Cape York Peninsula Marine Water Quality Synthesis

Technical Report for the CYP Water Quality Improvement Plan

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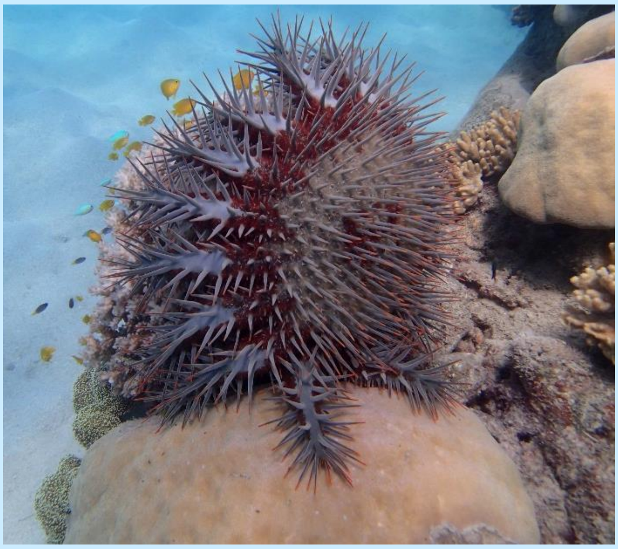

Howley Environmental Consulting

Cover Photos: Coral assemblage (top left) and Crown of Thorns starfish (top right) at Little Unchartered Reef (Christina Howley). Bottom: Flood plume waters at Princess Charlotte Bay, approximately 14km offshore (north) from the Kennedy River mouth (Jeff Shellberg, 29/1/2013).

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This report was produced under contract to South Cape York Catchments (SCYC) with funding from the Australian Government for the Cape York Water Quality Improvement Plan. The scope of the report, as identified by SCYC and the WQIP Science Advisory Panel, was to synthesize the available water quality data from eastern CYP and to provide a comparison of the data from the northern, central and southern CYP regions and the GBR water quality guidelines. While every effort has been made to ensure that the contents of this publication are factually correct, the author does not accept responsibility for the accuracy or completeness of the contents.

EXECUTIVE SUMMARY

The Cape York Peninsula (CYP) marine environment (far northern Great Barrier Reef) is considered to be in good condition compared to other parts of the Great Barrier Reef (GBR) or global coral reef ecosystems. This is attributed to a combination of factors, including good water quality due to lower levels of development within CYP catchments, as well as less pressure from recreational and commercial fishers, tourism and other boats. However, many of the assumptions in regards to the CYP marine condition are based on short-term studies in isolated areas or modelled water quality parameters. Threats to the CYP marine environment are generally poorly quantified in terms of actual impacts on marine receiving waters and ecosystems. This report presents a brief synthesis of the existing water quality data and publications from Cape York Peninsula, and a comparison of the data from the north, central and southern CYP regions with GBR water quality guidelines. The datasets analysed here include nutrient, chlorophyll-a and suspended sediment concentrations from the AIMS Long-Term Water Quality Monitoring Programme, Great Barrier Reef Marine Park Authority (GBRMPA) Marine Monitoring Programme and samples collected by the CSIRO eReefs program on a dry season and wet season Cape York trip. A synthesis of the marine ecosystems and key species populations data will be produced separately.

Several studies over the past 20 years have shown that water quality and coral reefs in eastern Cape York are generally in better condition than other GBR regions. Fabricius et al (2005) found that water around inshore reefs in northern Princess Charlotte Bay (PCB) had lower nutrient, sediment and chlorophyll-a concentrations than Wet Tropics reefs, correlating to higher live coral cover, coral species richness and fish abundance in PCB. The Long-Term Chlorophyll-a Monitoring Programme (Brodie et al 2007) found that inner-shelf waters adjacent to Cape York Peninsula had mean chlorophyll-*a* concentrations (0.21 μg/L) less than half that of inshore waters of the central and southern GBR (0.54 μg/L). While these studies indicate that CYP generally has better water quality than other GBR regions, flood plume monitoring from the Annan, Endeavour and Normanby rivers have shown that high concentrations of suspended sediments (SS) are discharged to the marine environment, where they regularly inundate inshore reefs and coastal seagrass meadows. In a comparison of Annan River and Daintree River flood events, Davies and Eyre (2005) found that the estimated SS load discharged from the Annan River was significantly higher than the sediment load from a larger magnitude flood event in the Daintree River. Nutrient yields from the Annan were also higher than those from the Daintree River for the events studied. Amongst GBR flood plume studies, plume samples from Princess Charlotte Bay (Normanby Basin event discharge) had the third highest mean SS concentration next to the Burdekin and Fitzroy River plumes (Howley et al, in prep; Devlin 2012). With the exception of the Normanby, few Cape York flood plumes have been sampled.

