5 (Sampling 2 depths) (5)	
Hull River mouth					** (Surface sampling only) (2)
Bedarra Island			5 (Sampling 2 depths) (5)	5 (Sampling 2 depths) (5)	
Triplets					** (Surface sampling only) (2)
Tully River mouth mooring	√	√	5 (Sampling 2 depths) (5)	5 (Sampling 2 depths) (5)	
Tully River					** (Surface sampling only) (1)
Burdekin					
Burdekin Focus Area					
Pelorus and Orpheus Island West	√		4 (Sampling 2 depths) (4)	5 (Sampling 2 depths) (5)	
Pandora Reef	√		4 (Sampling 2 depths) (4)	5 (Sampling 2 depths) (5)	
Cordelia Rocks					** (Surface sampling only)
Magnetic Island (Geoffrey Bay)	√		4 (Sampling 2 depths) (4)	5 (Sampling 2 depths) (5)	
Inner Cleveland Bay					** (Surface sampling only)
Cape Cleveland					** (Surface sampling only)
Haughton 2			4 (Sampling 2 depths) (4)	5 (Sampling 2 depths) (5)	
Haughton River mouth					** (Surface sampling only)
Barratta Creek					** (Surface sampling only)
Yongala IMOS NRS	√	√	12 (Sampling 2 depths) (12)		
Cape Bowling Green					** (Surface sampling only)
Plantation Creek					** (Surface sampling only)
Burdekin River mouth mooring	√	√	4 (Sampling 2 depths) (4)	5 (Sampling 2 depths) (5)	
Burdekin Mouth 2					** (Surface sampling only)
Burdekin Mouth 3					** (Surface sampling only)
Mackay-Whitsunday					

Site Location	Logger Deployment		Ambient sampling at fixed sites (proposed and 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/ CYWMP**	**Additional surface-sampling/year by JCU/ CYWMP**
Whitsunday focus area					
Double Cone Island	√		5 (Sampling 2 depths) (5)		
Hook Island W					** (Surface sampling only)
North Molle Island					** (Surface sampling only)
Pine Island	√		5 (Sampling 2 depths) (5)		
Seaforth Island	√		5 (Sampling 2 depths) (5)		
OConnell River mouth			5 (Sampling 2 depths) (5)		
Repulse Islands dive mooring	√	√	5 (Sampling 2 depths) (5)		
Rabbit Island NE					** (Surface sampling only)
Brampton Island					** (Surface sampling only)
Sand Bay					** (Surface sampling only)
Pioneer River mouth					** (Surface sampling only)

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Appendix 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 Authority. Site-specific GVs for all water quality variables are shown in Appendix C Table C-9.

Table B-1: Guidelines values for four cross-shelf water bodies 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-3).

** 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 provided by the 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 (TSS concentrations, Secchi depth, and turbidity measurements by FLNTUSB instruments, where available),
- 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 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 (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, etc.).

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

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

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

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

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

5. 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.

6. 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.

7. For the focus region summaries, the Index scores of all sampling locations within a focus region (e.g., 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 (e.g., all sites in the Wet Tropics region) are averaged and converted as above.

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

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

2. Guidelines from the Authority are consulted to select the appropriate aggregation (annual, wet, or dry season) and statistic (mean or median) for each site and indicator (Table C-9).

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

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

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 concentration, and turbidity 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 (e.g., 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 (e.g., 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, the use of remote sensing is a valid and practical way to estimate wet season marine conditions as well as the extent and frequency of wet season water types exposure on Reef ecosystems, including river plumes and resuspension events.

Following recommendations from the 2012–13 MMP report, marine areas exposed to wet season water types are mapped using MODIS true colour (TC) images and a surface water colour classification method 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). The TC method is based on a semi-automated classification of spectrally enhanced quasi-true colour MODIS images. It exploits the differences in water colour existing between the turbid coastal waters (including river plumes) and the marine ambient water, as well differences in water colour existing across coastal waters of the Reef during the wet season.

The wet season water types are produced using MODIS true colour imagery reclassified to six distinct colour classes defined by their colour properties. The wet season colour classes are regrouped into three wet season water types (primary, secondary and tertiary) characterised by different concentrations of optically active components (TSS, colour dissolved organic matter and Chl-*a*), which control the colour of the water and influence the light attenuation (Petus et al., 2018), and different pollutant concentrations (Petus et al. 2019).

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

Product / analysis Name	Management outcome	Refs	Data			
a. WS maps	Weekly composite maps Illustrating (qualitative) the composition of nearshore waters in the GBR during the wet season as well as the movements of river flood plumes	Alvarez-Romero et al., 2013	●			
b. Frequency maps	Provide a broad scale approach to reporting contaminant concentrations in the GBR marine environment Help defining water quality target concentration for ecosystem conservation	Devlin et al., 2015 Waterhouse et al., 2017a, 2018 Petus et al., 2018	●	●		
c. Load maps	Model the transport of land-sourced pollutants	Waterhouse et al., 2017a, 2018	●	●	●	
d. Susceptibility assessment	Explain changes in ecosystem condition / health	Thompson et al., 2018, McKenzie, 2018 Collier et al., 2014 Petus et al., 2014a Wenger et al., 2016	●	●		●
e. Exposure / potential risk maps & assessment	Evaluate the risk of ecosystems from river flood plume exposure. Use established risk management approaches (magnitude x likelihood)	Petus et al., 2014b, 2016 Waterhouse et al., 2017a, 2018	●	●		●
f. Integrated monitoring	Use combination / all products defined above	Devlin et al., 2015a, b, 2017b, Lønborg et al., 2016; Waterhouse et al., 2017a, b, 2018	●	●	●	●

Satellite data In-situ water quality Catchment load Ecosystem monitoring

Figure B-1: Operational monitoring products and assessment methods used to monitor the inshore water quality of the Great Barrier Reef through the MMP (blue references) and examples of regional studies using the MMP satellite monitoring products (black references) (Petus et al., 2019). WS: wet season.

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

Several operational monitoring products and frameworks have been developed using MODIS satellite imagery and the water colour classification method (Figure B-1). They are used within the annual MMP reports (Gruber et al., 2019). Classification methods and monitoring products are quickly described below (Great Barrier Reef Marine Park Authority 2019). All products focus on the Austral wet season, i.e., the December to April period.

Supervised classification using spectral signatures

Daily MODIS Level-0 data are acquired from the NASA Ocean Colour website (http://oceancolour.gsfc.nasa.gov) and converted into true colour images with a spatial resolution of approximately 500 × 500 m using SeaWiFS Data Analysis System 7.4 (SeaDAS; Baith et al., 2001). The method assumes that fully accurate atmospheric corrections are less crucial for turbid (case 2) Reef flood waters than it would be for clear (case 1) waters, and MODIS true-colour images are produced using Rayleigh corrected reflectance of MODIS bands 1, 4 and 3 (without an aerosol removal step). MODIS-Terra true colour images are also occasionally downloaded from the National Aeronautics and Space Administration (NASA)'s EOSDIS worldview website and processed to daily water type maps. MODIS-Terra are only used when MODIS data are too cloudy or unavailable, and when satellite information are required in near-real-time (rapid response mapping of flood events).

The true-colour images are then spectrally enhanced (from red-green-blue to hue-saturation-intensity colour system) and classified to six colour categories through a supervised classification using spectral signatures from typical wet season water masses types (including river plumes) in the Reef lagoon. The six colour classes are further reclassified into three wet season water types (primary, secondary and tertiary) corresponding to the three wet season water types, as described above and defined originally by Devlin and Schaffelke (2009) and Devlin et al. (2012). True-colour images for 2011 (very wet), 2016 and 2017 (dry) years, and from 2018 onward (2018 and 2019) were processed by BOM) and the slightly modified cloud mask (2017 case study), while all other years were processed in-house by TropWATER using previous methods

Production of weekly wet season water type maps (Figure B-1, a)

This supervised classification is used to classify daily MODIS images. Weekly wet season water type composites are then created to minimise the image area contaminated by dense cloud cover and intense sun glint (Álvarez-Romero et al., 2013). The minimum colour-class value of each cell/week is used to map the colour class with the maximum turbidity per pixel for each week of the wet season (i.e., assuming the colour classes represented a gradient in turbidity i.e., CC1 > CC2 > CC3 > CC4 > CC5 > CC6). All weekly composites are automatically cleaned and extra cleaning steps are applied if needed.

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 (CC 1-4). 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 CC7 (ambient ocean water) inwards towards the coast. This processing was performed 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 CC1 and CC2 (i.e. values < 3*) in the cleaned raster are replaced with pixels of CC1 and CC2 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. *The script is occasionally re-run using a different value than 3 in cases where moderately turbid inshore waters have evidently being removed during the cleaning process but that was not required this year.

In 2019–20, and extra cleaning steps were applied to weeks 1, 18, 20 and 21 to remove large misclassified areas offshore The cleaned weekly composites for weeks 1, 18, and 20, were created by a) generating a weekly map as usual using all daily images from the respective weeks (v1), b) generating a weekly map excluding the days that had large misclassified waters offshore due to sunglint and cloud (v2), and c) replacing the primary waters (CC 1-4) from the v2 maps with the primary waters from the v1 maps. Thus, the primary waters in the composite represent the minimum value per pixel from all daily images for the week whereas the offshore waters represent the minimum value per pixel from the daily images excluding the days with corrupted classification offshore.

Production of annual, multi-annual and typical Wet and Dry wet season water type maps (Figure B-1, b)

Weekly wet season water type composites are thus overlaid in ArcGIS (i.e., presence/absence of one wet season water type) and normalised, to compute each year a seasonal normalised frequency maps of occurrence of wet season water type. Pixel (or cell) values of these maps range from 1 to 22; with a value of 22 meaning that 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 wet season water types. Multi-annual composites are calculated over different time frames, including (i) the long-term (2002/03–2017/18: 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. 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 (e.g. 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 every 4 years (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.

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

Surface loading maps (Figure B-1, c)

Surface loading maps that model the transport of land-sourced pollutants (DIN, TSS and PN) are created using the eReefs marine model tracers for each river plume and dispersion of end of catchment loads (Figure B-1).

Susceptibility assessment (Figure B-1 d)

Frequency maps are also compared with ecological health information collected through the coral reef and seagrass components of the MMP (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 (Figure B-1d).

Mean long-term water quality concentrations across water types and colour classes

Additional information on wet season conditions are reported by characterising the long-term water quality concentrations across water types and colour classes.

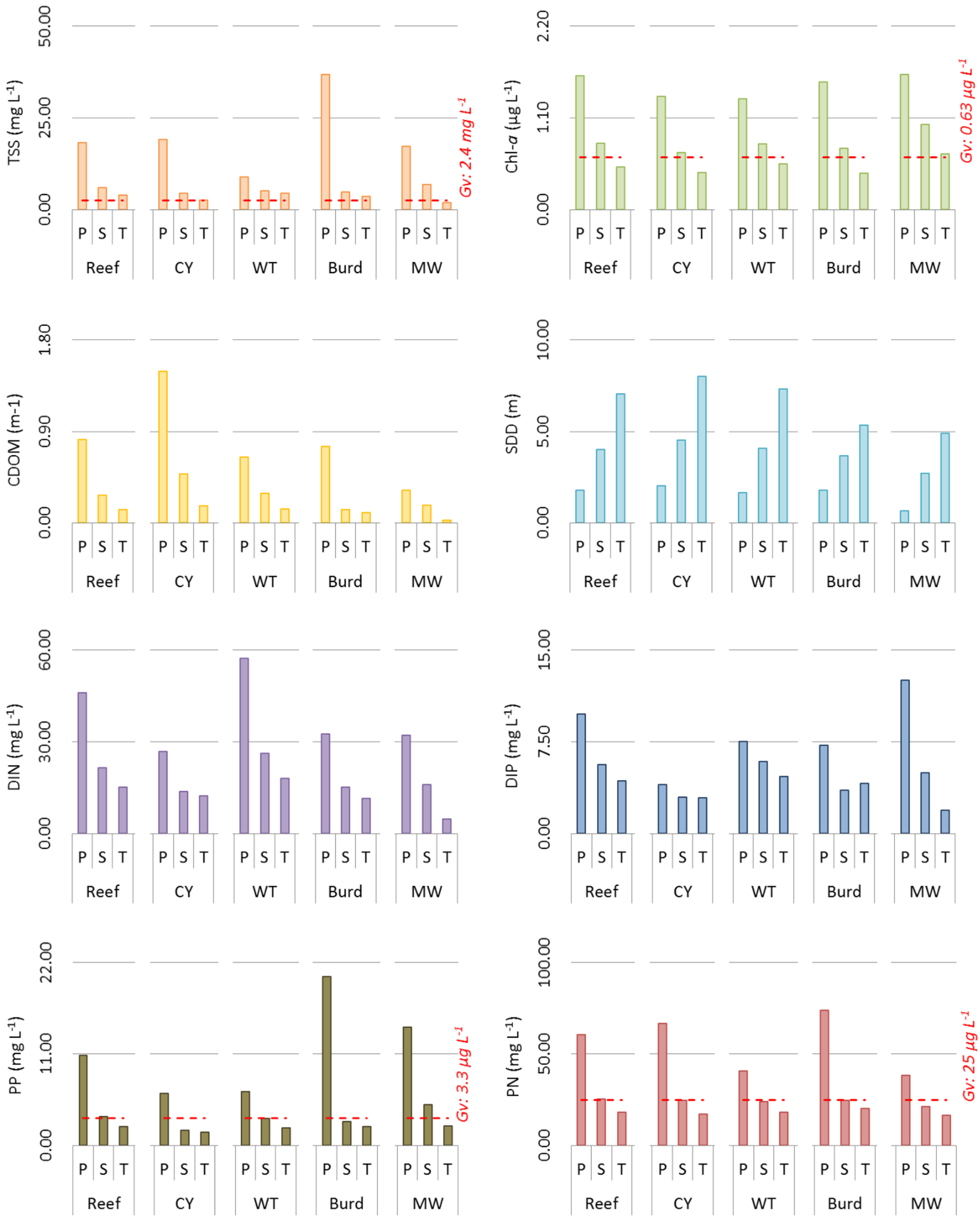

Figure B-2: Mean long-term (2004–2019) water quality concentrations across the three wet season water types in all focus regions. Red lines show the Reef-wide wet season GVs (Table B-3). The Burdekin region has the greatest average TSS, PP, and PN concentrations in the primary water type, which exceeded 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-2), where high TSS, PN and PP concentrations are likely to contribute to exceedances of the Reef-wide GVs.

Match-ups between sampled date and corresponding weekly wet season water type maps are performed at site location basis using the *extract tool of* the raster package (Hijmans et al., 2015) with bilinear interpolation method in R 3.2.4. This tool interpolates from the values of the four nearest raster cells (R 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 and colour classes (Figure 4-5) and the mean long-term water quality concentrations across the three wet season water types in all focus regions (Figure B-2) are presented. 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 and reporting year 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 CYWMP (since 2016–17). 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 field data collected from 2004 to 2019. Before 2016–17, the mean water quality concentrations were calculated using the JCU dataset only, assuming it was representative of high flow conditions. Long-term mean DIN, PP and PN concentrations were calculated as DIN = NO2+NO3+NH3, PP= TP-TDP and PN = TN-DIN, respectively.

Exposure maps and exposure assessment (Figure B-1, e)

Information on the long-term pollutant concentrations measured in the WS colour classes 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 (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 primary, secondary and tertiary water types. The *'likelihood of the exposure'* is estimated by calculating the frequency of occurrence of each wet season water type. The exposure for each of the water quality parameters defined is as the proportional exceedance of the guideline multiplied by the likelihood of exposure in each of the wet season water type and calculated as below. For each cell (500 m x 500 m):

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

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

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

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

where $water\ type$ is the primary, secondary or tertiary wet season water types, $[Poll.]_{water\ type}$ is the wet season or long-term mean TSS, Chl-*a*, PN, or PP concentration measured in each respective wet season water types and $guideline$ is the Reef-wide wet season GV from De'ath and Fabricius (2008) for TSS, Chl-*a*, PP, and PN (Table B-3).

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

Parameter	Unit	Reef-wide
Chlorophyll *a*	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-4).

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

Region	Water type	Number of samples								
		Salinity	Secchi depth	TSS	Chl-a	CDOM	DIN	PO4	PP	PN
Cape York	Primary	125	109	125	136	101	138	137	91	135
	Secondary	124	120	124	132	51	131	132	98	131
	Tertiary	61	47	61	61	25	63	63	52	63
	Marine	9	4	9	9	3	9	9	8	9
Wet Tropics	Primary	224	164	375	368	357	321	324	301	309
	Secondary	244	289	482	495	438	475	476	446	447
	Tertiary	109	121	172	172	141	169	169	166	167
	Marine	17	22	29	29	27	28	28	20	20
Burdekin	Primary	100	81	132	131	86	129	131	126	127
	Secondary	104	146	188	187	132	187	187	177	176
	Tertiary	28	35	47	45	37	47	47	43	45
	Marine	14	16	18	21	15	22	22	19	19
Mackay - Whitsunday	Primary	12	9	26	23	25	26	26	24	24
	Secondary	44	34	86	81	53	86	86	77	78
	Tertiary	10	9	18	18	9	17	17	17	17
Fitzroy	Primary	15		76	77	56	77	78	75	76
	Secondary	13		34	48	43	52	54	53	53
	Tertiary	2		2	7	4	7	7	6	7
	Marine			6	6	1	6	6	6	6
Burnett-Mary	Primary	7	7	20	20	11	11	20	20	11
	Secondary	2	5	12	12	5	8	12	11	8
	Tertiary	1		1	1		1	1	1	1

	Marine			3	3	1	3	3	3	3
Reef-wide	Primary	483	370	754	755	636	702	716	637	682
	Secondary	531	594	926	955	722	939	947	862	893
	Tertiary	211	212	301	304	216	304	304	285	300
	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 wet season water types:

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

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

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

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

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

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

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

The total exposure for Chl-*a*:

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

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 maximizing 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 the two 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 WQ 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, over 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 every 4 years (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. 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 2019 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-5. 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.

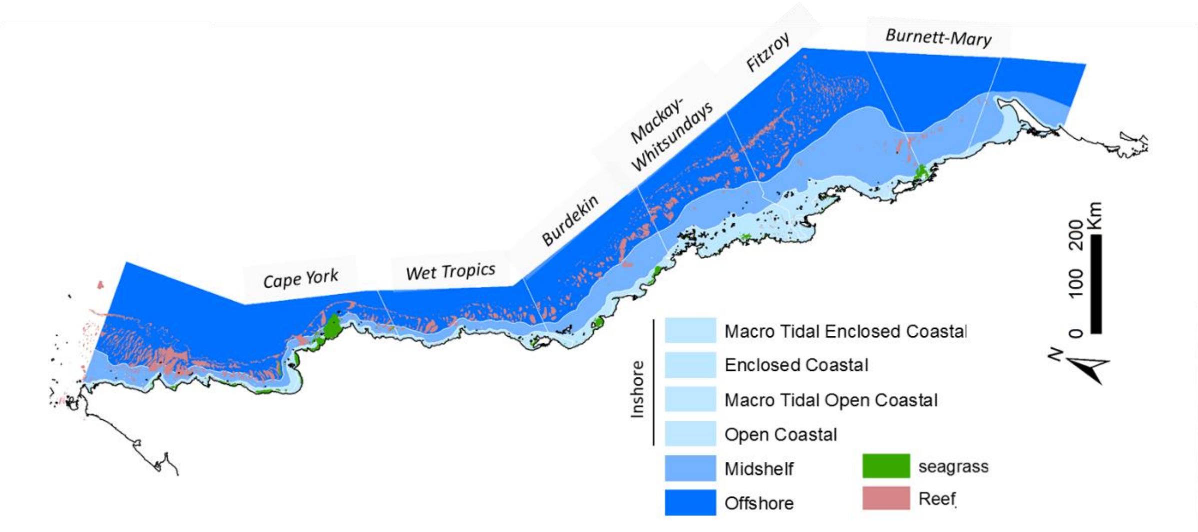

Figure B-3: Boundaries used for the Marine Park, each NRM region and the coral reefs and seagrass ecosystems. Coral reef and NRM layers derived from the Authority, supplied 2013. Seagrass layer is a composite of surveys conducted by Department of Agriculture and Fisheries, Qld.