An analysis of the available eastern Cape York water quality data showed generally low SS and chlorophyll-a concentrations in the open coastal, mid-shelf and offshore zones, indicating that ambient water quality remains in relatively good condition. However, insufficient data exists from the enclosed coastal zone to assess the current condition in that zone. Significant variations in water quality were identified between the north, south and central CYP marine zones. During the dry season, mean SS was almost twice as high in the central (Princess Charlotte Bay) region than in the southern or northern region. Median SS concentrations in the PCB open coastal (dry season) and offshore (dry and wet season) zones and the northern open coastal zone exceeded the GBR water quality guidelines. Dry season chlorophyll-a concentrations were highest in the south enclosed coastal zone and mean concentrations in this zone exceeded the GBR Guidelines. Maximum wet season chlorophyll-a concentrations were also detected in the southern enclosed coastal zone. However, limited chlorophyll-a data was available from the northern or central enclosed coastal zones for comparison. During the wet season, mean PN concentrations were highest in the northern region for all zones. Both PN and PP in a range of regions and zones exceeded the GBR water quality guidelines.

Regional variations detected in the combined water quality dataset may be a factor of sampling design (due to the nature of the combined dataset). A more thorough statistical analysis of the data, and/or specifically designed sampling programme, would be necessary to draw conclusions regarding the regional and seasonal variations in water quality. Wind-driven sediment resuspension is likely to contribute to the exceedances of the GBR Guidelines.

Despite the importance of the CYP region of the GBR for maintaining relatively good coral condition, intact seagrass meadows and healthy populations of dugongs, turtles and fish, there is currently very little regular monitoring of ambient or flood plume water quality in the CYP region. Data is particularly limited for the enclosed coastal zone and for the northern region. The influence of shipping on sediment re-suspension, which is likely to have a significant impact on water quality near the shipping channels, has also not been documented by any monitoring programs. Additional monitoring of both ambient and flood event water quality across all regions of eastern CYP will be necessary to identify future changes resulting from the on-going and expanding anthropogenic activities such as grazing, horticulture, road development, shipping and mining.

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1 Introduction

The Cape York Peninsula (CYP) marine environment (far northern Great Barrier Reef) is considered to be in good condition compared to other parts of the Great Barrier Reef (GBR) or global coral reef ecosystems. In addition to healthy coral reefs and seagrass meadows, this region has high fisheries values and harbours significant populations of rare or threatened marine turtles, dugongs and dolphins. This is attributed to a combination of factors, including good water quality resulting from lower levels of development within CYP catchments, as well as less pressure from recreational and commercial fishers, tourism and other boats. However, many of the assumptions in regards to the CYP marine condition are based on short-term studies in isolated areas or modelled water quality parameters. Threats and impacts to the CYP marine environment are generally poorly documented or quantified. This report will synthesise the available water quality data for eastern CYP marine waters, compare the results from different regions of Cape York under the influence of different river systems, and review the literature on CYP water quality. The datasets analysed here include nutrient, chlorophyll-a and suspended sediments from the AIMS Long-Term Monitoring Water Quality Programme, Great Barrier Reef Marine Park Authority (GBRMPA) Marine Monitoring Programme (Howley et al, in prep) and samples collected by the CSIRO eReefs program on a dry season and wet season Cape York trip (Oubelkheir et al, unpublished). A synthesis of the marine ecosystems and key species populations data will be produced separately.

2 Literature Review

2.1 Ambient Water Quality Studies

In a comparison of in-shore (<20km from the coast) coral reef condition between Princess Charlotte Bay (PCB) in Cape York and the Wet Tropics, Fabricius et al (2005) found that water around most of the Wet Tropics reefs had higher nutrient, sediment and chlorophyll concentrations than around PCB reefs. Mean suspended solids, chlorophyll, particulate nitrogen, particulate phosphorus and nitrate were higher in the Wet Tropics than in PCB during the study visits. These water quality variations were correlated to higher total algal cover in the Wet Tropics and higher live coral cover, coral species richness and fish abundance in PCB. The water quality variations are presumed to be related to differences in land-use between the northern PCB region and the Wet Tropics. The Stewart River is the closest major river discharging to the PCB study region (Figure 1). Smaller creeks such as Massey Creek, Breakfast Creek and Scrubby Creek also discharge in this area. The region of the Fabricius et al (2005) study may also be occasionally exposed to flood plume water from the Normanby River. The dominant land-use in the PCB region is current and historic cattle grazing, which is likely to have increased sediment loads in some of these systems (Brooks et al 2013). However, unlike the Wet Tropics, there is no significant horticultural land use in the catchments draining into the study area. Significant natural variations in geology, vegetation type and slope between the two study areas may also attribute to the differences in water quality.