B-4 References

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Appendix C: Additional information

C-1 Continuous FLNTU data

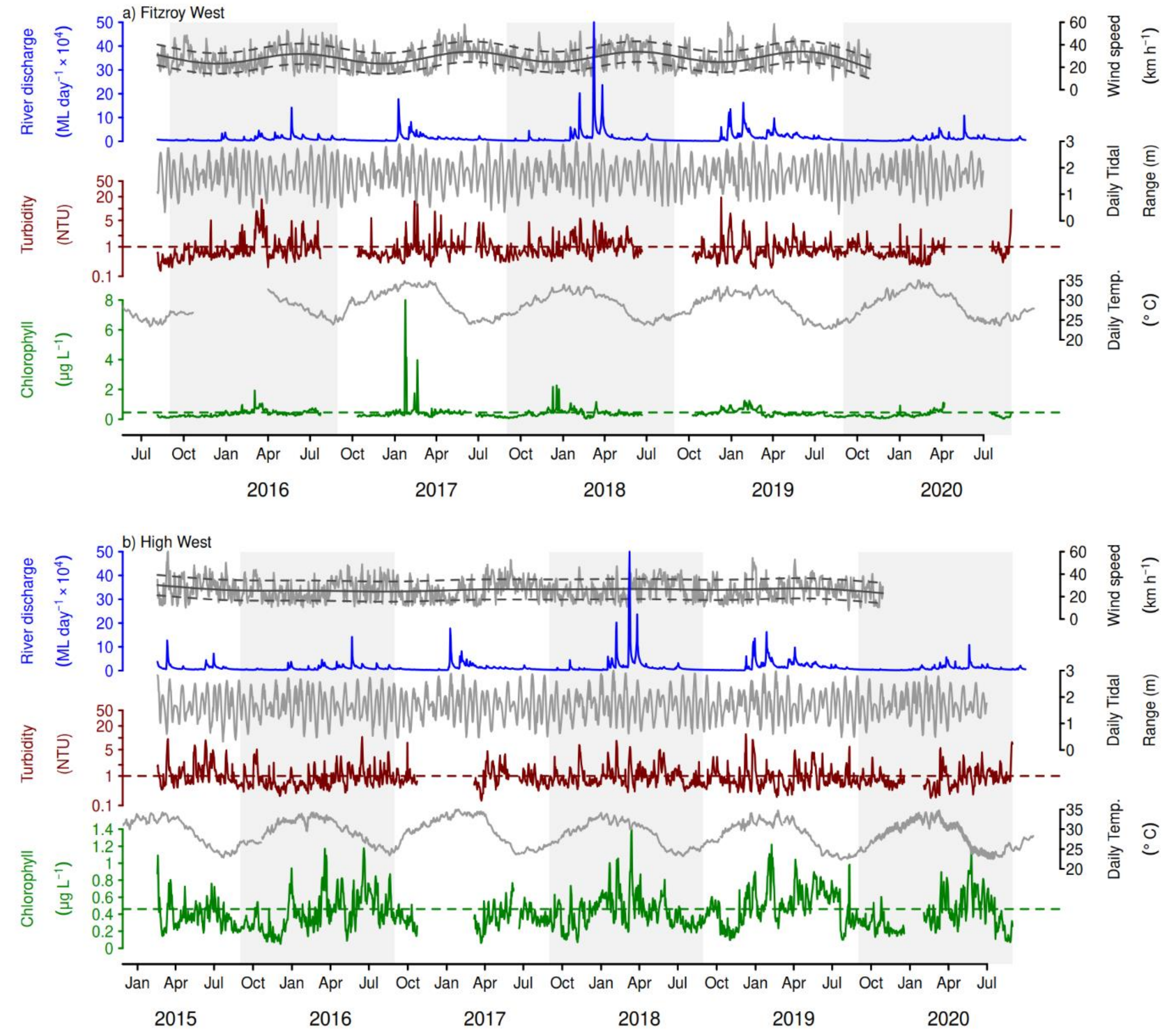
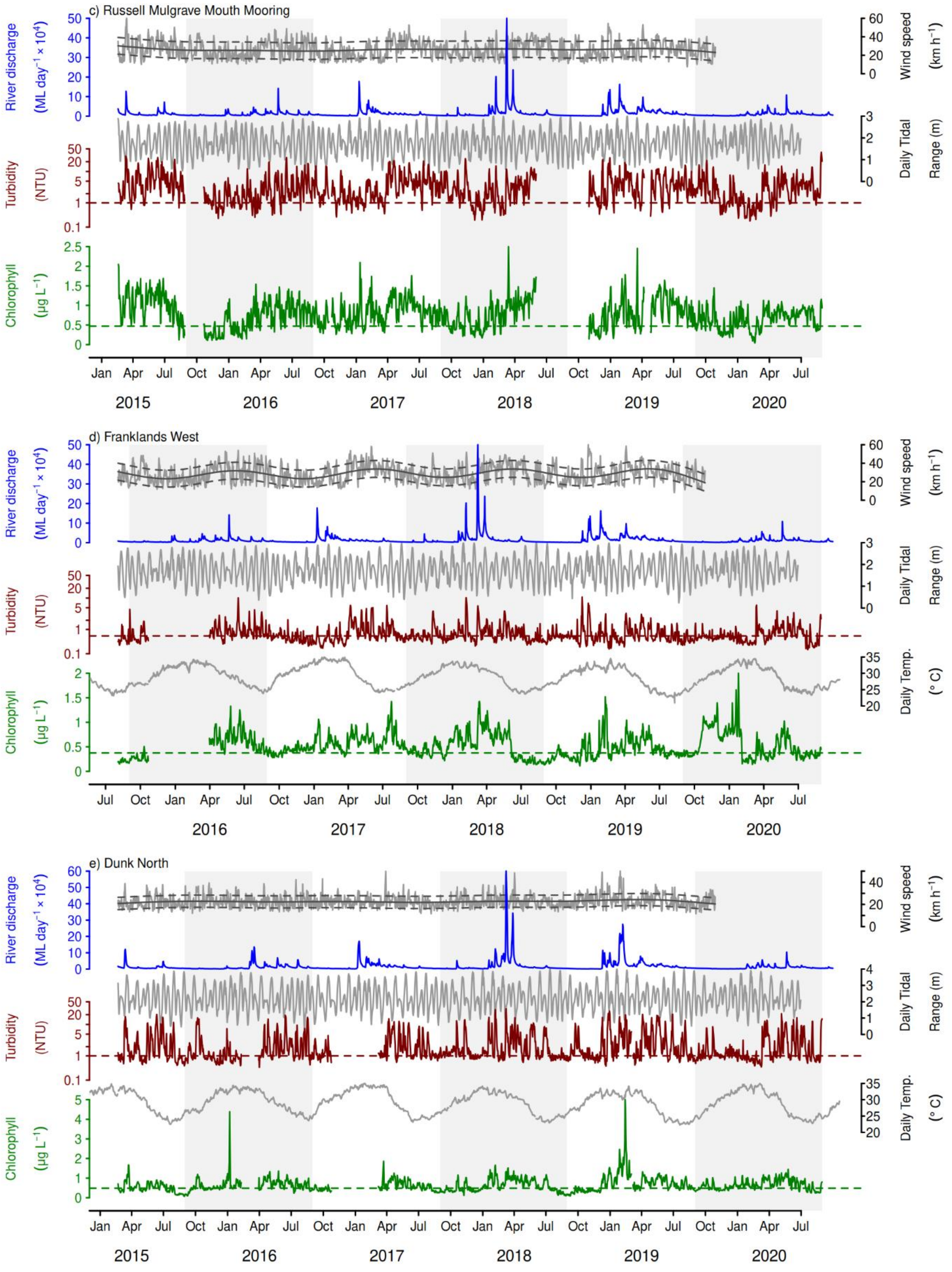
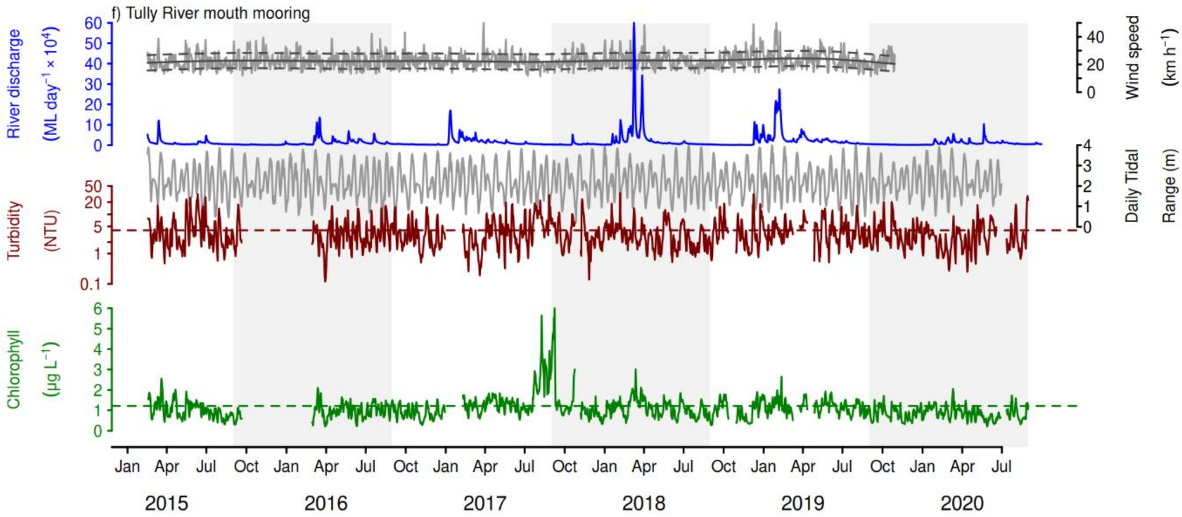
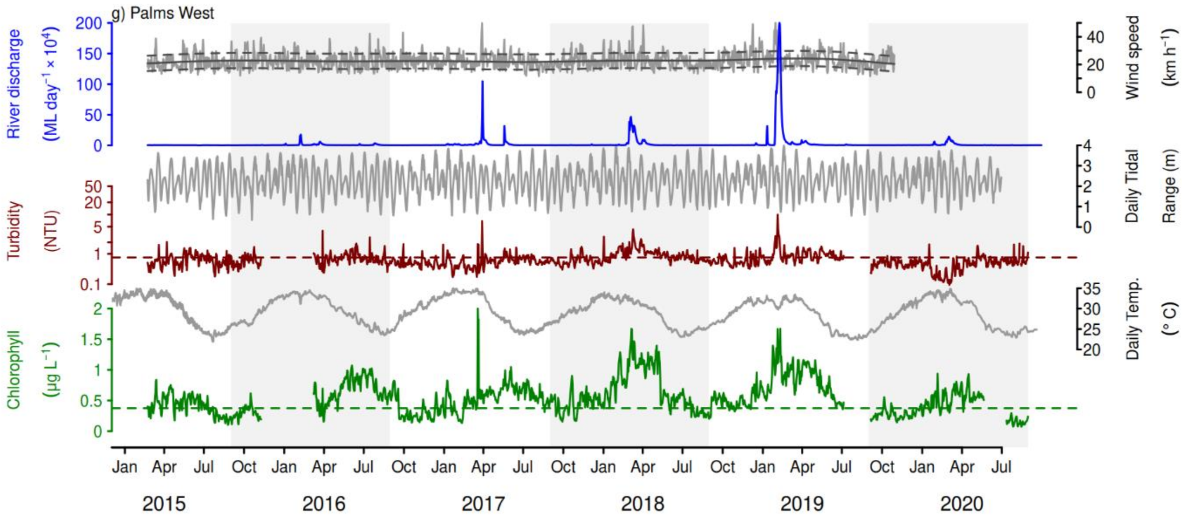
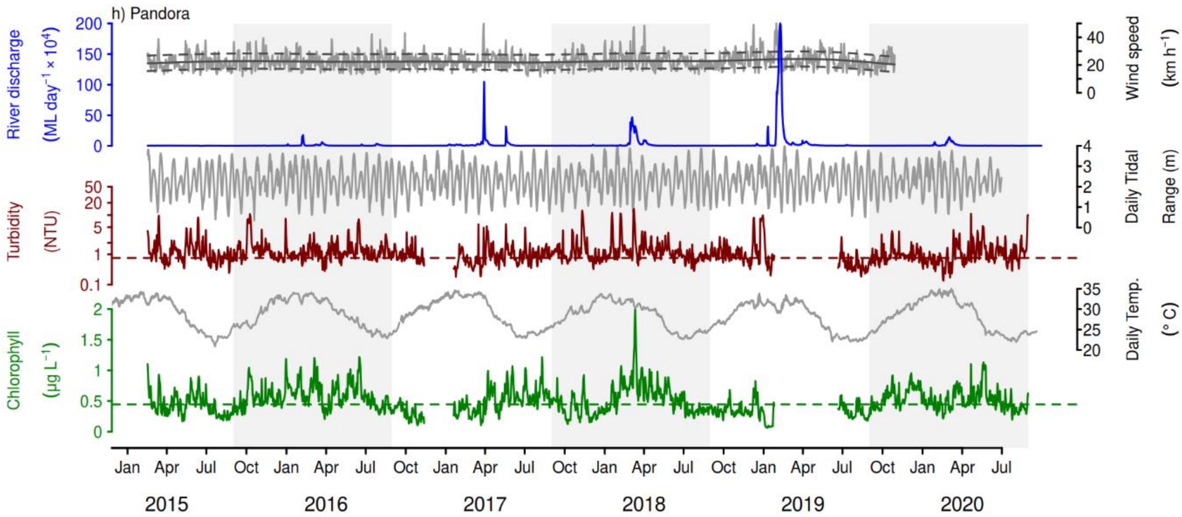


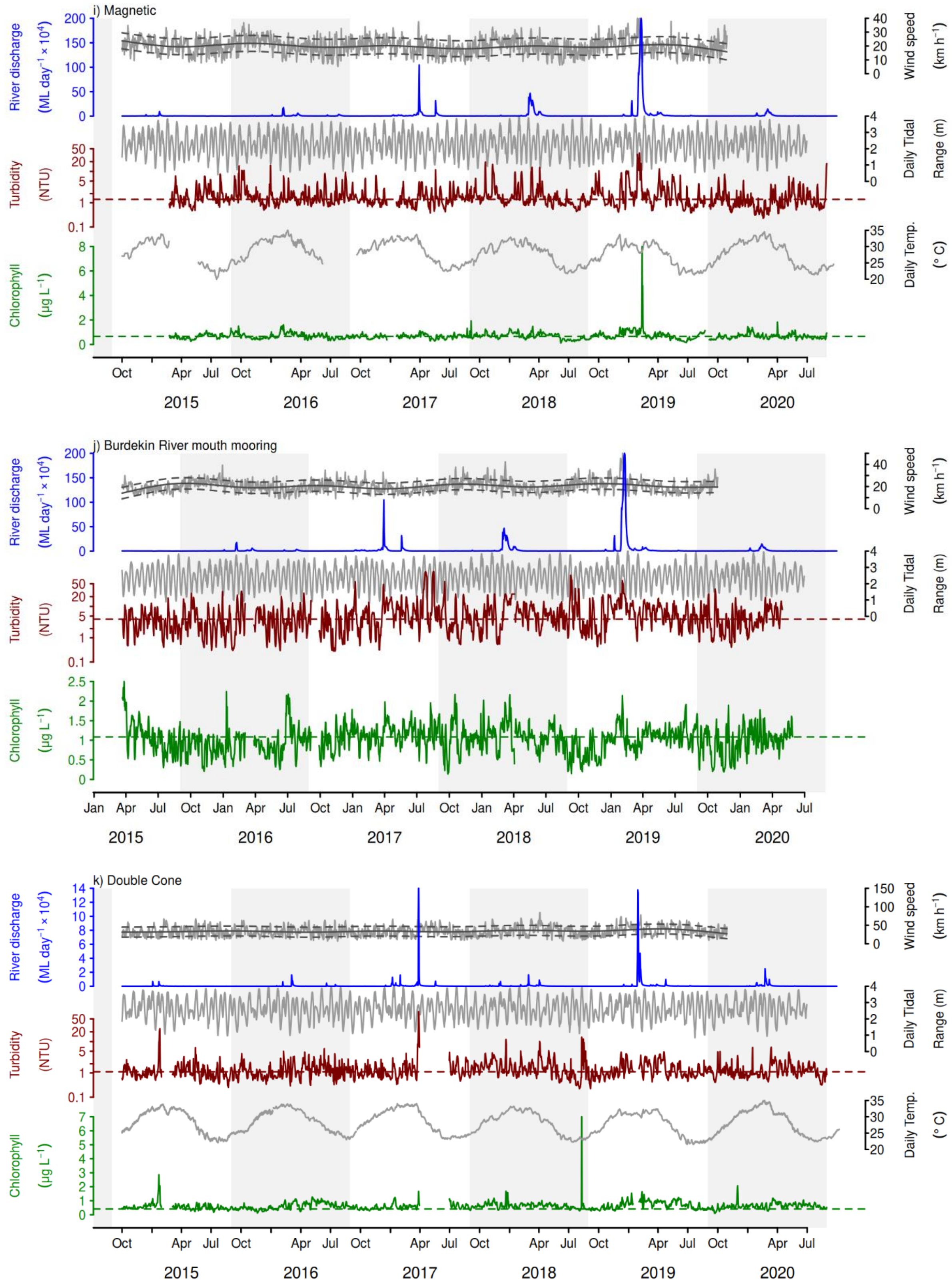
Figure C-1: Time-series of daily means of chlorophyll and turbidity collected by moored ECO FLNTUSB instruments; coloured dashed lines represent the Water Quality GVs. Daily river discharge from the nearest river, daily wind speeds from the nearest weather stations, daily tidal range from the nearest tidal gauge, and daily temperature are also shown. Locations of loggers are shown in Figure 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; and n) Repulse.


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

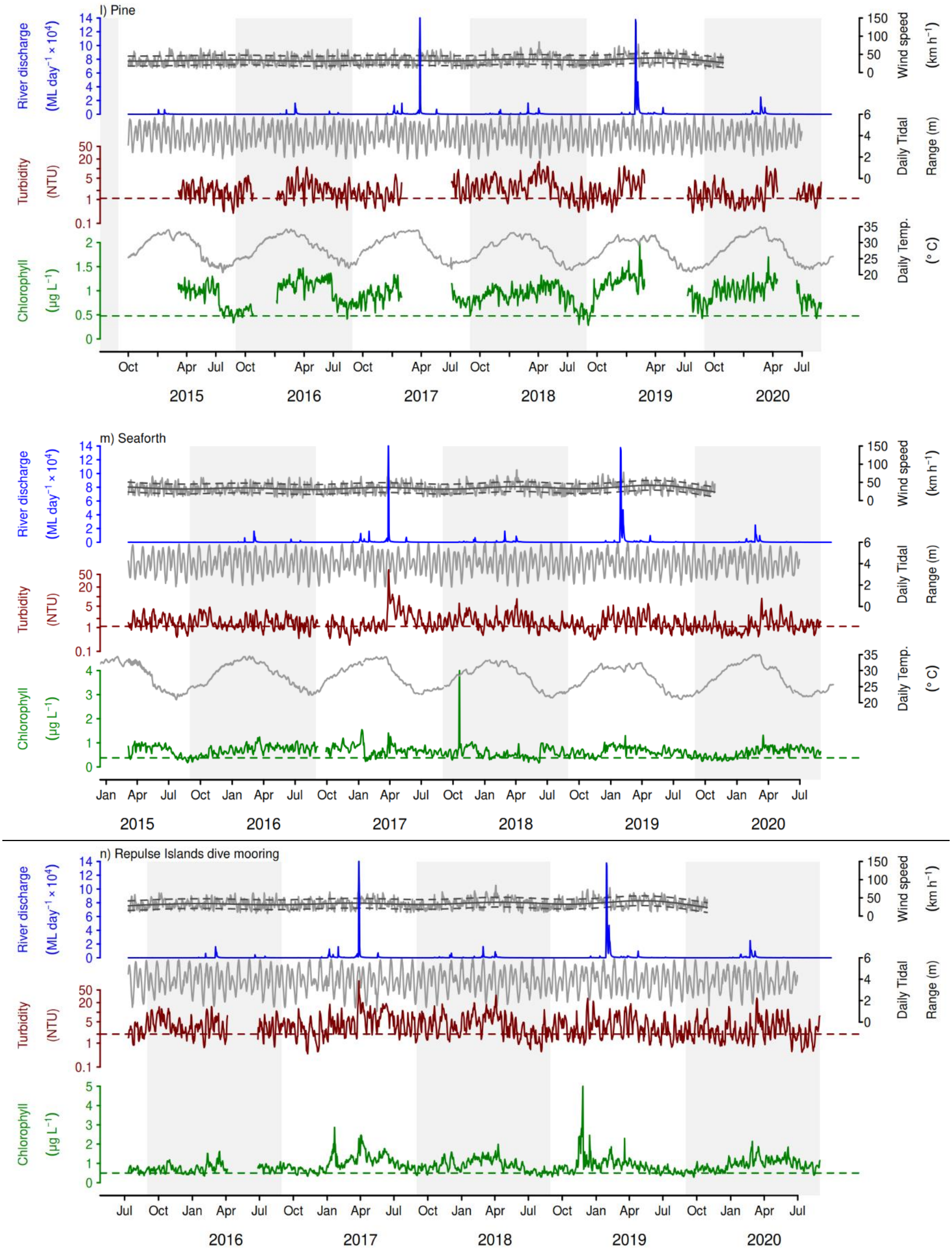

f) Tully River mouth mooring
River discharge
(ML day^{-1} × 10^4)
Turbidity
(NTU)
Chlorophyll
(µg L^{-1})
Wind speed
(km h^{-1})
Daily Tidal
Range (m)
Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul
2015 2016 2017 2018 2019 2020


g) Palms West
River discharge
(ML day^{-1} × 10^4)
Turbidity
(NTU)
Chlorophyll
(µg L^{-1})
Wind speed
(km h^{-1})
Daily Tidal
Range (m)
Daily Temp.
(° C)
Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul
2015 2016 2017 2018 2019 2020


h) Pandora
River discharge
(ML day^{-1} × 10^4)
Turbidity
(NTU)
Chlorophyll
(µg L^{-1})
Wind speed
(km h^{-1})
Daily Tidal
Range (m)
Daily Temp.
(° C)
Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul
2015 2016 2017 2018 2019 2020



i) Magnetic
j) Burdekin River mouth mooring
k) Double Cone
River discharge
(ML day⁻¹ × 10⁴)
Turbidity
(NTU)
Chlorophyll
(µg L⁻¹)
Wind speed
(km h⁻¹)
Daily Tidal
Range (m)
Daily Temp.
(° C)
Jan
Apr
Jul
Oct
2015
2016
2017
2018
2019
2020


l) Pine
River discharge (ML day⁻¹ × 10⁴)
Turbidity (NTU)
Chlorophyll (µg L⁻¹)
Wind speed (km h⁻¹)
Daily Tidal Range (m)
Daily Temp. (° C)
2015
2016
2017
2018
2019
2020
m) Seaforth
n) Repulse Islands dive mooring

C-2 Continuous temperature and salinity

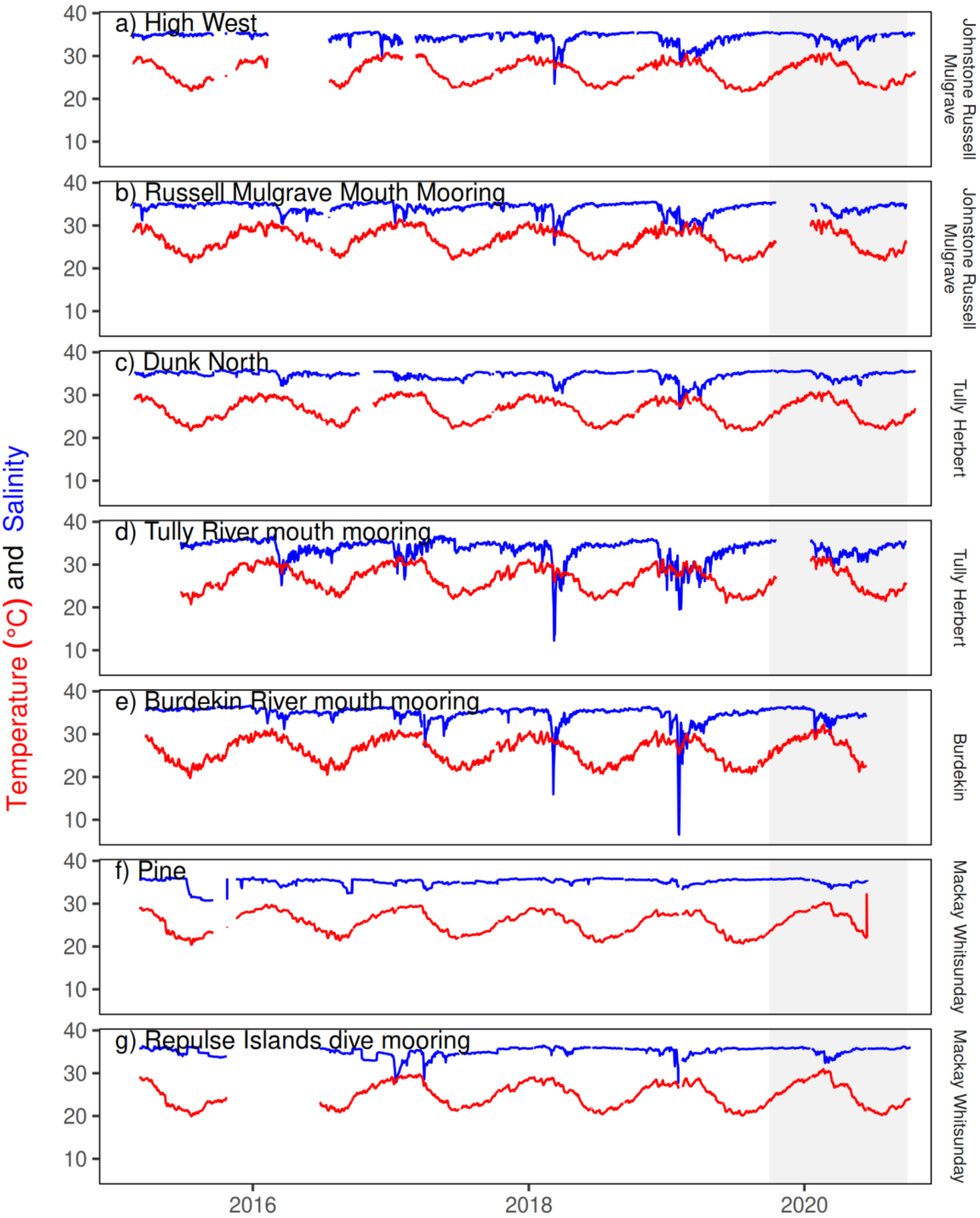


Figure C-2: Time series of daily means of temperature and salinity derived from moored Sea-Bird Electronics (SBE) CTDs. Sub-figures represent instrument locations at: a) High West, b) Russel Mulgrave Mouth Mooring, c) Dunk North, d) Tully River Mouth Mooring, e) Burdekin Mouth Mooring, f) Pine, and g) Repulse.

C-3 Summary statistics for all sites

Table C-1: Water quality results for Cape York sampling sites within the enclosed coastal (EC), open coastal (OC) and mid-shelf (MS) water bodies compared against the Draft Eastern Cape York Water Quality Guidelines (2019). Guidelines vary for each water body and focus region based on available data. For the EC water body, wet season GVs have been designated for each focus region, therefore the statistics are presented separately for dry season and wet season results. OC water body guidelines (all focus regions) include both wet season and dry season GVs except for NH_3 and Secchi depth which have annual GVs. As a result, the OC water body results for each focus region are presented in separate tables for the combined annual results, wet season and dry season. MS water body guidelines (all focus regions) are based on annual concentrations; therefore, only the annual (wet and dry season combined) results are presented for each focus region in this water body. Flood event sample results are not included in the statistics calculated for these tables. Results that exceed the relevant GVs are shaded in red.

ENCLOSED COASTAL DRY SEASON 2019–2020											
Region/ Water body	Site[1]	Measure	N	Mean	Quantiles					Guidelines	
					Q5	Q20	Median	Q80	Q95	Statistic	Dry[2]
	Endeavour Basin	DIN (µg L⁻¹)	4	7.01	4.00	5.28	6.43	8.51	10.85		
		DOC (mg L⁻¹)	4	1.37	1.11	1.14	1.29	1.57	1.75		--
		DON (µg L⁻¹)	4	99.77	71.52	75.36	83.63	117.72	150.61		--
		DOP (µg L⁻¹)	4	3.80	2.00	2.58	3.91	5.07	5.45		--
		Chl a (µg L⁻¹)	4	0.35	0.09	0.22	0.38	0.50	0.58		--
		NH3 (µgL⁻¹)	4	4.08	1.62	2.50	3.67	5.50	7.13		--
		NO_x (µg L⁻¹)	4	2.93	2.26	2.32	2.76	3.47	3.84		--
		PN (µg L⁻¹)	4	29.75	16.84	22.36	29.51	37.05	43.01		--
		PO_4 (µg L⁻¹)	4	1.26	0.46	0.91	1.46	1.68	1.77		--
		POC (µg L⁻¹)	4	183.60	101.81	140.24	189.20	229.20	257.55		--
		PP (µg L⁻¹)	4	3.08	1.28	1.38	2.91	4.71	5.13		--
		Secchi (m)	4	2.6	1.9	2.0	2.4	3.1	3.6		--
		SiO_4 (µg L⁻¹)	4	313.65	169.46	201.01	229.96	392.82	575.02		--
		TSS (mg L⁻¹)	4	1.8	0.6	1.1	1.9	2.5	2.9		
	Normanby River	DIN (µg L⁻¹)	7	8.23	4.20	5.33	6.60	11.45	12.87		--
		DOC (µg L⁻¹)	7	1.78	1.34	1.59	1.78	1.98	2.15		--
		DON (µg L⁻¹)	7	103.72	88.86	90.49	92.35	120.60	122.51		--
		DOP (µg L⁻¹)	7	3.92	2.36	2.83	3.33	4.28	6.67		--

ENCLOSED COASTAL DRY SEASON 2019–2020											
Region/ Water body	Site[1]	Measure	N	Mean	Quantiles					Guidelines	
					Q5	Q20	Median	Q80	Q95	Statistic	Dry[2]
Cape York Enclosed Coastal Water body		Chl a (µg L^{-1})	6	0.72	0.53	0.62	0.70	0.87	0.92		--
		NH_3 (µgL^{-1})	7	5.25	2.33	3.16	5.72	6.06	8.30		--
		NO_x (µg L^{-1})	7	2.98	0.95	1.35	1.66	5.24	6.85		--
		PN (µg L^{-1})	5	40.53	31.93	33.95	41.50	45.45	49.80		--
		PO_4 (µg L^{-1})	7	2.06	1.64	1.88	1.95	2.32	2.45		--
		POC (mg L^{-1})	5	256.08	205.45	228.93	243.25	278.65	324.10		--
		PP (µg L^{-1})	3	25.81	5.51	6.26	7.74	41.75	58.76		--
		Secchi (m)	5	0.7	0.2	0.4	0.4	1.2	1.5		--
		SiO_4 (µg L^{-1})	7	192.00	42.77	65.45	154.26	312.27	337.51		--
		TSS (mg L^{-1})	7	50.2	6.1	7.2	11.0	69.2	154.9		--
	Stewart River	DIN (µg L^{-1})	3	9.02	8.26	8.33	8.46	9.59	10.16		
		DOC (µg L^{-1})	3	1.65	1.61	1.63	1.67	1.68	1.68		--
		DON (µg L^{-1})	3	102.98	99.34	101.07	104.54	105.21	105.54		--
		DOP (µg L^{-1})	3	4.07	3.65	3.66	3.68	4.41	4.77		--
		Chl a (µg L^{-1})	3	0.7	0.5	0.5	0.5	0.9	1.1		--
		NH_3 (µgL^{-1})	3	3.70	2.57	2.59	2.63	4.60	5.58		--
		NO_x (µg L^{-1})	3	5.32	4.56	4.91	5.61	5.78	5.87		--
		PN (µg L^{-1})	3	49.17	43.23	43.90	45.25	53.65	57.85		--
		PO_4 (µg L^{-1})	3	2.89	2.36	2.52	2.83	3.25	3.46		--
		POC (mg L^{-1})	3	288.75	220.68	226.45	238.00	340.90	392.35		--
		PP (µg L^{-1})	3	5.73	4.58	4.81	5.27	6.57	7.22		--
		Secchi (m)	2	2.3	2.2	2.2	2.3	2.4	2.4		--
		SiO_4 (µg L^{-1})	3	179.20	164.08	165.48	168.29	190.73	201.95		--
		TSS (mg L^{-1})	3	3.9	2.6	2.8	3.0	4.9	5.8		

1 No dry season monitoring on the Pascoe River
2 There are no annual or dry season guidelines for the Cape York enclosed coastal water body (wet season only)

ENCLOSED COASTAL WET SEASON 2019–2020											
Region/ Water body	Site	Measure	N	Mean	Quantiles					Guidelines	
					Q5	Q20	Median	Q80	Q95	Statistic	Wet
Cape York Enclosed Coastal Water body	Endeavour Basin	DIN (µg L⁻¹)	6	12.94	2.46	3.80	6.60	8.14	39.89		
		DOC (mg L⁻¹)	7	1.99	1.45	1.49	1.57	1.80	3.64		
		DON (µg L⁻¹)	6	91.97	65.02	76.50	88.46	113.54	121.13		
		DOP (µg L⁻¹)	7	2.73	0.43	1.00	3.16	3.54	4.65		
		Chl a (µg L⁻¹)	7	0.23	0.06	0.10	0.11	0.45	0.55	20th-50th-80th	0.2-0.6-0.8
		NH_3 (µgL⁻¹)	5	15.43	3.09	5.48	6.79	24.79	36.98	20th-50th-80th	2-4-6
		NO_x (µg L⁻¹)	7	4.56	1.51	1.90	2.75	8.31	10.31	20th-50th-80th	1.5-2.5-9.6
		PN (µg L⁻¹)	7	29.04	17.82	19.36	22.76	35.25	50.62		
		PO_4 (µg L⁻¹)	7	1.18	0.31	0.31	1.18	2.00	2.33	20th-50th-80th	<2.0-2.0-3.4
		POC (µg L⁻¹)	7	199.85	108.03	108.95	205.93	237.95	350.20		
		PP (µg L⁻¹)	7	3.02	1.09	1.57	2.17	5.13	5.80		
		Secchi (m)	6	2.4	1.5	1.6	2.5	3.1	3.2	20th-50th-80th	1.8-3.0-4.4
		SiO_4 (µg L⁻¹)	7	551.49	53.43	125.04	130.89	586.65	2032.55		
		TSS (mg L⁻¹)	7	2.8	0.1	0.2	0.8	6.7	8.2	20th-50th-80th	3-4-5
	Normanby River	DIN (µg L⁻¹)	16	10.71	3.30	4.32	5.87	8.70	36.77		
		DOC (mg L⁻¹)	16	2.09	1.40	1.61	1.76	2.35	4.29		
		DON (µg L⁻¹)	16	103.09	80.11	88.83	95.15	114.78	143.77		
		DOP (µg L⁻¹)	16	2.66	0.61	1.76	2.26	3.44	4.78		
		Chl a (µg L⁻¹)	12	0.8	0.4	0.4	0.7	1.1	1.4	20th-50th-80th	0.4-0.7-0.9
		NH_3 (µgL⁻¹)	16	4.90	1.14	1.54	3.03	6.55	13.13	20th-50th-80th	2-4-6
		NO_x (µg L⁻¹)	12	3.1	0.7	1.9	2.9	3.0	7.2	20th-50th-80th	<1-1.0-4.0
		PN (µg L⁻¹)	16	138.96	40.22	71.25	84.63	128.00	468.00		
		PO_4 (µg L⁻¹)	12	2.7	1.7	2.1	2.6	3.2	3.7	20th-50th-80th	<2-2.0-3.0
		POC (µg L⁻¹)	14	980.67	218.31	337.70	552.13	843.60	3664.20		
		PP (µg L⁻¹)	16	10.52	4.03	5.27	6.81	14.56	24.35		

Cape York Enclosed Coastal Water body		Secchi (m)	7	1.1	0.6	0.7	0.9	1.5	2.0	20th-50th-80th	1.0-1.5-2.6
		SiO_4 (µg L^{-1})	16	667.75	115.70	338.91	385.66	514.22	2502.12		
		TSS (mg L^{-1})	16	50.0	3.9	7.0	12.0	22.0	312.5	20th-50th-80th	4-6-13
	Stewart River	DIN (µg L^{-1})	10	6.46	3.33	4.02	6.55	8.29	10.28		
		DOC (mgL^{-1})	11	1.52	1.33	1.42	1.45	1.52	1.88		
		DON (µgL^{-1})	11	84.14	74.48	75.07	84.45	90.24	97.82		
		DOP (µgL^{-1})	11	2.62	1.07	1.73	2.26	3.34	4.89		
		Chla (µgL^{-1})	11	0.37	0.16	0.24	0.33	0.48	0.64	20^{th}-50^{th}-80^{th}	0.3-0.4-0.8
		NH_3 (µgL^{-1})	10	3.87	1.46	1.84	4.32	5.36	5.68	20^{th}-50^{th}-80^{th}	2-2-4
		NOx (µgL^{-1})	11	2.58	1.41	1.70	2.28	2.84	4.92	20^{th}-50^{th}-80^{th}	1.0-1.5-3.0
		PN (µgL^{-1})	11	45.93	32.38	33.75	45.50	56.50	64.00		
		PO4 (µgL^{-1})	11	2.07	1.42	1.65	1.94	2.52	2.78	20^{th}-50^{th}-80^{th}	<2-2.0-3.0
		POC (mg L^{-1})	11	319.55	173.88	214.00	272.00	418.00	490.00		
		PP (µgL^{-1})	11	3.30	0.96	1.49	3.25	4.80	6.45		
		Secchi (m)	6	3.6	1.9	3.5	3.6	4.5	4.9	20^{th}-50^{th}-80^{th}	1.6-3.1-4.6
		SiO_4 (µg L^{-1})	11	222.26	79.47	102.84	149.59	205.69	610.05		
		TSS (mgL^{-1})	11	2.2	0.8	1.0	1.6	2.2	5.6	20^{th}-50^{th}-80^{th}	3-5-6
	Pascoe River	DIN (µg L^{-1})	4	31.54	3.32	4.61	11.09	50.28	88.38		
		DOC (µg L^{-1})	4	2.29	1.23	1.34	1.65	2.98	4.26		
		DON (µg L^{-1})	4	101.55	78.68	79.99	83.93	116.06	149.11		
		DOP (µg L^{-1})	4	1.15	0.47	0.59	1.17	1.72	1.80		
		Chl a (µg L^{-1})	4	0.26	0.20	0.21	0.24	0.30	0.35	20^{th}-50^{th}-80^{th}	0.5–0.7-1.2
		NH3 (µgL^{-1})	4	5.80	1.02	2.23	3.55	8.47	13.74	20^{th}-50^{th}-80^{th}	2-2-3
		NO_x (µg L^{-1})	4	25.74	2.31	2.38	7.54	41.81	74.64	20^{th}-50^{th}-80^{th}	<1-1.5-4.0
		PN (µg L^{-1})	4	50.75	39.54	39.65	42.00	58.35	74.21		
		PO_4 (µg L^{-1})	4	2.41	2.23	2.31	2.45	2.53	2.55	20^{th}-50^{th}-80^{th}	2.0-3.0–3.5
		POC (mg L^{-1})	3	319.21	214.04	265.90	369.63	382.60	389.09		
		PP (µg L^{-1})	4	3.79	1.95	2.23	2.79	4.96	7.05		
		Secchi (m)	4	3.2	1.5	2.3	3.2	4.1	4.8	20^{th}-50^{th}-80^{th}	>2-3-5
		SiO_4	4	2340.26	85.20	130.42	1887.40	4368.96	5229.33		
		TSS (mg L^{-1})	4	4.6	0.8	1.0	1.4	7.0	13.0	20^{th}-50^{th}-80^{th}	4-4-8

OPEN COASTAL ANNUAL[1] (WET and DRY SEASON COMBINED) 2019–2020											
Region/ Water body	Site	Measure	N	Mean	Quantiles					Guidelines	
					Q5	Q20	Median	Q80	Q95	Statistic	Base Flow/ Annual
	Endeavour Basin	DIN (µg L^{-1})	37	8.14	0.85	3.03	5.70	8.60	32.57		
		DOC (mg L^{-1})	41	1.47	1.01	1.25	1.35	1.64	2.15		
		DON (µg L^{-1})	36	74.50	33.14	51.73	75.97	91.60	108.62		
		DOP (µg L^{-1})	41	3.47	1.00	2.32	3.87	4.49	5.23		
		Chl a (µg L^{-1})	39	0.20	0.08	0.10	0.11	0.30	0.48		
		NH_3 (µgL^{-1})	33	6.94	1.41	2.13	3.61	5.56	29.85	20^{th}-50^{th}-80^{th}	0-1-3
		NO_x (µg L^{-1})	41	1.93	0.28	0.47	1.59	2.89	5.23	20^{th}-50^{th}-80^{th}	0.14-0.35-1.05
		PN (µg L^{-1})	41	23.11	12.00	15.01	21.01	31.75	40.80		
		PO_4 (µg L^{-1})	41	1.29	0.31	0.31	1.27	2.27	2.85	20^{th}-50^{th}-80^{th}	0.31-1.40-2.64
		POC (µg L^{-1})	41	165.46	74.00	92.25	140.73	225.20	310.25		
		PP (µg L^{-1})	41	1.78	0.87	0.93	1.55	2.46	2.96		
		Secchi (m)	19	7.5	4.8	5.4	6.6	10.1	11.9	Mean	≥10
		SiO_4 (µg L^{-1})	41	129.44	28.05	46.75	68.25	136.50	177.64		
		TSS (mg L^{-1})	41	1.0	0.2	0.3	0.7	1.5	2.2		
	Normanby River	DIN (µg L^{-1})	21	5.29	3.26	3.52	4.55	6.61	8.91		
		DOC (mg L^{-1})	21	1.77	1.33	1.44	1.59	1.71	2.02		
		DON (µg L^{-1})	21	87.61	77.12	79.26	85.21	95.69	109.39		
		DOP (µg L^{-1})	21	1.63	0.14	0.73	1.45	2.74	3.28		
		Chl a (µg L^{-1})	21	0.41	0.10	0.20	0.32	0.48	1.12		
		NH3 (µgL^{-1})	21	2.86	1.23	1.52	2.44	4.25	5.02	20^{th}-50^{th}-80^{th}	0-1-3
		NO_x (µg L^{-1})	21	2.43	1.23	1.59	1.92	2.83	5.47	20^{th}-50^{th}-80^{th}	0.14-0.35-1.05
		PN (µg L^{-1})	21	43.72	27.00	30.38	41.00	55.25	62.75		
		PO_4 (µg L^{-1})	21	2.42	1.38	1.86	2.24	2.73	3.94	20^{th}-50^{th}-80^{th}	0.31-1.40-2.64
		POC (µg L^{-1})	21	342.86	190.50	222.75	311.25	463.75	550.50		
		PP (µg L^{-1})	19	3.60	1.55	1.95	2.48	4.83	9.01		
		Secchi (m)	11	3.6	2.1	2.8	3.4	4.5	4.9	Mean	≥10

		SiO_4 (µg L^{-1})	21	116.31	37.40	46.75	98.17	158.94	289.83		
		TSS (mg L^{-1})	21	2.3	0.9	1.2	1.9	3.0	5.2		
Cape York Open Coastal Water body	Stewart River	DIN (µg L^{-1})	19	5.45	3.14	3.87	5.09	6.51	8.96		
		DOC (mg L^{-1})	20	1.37	1.12	1.28	1.41	1.46	1.49		
		DON (µg L^{-1})	20	84.16	71.94	76.39	82.53	91.88	101.01		
		DOP (µg L^{-1})	20	2.56	0.22	1.38	2.62	3.98	4.70		
		Chla (µgL^{-1})	20	0.24	0.10	0.10	0.22	0.36	0.42		
		NH_3 (µgL^{-1})	20	2.96	1.03	1.95	2.73	4.13	5.07	20^{th}-50^{th}-80^{th}	0-1-3
		NO_x (µg L^{-1})	20	2.48	1.11	1.49	2.19	3.15	5.38	20^{th}-50^{th}-80^{th}	0.14-0.35-1.05
		PN (µg L^{-1})	20	34.49	14.96	22.65	28.13	47.80	69.20		
		PO_4 (µg L^{-1})	20	2.26	1.69	1.87	2.31	2.59	2.85	20^{th}-50^{th}-80^{th}	0.31-1.40-2.64
		POC (µg L^{-1})	19	249.23	97.88	157.00	212.75	352.05	434.40		
		PP (µg L^{-1})	20	2.43	1.21	1.24	1.86	4.07	4.82		
		Secchi (m)	10	5.8	3.0	3.9	4.6	8.8	10.1	Mean	≥ 10
		SiO_4 (µg L^{-1})	20	86.95	11.69	46.75	81.81	122.48	171.09		
		TSS (mgL^{-1})	20	1.6	0.5	0.8	1.2	1.9	2.9		