The regional differences found by Fabricius et al (2005) were consistent with regional differences identified by the AIMS Long-term Chlorophyll-a monitoring program (Brodie et al. 2007). Sampling for the Long-Term Chlorophyll-a Monitoring Programme initiated in 1992 was carried out at stations in nine GBR regional zones including both inshore (<25 km from the coast) and offshore locations. The Far North transect ("FN-CL") included transects from Cooktown to Osprey reef, Lizard Island, and the outer PCB region, where sampling was conducted between 1993 and 2004. Additional samples were collected along a transect from the Endeavour River to Emily Reef between 2003 and 2004. Inshore waters of the central and southern GBR had mean chlorophyll *a* concentrations (0.54 µg/L) approximately twice the mean concentration measured in the inner-shelf waters adjacent to Cape York Peninsula (0.21 µg/L). In addition to the lower in-shore chlorophyll-a concentrations in CYP, cross-shelf differences were not observed among the Far Northern, Lizard Island and Cooktown-Osprey transect stations. This is in contrast to other GBR transects, where chlorophyll-a concentrations are significantly higher towards the coast than at the offshore locations (Brodie et al. 2007).

The difference in inshore chlorophyll-a concentrations was attributed to lower nutrient levels in CYP river discharges as a result of catchment area and differences in land use, including "low-density cattle grazing, no cropping and low human population numbers" in the FN-CL region compared to intensive grazing, cropping and other development in the central and southern GBR regions. The lower levels of chlorophyll-a indicate less phytoplankton growth and thus reduced levels of "marine snow", which could be a key factor in the difference in reef condition between PCB and the Wet Tropics (Brodie et al. 2007).

2.2 Flood Event/ Flood Plume Water Quality Studies

In addition to the PCB coral reef/ water quality and long-term chlorophyll-a studies, which were primarily monitoring ambient (wet and dry season) water quality conditions, several studies have focused on water quality in flood plumes discharged from Cape York Rivers to the coastal waters. In the monsoonal catchments of CYP, most runoff to the GBR occurs in a single wet-season flood (Furnas 2003). Flood event studies have focused on flood plumes from the Annan River in southeastern CYP (Figure 1; Davies and Eyre 2005) and the Normanby River at PCB (Howley et al. in prep). Changes in water quality at Boulder Reef during a flood event in the Endeavour River have also been monitored (Davies and Hughes 1983). However, aside from the detailed Normanby flood studies, the concentrations, loads and aerial extent of flood plumes from most CYP rivers remain largely undocumented.

Davies and Hughes (1983) monitored sediment and water flux at Boulder Reef in April 1982 before, during and after the passage of Cyclone Dominic, which resulted in record flooding in the Endeavour River (50,000 ML/day). Sediment loads at Boulder Reef (15km offshore) increased by more than an order of magnitude during the flood, with suspended sediment concentrations at the reef exceeding 200mg/L. The increased sediment loads consisted of both reef-derived sediment and a “substantial” terrigenous component (illite and kaolinite) believed to originate from the Endeavour River. After the first flood pulse, a second, smaller pulse of terrigenous material reached Boulder Reef four days after the passage of Dominic. During the second, smaller pulse, the concentration of particulate terrigenous sediment averaged 18mg/L (Davies and Hughes 1983).

Based on the magnitude of the flood recorded in the Endeavour River, Davies and Hughes (1983) concluded that terrigenous sediment (clay) is getting out to the inner-shelf reefs near Cooktown approximately every five years, in amounts ranging from an estimated 135-228 tonnes per event. Coral cores from Boulder Reef confirmed that illite and kaolinite clays constituted an estimated 4-5 percent of the cores. The clays appeared to have no detrimental effect on the growth of the coral during the Holocene Epoch, however the authors noted that the current reef surface was relatively barren. Further work on the coral cores was recommended to identify any mineralogic variations in time that could be associated with changes in land-use.

The concentration of suspended sediments (>18 mg/L) detected by Davies and Hughes (1983) in flood waters 15 km offshore from the Endeavour River is high compared to concentrations measured in PCB flood plumes, where beyond 10 km from the river mouths, all suspended sediment concentrations were below 10 mg/L (Howley et al. in prep). This may correspond to the higher sediment concentrations discharged from the Endeavour or Annan Rivers during major flood events, and/or higher discharge velocities at the mouth of these rivers reducing sedimentation levels.

Davies and Eyre (2005) measured the loads of suspended sediment and nutrients discharged to the GBR from the Annan River during a minor flood event (2654 Ml total event discharge) in February 1995 (9/2/95 to 13/2/95). The Annan was sampled from a bridge 5 km upstream from the mouth during the rising and falling stages of the flood. Samples were also collected across the estuary and the turbid flood plume which was 1m thick and extended 2km offshore into Walker Bay. (As a comparison, MODIS imagery from a February 2015 flood event shows the Annan flood plume extending at least 15 km offshore to Egret Reef- Figure 2). Suspended sediment (SS) concentrations ranged from 110 mg/L in the estuary at low salinities to 20 mg/L at 35ppt. The saltwater end member SS concentration (20 mg/L) detected in the Annan River from a small flood event is similar to the concentrations (18mg/L) detected at Boulder Reef following a much larger flood event in the Endeavour River. No monitoring of the flood plumes from the Endeavour or Annan Rivers has been conducted during major flood events, despite the proximity of these rivers to the inshore reefs of the GBR.