1 No annual calculations produced for Pascoe River, as only monitored during the Wet Season.

OPEN COASTAL DRY SEASON 2019–2020											
Region/ Water body	Site[1]	Measure	N	Mean	Quantiles					Guidelines	
					Q5	Q20	Median	Q80	Q95	Statistic	Dry
Cape York	Endeavour Basin	DIN (µg L^{-1})	12	5.03	2.19	3.17	5.57	6.03	7.69		
		DOC (µgL^{-1})	12	1.26	1.01	1.12	1.32	1.37	1.38		
		DON (µgL^{-1})	12	78.73	67.32	70.90	79.33	83.84	93.11		
		DOP (µgL^{-1})	12	4.35	3.00	3.58	4.49	5.10	5.50		
		Chla (µgL^{-1})	12	0.25	0.10	0.10	0.22	0.39	0.52	20^{th}-50^{th}-80^{th}	0.16–0.25–0.46
		NH_3 (µgL^{-1})	12	2.78	1.27	1.76	3.00	3.51	4.06		
		NOx (µgL^{-1})	12	2.26	0.94	1.17	2.14	2.74	4.37	20^{th}-50^{th}-80^{th}	0.14-0.32-1.05
		PN (µgL^{-1})	12	23.96	13.93	15.75	20.88	31.70	36.77	Mean	≤16
		PO4 (µgL^{-1})	12	1.84	0.31	0.62	2.24	2.78	2.85	20^{th}-50^{th}-80^{th}	0.62-1.86-2.74
		POC (µg L^{-1})	12	186.06	93.70	126.10	175.71	256.55	280.91		
		PP (µgL^{-1})	12	1.43	0.62	0.91	1.47	1.85	2.23	mean	≤ 2.3

Open Coastal		Secchi (m)	8	6.2	4.5	5.4	5.8	7.0	8.4		
		SiO_4 (µg L⁻¹)	12	73.11	30.62	33.66	56.10	115.66	126.15		
		TSS (mgL⁻¹)	12	0.7	0.2	0.3	0.6	1.0	1.5	Mean	≤1.6
	Normanby River	DIN (µg L⁻¹)	6	6.77	4.94	6.20	6.53	7.18	9.03		
		DOC (mg L⁻¹)	6	1.72	1.56	1.61	1.67	1.79	1.96		
		DON (µg L⁻¹)	6	89.34	75.54	78.20	87.17	98.47	107.41		
		DOP (µg L⁻¹)	6	2.58	1.15	2.10	2.99	3.28	3.30		
		Chl a (µg L⁻¹)	6	0.32	0.10	0.10	0.38	0.47	0.48	20th-50th-80th	0.16–0.25–0.46
		NH3 (µgL⁻¹)	6	4.35	3.10	4.18	4.56	5.02	5.05		
		NO_x (µg L⁻¹)	6	2.42	1.61	1.66	1.83	2.13	4.63	20th-50th-80th	0.14-0.32-1.05
		PN (µg L⁻¹)	6	31.79	21.75	27.00	30.63	41.00	41.38	Mean	≤16
		PO_4 (µg L⁻¹)	6	1.94	1.79	1.84	1.91	1.97	2.17	20th-50th-80th	0.62-1.86-2.74
		POC (µg L⁻¹)	6	254.21	171.38	190.50	238.75	274.25	382.06		
		PP (µg L⁻¹)	5	2.85	1.55	1.55	1.86	3.53	5.76	mean	≤ 2.3
		Secchi (m)	3	3.3	1.7	2.3	3.4	4.4	4.8		
		SiO_4 (µg L⁻¹)	6	118.04	91.16	98.17	100.51	158.94	160.69		
		TSS (mg L⁻¹)	6	2.7	0.7	1.1	2.5	4.2	5.2	Mean	≤ 1.6
Cape York Open Coastal Water body	Stewart River	DIN (µg L⁻¹)	4	5.0	4.1	4.5	4.9	5.5	6.1		
		DOC (mgL⁻¹)	4	1.5	1.4	1.4	1.5	1.5	1.5		
		DON (µgL⁻¹)	4	97.9	92.4	95.0	99.1	101.4	101.8		
		DOP (µgL⁻¹)	4	4.5	4.0	4.3	4.7	4.8	4.9		
		Chla (µgL⁻¹)	4	0.25	0.21	0.21	0.22	0.28	0.34	20th-50th-80th	0.16–0.25–0.46
		NH_3 (µgL⁻¹)	4	2.8	2.1	2.3	2.6	3.2	3.8		
		NOx (µgL⁻¹)[2]	4	2.2	2.0	2.1	2.2	2.4	2.5	20th-50th-80th	0.14-0.32-1.05
		PN (µgL⁻¹)	4	17.1	2.4	9.5	20.9	26.2	26.4	Mean	≤ 16
		PO4 (µgL⁻¹)	4	2.8	2.5	2.6	2.8	2.9	3.0	20th-50th-80th	0.62-1.86-2.74
		POC (µg L⁻¹)	4	130.1	16.3	65.3	153.8	204.4	210.7		
		PP (µgL⁻¹)	4	1.5	1.2	1.2	1.4	1.7	1.8	mean	≤ 2.3
		Secchi (m)	2	3.5	2.6	2.9	3.5	4.1	4.4		
		SiO_4 (µg L⁻¹)	4	94.7	76.2	80.4	88.8	106.6	121.3		
		TSS (mgL⁻¹)	4	1.9	1.1	1.2	1.9	2.5	2.7	Mean	≤1.6

1 No dry season samples were collected from the Pascoe River transect

OPEN COASTAL WET SEASON 2019- 2020											
Region/ Water body	Site	Measure	N	Mean	Quantiles					Guidelines	
					Q5	Q20	Median Q50	Q80	Q95	Statistic	Wet
		DIN ($\mu g\ L^{-1}$)	25	9.64	0.82	2.89	6.08	11.42	32.59		
		DOC (($\mu g L^{-1}$)	29	1.55	0.98	1.27	1.43	1.82	2.38		
		DON ($\mu g L^{-1}$)	24	72.39	26.97	46.39	73.75	98.08	123.44		
		DOP ($\mu g L^{-1}$)	29	3.10	0.59	1.51	3.72	4.45	4.68		
		Chl a ($\mu g L^{-1}$)	27	0.18	0.07	0.10	0.11	0.29	0.32	20^{th}-50^{th}-	0.30-0.46-0.78
		NH_3 ($\mu g L^{-1}$)	21	9.32	1.54	3.01	4.33	14.43	32.29		
	Endeavour Basin	NOx ($\mu g L^{-1}$)	29	1.79	0.28	0.28	1.51	2.99	4.89	20^{th}-50^{th}-	0.20-0.45-0.98
		PN ($\mu g L^{-1}$)	29	22.76	12.05	14.13	21.01	30.21	43.02	20^{th}-50^{th}-	14-20-26
		PO_4 ($\mu g L^{-1}$)	29	1.06	0.31	0.31	0.31	2.02	2.29	20^{th}-50^{th}-	0.16-0.93-1.86
		POC ($\mu g\ L^{-1}$)	29	156.93	69.99	89.12	121.36	203.27	312.74		
		PP ($\mu g L^{-1}$)	29	1.92	0.93	0.99	1.55	2.57	3.60	20^{th}-50^{th}-	2.2-3.0-3.9
		Secchi (m)	11	8.4	5.1	5.4	8.1	11.0	12.2		
		SiO_4 ($\mu g\ L^{-1}$)	29	152.75	26.91	54.23	101.11	149.19	315.07		
		TSS ($mg L^{-1}$)	29	1.1	0.2	0.3	0.8	1.6	2.3	20^{th}-50^{th}-	1.1-1.7-2.2
		DIN ($\mu g\ L^{-1}$)	15	4.70	3.12	3.30	4.01	5.43	8.62		
		DOC (mg	15	1.80	1.32	1.39	1.49	1.66	2.98		
		DON ($\mu g\ L^{-1}$)	15	86.91	77.19	80.48	85.00	90.91	103.18		
		DOP ($\mu g\ L^{-1}$)	15	1.24	0.13	0.26	1.29	2.06	2.50		
		Chl a ($\mu g\ L^{-1}$)	15	0.45	0.17	0.21	0.32	0.52	1.22	20^{th}-50^{th}-	0.30-0.46-0.78
	Normanby River	NH3 ($\mu g L^{-1}$)	15	2.26	1.21	1.45	2.18	2.60	4.15		
		NO_x ($\mu g\ L^{-1}$)	15	2.43	1.14	1.51	1.95	2.88	4.91	20^{th}-50^{th}-	0.20-0.45-0.98
		PN ($\mu g\ L^{-1}$)	14	45.9	30.1	36.7	45.4	56.6	60.2	20^{th}-50^{th}-	14-20-26
		PO_4 ($\mu g\ L^{-1}$)	15	2.62	1.36	2.06	2.47	3.06	4.18	20^{th}-50^{th}-	0.16-0.93-1.86
		POC ($\mu g\ L^{-1}$)	15	378.33	215.66	229.55	367.75	466.50	625.88		
		PP ($\mu g\ L^{-1}$)	14	3.87	1.96	2.12	2.63	4.83	9.09	20^{th}-50^{th}-	2.2-3.0-3.9
		Secchi (m)	8	3.7	2.7	3.0	3.8	4.5	4.7		
		SiO_4 ($\mu g\ L^{-1}$)	15	115.62	36.00	44.88	84.14	154.26	299.65		
Cape York		TSS ($mg\ L^{-1}$)	15	2.2	1.0	1.4	1.7	2.8	4.4	20^{th}-50^{th}-	1.1-1.7-2.2
Open Coastal		DIN ($\mu g\ L^{-1}$)	15	5.56	3.06	3.54	5.26	7.08	9.37		
	Stewart River	DOC ($mg L^{-1}$)	16	1.35	1.12	1.27	1.40	1.46	1.48		
Water body		DON ($\mu g L^{-1}$)	16	80.72	71.21	75.85	80.52	85.46	90.66		
		DOP ($\mu g L^{-1}$)	16	2.07	0.22	1.24	2.14	2.82	3.70		

		Chla (μgL^{-1})	16	0.24	0.10	0.10	0.22	0.38	0.42	20th-50th-	0.30-0.46-0.78
		NH_3 (μgL^{-1})	16	3.00	1.01	1.92	2.94	4.64	5.08		
		NOx (μgL^{-1})	16	2.55	0.93	1.43	2.16	3.17	5.72	20th-50th-	0.20-0.45-0.98
		PN (μgL^{-1})	16	38.84	19.81	25.75	36.38	53.00	70.00	20th-50th-	14-20-26
		PO4 (μgL^{-1})	16	2.13	1.59	1.83	2.21	2.49	2.59	20th-50th-	0.16-0.93-1.86
		POC (μg	15	281.00	143.28	166.40	226.25	354.95	492.70		
		PP (μgL^{-1})	16	2.67	1.11	1.40	2.17	4.23	5.12	20th-50th-	2.2-3.0-3.9
		Secchi (m)	8	6.3	3.7	4.2	5.1	9.4	10.1		
		SiO_4 (μg L^{-1})	16	85.02	11.69	46.75	74.79	121.54	182.31		
		TSS (mgL^{-1})	16	1.5	0.5	0.8	1.1	1.5	3.3	20th-50th-	1.1-1.7-2.2
	Pascoe River	DIN (μg L^{-1})	15	6.21	3.91	4.64	5.47	7.45	9.39		
		DOC (μg L^{-1})	17	1.28	1.12	1.15	1.27	1.39	1.43		
		DON (μg L^{-1})	15	92.09	77.51	81.77	86.29	106.58	116.26		
		DOP (μg L^{-1})	16	2.02	0.49	1.38	2.16	2.74	2.90		
		Chl a (μg L^{-1})	17	0.36	0.10	0.22	0.26	0.33	0.87	20th-50th-	0.30-0.46-0.78
		NH3 (μgL^{-1})	16	3.58	1.62	2.11	3.81	4.60	5.56		
		NO_x (μg L^{-1})	15	2.53	0.93	1.48	1.90	4.01	5.74	20th-50th-	0.20-0.45-0.98
		PN (μg L^{-1})	16	54	23	28	36	94	120	20th-50th-	14-20-26
		PO_4 (μg L^{-1})	17	2.32	1.55	1.72	2.24	2.80	3.55	20th-50th-	0.16-0.93-1.86
		POC (mg	15	434	126	172	292	647	1046		
		PP (μg L^{-1})	17	2.04	1.15	1.38	1.86	2.73	3.28	20th-50th-	2.2-3.0-3.9
		Secchi (m)	8	5.5	3.4	4.0	5.3	6.4	8.6		
		SiO_4	17	141.48	58.90	79.47	140.24	154.26	229.99		
		TSS (mg L^{-1})	17	1.0	0.4	0.5	0.9	1.4	2.2	20th-50th-	1.1-1.7-2.2

MID-SHELF ANNUAL[1] (WET and DRY SEASON COMBINED) 2019–2020											
Region/ Water body	Site	Measure	N	Mean	Quantiles					Guidelines	
					Q5	Q20	Median	Q80	Q95	Statistic	Base Flow/ Annual
Cape York Mid-shelf Water body	Endeavour Basin	DIN (µg L⁻¹)	9	5.01	0.36	1.58	6.46	6.62	10.39		
		DOC (mg L⁻¹)	9	65.40	44.81	52.71	65.83	76.96	84.74		
		DON (µg L⁻¹)	9	1.29	0.92	0.96	1.28	1.52	1.85		
		DOP (µg L⁻¹)	9	3.66	1.52	2.73	3.70	4.89	5.27		
		Chl a (µg L⁻¹)	9	0.15	0.06	0.09	0.10	0.23	0.29	20th-50th-80th	0.18-0.27-0.45
		NH_3 (µg L⁻¹)	7	4.28	0.44	1.51	3.43	5.79	10.74	20th-50th-80th	0-1-3
		NO_x (µg L⁻¹)	9	1.68	0.28	0.28	1.12	3.07	3.51	20th-50th-80th	0.17-0.35-0.84
		PN (µg L⁻¹)	9	22.37	10.10	12.51	21.00	29.01	42.52	20th-50th-80th	14-18-22
		PO_4 (µg L⁻¹)	9	1.06	0.31	0.31	0.48	1.79	2.63	20th-50th-80th	0.16-0.62-2.02
		POC (µg L⁻¹)	9	175.46	76.33	81.32	155.00	256.43	334.80		
		PP (µg L⁻¹)	9	1.42	0.55	0.77	1.24	1.76	3.08	20th-50th-80th	1.5-2.0-2.8
		Secchi (m)	5	11.9	7.3	9.3	10.9	14.3	17.5	Mean	≥10
		SiO_4 (µg L⁻¹)	9	44.93	23.37	25.53	51.42	61.68	68.58		
		TSS (mg L⁻¹)	9	0.5	0.1	0.1	0.4	0.8	1.4	20th-50th-80th	0.9-1.5-2.3
	Normanby Basin	DIN (µg L⁻¹)	8	5.43	3.33	3.81	5.43	7.17	7.44		
		DOC (mg L⁻¹)	8	1.40	1.20	1.23	1.43	1.54	1.61		
		DON (µg L⁻¹)	8	92.43	76.52	77.27	80.97	90.06	139.46		
		DOP (µg L⁻¹)	8	1.89	0.26	0.82	2.15	2.83	3.16		
		Chl a (µg L⁻¹)	8	0.24	0.10	0.10	0.22	0.38	0.41	20th-50th-80th	0.18-0.27-0.45
		NH_3 (µgL⁻¹)	8	3.30	1.39	2.28	3.08	4.61	5.19	20th-50th-80th	0-1-3
		NO_x (µg L⁻¹)	7	1.81	1.38	1.53	1.66	2.03	2.51	20th-50th-80th	0.17-0.35-0.84
		PN (µg L⁻¹)	6	22.3	15.1	15.3	21.1	24.0	33.8	20th-50th-80th	14-18-22
		PO_4 (µg L⁻¹)	8	2.22	1.67	2.00	2.15	2.51	2.86	20th-50th-80th	0.16-0.62-2.02
		POC (µg L⁻¹)	7	208.96	110.15	124.10	139.50	240.45	449.20		
		PP (µg L⁻¹)	8	1.87	0.93	1.00	1.55	2.04	3.92	20th-50th-80th	1.5-2.0-2.8
		Secchi (m)	4	7.1	4.5	4.8	6.7	9.3	10.4	Mean	≥10
		SiO_4 (µg L⁻¹)	8	55.5	11.7	31.3	63.1	71.1	86.9		
		TSS (mg L⁻¹)	8	1.6	0.1	0.3	1.0	1.9	4.6	20th-50th-80th	0.9-1.5-2.3
		DIN (µg L⁻¹)	10	5.73	4.23	4.91	5.83	6.60	7.25		

Cape York Mid-shelf Water body	Stewart River	DOC (mgL^{-1})	10	1.32	1.18	1.23	1.31	1.43	1.46		
		DON (µgL^{-1})	10	80.46	75.30	76.23	77.21	84.02	91.41		
		DOP (µgL^{-1})	10	2.79	0.62	1.67	2.71	4.00	5.10		
		Chla (µgL^{-1})	9	0.14	0.10	0.10	0.10	0.20	0.25	20^{th}-50^{th}-80^{th}	0.18-0.27-0.45
		NH_3 (µgL^{-1})	10	3.24	1.47	1.93	2.86	4.70	5.33	20^{th}-50^{th}-80^{th}	0-1-3
		NOx (µgL^{-1})	10	2.49	0.93	1.72	2.05	3.62	4.60	20^{th}-50^{th}-80^{th}	0.17-0.35-0.84
		PN (µgL^{-1})	10	29.70	18.06	19.75	31.25	35.10	40.25	20^{th}-50^{th}-80^{th}	14-18-22
		PO_4 (µgL^{-1})	10	2.13	1.78	1.82	1.98	2.47	2.67	20^{th}-50^{th}-80^{th}	0.16-0.62-2.02
		POC (µg L^{-1})	10	240.50	139.99	155.85	260.38	284.20	342.41		
		PP (µgL^{-1})	10	2.04	0.62	0.87	1.25	3.11	5.07	20^{th}-50^{th}-80^{th}	1.5-2.0-2.8
		Secchi (m)	5	7.4	5.6	6.8	7.5	8.1	8.8	Mean	≥10
		SiO_4 (µg L^{-1})	10	64.98	11.69	47.21	72.46	86.01	96.06		
		TSS (mgL^{-1})	10	1.1	0.4	0.5	1.1	1.6	1.9	20^{th}-50^{th}-80^{th}	0.9-1.5-2.3
	Pascoe River Wet Season Data only	DIN (µg L^{-1})	26	5.55	3.67	4.26	4.98	6.29	8.26		
		DOC (µg L^{-1})	26	1.28	1.06	1.09	1.19	1.35	1.79		
		DON (µg L^{-1})	26	84.46	72.76	74.92	77.45	93.35	107.99		
		DOP (µg L^{-1})	26	1.85	0.32	1.00	1.77	2.49	3.31		
		Chl a (µg L^{-1})	25	0.30	0.10	0.10	0.29	0.39	0.55	20th-50th-80th	0.18-0.27-0.45
		NH3 (µgL^{-1})	26	2.93	1.56	1.92	3.14	3.65	4.11	20th-50th-80th	0-1-3
		NO_x (µg L^{-1})	26	2.62	0.85	1.61	2.31	3.60	4.47	20th-50th-80th	0.17-0.35-0.84
		PN (µg L^{-1})	26	57	14	22	41	77	151	20th-50th-80th	14-18-22
		PO_4 (µg L^{-1})	26	2.14	1.49	1.67	1.94	2.54	3.26	20th-50th-80th	0.16-0.62-2.02
		POC (mg L^{-1})	19	312	101	146	239	530	582		
		PP (µg L^{-1})	26	1.78	0.93	1.18	1.80	2.17	2.98	20th-50th-80th	1.5-2.0-2.8
		Secchi (m)	14	8.6	5.9	6.9	9.5	9.7	10.5	Mean	≥10
		SiO_4	26	110.48	38.57	56.10	100.51	130.89	234.90		
		TSS (mg L^{-1})	26	0.8	0.1	0.4	0.8	1.0	2.2	20th-50th-80th	0.9-1.5-2.3

Table C-2: Summary statistics for water quality parameters at individual monitoring sites (other than those in the Cape York region) from 1 September 2019 to 31 August 2020. N = number of sampling occasions. See Section 2 for descriptions of each analyte and its abbreviation. Mean and median values that exceed available Water Quality Guidelines (DERM, 2009; Great Barrier Reef Marine Park Authority, 2010) are shaded in red.

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines			
						Q5	Q20	Q80	Q95	Statistic	Annual	Dry	Wet
Wet Tropics	Cape Tribulation (C1)	DIN ($\mu g\ L^{-1}$)	3	6.77	8.02	3.61	5.08	8.71	9.06				
		DOC ($\mu g\ L^{-1}$)	3	888	868	832	844	928	958				
		DON ($\mu g\ L^{-1}$)	3	71.55	70.64	56.84	61.44	81.47	86.89				
		DOP ($\mu g\ L^{-1}$)	3	4.31	3.79	3.65	3.70	4.82	5.33				
		Chl a ($\mu g\ L^{-1}$)	3	0.30	0.29	0.26	0.27	0.33	0.35	Mean	0.45		
		NO_x ($\mu g\ L^{-1}$)	3	0.88	0.60	0.31	0.41	1.29	1.63	Median	0.35		
		PN ($\mu g\ L^{-1}$)	3	11.03	11.00	10.80	10.87	11.18	11.27	Mean	20.00		
		PO_4 ($\mu g\ L^{-1}$)	3	1.01	0.85	0.36	0.53	1.46	1.76	Median	2.00		
		POC ($\mu g\ L^{-1}$)	3	87.13	84.02	79.43	80.96	92.67	97.00				
		PP ($\mu g\ L^{-1}$)	3	2.06	2.00	1.91	1.94	2.17	2.25	Mean	2.80		
		Secchi (m)	3	7.83	7.00	3.85	4.90	10.60	12.40	Mean	10.00		
		SiO_4 ($\mu g\ L^{-1}$)	3	109.20	130.76	64.46	86.56	136.15	138.85				
		TSS ($mg\ L^{-1}$)	3	0.90	0.64	0.42	0.49	1.26	1.57	Mean	2.00		
	Port Douglas (C4)	DIN ($\mu g\ L^{-1}$)	3	4.53	3.61	2.66	2.98	5.89	7.04				
		DOC ($\mu g\ L^{-1}$)	3	915	888	823	845	980	1026				
		DON ($\mu g\ L^{-1}$)	3	68.87	62.93	62.56	62.68	73.88	79.35				
		DOP ($\mu g\ L^{-1}$)	3	4.65	3.95	3.88	3.90	5.25	5.90				
		Chl a ($\mu g\ L^{-1}$)	3	0.22	0.19	0.18	0.18	0.25	0.29	Median	0.30	0.32	0.63
		NO_x ($\mu g\ L^{-1}$)	3	0.92	0.63	0.44	0.50	1.28	1.61	Median	0.31		
		PN ($\mu g\ L^{-1}$)	3	10.02	10.25	9.39	9.68	10.42	10.50	Median	14.00	16.00	25.00
		PO_4 ($\mu g\ L^{-1}$)	3	0.95	1.08	0.39	0.62	1.32	1.43	Median	2.00		
		POC ($\mu g\ L^{-1}$)	3	70.90	67.46	66.87	67.07	74.04	77.33				
		PP ($\mu g\ L^{-1}$)	3	2.37	2.01	1.53	1.69	2.98	3.47	Median	2.00	2.30	3.30
		Secchi (m)	3	7.00	6.50	2.90	4.10	9.80	11.45	Median	13.00		
		SiO_4 ($\mu g\ L^{-1}$)	3	141.64	141.71	63.79	89.76	193.54	219.45				
		TSS ($mg\ L^{-1}$)	3	1.39	0.84	0.81	0.82	1.85	2.35	Median	1.20	1.60	2.40
	Double Island (C5)	DIN ($\mu g\ L^{-1}$)	3	6.18	2.49	2.33	2.38	9.25	12.63				
		DOC ($\mu g\ L^{-1}$)	3	859	871	808	829	892	902				
		DON ($\mu g\ L^{-1}$)	3	68.28	60.62	57.76	58.71	76.31	84.16				
		DOP ($\mu g\ L^{-1}$)	3	4.49	3.72	3.58	3.62	5.20	5.95				
		Chl a ($\mu g\ L^{-1}$)	3	0.26	0.26	0.22	0.23	0.28	0.29	Median	0.30	0.32	0.63
		NO_x ($\mu g\ L^{-1}$)	3	0.64	0.70	0.32	0.45	0.85	0.92	Median	0.31		
		PN ($\mu g\ L^{-1}$)	3	11.17	11.51	9.80	10.37	12.04	12.31	Median	14.00	16.00	25.00
		PO_4 ($\mu g\ L^{-1}$)	3	1.03	1.16	0.39	0.65	1.44	1.58	Median	2.00		
		POC ($\mu g\ L^{-1}$)	3	83.16	80.32	71.72	74.59	91.16	96.58				
		PP ($\mu g\ L^{-1}$)	3	2.33	2.35	1.74	1.94	2.73	2.91	Median	2.00	2.30	3.30
		Secchi (m)	3	8.17	7.00	3.85	4.90	11.20	13.30	Median	13.00		
		SiO_4 ($\mu g\ L^{-1}$)	3	96.47	79.71	62.26	68.08	121.50	142.40				
		TSS ($mg\ L^{-1}$)	3	1.21	0.87	0.69	0.75	1.60	1.97	Median	1.20	1.60	2.40
	Green Island (C11)	DIN ($\mu g\ L^{-1}$)	3	6.42	2.24	2.08	2.14	9.86	13.68				
		DOC ($\mu g\ L^{-1}$)	3	904	903	881	888	920	928				
		DON ($\mu g\ L^{-1}$)	3	55.23	57.26	38.61	44.83	66.04	70.43				
		DOP ($\mu g\ L^{-1}$)	3	4.83	4.57	4.50	4.52	5.08	5.33				
		Chl a ($\mu g\ L^{-1}$)	3	0.16	0.15	0.14	0.15	0.18	0.19	Median	0.30	0.32	0.63
		NO_x ($\mu g\ L^{-1}$)	3	0.67	0.56	0.40	0.46	0.85	1.00	Median	0.31		
		PN ($\mu g\ L^{-1}$)	3	9.26	9.57	8.31	8.73	9.85	10.00	Median	14.00	16.00	25.00
		PO_4 ($\mu g\ L^{-1}$)	3	1.34	1.08	1.08	1.08	1.55	1.78	Median	2.00		

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines			
						Q5	Q20	Q80	Q95	Statistic	Annual	Dry	Wet
		POC (µg L⁻¹)	3	53.56	53.10	53.09	53.09	53.94	54.36				
		PP (µg L⁻¹)	3	1.41	1.66	0.92	1.17	1.71	1.73	Median	2.00	2.30	3.30
		Secchi (m)	3	11.33	10.00	7.30	8.20	14.20	16.30	Median	13.00		
		SiO_4 (µg L⁻¹)	3	89.37	93.40	48.08	63.19	116.36	127.84				
		TSS (mg L⁻¹)	3	0.31	0.15	0.14	0.14	0.45	0.61	Median	1.20	1.60	2.40
	Yorkey's Knob (C6)	DIN (µg L⁻¹)	3	4.19	3.89	2.28	2.81	5.50	6.31				
		DOC (µg L⁻¹)	3	904	888	841	857	948	978				
		DON (µg L⁻¹)	3	79.12	76.76	67.28	70.44	87.32	92.61				
		DOP (µg L⁻¹)	3	4.65	3.95	3.95	3.95	5.20	5.83				
		Chl a (µg L⁻¹)	3	0.31	0.26	0.17	0.20	0.42	0.50	Mean	0.45		
		NO_x (µg L⁻¹)	3	0.72	0.46	0.33	0.37	1.02	1.31	Median	0.35		
		PN (µg L⁻¹)	3	13.08	11.90	10.93	11.25	14.67	16.06	Mean	20.00		
		PO_4 (µg L⁻¹)	3	1.06	0.85	0.36	0.53	1.55	1.90	Median	2.00		
		POC (µg L⁻¹)	3	110.50	98.69	74.37	82.47	136.16	154.90				
		PP (µg L⁻¹)	3	3.52	2.19	2.04	2.09	4.69	5.93	Mean	2.80		
		Secchi (m)	3	5.00	5.00	2.30	3.20	6.80	7.70	Mean	10.00		
		SiO_4 (µg L⁻¹)	3	134.29	131.25	72.91	92.36	175.62	197.80				
		TSS (mg L⁻¹)	3	2.57	0.93	0.73	0.80	4.01	5.55	Mean	2.00		
	Fairlead Buoy (C8)	DIN (µg L⁻¹)	3	3.35	2.38	2.13	2.21	4.29	5.25				
		DOC (µg L⁻¹)	3	914	898	860	873	952	979				
		DON (µg L⁻¹)	3	65.34	67.45	35.44	46.11	84.99	93.75				
		DOP (µg L⁻¹)	3	4.44	4.03	3.75	3.84	4.96	5.42				
		Chl a (µg L⁻¹)	3	0.32	0.25	0.25	0.25	0.37	0.43	Mean	0.45		
		NO_x (µg L⁻¹)	3	0.67	0.67	0.32	0.43	0.90	1.01	Median	0.35		
		PN (µg L⁻¹)	3	12.71	12.92	11.63	12.06	13.40	13.64	Mean	20.00		
		PO_4 (µg L⁻¹)	3	1.06	1.08	0.39	0.62	1.50	1.71	Median	2.00		
		POC (µg L⁻¹)	3	110.33	101.73	97.01	98.59	120.36	129.67				
		PP (µg L⁻¹)	3	3.34	3.42	2.77	2.98	3.71	3.85	Mean	2.80		
		Secchi (m)	3	3.83	4.00	3.10	3.40	4.30	4.45	Mean	10.00		
		SiO_4 (µg L⁻¹)	3	117.46	122.82	83.64	96.70	139.30	147.54				
		TSS (mg L⁻¹)	3	1.86	1.49	1.39	1.42	2.23	2.59	Mean	2.00		
	Fitzroy West (RM1)	DIN (µg L⁻¹)	5	6.29	5.99	2.86	4.00	8.19	10.40				
		DOC (µg L⁻¹)	5	915	896	853	868	935	1022				
		DON (µg L⁻¹)	5	84.15	71.41	61.88	68.29	105.09	114.06				
		DOP (µg L⁻¹)	5	4.77	4.49	3.58	4.09	5.50	6.19				
		Chl a (µg L⁻¹)	5	0.31	0.26	0.14	0.19	0.35	0.64	Mean	0.45		
		NO_x (µg L⁻¹)	5	1.31	0.91	0.44	0.61	2.20	2.39	Median	0.35		
		PN (µg L⁻¹)	5	17.36	18.30	11.70	11.79	21.05	23.95	Mean	20.00		
		PO_4 (µg L⁻¹)	5	0.65	0.62	0.31	0.31	0.77	1.24	Median	2.00		
		POC (µg L⁻¹)	5	142.96	143.53	89.95	95.12	188.94	197.26				
		PP (µg L⁻¹)	5	2.00	1.94	1.81	1.89	2.18	2.20	Mean	2.80		
		Secchi (m)	5	8.70	6.00	6.00	6.00	11.40	14.10	Mean	10.00		
		SiO_4 (µg L⁻¹)	5	96.62	83.15	66.12	67.51	107.53	158.76				
		TSS (mg L⁻¹)	5	0.95	0.77	0.69	0.71	1.14	1.45	Mean	2.00		
	RM3 (RM3)	DIN (µg L⁻¹)	9	6.58	7.09	1.90	3.51	8.95	11.02				
		DOC (µg L⁻¹)	9	1003	986	869	910	1106	1120				
		DON (µg L⁻¹)	9	91.37	93.13	66.99	76.09	105.80	115.89				
		DOP (µg L⁻¹)	9	4.54	4.43	3.66	3.75	5.37	5.78				
		Chl a (µg L⁻¹)	9	0.25	0.23	0.17	0.19	0.27	0.36	Median	0.30	0.32	0.63
		NO_x (µg L⁻¹)	9	3.26	2.00	0.61	0.95	4.86	7.83	Median	0.31		

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines			
						Q5	Q20	Q80	Q95	Statistic	Annual	Dry	Wet
		PN (µg L^{-1})	9	26.07	18.03	11.44	13.67	40.04	50.09	Median	14.00	16.00	25.00
		PO_4 (µg L^{-1})	9	1.45	1.32	0.43	0.71	2.10	2.48	Median	2.00		
		POC (µg L^{-1})	9	229.24	193.68	74.46	100.16	355.64	466.86				
		PP (µg L^{-1})	9	1.77	1.81	1.36	1.52	1.93	2.15	Median	2.00	2.30	3.30
		Secchi (m)	9	9.11	8.00	4.40	6.20	10.80	17.10	Median	13.00		
		SiO_4 (µg L^{-1})	9	112.48	107.53	54.09	60.41	151.00	208.55				
		TSS (mg L^{-1})	9	0.83	0.86	0.42	0.69	1.00	1.24	Median	1.20	1.60	2.40
	High West (RM8)	DIN (µg L^{-1})	9	9.20	9.75	4.12	7.49	10.95	14.29				
		DOC (µg L^{-1})	9	1018	1003	885	927	1097	1191				
		DON (µg L^{-1})	9	91.96	89.97	69.36	77.15	103.68	122.59				
		DOP (µg L^{-1})	9	4.38	4.12	2.19	3.39	5.88	6.25				
		Chl a (µg L^{-1})	9	0.31	0.28	0.18	0.20	0.42	0.52	Mean	0.45		
		NO_x (µg L^{-1})	9	4.93	4.38	1.31	2.40	6.83	11.12	Median	0.35		
		PN (µg L^{-1})	9	26.60	18.90	16.96	17.92	36.75	45.99	Mean	20.00		
		PO_4 (µg L^{-1})	9	1.95	2.02	0.94	1.22	2.57	3.17	Median	2.00		
		POC (µg L^{-1})	9	215.77	193.38	119.37	135.25	311.00	371.96				
		PP (µg L^{-1})	9	2.37	2.12	1.83	1.94	2.74	3.44	Mean	2.80		
		Secchi (m)	9	7.61	6.00	5.20	5.50	10.40	11.90	Mean	10.00		
		SiO_4 (µg L^{-1})	9	158.15	115.71	56.55	81.80	195.82	338.27				
		TSS (mg L^{-1})	9	1.10	1.16	0.67	0.81	1.39	1.57	Mean	2.00		
	Russell Mulgrave Mouth Mooring (RM10)	DIN (µg L^{-1})	10	12.14	9.89	3.59	3.77	14.60	31.43				
		DOC (µg L^{-1})	10	1010	1010	889	926	1104	1144				
		DON (µg L^{-1})	10	84.98	91.39	65.90	71.85	96.01	96.82				
		DOP (µg L^{-1})	10	4.34	4.44	2.99	3.58	5.19	5.50				
		Chl a (µg L^{-1})	10	0.59	0.59	0.30	0.35	0.82	0.92	Mean	0.45		
		NO_x (µg L^{-1})	10	7.56	3.70	0.85	0.97	10.10	24.30	Median	0.35		
		PN (µg L^{-1})	10	37.54	24.24	13.66	18.98	68.34	72.54	Mean	20.00		
		PO_4 (µg L^{-1})	10	2.14	2.32	0.55	1.29	2.83	3.56	Median	2.00		
		POC (µg L^{-1})	10	309.67	265.84	116.40	153.86	556.95	575.71				
		PP (µg L^{-1})	10	5.07	4.90	3.05	3.64	5.90	7.94	Mean	2.80		
		Secchi (m)	10	3.30	2.75	1.73	2.00	5.00	5.82	Mean	10.00		
		SiO_4 (µg L^{-1})	10	345.21	221.08	102.53	154.51	349.38	997.75				
		TSS (mg L^{-1})	10	3.08	2.27	1.57	1.82	2.89	7.38	Mean	2.00		
	Franklands West (RM7)	DIN (µg L^{-1})	9	8.71	7.95	3.74	4.64	12.57	16.49				
		DOC (µg L^{-1})	9	971	983	862	888	1055	1071				
		DON (µg L^{-1})	9	83.16	89.33	57.03	65.36	96.37	107.46				
		DOP (µg L^{-1})	9	4.32	4.09	3.61	3.78	4.81	5.45				
		Chl a (µg L^{-1})	9	0.21	0.22	0.12	0.19	0.24	0.28	Median	0.30	0.32	0.63
		NO_x (µg L^{-1})	9	3.67	1.75	0.74	1.52	5.32	10.63	Median	0.31		
		PN (µg L^{-1})	9	22.80	16.45	12.24	14.17	30.65	44.30	Median	14.00	16.00	25.00
		PO_4 (µg L^{-1})	9	1.48	1.24	0.46	0.74	2.21	2.70	Median	2.00		
		POC (µg L^{-1})	9	206.82	155.29	89.19	137.95	285.38	408.34				
		PP (µg L^{-1})	9	1.65	1.69	1.22	1.36	1.85	2.19	Median	2.00	2.30	3.30
		Secchi (m)	9	9.17	8.00	5.70	7.80	10.90	14.80	Median	13.00		
		SiO_4 (µg L^{-1})	9	105.72	80.65	47.13	68.89	146.15	217.14				
		TSS (mg L^{-1})	9	0.70	0.63	0.40	0.47	0.90	1.15	Median	1.20	1.60	2.40
	Clump Point East (TUL2)	DIN (µg L^{-1})	9	7.25	8.72	2.84	4.18	10.27	10.76				
		DOC (µg L^{-1})	9	997	1008	876	969	1054	1085				
		DON (µg L^{-1})	9	85.04	84.95	67.18	71.43	96.92	110.23				
		DOP (µg L^{-1})	9	4.42	4.41	3.39	3.94	5.06	5.28				
		Chl a (µg L^{-1})	9	0.28	0.26	0.12	0.20	0.29	0.55	Median	0.30	0.32	0.63

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines			
						Q5	Q20	Q80	Q95	Statistic	Annual	Dry	Wet
		NO_x (µg L⁻¹)	9	3.11	1.09	0.68	0.81	6.02	7.07	Median	0.31		
		PN (µg L⁻¹)	9	23.32	16.83	13.64	14.00	37.75	39.97	Median	14.00	16.00	25.00
		PO_4 (µg L⁻¹)	9	1.50	1.24	0.40	0.73	2.34	2.75	Median	2.00		
		POC (µg L⁻¹)	9	200.12	173.91	100.79	115.96	295.00	343.28				
		PP (µg L⁻¹)	9	1.95	1.85	1.03	1.41	2.57	3.22	Median	2.00	2.30	3.30
		Secchi (m)	9	12.25	11.50	5.73	8.40	17.00	20.65	Median	13.00		
		SiO_4 (µg L⁻¹)	9	94.98	70.79	42.54	45.49	135.89	201.07				
		TSS (mg L⁻¹)	9	0.61	0.57	0.23	0.41	0.84	1.05	Median	1.20	1.60	2.40
	Dunk North (TUL3)	DIN (µg L⁻¹)	9	6.68	8.02	2.38	2.91	8.92	12.22				
		DOC (µg L⁻¹)	9	1022	1006	897	981	1096	1150				
		DON (µg L⁻¹)	9	86.37	74.87	67.43	69.16	106.40	113.62				
		DOP (µg L⁻¹)	9	4.46	4.56	3.56	3.68	5.08	5.56				
		Chl a (µg L⁻¹)	9	0.33	0.28	0.13	0.19	0.43	0.66	Mean	0.45		
		NO_x (µg L⁻¹)	9	3.23	3.48	0.28	0.34	5.51	7.54	Median	0.35		
		PN (µg L⁻¹)	9	30.24	17.19	13.05	15.18	37.50	67.02	Mean	20.00		
		PO_4 (µg L⁻¹)	9	1.33	0.85	0.37	0.56	2.28	2.50	Median	2.00		
		POC (µg L⁻¹)	9	260.99	158.59	99.32	130.07	397.08	535.00				
		PP (µg L⁻¹)	9	2.41	2.48	1.72	1.98	2.80	3.04	Mean	2.80		
		Secchi (m)	9	5.44	5.00	3.50	4.10	6.80	8.30	Mean	10.00		
		SiO_4 (µg L⁻¹)	9	128.55	119.31	43.25	75.95	182.25	221.81				
		TSS (mg L⁻¹)	9	1.17	1.23	0.46	0.67	1.57	2.08	Mean	2.00		
	Dunk Island South East (TUL5)	DIN (µg L⁻¹)	9	6.98	6.31	4.68	5.42	8.84	10.26				
		DOC (µg L⁻¹)	9	994	998	878	943	1067	1070				
		DON (µg L⁻¹)	9	87.68	92.65	71.15	76.01	95.43	102.20				
		DOP (µg L⁻¹)	9	4.63	4.40	3.86	4.08	5.41	5.70				
		Chl a (µg L⁻¹)	9	0.35	0.34	0.17	0.30	0.41	0.54	Mean	0.45		
		NO_x (µg L⁻¹)	9	2.69	1.40	0.55	0.99	4.25	6.36	Median	0.35		
		PN (µg L⁻¹)	9	27.29	16.50	14.42	15.86	37.95	56.97	Mean	20.00		
		PO_4 (µg L⁻¹)	9	1.52	1.47	0.60	0.74	2.22	2.80	Median	2.00		
		POC (µg L⁻¹)	9	210.52	172.21	111.99	124.90	313.97	384.32				
		PP (µg L⁻¹)	9	2.33	2.50	1.63	2.05	2.60	2.83	Mean	2.80		
		Secchi (m)	9	7.39	6.50	3.70	5.20	9.40	13.60	Mean	10.00		
		SiO_4 (µg L⁻¹)	9	110.10	99.02	42.25	66.10	153.19	198.02				
		TSS (mg L⁻¹)	9	1.01	1.02	0.58	0.78	1.22	1.42	Mean	2.00		
	Between Tam O'Shanter and Timana (TUL6)	DIN (µg L⁻¹)	8	9.43	9.20	2.07	4.31	13.23	17.75				
		DOC (µg L⁻¹)	8	1075	1093	926	1000	1146	1178				
		DON (µg L⁻¹)	8	95.23	88.62	76.18	78.13	112.23	124.80				
		DOP (µg L⁻¹)	8	4.70	4.71	3.16	3.87	5.59	5.90				
		Chl a (µg L⁻¹)	8	0.40	0.31	0.19	0.22	0.57	0.72	Mean	0.45		
		NO_x (µg L⁻¹)	8	4.07	2.12	0.32	0.43	6.06	12.05	Median	0.35		
		PN (µg L⁻¹)	8	42.56	27.58	14.90	17.51	54.62	103.27	Mean	20.00		
		PO_4 (µg L⁻¹)	8	1.19	0.97	0.42	0.65	1.92	2.12	Median	2.00		
		POC (µg L⁻¹)	8	338.04	273.57	137.43	170.04	551.47	609.29				
		PP (µg L⁻¹)	8	3.50	3.00	2.42	2.52	4.52	5.27	Mean	2.80		
		Secchi (m)	8	4.50	4.50	2.85	3.50	5.60	6.32	Mean	10.00		
		SiO_4 (µg L⁻¹)	8	155.39	145.86	51.08	72.75	247.49	270.58				
		TSS (mg L⁻¹)	8	1.76	1.65	1.05	1.44	2.05	2.62	Mean	2.00		
	Bedarra (TUL8)	DIN (µg L⁻¹)	9	7.75	7.98	2.32	2.74	12.41	15.16				
		DOC (µg L⁻¹)	9	1040	1016	903	963	1137	1162				
		DON (µg L⁻¹)	9	80.84	77.92	65.78	70.84	91.31	96.83				

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines			
						Q5	Q20	Q80	Q95	Statistic	Annual	Dry	Wet
		DOP (µg L⁻¹)	9	4.48	4.33	3.71	3.94	5.13	5.50				
		Chl a (µg L⁻¹)	9	0.34	0.32	0.23	0.28	0.37	0.50	Mean	0.45		
		NO_x (µg L⁻¹)	9	3.77	2.28	0.41	0.62	6.93	9.72	Median	0.35		
		PN (µg L⁻¹)	9	30.84	22.22	14.31	16.08	45.62	59.75	Mean	20.00		
		PO_4 (µg L⁻¹)	9	1.29	0.85	0.37	0.51	2.16	2.59	Median	2.00		
		POC (µg L⁻¹)	9	256.07	199.58	107.53	135.66	396.92	475.69				
		PP (µg L⁻¹)	9	2.66	2.65	2.01	2.29	2.96	3.42	Mean	2.80		
		Secchi (m)	9	6.28	6.00	3.70	4.30	8.20	9.40	Mean	10.00		
		SiO_4 (µg L⁻¹)	9	153.90	172.98	49.56	65.69	235.60	256.03				
		TSS (mg L⁻¹)	9	1.12	1.14	0.53	0.79	1.48	1.78	Mean	2.00		
	Tully River mouth mooring (TUL10)	DIN (µg L⁻¹)	10	8.98	7.14	3.40	4.67	12.05	19.32				
		DOC (µg L⁻¹)	10	1143	1156	984	1032	1212	1293				
		DON (µg L⁻¹)	10	89.87	86.64	70.19	77.55	107.94	112.18				
		DOP (µg L⁻¹)	10	4.51	4.64	3.08	3.74	5.31	5.71				
		Chl a (µg L⁻¹)	10	0.64	0.76	0.25	0.39	0.88	0.95	Median	1.10		
		NO_x (µg L⁻¹)	10	5.04	3.50	0.44	0.99	6.41	14.19	Median	3.00		
		PO_4 (µg L⁻¹)	10	1.43	1.12	0.48	0.76	2.25	2.56	Median	3.00		
		POC (µg L⁻¹)	10	378.75	370.71	143.15	221.14	549.23	626.26				
		Secchi (m)	10	2.95	2.50	2.23	2.50	3.60	4.55	Median	1.60		
		SiO_4 (µg L⁻¹)	10	357.72	327.92	75.61	79.19	465.70	821.41				
		TSS (mg L⁻¹)	10	3.25	3.13	2.04	2.75	3.56	4.80	Median	5.00		
Burdekin	Palms West (BUR1)	DIN (µg L⁻¹)	9	6.34	6.20	3.65	3.99	7.63	10.46				
		DOC (µg L⁻¹)	9	1064	1016	879	950	1185	1320				
		DON (µg L⁻¹)	9	82.19	79.14	73.62	75.77	85.01	98.28				
		DOP (µg L⁻¹)	9	3.22	2.90	0.77	1.54	4.75	6.38				
		Chl a (µg L⁻¹)	9	0.24	0.26	0.15	0.20	0.30	0.31	Median	0.35	0.32	0.63
		NO_x (µg L⁻¹)	9	2.59	2.24	0.71	1.46	3.60	4.91	Median	0.28		
		PN (µg L⁻¹)	9	32.74	34.15	9.90	14.27	47.85	58.83	Median	12.00	16.00	25.00
		PO_4 (µg L⁻¹)	9	2.21	2.09	0.56	1.16	3.36	4.04	Median	1.00		
		POC (µg L⁻¹)	9	248.17	263.24	64.70	111.57	330.12	447.41				
		PP (µg L⁻¹)	9	2.36	2.32	1.52	1.83	2.72	3.34	Median	2.20	2.30	3.30
		Secchi (m)	9	7.43	5.00	4.00	4.12	10.20	14.40	Mean	10.00		
		SiO_4 (µg L⁻¹)	9	83.97	70.13	36.57	49.47	119.75	160.43				
		TSS (mg L⁻¹)	9	0.75	0.54	0.23	0.34	1.04	1.70	Median	1.20	1.60	2.40
	Pandora (BUR2)	DIN (µg L⁻¹)	9	6.73	7.03	3.01	4.38	8.17	11.86				
		DOC (µg L⁻¹)	9	1032	1023	886	950	1115	1176				
		DON (µg L⁻¹)	9	78.52	79.25	64.07	67.85	87.59	90.29				
		DOP (µg L⁻¹)	9	3.62	3.17	1.41	2.37	4.77	6.72				
		Chl a (µg L⁻¹)	9	0.24	0.24	0.10	0.15	0.31	0.38	Median	0.35	0.32	0.63
		NO_x (µg L⁻¹)	9	2.26	2.34	0.43	0.62	3.75	5.20	Median	0.28		
		PN (µg L⁻¹)	9	34.36	31.15	13.85	14.77	49.20	68.35	Median	12.00	16.00	25.00
		PO_4 (µg L⁻¹)	9	1.97	2.09	0.46	0.88	3.07	3.28	Median	1.00		
		POC (µg L⁻¹)	9	269.11	197.08	125.06	133.89	413.18	529.79				
		PP (µg L⁻¹)	9	2.81	2.56	1.80	2.26	3.22	4.21	Median	2.20	2.30	3.30
		Secchi (m)	9	5.02	4.50	2.62	3.40	6.50	8.60	Mean	10.00		
		SiO_4 (µg L⁻¹)	9	94.58	92.33	41.24	62.98	120.27	158.14				
		TSS (mg L⁻¹)	9	1.56	1.46	0.51	0.85	1.70	3.53	Median	1.20	1.60	2.40
	Magnetic (BUR4)	DIN (µg L⁻¹)	9	7.20	7.25	3.40	4.78	9.33	11.01				
		DOC (µg L⁻¹)	9	1109	1081	932	1011	1204	1279				
		DON (µg L⁻¹)	9	85.12	86.42	71.98	81.05	90.20	95.89				
		DOP (µg L⁻¹)	9	3.80	3.05	1.45	1.68	5.51	7.09				

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines			
						Q5	Q20	Q80	Q95	Statistic	Annual	Dry	Wet
		Chl a (μg L^{-1})	9	0.32	0.33	0.24	0.25	0.37	0.42	Median	0.59	0.32	0.63
		NO_x (μg L^{-1})	9	3.22	2.41	1.09	1.36	5.17	6.02	Median	0.28		
		PN (μg L^{-1})	9	39.33	33.67	11.86	18.04	60.76	75.20	Median	17.00	16.00	25.00
		PO_4 (μg L^{-1})	9	2.13	1.82	0.65	1.30	3.10	3.97	Median	1.00		
		POC (μg L^{-1})	9	313.32	281.41	97.14	152.72	467.09	583.59				
		PP (μg L^{-1})	9	3.19	3.35	1.55	1.95	4.41	4.82	Mean	2.80		
		Secchi (m)	9	4.06	4.00	2.70	3.30	4.90	5.50	Median	4.00		
		SiO_4 (μg L^{-1})	9	137.34	105.58	87.15	92.76	172.04	241.26				
		TSS (mg L^{-1})	9	1.85	1.48	1.05	1.08	2.39	3.61	Median	1.90	1.60	2.40
	Haughton 2 (BUR7)	DIN (μg L^{-1})	9	6.90	6.93	2.44	3.77	9.97	11.85				
		DOC (μg L^{-1})	9	1107	1109	927	993	1231	1281				
		DON (μg L^{-1})	9	80.04	83.00	60.42	74.82	86.71	92.09				
		DOP (μg L^{-1})	9	3.89	3.73	1.60	2.25	5.25	6.60				
		Chl a (μg L^{-1})	9	0.30	0.35	0.15	0.19	0.38	0.40	Mean	0.45		
		NO_x (μg L^{-1})	9	2.23	2.11	0.47	0.93	3.49	3.78	Median	1.00		
		PN (μg L^{-1})	9	39.63	43.00	12.51	13.79	60.76	81.23	Median	13.00	16.00	25.00
		PO_4 (μg L^{-1})	9	1.87	2.19	0.46	0.88	2.53	3.06	Median	2.00		
		POC (μg L^{-1})	9	344.31	331.65	98.50	108.86	547.33	750.83				
		PP (μg L^{-1})	9	2.86	2.87	2.14	2.49	3.31	3.33	Median	2.10	2.30	3.30
		Secchi (m)	9	5.52	4.50	3.44	3.68	7.20	9.60	Mean	10.00		
		SiO_4 (μg L^{-1})	9	117.73	97.26	62.18	66.39	128.57	254.82				
		TSS (mg L^{-1})	9	1.54	1.59	0.84	1.20	1.98	2.06	Median	1.20	1.60	2.40
	Yongala (BUR10)	DIN (μg L^{-1})	11	6.34	4.38	3.24	3.47	9.77	13.41				
		DOC (μg L^{-1})	11	990	981	903	932	1031	1116				
		DON (μg L^{-1})	11	83.65	82.05	57.82	62.16	102.24	111.68				
		DOP (μg L^{-1})	11	5.05	5.65	2.94	4.26	5.88	6.16				
		Chl a (μg L^{-1})	11	0.16	0.16	0.10	0.11	0.20	0.24	Median	0.33	0.32	0.63
		NO_x (μg L^{-1})	11	1.24	0.81	0.49	0.60	1.54	3.31	Median	0.28		
		PN (μg L^{-1})	11	11.29	11.06	9.40	9.50	13.07	14.04	Median	14.00	16.00	25.00
		PO_4 (μg L^{-1})	11	0.97	0.77	0.35	0.54	1.39	1.94	Median	1.00		
		POC (μg L^{-1})	11	74.70	76.02	57.57	61.73	89.91	92.72				
		PP (μg L^{-1})	11	1.41	1.18	0.95	1.04	1.90	2.08	Median	2.00	2.30	3.30
		Secchi (m)	11	15.18	16.00	12.00	14.00	17.00	17.50	Mean	10.00		
		SiO_4 (μg L^{-1})	11	52.69	53.72	36.66	39.47	61.52	76.83				
		TSS (mg L^{-1})	11	0.14	0.15	0.05	0.08	0.21	0.22	Median	0.80	1.60	2.40
	Burdekin River mouth mooring (BUR13)	DIN (μg L^{-1})	9	9.56	8.38	3.67	5.57	11.14	20.60				
		DOC (μg L^{-1})	9	1300	1214	952	1035	1479	1829				
		DON (μg L^{-1})	9	91.72	91.06	76.61	83.22	101.47	106.68				
		DOP (μg L^{-1})	9	4.07	3.47	2.61	2.96	5.68	6.15				
		Chl a (μg L^{-1})	9	1.60	0.91	0.31	0.47	1.87	4.93	Median	1.00		
		NO_x (μg L^{-1})	9	3.76	3.39	0.38	0.99	5.66	7.81	Median	4.00		
		PO_4 (μg L^{-1})	9	2.35	2.40	0.99	1.79	2.93	3.60	Median	1.00		
		POC (μg L^{-1})	9	513.88	343.71	131.39	200.96	776.15	1152.86				
		Secchi (m)	9	2.62	1.80	1.20	1.50	2.92	6.40	Median	1.50		
		SiO_4 (μg L^{-1})	9	413.91	305.05	71.58	108.58	781.45	934.16				
		TSS (mg L^{-1})	9	4.65	5.45	1.02	2.01	6.83	8.03	Median	2.00		
Mackay-Whitsunday	Double Cone (WHI1)	DIN (μg L^{-1})	5	7.12	5.81	2.14	2.24	12.05	13.36				
		DOC (μg L^{-1})	5	896	898	828	836	943	973				
		DON (μg L^{-1})	5	69.84	70.81	54.61	63.56	79.02	81.18				
		DOP (μg L^{-1})	5	5.13	5.03	1.90	3.90	6.44	8.35				
		Chl a (μg L^{-1})	5	0.40	0.46	0.23	0.26	0.48	0.55	Median	0.36	0.32	0.63
		NO_x (μg L^{-1})	5	1.32	0.70	0.34	0.50	2.02	3.05	Median	1.00		

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines			
						Q5	Q20	Q80	Q95	Statistic	Annual	Dry	Wet
		PN (µg L^{-1})	5	22.13	14.20	12.30	13.14	24.37	46.64	Mean	14.00		
		PO_4 (µg L^{-1})	5	1.29	1.39	0.42	0.74	1.84	2.03	Median	1.00		
		POC (µg L^{-1})	5	177.08	128.92	108.92	121.15	195.70	330.73				
		PP (µg L^{-1})	5	3.17	2.48	2.05	2.28	4.09	4.95	Median	2.30	2.30	3.30
		Secchi (m)	5	5.60	7.00	2.80	3.70	7.10	7.40	Mean	10.00		
		SiO_4 (µg L^{-1})	5	71.24	63.06	46.60	50.31	97.85	98.36				
		TSS (mg L^{-1})	5	2.02	1.02	1.00	1.01	2.66	4.39	Median	1.40	1.60	2.40
	Pine (WHI4)	DIN (µg L^{-1})	5	11.35	7.98	2.56	5.42	14.34	26.48				
		DOC (µg L^{-1})	5	905	918	794	878	963	971				
		DON (µg L^{-1})	5	77.33	76.87	63.25	71.23	87.57	87.76				
		DOP (µg L^{-1})	5	4.77	5.19	3.16	4.27	5.50	5.73				
		Chl a (µg L^{-1})	5	0.55	0.46	0.35	0.38	0.67	0.89	Median	0.36	0.32	0.63
		NO_x (µg L^{-1})	5	2.85	1.79	0.78	1.46	3.49	6.73	Median	1.00		
		PN (µg L^{-1})	5	15.97	16.30	12.79	14.06	18.29	18.39	Mean	14.00		
		PO_4 (µg L^{-1})	5	1.69	1.78	0.60	0.79	2.35	2.91	Median	1.00		
		POC (µg L^{-1})	5	146.06	159.34	111.06	122.80	163.51	173.60				
		PP (µg L^{-1})	5	3.53	2.71	2.16	2.55	3.74	6.47	Median	2.30	2.30	3.30
		Secchi (m)	5	4.20	4.00	2.40	3.60	5.20	5.80	Mean	10.00		
		SiO_4 (µg L^{-1})	5	68.64	69.45	47.06	47.53	89.17	89.97				
		TSS (mg L^{-1})	5	3.42	3.29	0.78	1.21	4.40	7.43	Median	1.40	1.60	2.40
	Seaforth (WHI5)	DIN (µg L^{-1})	5	8.44	7.11	1.67	2.91	15.01	15.51				
		DOC (µg L^{-1})	5	875	891	791	851	911	933				
		DON (µg L^{-1})	5	71.99	73.30	53.43	56.12	81.60	95.48				
		DOP (µg L^{-1})	5	4.71	5.19	3.27	4.01	5.37	5.70				
		Chl a (µg L^{-1})	5	0.47	0.41	0.28	0.30	0.66	0.70	Median	0.36	0.32	0.63
		NO_x (µg L^{-1})	5	2.06	1.47	0.35	0.35	3.60	4.52	Median	1.00		
		PN (µg L^{-1})	5	16.25	15.63	14.66	15.33	17.36	18.27	Mean	14.00		
		PO_4 (µg L^{-1})	5	1.53	1.55	0.43	0.81	2.28	2.60	Median	1.00		
		POC (µg L^{-1})	5	147.72	152.04	123.63	132.25	159.07	171.63				
		PP (µg L^{-1})	5	3.63	2.81	1.90	2.16	5.61	5.68	Median	2.30	2.30	3.30
		Secchi (m)	5	5.30	6.00	2.80	3.70	7.00	7.00	Mean	10.00		
		SiO_4 (µg L^{-1})	5	65.30	57.44	42.49	50.28	87.84	88.43				
		TSS (mg L^{-1})	5	2.12	1.83	0.90	1.03	2.66	4.16	Median	1.40	1.60	2.40
	OConnell River mouth (WHI6)	DIN (µg L^{-1})	5	10.14	5.29	1.85	2.77	14.27	26.54				
		DOC (µg L^{-1})	5	1187	1101	1015	1074	1365	1377				
		DON (µg L^{-1})	5	87.02	88.56	75.21	76.00	96.84	98.50				
		DOP (µg L^{-1})	5	6.02	6.19	4.69	5.53	6.64	7.06				
		Chl a (µg L^{-1})	5	1.37	0.98	0.95	0.96	1.62	2.34	Median	1.30		
		NO_x (µg L^{-1})	5	2.41	1.02	0.65	0.82	2.79	6.76	Median	4.00		
		PO_4 (µg L^{-1})	5	2.52	2.17	1.04	1.36	3.70	4.35	Median	3.00		
		POC (µg L^{-1})	5	360.50	326.90	285.53	294.74	435.01	460.30				
		Secchi (m)	5	2.10	2.00	1.60	1.90	2.20	2.80	Median	1.60		
		SiO_4 (µg L^{-1})	5	159.80	177.46	81.00	99.62	196.81	244.13				
		TSS (mg L^{-1})	5	4.64	4.13	2.06	3.60	6.52	6.88	Median	5.00		
	Repulse Islands dive mooring (WHI7)	DIN (µg L^{-1})	5	11.19	12.81	2.99	3.77	17.17	19.20				
		DOC (µg L^{-1})	5	982	1013	851	911	1060	1074				
		DON (µg L^{-1})	5	78.21	80.51	55.30	68.93	91.15	95.16				
		DOP (µg L^{-1})	5	4.57	4.88	2.25	4.10	5.81	5.81				
		Chl a (µg L^{-1})	5	0.47	0.52	0.33	0.37	0.56	0.58	Mean	0.45		
		NO_x (µg L^{-1})	5	2.17	0.95	0.69	0.75	3.23	5.24	Median	0.25		
		PN (µg L^{-1})	5	21.41	20.02	13.66	15.79	27.18	30.38	Median	18.00	16.00	25.00

Region	Site	Measure	N	Mean	Median	Quantiles				Guidelines			
						Q5	Q20	Q80	Q95	Statistic	Annual	Dry	Wet
		PO_4 (µg L^{-1})	5	1.98	2.32	0.42	0.74	2.73	3.70	Median	2.00		
		POC (µg L^{-1})	5	198.45	206.34	123.05	133.38	263.78	265.70				
		PP (µg L^{-1})	5	4.67	4.68	2.70	3.93	5.81	6.24	Median	2.10	2.30	3.30
		Secchi (m)	5	4.70	3.00	2.00	2.00	6.60	9.90	Mean	10.00		
		SiO_4 (µg L^{-1})	5	99.41	99.51	63.05	87.44	119.61	127.44				
		TSS (mg L^{-1})	5	4.05	3.55	0.69	1.27	5.67	9.09	Median	1.60	1.60	2.40

Table C-3: Summary of turbidity measurements from moored loggers in all regions except Cape York (site locations in Section 5) for the last three water years. N = number of daily means in the time-series; SE = standard error; '% d> Trigger' refers to the percentage of days each year with mean or median values above the site-specific water quality guideline values (Table C-9). Red shading indicates the annual means or medians that exceeded guideline values. '% d> 5 NTU' refers to the percentage of days above 5 NTU, a threshold suggested by Cooper et al. (2007, 2008) above which hard corals are likely to experience photo-physiological stress.

Subregion	Site	Oct 2017 - Sept 2018						Oct 2018 - Sept 2019						Oct 2019 - Sept 2020					
		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
Johnstone Russell Mulgrave	Fitzroy West	264	1.32	0.05	1.03	50.76	1.14	357	1.14	0.07	0.87	33.33	1.40	233	0.92	0.05	0.78	24.14	0.43
	Franklands West	365	0.97	0.05	0.68	65.21	1.37	365	0.92	0.05	0.66	60.82	1.10	335	0.85	0.03	0.67	62.69	0.60
	High West	365	1.28	0.06	0.95	44.93	1.92	365	1.23	0.07	0.87	37.81	1.92	289	1.14	0.05	0.87	36.68	1.38
	Russell Mulgrave Mouth Mooring	244	3.47	0.22	2.16	79.51	21.31	335	4.92	0.23	3.46	89.59	35.65	335	3.42	0.24	2.01	76.42	19.10
Tully Herbert	Dunk North	365	3.00	0.20	1.38	76.44	16.44	365	3.63	0.24	1.50	74.52	21.61	335	2.69	0.18	1.23	68.66	14.93
	Tully River mouth mooring	365	3.86	0.18	2.90	32.39	20.74	365	4.63	0.19	3.84	46.86	30.50	335	3.76	0.21	2.78	28.53	19.23
Burdekin	Burdekin River mouth mooring	365	7.80	0.49	5.42	60.99	53.30	365	7.72	0.38	5.67	65.48	56.99	264	5.30	0.31	3.68	44.34	36.79
	Magnetic	365	2.18	0.13	1.45	58.63	7.12	365	2.72	0.21	1.51	58.07	12.46	335	1.62	0.09	1.14	39.40	3.58
	Palms West	365	1.01	0.02	0.91	63.56	0.00	304	0.99	0.04	0.85	55.59	0.33	335	0.65	0.01	0.64	22.22	0.00
	Pandora	365	1.65	0.10	1.12	85.48	4.38	219	1.34	0.12	0.84	55.71	5.02	335	1.33	0.06	1.02	73.13	1.49
Mackay-Whitsunday	Double Cone	365	1.83	0.09	1.38	65.48	3.84	365	1.54	0.05	1.21	57.06	0.00	335	1.45	0.05	1.17	57.31	0.90
	Pine	365	3.35	0.13	2.56	85.21	19.45	232	2.68	0.15	1.89	78.45	13.36	275	2.03	0.11	1.44	64.36	7.27
	Repulse Islands dive mooring	365	5.01	0.21	3.79	74.52	39.18	365	4.20	0.20	2.90	67.40	27.40	335	3.58	0.19	2.66	60.60	19.10
	Seaforth	365	1.86	0.05	1.53	80.55	1.64	365	1.68	0.05	1.37	66.30	1.37	335	1.47	0.05	1.17	54.33	1.79

C-4 Data used to generate remote sensing maps

Table C-4: Summary of water quality data collected across the wet season colour classes (CC1–6) and water types (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 CYWMP since 2016–17 and by JCU since 2003–04 and up to 2018–19. No Data = nd.

				TSS (mg L^{-1})	Chla (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 region	multi-annual	CC1	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
	2019–20	CC1	mean	121.67	1.08	Nd.	0.36	16.61	5.37	13.94	270.62
			SD	140.56	0.40		0.00	5.67	2.82	5.72	209.46
			min	11.00	0.59		0.36	8.68	2.79	6.19	87.22
			max	320.00	1.57		0.36	21.56	9.29	19.82	563.78
			count	3	3		1	3	3	3	3
	multi-annual	CC2	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
	2019–20	CC2	mean	71.31	1.27	0.41	0.94	20.19	6.19	14.15	167.00
			SD	119.43	0.25	0.00	0.64	9.90	3.74	13.91	136.71
			min	3.56	0.86	0.41	0.36	8.68	2.79	3.10	24.34
			max	310.00	1.55	0.41	2.00	36.26	13.32	41.34	425.81
			count	5	5	1	4	5	5	5	5
	multi-annual	CC3	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
	2019–20	CC3	mean	10.90	11.65	0.98	1.00	5.00	2.67	11.77	200.79
			SD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			min	10.90	11.65	0.98	1.00	5.00	2.67	11.77	200.79
			max	10.90	11.65	0.98	1.00	5.00	2.67	11.77	200.79
			count	1	1	1	1	1	1	1	1
	multi-annual	CC4	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
			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
	2019–20	CC4	mean	4.23	0.55	0.13	4.28	10.08	1.73	5.37	56.12
			SD	5.77	0.39	0.08	3.54	14.41	1.02	4.08	32.00
			min	0.08	0.10	0.04	0.70	1.54	0.31	0.93	12.84

			max	22.00	1.46	0.33	14.00	74.76	4.14	15.18	123.30
			count	23	22	15	20	23	23	23	23
	multi-annual	P	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
	2019–20	P	mean	25.93	1.08	0.20	3.49	12.12	2.80	7.74	98.08
			SD	75.04	1.98	0.22	3.43	13.57	2.63	7.73	113.57
			min	0.08	0.10	0.04	0.36	1.54	0.31	0.93	12.84
			max	320.00	11.65	0.98	14.00	74.76	13.32	41.34	563.78
			count	32	31	17	26	32	32	32	32
	multi-annual	S (or CC5)	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
	2019–20	S (or CC5)	mean	2.07	0.33	0.12	5.05	9.86	1.69	3.24	42.54
			SD	3.63	0.28	0.22	2.81	11.63	1.09	2.57	28.82
			min	0.01	0.05	0.01	0.30	0.51	0.31	0.62	7.74
			max	24.00	1.91	1.93	16.00	86.38	4.90	17.96	210.50
			count	123	122	76	113	123	123	123	123
	multi-annual	T (or CC6)	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
	2019–20	T (or CC6)	mean	0.75	0.16	0.05	9.50	6.59	1.52	1.69	29.96
			SD	1.64	0.08	0.03	4.38	5.02	1.02	1.22	17.06
			min	0.05	0.06	0.00	0.65	0.48	0.31	0.66	10.44
			max	13.50	0.47	0.16	21.00	30.87	4.65	9.14	82.34
			count	66	65	32	62	66	66	66	66

Table C-5: Summary of water quality data collected in the Cape York region across the wet season colour classes (CC1–6) and water types (primary, secondary, tertiary) as part of the wet season event sampling of the MMP. Multi-years samples were collected between December and April by CYWMP since 2016–17 and up to 2018–19. No Data = nd.

				TSS (mg L⁻¹)	Chla (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	multi-annual	CC1	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
	2019–20	CC1	mean	121.67	1.08	nd.	0.36	16.61	5.37	13.94	270.62
			SD	140.56	0.40		0.00	5.67	2.82	5.72	209.46
			min	11.00	0.59		0.36	8.68	2.79	6.19	87.22
			max	320.00	1.57		0.36	21.56	9.29	19.82	563.78
			count	3	3		1	3	3	3	3
	multi-annual	CC2	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
	2019–20	CC2	mean	88.25	1.31	nd.	0.59	19.85	6.81	16.38	202.67
			SD	128.04	0.27		0.21	11.04	3.95	14.73	130.40
			min	12.00	0.86		0.36	8.68	2.79	3.10	96.46
			max	310.00	1.55		0.86	36.26	13.32	41.34	425.81
			count	4	4		3	4	4	4	4
	multi-annual	CC3	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
	2019–20	CC3	mean	nd.							
			SD								
			min								
			max								
			count								
	multi-annual	CC4	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
	2019–20	CC4	mean	7.87	0.61	0.10	1.83	14.20	1.94	6.91	60.39
			SD	7.61	0.39	0.00	1.20	21.54	0.64	5.56	30.30
			min	0.12	0.10	0.10	0.70	2.01	0.31	0.93	19.32

			max	22.00	1.30	0.10	3.50	74.76	2.59	15.18	112.45
			count	9	8	1	6	9	9	9	9
	multi-annual	P	mean	19.13	1.36	1.49	2.03	26.72	3.98	6.22	66.59
			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
	2019–20	P	mean	49.30	0.89	0.10	1.31	16.06	3.80	10.59	135.38
			SD	100.81	0.48	0.00	1.13	17.41	3.21	9.79	143.94
			min	0.12	0.10	0.10	0.36	2.01	0.31	0.93	19.32
			max	320.00	1.57	0.10	3.50	74.76	13.32	41.34	563.78
			count	16	15	1	10	16	16	16	16
	multi-annual	S (or CC5)	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
	2019–20	S (or CC5)	mean	3.36	0.30	0.33	4.32	10.87	1.89	3.64	44.51
			SD	5.19	0.23	0.58	2.52	14.62	0.82	3.37	28.05
			min	0.12	0.05	0.06	0.30	0.51	0.31	0.62	10.78
			max	24.00	1.13	1.93	11.80	86.38	3.38	17.96	144.93
			count	49	48	9	39	49	49	49	49
	multi-annual	T (or CC6)	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
	2019–20	T (or CC6)	mean	1.05	0.15	0.06	8.38	6.26	1.98	1.75	32.78
			SD	2.36	0.08	0.00	3.05	4.92	0.81	1.60	17.66
			min	0.05	0.07	0.05	0.65	0.48	0.31	0.91	12.49
			max	13.50	0.32	0.06	16.36	30.87	4.65	9.14	76.71
			count	30	29	2	27	30	30	30	30

Table C-6: Summary of water quality data collected in the Wet Tropics region across the wet season colour classes (CC1–6) and water types (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.

Region	Period	Colour class	Statistic	TSS (mg L-1)	Chla (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	multi-annual	CC1	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
	2019–20	CC1	mean	Nd.							
			SD								
			min								
			max								
			count								
	multi-annual	CC2	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
	2019–20	CC2	mean	Nd.							
			SD								
			min								
			max								
			count								
	multi-annual	CC3	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
	2019–20	CC3	mean	Nd.							
			SD								
			min								
			max								
			count								
	multi-annual	CC4	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
	2019–20	CC4	mean	1.28	0.34	0.11	6.14	7.01	1.14	3.21	31.95
			SD	1.06	0.19	0.05	3.83	5.50	0.77	1.22	14.11

			min	0.22	0.15	0.04	2.50	2.38	0.31	1.64	12.84
			max	2.89	0.71	0.19	14.00	18.41	2.87	5.57	53.89
			count	7	7	7	7	7	7	7	7
	multi-annual	P	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
	2019–20	P	mean	1.28	0.34	0.11	6.14	7.01	1.14	3.21	31.95
			SD	1.06	0.19	0.05	3.83	5.50	0.77	1.22	14.11
			min	0.22	0.15	0.04	2.50	2.38	0.31	1.64	12.84
			max	2.89	0.71	0.19	14.00	18.41	2.87	5.57	53.89
			count	7	7	7	7	7	7	7	7
	multi-annual	S (or CC5)	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
	2019–20	S (or CC5)	mean	0.97	0.32	0.09	5.83	10.36	1.31	2.60	38.69
			SD	0.81	0.26	0.06	2.76	11.20	1.11	1.43	34.44
			min	0.01	0.08	0.01	2.00	1.82	0.31	0.62	7.74
			max	3.20	1.06	0.27	13.00	76.30	4.34	6.42	210.50
			count	45	45	43	45	45	45	45	45
	multi-annual	T (or CC6)	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
	2019–20	T (or CC6)	mean	0.44	0.15	0.04	10.76	7.93	1.15	1.39	23.55
			SD	0.28	0.06	0.03	5.11	5.49	0.98	0.38	11.76
			min	0.07	0.06	0.00	4.00	1.61	0.31	0.66	10.44
			max	0.86	0.32	0.16	21.00	23.64	4.01	2.20	50.10
			count	26	26	20	25	26	26	26	26

Table C-7: Summary of water quality data collected in the Burdekin region across the wet season colour classes (CC1–6) and water types (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.

Region	Period	Colour class	Statistic	TSS (mg L-1)	Chla (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	multi-annual	CC1	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
	2019–20	CC1	mean	Nd.							
			SD								
			min								
			max								
			count								
	multi-annual	CC2	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
	2019–20	CC2	mean	3.56	1.11	0.41	2.00	21.56	3.72	5.25	24.34
			SD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			min	3.56	1.11	0.41	2.00	21.56	3.72	5.25	24.34
			max	3.56	1.11	0.41	2.00	21.56	3.72	5.25	24.34
			count	1	1	1	1	1	1	1	1
	multi-annual	CC3	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
	2019–20	CC3	mean	10.90	11.65	0.98	1.00	5.00	2.67	11.77	200.79
			SD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			min	10.90	11.65	0.98	1.00	5.00	2.67	11.77	200.79
			max	10.90	11.65	0.98	1.00	5.00	2.67	11.77	200.79
			count	1	1	1	1	1	1	1	1
	multi-annual	CC4	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
	2019–20	CC4	mean	2.67	0.70	0.14	4.77	8.92	2.33	5.29	74.69
			SD	2.44	0.47	0.10	3.54	3.83	1.27	2.47	34.64
			min	0.08	0.10	0.04	1.60	2.59	0.62	2.69	20.94

			max	6.70	1.46	0.33	11.00	15.47	4.14	9.60	123.30
			count	6	6	6	6	6	6	6	6
	multi-annual	P	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
	2019–20	P	mean	3.81	2.12	0.28	3.95	10.01	2.55	6.09	84.16
			SD	3.43	3.63	0.29	3.39	5.63	1.19	3.03	55.81
			min	0.08	0.10	0.04	1.00	2.59	0.62	2.69	20.94
			max	10.90	11.65	0.98	11.00	21.56	4.14	11.77	200.79
			count	8	8	8	8	8	8	8	8
	multi-annual	S (or CC5)	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
	2019–20	S (or CC5)	mean	0.90	0.23	0.11	4.98	7.16	2.40	2.56	47.43
			SD	0.56	0.13	0.07	2.88	2.47	1.19	1.08	18.06
			min	0.08	0.10	0.02	2.80	2.03	0.31	1.24	14.94
			max	2.40	0.50	0.25	16.00	11.94	4.90	5.21	82.70
			count	21	21	16	21	21	21	21	21
	multi-annual	T (or CC6)	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
	2019–20	T (or CC6)	mean	0.68	0.20	0.06	9.64	4.32	1.16	2.13	33.25
			SD	0.56	0.09	0.04	4.75	1.98	1.12	0.93	15.26
			min	0.05	0.10	0.02	3.80	2.24	0.31	0.91	13.14
			max	1.70	0.36	0.15	17.00	8.32	3.04	3.73	61.04
			count	9	9	9	9	9	9	9	9

Table C-8: Summary of water quality data collected in the Mackay-Whitsunday region across the wet season colour classes (CC1–CC6) and water types (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.

Region	Period	Colour class	Statistic	TSS (mg L-1)	Chla (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	multi-annual	CC1	mean	73.00	3.69	1.13	0.35	44.00	13.67	25.67	73.67
			SD	36.12	2.26	0.44	0.12	26.99	8.38	7.72	40.20
			min	24.00	1.42	0.76	0.20	15.00	5.00	15.00	32.00
			max	110.00	6.78	1.75	0.50	80.00	25.00	33.00	128.00
			count	3	3	3	3	3	3	3	3
	2019–20	CC1	mean	Nd.							
			SD								
			min								
			max								
			count								
	multi-annual	CC2	mean	22.35	0.92	0.11	Nd.	27.50	8.00	14.50	32.00
			SD	16.65	0.65	0.03		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
	2019–20	CC2	mean	Nd.							
			SD								
			min								
			max								
			count								
	multi-annual	CC3	mean	14.00	1.35	0.14	Nd.	58.50	8.00	12.50	15.00
			SD	0.00	0.05	0.00		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
	2019–20	CC3	mean	Nd.							
			SD								
			min								
			max								
			count								
	multi-annual	CC4	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
	2019–20	CC4	mean	1.60	0.67	0.27	3.00	1.54	0.46	7.07	75.49
			SD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			min	1.60	0.67	0.27	3.00	1.54	0.46	7.07	75.49

			max	1.60	0.67	0.27	3.00	1.54	0.46	7.07	75.49
			count	1	1	1	1	1	1	1	1
	multi-annual	P	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
	2019–20	P	mean	1.60	0.67	0.27	3.00	1.54	0.46	7.07	75.49
			SD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			min	1.60	0.67	0.27	3.00	1.54	0.46	7.07	75.49
			max	1.60	0.67	0.27	3.00	1.54	0.46	7.07	75.49
			count	1	1	1	1	1	1	1	1
	multi-annual	S (or CC5)	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
	2019–20	S (or CC5)	mean	3.48	0.76	0.09	4.38	7.99	0.72	6.14	39.35
			SD	3.13	0.48	0.06	3.11	4.22	0.27	2.27	15.60
			min	0.25	0.20	0.03	2.00	1.82	0.31	2.50	24.44
			max	9.50	1.91	0.23	11.00	14.07	1.08	10.74	66.24
			count	8	8	8	8	8	8	8	8
	multi-annual	T (or CC6)	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
	2019–20	T (or CC6)	mean	0.63	0.47	0.04	7.00	2.17	0.31	3.95	82.34
			SD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			min	0.63	0.47	0.04	7.00	2.17	0.31	3.95	82.34
			max	0.63	0.47	0.04	7.00	2.17	0.31	3.95	82.34
			count	1	1	1	1	1	1	1	1

C-5 Site-specific Guideline Values for MMP sites

Table C-9: Site-specific Guideline Values (GVs) used for comparison with water quality monitoring data. These GVs are used to calculate the annual condition version of the WQ Index for each water quality sampling location and 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, etc.). Bold GVs are those applied to monitoring data.

					Annual		Dry	Wet
Group	Site codes	Water Body	Measure	DOF	Mean	Median	Median	Median
1	C1,C6,C8,RM1,RM4,RM8,TUL1	Open Coastal waters	Chla (μgL⁻¹)	H	0.45		**0.32**	**0.63**
			NOx (μgL⁻¹)	H		**0.35**		
			Turbidity (NTU)	H		**1.00**		
			PN (μgL⁻¹)	H	20.00		**16.00**	**25.00**
			PO4 (μgL⁻¹)	H		**2.00**		
			PP (μgL⁻¹)	H	2.80		**2.30**	**3.30**
			Secchi (m)	L	**10.00**			
			TSS (mgL⁻¹)	H	2.00		**1.60**	**2.40**
2	RM9,RM10,TUL3,TUL4,TUL5,TUL6,TUL8,TUL9	Open Coastal waters	Chla (μgL⁻¹)	H	0.45		**0.32**	**0.63**
			NOx (μgL⁻¹)	H		**0.35**		
			Turbidity (NTU)	H		**1.00**		
			PN (μgL⁻¹)	H	20.00		**16.00**	**25.00**
			PO4 (μgL⁻¹)	H		**2.00**		
			PP (μgL⁻¹)	H	2.80		**2.30**	**3.30**
			Secchi (m)	L	**10.00**			
			TSS (mgL⁻¹)	H	2.00		**1.60**	**2.40**
3	C4,C5,C11,RM2,RM3,RM5,RM6,RM7,TUL2	Mid-shelf waters	Chla (μgL⁻¹)	H		0.30	**0.32**	**0.63**
			NOx (μgL⁻¹)	H		**0.31**		
			Turbidity (NTU)	H		**0.60**		
			PN (μgL⁻¹)	H		14.00	**16.00**	**25.00**
			PO4 (μgL⁻¹)	H		**2.00**		
			PP (μgL⁻¹)	H		2.00	**2.30**	**3.30**
			Secchi (m)	L		**13.00**		
			TSS (mgL⁻¹)	H		1.20	**1.60**	**2.40**
4	RM12,TUL11	Mid-estuarine waters	Chla (μgL⁻¹)	H		**2.00**		
			NOx (μgL⁻¹)	H		**15.00**		
			Turbidity (NTU)	H		**5.00**		
			PN (μgL⁻¹)	H				
			PO4 (μgL⁻¹)	H		**3.00**		
			PP (μgL⁻¹)	H				
			Secchi (m)	L		**1.50**		
			TSS (mgL⁻¹)	H		**7.00**		
5	TUL7,TUL10	Lower estuarine waters	Chla (μgL⁻¹)	H		**1.10**		
			NOx (μgL⁻¹)	H		**3.00**		
			Turbidity (NTU)	H		**4.00**		

					Annual		Dry	Wet
Group	Site codes	Water Body	Measure	DOF	Mean	Median	Median	Median
			PN (µgL^{-1})	H				
			PO4 (µgL^{-1})	H		3.00		
			PP (µgL^{-1})	H				
			Secchi (m)	L		1.60		
			TSS (mgL^{-1})	H		5.00		
6	BUR1,BUR2	Open Coastal waters	Chla (µgL^{-1})	H		0.35	0.32	0.63
			NOx (µgL^{-1})	H		0.28		
			Turbidity (NTU)	H		0.80		
			PN (µgL^{-1})	H		12.00	16.00	25.00
			PO4 (µgL^{-1})	H		1.00		
			PP (µgL^{-1})	H		2.20	2.30	3.30
			Secchi (m)	L	10.00			
			TSS (mgL^{-1})	H		1.20	1.60	2.40
7	BUR3	Open Coastal waters	Chla (µgL^{-1})	H	0.45		0.32	0.63
			NOx (µgL^{-1})	H		0.28		
			Turbidity (NTU)	H		0.80		
			PN (µgL^{-1})	H	20.00		16.00	25.00
			PO4 (µgL^{-1})	H		1.00		
			PP (µgL^{-1})	H	2.80		2.30	3.30
			Secchi (m)	L	10.00			
			TSS (mgL^{-1})	H	2.00		1.60	2.40
8	BUR4	Open Coastal waters	Chla (µgL^{-1})	H		0.59	0.32	0.63
			NOx (µgL^{-1})	H		0.28		
			Turbidity (NTU)	H		1.30		
			PN (µgL^{-1})	H		17.00	16.00	25.00
			PO4 (µgL^{-1})	H		1.00		
			PP (µgL^{-1})	H	2.80		2.30	3.30
			Secchi (m)	L		4.00		
			TSS (mgL^{-1})	H		1.90	1.60	2.40
9	BUR5	Open Coastal waters	Chla (µgL^{-1})	H		0.60	0.32	0.63
			NOx (µgL^{-1})	H		0.50		
			Turbidity (NTU)	H		3.00		
			PN (µgL^{-1})	H	20.00		16.00	25.00
			PO4 (µgL^{-1})	H		2.00		
			PP (µgL^{-1})	H	2.80		2.30	3.30
			Secchi (m)	L		3.00		
			TSS (mgL^{-1})	H		5.00	1.60	2.40
10	BUR6.BUR7	Open Coastal waters	Chla (µgL^{-1})	H	0.45		0.32	0.63
			NOx (µgL^{-1})	H		1.00		
			Turbidity (NTU)	H	2.00			
			PN (µgL^{-1})	H		13.00	16.00	25.00
			PO4 (µgL^{-1})	H		2.00		
			PP (µgL^{-1})	H		2.10	2.30	3.30

					Annual		Dry	Wet
Group	Site codes	Water Body	Measure	DOF	Mean	Median	Median	Median
			Secchi (m)	L	**10.00**			
			TSS (mgL⁻¹)	H		1.20	**1.60**	**2.40**
11	BUR8,BUR9	Enclosed Coastal waters	Chla (µgL⁻¹)	H		**1.00**		
			NOx (µgL⁻¹)	H		**4.00**		
			Turbidity (NTU)	H		**4.00**		
			PN (µgL⁻¹)	H				
			PO4 (µgL⁻¹)	H		**1.00**		
			PP (µgL⁻¹)	H				
			Secchi (m)	L		**1.50**		
			TSS (mgL⁻¹)	H		**2.00**		
12	BUR10	Mid-shelf waters	Chla (µgL⁻¹)	H		0.33	**0.32**	**0.63**
			NOx (µgL⁻¹)	H		**0.28**		
			Turbidity (NTU)	H		**0.50**		
			PN (µgL⁻¹)	H		14.00	**16.00**	**25.00**
			PO4 (µgL⁻¹)	H		**1.00**		
			PP (µgL⁻¹)	H		2.00	**2.30**	**3.30**
			Secchi (m)	L	**10.00**			
			TSS (mgL⁻¹)	H		0.80	**1.60**	**2.40**
13	BUR11,BUR12	Open Coastal waters	Chla (µgL⁻¹)	H	0.45		**0.32**	**0.63**
			NOx (µgL⁻¹)	H		**1.00**		
			Turbidity (NTU)	H		**2.00**		
			PN (µgL⁻¹)	H	20.00		**16.00**	**25.00**
			PO4 (µgL⁻¹)	H		**2.00**		
			PP (µgL⁻¹)	H	2.80		**2.30**	**3.30**
			Secchi (m)	L	**10.00**			
			TSS (mgL⁻¹)	H	2.00		**1.60**	**2.40**
14	BUR13,BUR14,BUR15	Enclosed Coastal waters	Chla (µgL⁻¹)	H		**1.00**		
			NOx (µgL⁻¹)	H		**4.00**		
			Turbidity (NTU)	H		**4.00**		
			PN (µgL⁻¹)	H				
			PO4 (µgL⁻¹)	H		**1.00**		
			PP (µgL⁻¹)	H				
			Secchi (m)	L		**1.50**		
			TSS (mgL⁻¹)	H		**2.00**		
15	WHI1,WHI2,WHI3,WHI4,WHI5	Open Coastal waters	Chla (µgL⁻¹)	H		0.36	**0.32**	**0.63**
			NOx (µgL⁻¹)	H		**1.00**		
			Turbidity (NTU)	H		**1.10**		
			PN (µgL⁻¹)	H	14.00		**16.00**	**25.00**
			PO4 (µgL⁻¹)	H		**1.00**		
			PP (µgL⁻¹)	H		2.30	**2.30**	**3.30**
			Secchi (m)	L	**10.00**			
			TSS (mgL⁻¹)	H		1.40	**1.60**	**2.40**
16	WHI6	Enclosed Coastal waters	Chla (µgL⁻¹)	H		**1.30**		

Group	Site codes	Water Body	Measure	DOF	Annual Mean	Annual Median	Dry Median	Wet Median
			NOx (µgL⁻¹)	H		**4.00**		
			Turbidity (NTU)	H		**4.00**		
			PN (µgL⁻¹)	H				
			PO4 (µgL⁻¹)	H		**3.00**		
			PP (µgL⁻¹)	H				
			Secchi (m)	L		**1.60**		
			TSS (mgL⁻¹)	H		**5.00**		
17	WHI7,WHI10	Open Coastal waters	Chla (µgL⁻¹)	H	0.45		**0.32**	**0.63**
			NOx (µgL⁻¹)	H		**0.25**		
			Turbidity (NTU)	H	**2.00**			
			PN (µgL⁻¹)	H		18.00	**16.00**	**25.00**
			PO4 (µgL⁻¹)	H		**2.00**		
			PP (µgL⁻¹)	H		2.10	**2.30**	**3.30**
			Secchi (m)	L	**10.00**			
			TSS (mgL⁻¹)	H		1.60	**1.60**	**2.40**
18	WHI8,WHI11	Open Coastal waters	Chla (µgL⁻¹)	H	0.45		**0.32**	**0.63**
			NOx (µgL⁻¹)	H		**1.00**		
			Turbidity (NTU)	H	**2.00**			
			PN (µgL⁻¹)	H	20.00		**16.00**	**25.00**
			PO4 (µgL⁻¹)	H		**2.00**		
			PP (µgL⁻¹)	H	2.80		**2.30**	**3.30**
			Secchi (m)	L	**10.00**			
			TSS (mgL⁻¹)	H	2.00		**1.60**	**2.40**
19	WHI9	Open Coastal waters	Chla (µgL⁻¹)	H	0.45		**0.32**	**0.63**
			NOx (µgL⁻¹)	H		**0.25**		
			Turbidity (NTU)	H	**1.00**			
			PN (µgL⁻¹)	H		18.00	**16.00**	**25.00**
			PO4 (µgL⁻¹)	H		**2.00**		
			PP (µgL⁻¹)	H		2.10	**2.30**	**3.30**
			Secchi (m)	L	**10.00**			
			TSS (mgL⁻¹)	H		1.60	**1.60**	**2.40**
20	WHI10.1,WHI10.2	Open Coastal waters	Chla (µgL⁻¹)	H	0.45		**0.32**	**0.63**
			NOx (µgL⁻¹)	H		**1.00**		
			Turbidity (NTU)	H			**2.00**	**12.00**
			PN (µgL⁻¹)	H	20.00		**16.00**	**25.00**
			PO4 (µgL⁻¹)	H		**2.00**		
			PP (µgL⁻¹)	H	2.80		**2.30**	**3.30**
			Secchi (m)	L	**10.00**			
			TSS (mgL⁻¹)	H	2.00		**1.60**	**2.40**

C-6 Regional exposure assessments for waterbodies

Regional results of the exposure assessment are shown for each waterbody in Figure C-2.

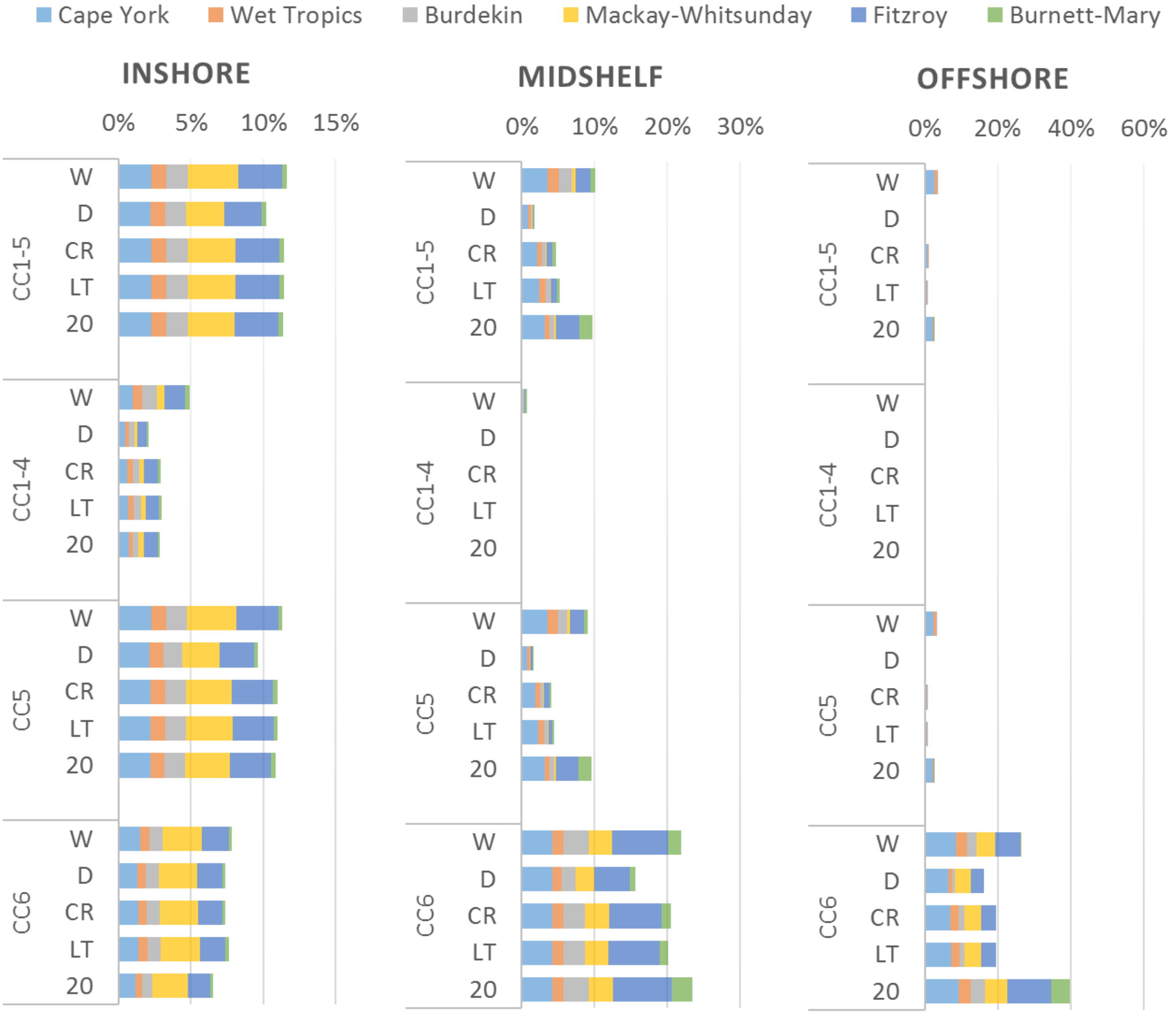


Figure C-3: Percentages (%) of the Reef lagoon (total 348,839 km2) and division by regional waterbodies affected by the primary and secondary wet season water types combined, and the three wet season water types individually during the current wet season and for a range of reference periods (long-term (LT), typical wet (W), typical dry(D) and coral recovery (CR) period composites). (and/or in the case of extremely wet year or specific event patterns). Areas and percentage are only calculated for frequencies > 0.1. Inshore waters include the macro-tidal enclosed coastal, enclosed coastal, macro-tidal open coastal and open coastal waterbodies combined.

Figure C-4: Areas (in km² 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-7 Pesticide monitoring results

Table C-10: Concentration of PSII herbicides and other pesticides measured at the Dunk Island and High Island sites in 2019–20.

Site Name	Deployment Dates						Concentration of PSII herbicides (ng/L)													Concentration of other pesticides (ng/L)													
	Deployment	Retrieval	Sample type	Days Deployed	Flow Rate (m/s)	Sample Name	Ametryn*	Atrazine*	Diuron*	Hexazinone*	Tebuthiuron*	Bromacil*	Fluometuron*	Metribuzin*	Prometryn*	Propazine*	Simazine*	Terbuthylazine*	Terbutryn*	Atrazine desethyl	Atrazine desisopropyl	Metolachlor* (S+R)	2,4-D*	2,4-DB	Haloxyfop*	MCPA*	Fluazifop	Fluroxypyr*	Imazapic*	Imidacloprid*	Metsulfuron methyl*	Tebuconazole	% species affected
Dunk Island	17/11/2019	7/12/2019	ED DUN1119	20	0.272	ED_DUN1119	n.d.	0.040	0.110	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.020	0.020	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.16
	7/12/2019	8/01/2020	ED DUN1219	32	0.219	ED_DUN1219	n.d.	0.030	0.150	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.010	0.010	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.13
	8/01/2020	10/02/2020	ED DUN0120	33	0.239	ED_DUN0120	n.d.	0.210	1.30	0.570	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.100	0.110	n.d.	0.010	0.020	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.33
	10/02/2020	6/03/2020	ED DUN0220	25	0.252	ED_DUN0220	n.d.	0.530	1.96	0.750	n.d.	n.d.	n.d.	n.d.	<BLK	n.d.	0.030	n.d.	n.d.	n.d.	n.d.	0.080	0.170	n.d.	0.010	0.030	n.d.	n.d.	n.d.	n.d.	0.040	n.d.	0.34
	6/03/2020	2/04/2020	ED DUN0320	27	0.255	ED_DUN0320	n.d.	0.680	3.10	1.10	0.150	0.110	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.040	n.d.	0.230	0.180	n.d.	0.020	0.040	n.d.	n.d.	n.d.	0.240	0.040	n.d.	0.44
	2/04/2020	13/05/2020	ED DUN0420	41	0.208	ED_DUN0420	n.d.	0.620	1.11	0.410	0.200	0.030	n.d.	n.d.	n.d.	0.010	0.020	0.020	n.d.	0.080	n.d.	0.170	0.100	n.d.	0.010	0.010	n.d.	n.d.	n.d.	0.080	0.030	n.d.	0.34
High Island	16/11/2019	8/12/2019	ED HIG1119	22	0.223	ED_HIG1119	n.d.	0.070	0.130	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	<BLK	0.050	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.22
	7/12/2019	8/01/2020	ED HIG1219	32	0.254	ED_HIG1219	n.d.	0.130	0.510	0.090	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.030	0.090	n.d.	<BLK	n.d.	n.d.	n.d.	n.d.	n.d.	0.050	n.d.	0.10
	9/01/2020	7/02/2020	ED HIG0120	29	0.244	ED_HIG0120	n.d.	1.06	3.45	0.870	0.030	n.d.	n.d.	n.d.	n.d.	n.d.	0.020	n.d.	n.d.	0.080	n.d.	0.460	0.220	n.d.	0.040	0.070	n.d.	n.d.	n.d.	0.480	0.060	n.d.	0.55
	7/02/2020	4/03/2020	ED HIG0220	26	0.232	ED_HIG0220	n.d.	0.270	2.50	0.600	0.020	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.320	0.160	n.d.	0.080	0.030	n.d.	n.d.	n.d.	0.150	0.050	n.d.	0.45
	5/03/2020	4/04/2020	ED HIG0320	30	0.322	ED_HIG0320	n.d.	1.16	4.29	1.27	0.120	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.100	n.d.	0.290	0.300	n.d.	0.020	0.040	n.d.	n.d.	n.d.	0.620	0.060	n.d.	0.46
	4/04/2020	11/05/2020	ED HIG0420	37	0.271	ED_HIG0420	n.d.	1.03	1.85	0.680	0.190	n.d.	n.d.	n.d.	n.d.	n.d.	0.050	n.d.	n.d.	0.290	n.d.	0.270	0.120	n.d.	0.030	0.020	n.d.	n.d.	n.d.	0.220	0.070	n.d.	0.42
Summary																																	
Samples (n)							12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	
Detects (n)							0	12	12	9	6	2	0	0	1	1	4	1	0	5	0	9	9	0	12	11	0	0	0	6	8	0	
% Detects							0	100	100	75	50	17	0	0	8	8	33	8	0	42	0	75	75	0	100	92	0	0	0	50	67	0	
Minimum concentration							n.d.	0.040	0.110	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.010	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	
Maximum concentration							n.d.	1.16	4.29	1.27	0.200	0.110	n.d.	n.d.	<BLK	0.010	0.030	0.020	n.d.	0.290	n.d.	0.460	0.300	n.d.	0.080	0.070	n.d.	n.d.	n.d.	0.620	0.070	n.d.	

(*included in ms-PAF method)

Table C-11: Concentration of PSII herbicides and other pesticides measured at the Flat Top Island, Repulse Bay and Sandy Creek sites in 2019–20.

Site Name	Deployment Dates		Sample type	Concentration of PSII herbicides (ng/L)													Concentration of other pesticides (ng/L)													Sample type	Concentration of pesticides (ng/L)				% species affected
	Deployment	Retrieval		Ametryn*	Atrazine*	Diuron*	Hexazinone*	Tebuthiuron*	Bromacil*	Fluometuron*	Metribuzin*	Prometryn*	Propazine*	Simazine*	Terbuthylazine*	Terbutryn*	Atrazine desethyl	Atrazine desisopropyl	Metolachlor* (S+R)	2,4-D*	2,4-DB	Haloxyfop*	MCPA*	Fluazifop	Fluroxypyr*	Imazapic*	Imidacloprid*	Metsulfuron methyl*	Tebuconazole		Propiconazole	Pendimethalin*	Chlorpyriphos*	Trifluralin	
Flat Top Island	7/11/2019	13/12/2019	ED	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	1.07	n.d.	n.d.	n.d.	0.040	n.d.	n.d.	PDMS	n.d.	n.d.	<BLK	n.d.	0.55
	Sampler lost																																		
	16/01/2020	13/02/2020	ED	0.890	10.8	77.7	16.2	0.080	n.d.	n.d.	0.620	n.d.	0.440	n.d.	n.d.	n.d.	0.640	n.d.	4.51	1.94	n.d.	n.d.	0.470	n.d.	n.d.	n.d.	2.96	0.160	n.d.	PDMS	0.346	0.021	0.125	<BLK	2.79
Repulse Bay	7/11/2019	13/12/2019	ED	n.d.	0.040	1.53	0.060	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.020	n.d.	n.d.	n.d.	0.070	n.d.	n.d.	n.d.	0.120	n.d.	n.d.	PDMS	n.d.	n.d.	<BLK	<BLK	0.33
	15/12/2019	16/01/2020	ED	0.050	1.94	7.14	8.58	0.020	1.69	n.d.	n.d.	n.d.	0.030	n.d.	n.d.	n.d.	n.d.	n.d.	1.89	0.450	n.d.	n.d.	0.240	n.d.	n.d.	n.d.	1.88	n.d.	n.d.	PDMS	n.d.	n.d.	<BLK	<BLK	0.91
	16/01/2020	13/02/2020	ED	0.080	7.11	27.1	14.4	0.110	0.830	n.d.	n.d.	n.d.	0.150	n.d.	n.d.	n.d.	0.490	n.d.	2.41	0.810	n.d.	n.d.	0.350	n.d.	n.d.	n.d.	2.83	n.d.	n.d.	PDMS	0.400	0.009	<BLK	n.d.	1.15
	13/02/2020	17/04/2020	ED	0.200	5.34	20.6	14.5	0.410	8.54	n.d.	n.d.	n.d.	0.130	n.d.	n.d.	n.d.	n.d.	n.d.	3.02	0.240	n.d.	n.d.	0.070	n.d.	n.d.	n.d.	5.22	0.160	n.d.	PDMS	0.729	n.d.	<BLK	n.d.	0.99
Sandy Creek	7/11/2019	13/12/2019	ED	1.37	12.7	91.5	21.9	0.080	n.d.	n.d.	0.760	n.d.	0.730	0.080	n.d.	n.d.	2.72	0.540	8.29	1.88	n.d.	0.020	0.290	n.d.	n.d.	n.d.	3.33	0.140	n.d.	PDMS	n.d.	n.d.	<BLK	<BLK	2.83
	Sampler lost																																		
	16/01/2020	13/02/2020	ED	n.d.	0.190	1.09	0.370	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.070	n.d.	n.d.	n.d.	0.520	n.d.	n.d.	n.d.	0.030	n.d.	n.d.	PDMS	0.942	0.063	0.575	0.001	1.61
Summary																																			
Samples (n)				8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8		8	8	8	8	
Detects (n)				5	7	7	7	5	3	0	2	0	4	1	0	0	3	1	7	5	0	1	8	0	0	0	8	3	0		4	3	8	5	
% Detects				63	88	88	88	63	38	0	25	0	50	13	0	0	38	13	88	63	0	13	100	0	0	0	100	38	0		50	38	100	63	
Minimum concentration				n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.070	n.d.	n.d.	n.d.	0.030	n.d.	n.d.		n.d.	n.d.	<BLK	n.d.	
Maximum concentration				1.37	12.7	91.5	21.9	0.410	8.54	n.d.	n.d.	n.d.	0.730	0.080	n.d.	n.d.	2.72	0.540	8.29	1.88	n.d.	0.020	0.520	n.d.	n.d.	n.d.	5.22	0.160	n.d.		0.942	0.063	0.575	0.001	

(*included in ms-PAF method)

C-8 References

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Cooper TF, Ridd PV, Ulstrup KE, Humphrey C, Slivkoff M, Fabricius KE (2008). Temporal dynamics in coral bioindicators for water quality on coastal coral reefs of the Great Barrier Reef. Marine and Freshwater Research 59:703-716.

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

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

Great Barrier Reef Marine Park Authority. Water quality guidelines for the Great Barrier Reef. Basin-level objectives for Wet Tropics, Townsville, and Mackay-Whitsundays regions. URL: http://www.gbrmpa.gov.au/our-work/threats-to-the-reef/declining-water-quality?a=1394. Accessed Jan 2019.

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

Appendix D. Scientific publications and presentations associated with the program, 2019–20

D-1 Publications

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

Howley, C. Natural and anthropogenic drivers of water quality in the Normanby Basin and Princess Charlotte Bay. PhD thesis, Griffith University, November 2020.

Data used for model validation:

Baird, M. E., K. Wild-Allen, J. Parslow, M. Mongin, B. Robson, J. Skerratt, F. Rizwi, M. Soja-Woźniak, E. Jones, M. Herzfeld, N. Margvelashvili, J. Andrewartha, C. Langlais, M. Adams, N. Cherukuru, S. Hadley, P. Ralph, T. Schroeder, A. Steven, U. Rosebrock, L. Laiolo, M. Gustafsson, and D. Harrison (2020). CSIRO Environmental Modelling Suite (EMS): Scientific description of the optical and biogeochemical models (vB3p0). Geoscientific Model Development.13:4503-4553.

Skerratt, J. and M. Baird. 2020. Technical assessment of the eReefs biogeochemical (BGC) simulation [gbr4_H2p0_B3p1_Chyd_Dcrt] against observations and comparison with BGC version B3p0. Commonwealth Scientific and Industrial Research Organisation.

Skerratt J.H., M. Mongin, K. A. Wild-Allen, M. E. Baird, B. J. Robson, B. Schaffelke, M. Soja-Wozniak, N Margvelashvili, C. H. Davies, A. J. Richardson, A. D. L. Steven (2019) Simulated nutrient and plankton dynamics in the Great Barrier Reef (2011-2016). J. Mar. Sys. 192, 51-74.

Steven, Andrew D. L., Mark E. Baird, Richard Brinkman, Nicholas J. Car, Simon J. Cox, Mike Herzfeld, Jonathan Hodge, Emlyn Jones, Edward King, Nugzar Margvelashvili, Cedric Robillot, Barbara Robson, Thomas Schroeder, Jenny Skerratt, Sharon Tickell, Narendra Tuteja, Karen Wild-Allen & Jonathan Yu (2019): eReefs: An operational information system for managing the Great Barrier Reef, Journal of Operational Oceanography, DOI: 10.1080/1755876X.2019.1650589

Spare samples provided for: Erler, D., Farid, H.T., Glaze, T.D. et al. Coral skeletons reveal the history of nitrogen cycling in the coastal Great Barrier Reef. Nat Commun 11, 1500 (2020). https://doi.org/10.1038/s41467-020-15278-w

D-2 Presentations

Gruber R and R Brinkman. *Water quality research and monitoring at AIMS*. Open Q&A and site visit to Rocks Farming Company with Pioneer Burdekin canegrowers, Burdekin Valley, QLD, November 2020.

Gruber R. *How and why we monitor water quality on the Great Barrier Reef.* Online public webinar presenting MMP and IMOS data, 20 August 2020. Recorded and can be watched online: https://www.youtube.com/watch?v=oVf-1L2-uNM.

Gruber R, et al. *Water quality research and monitoring at AIMS*. Presented to Herbert region canegrowers at AIMS site visit and open Q&A, Townsville, QLD, October 2019. This visit was filmed and a short version can be watched online: https://www.youtube.com/watch?v=76HvMRRT5Fo.

Lewis S. *Burdekin sediment budgets* to the NQ Conservation Council at the 'Ensuring a viable Burdekin Basin' workshop. Presentation 11 September 2020.

Lewis S. *Sources, transport, fate and impacts of sediments and nutrients in the Great Barrier Reef.* JCU Student Lecture (3rd year and Masters level students), 30 March 2020.

Lewis S. *Tracking sediment from the catchment to reef* at the RBMS River Fest conference for World Rivers Day Presentation. Presentation 29 September 2020.

Moran D, et al. *Water quality research and monitoring at AIMS*. Presented to Pioneer Burdekin region canegrowers at AIMS site visit, Townsville, QLD, November 2020.