The high (>20 mg/L) SS concentrations measured by Davies and Eyre (2005) within the Annan flood plume resulted in low chlorophyll-a concentrations, which remained below 0.4 µg/L. Phytoplankton growth is generally limited at SS > 10mg/L (Dagg et al. 2004). Elevated total nitrogen (TN; 42µM) in the upper estuary during the flood event was removed rapidly at low salinities and concentrations remained relatively constant (20-30µM) across the plume until further removal was evident at the plume face. The majority of nitrogen entered the Annan estuary as dissolved organic nitrogen (DON) and left as particulate organic nitrogen (PON). Ammonium (NH_4) concentrations within the estuary and flood plume ranged from approximately 1.0 µM to 3.0 µM, while nitrogen oxides (NO_x) concentrations reached a maximum of 5 µM. Dissolved NH_4 was added to the estuary in the vicinity of the mouth in considerable amounts. The authors theorised that the source of NH_4 could be the decomposition of PON in the water column or inputs from the flushing of mangrove channels. Lower estuary NH_4 sources were also identified in the Normanby River flood plumes, where they were potentially attributed to release from intertidal and supratidal mudflats (Howley et al. in prep). Saltflats also surround the lower Esk River which enters the Annan River near the mouth. When inundated, these saltflats could also provide a source of dissolved inorganic nitrogen (DIN) to Annan River plumes. (Note: nutrient concentrations are approximated from published graphs.)

Total phosphorus (TP) concentrations measured during the Annan River flood event study were 0.89 µM at the riverine end member of the estuary with a large proportion removed at low salinities via sedimentation (Davies and Eyre 2005). TP concentrations outside the plume were low (0.12 µM). Dissolved inorganic phosphorus (DIP) concentrations ranged from 0.15 µM to 0.20 µM at low salinities, and were removed conservatively to concentrations below 0.05 µM. According to the authors, DIP removal above 15 ppt could best be explained by adsorption to particulate material and subsequent sedimentation. Based on DIP and salinity mixing diagrams, the remaining DIP was biologically removed at the plume water front.

In addition to assessing the concentrations and transformations of nutrients and sediment across the Annan River estuary and flood plume, Davies and Eyre (2005) calculated loads of these materials discharged from the Annan during the minor flood event. Gross fluxes from the Annan catchment totalled 194 kg of TP (0.073 kg/mm/km^2) and 3180 TN (1.198 kg/mm/km^2) over the 6 days of the event. The particulate inorganic (PIP) fraction represented 85% of the TP flux. More than 50% of the TN flux occurred as DON, while DIN accounted for 12% of TN and particulate fractions were 30% of TN. Total SS event loads were calculated at 1,406,300 kg. The authors compared the results from the Annan flood event with a larger flood event (178,050 ML total event discharge) and plume discharged from the Daintree River in March of the same year (1995). Not surprisingly due to the differences in flood magnitudes, the nitrogen and phosphorus event loads were generally one to two orders of magnitude higher in the Daintree River event. SS loads however, were significantly higher from the Annan River than the Daintree (189,667 kg). In contrast to the nutrient loads, yields from the catchments showed slightly higher nitrogen yields from the Annan (particularly DON) and phosphorus yields that were twice as high as the Daintree (particularly PIP). The authors concluded that the elevated export coefficients from the Annan probably reflect the high erodibility of the Annan catchment and the propensity for this material to become mobilised, particularly during a first flush event. They also concluded that the higher organic nitrogen fractions in the Annan may reflect the overall undisturbed nature of the catchment (Davies and Eyre 2005).

2.2.1 Normanby Basin Flood Plumes

Howley et al. (in prep) examined nutrient, suspended sediment and chlorophyll-a concentrations discharged from the Normanby River to PCB mid-shelf reefs during three flood events. The Normanby River Basin in southeastern Cape York Peninsula (-15.148°E 144.359°S) is the fourth largest catchment (24,550 km^2) discharging to the GBR lagoon and the largest catchment in CYP. The Normanby has three distributaries- the Kennedy, Normanby and Bizant (Figure 3). The average annual discharge from the Normanby distributary is estimated at 2,806 GL (Wallace et al, 2015). Following major flood events, plumes of fine sediment, nutrients and organic matter can extend over 70 km from the Normanby, Kennedy and Bizant estuaries to the outer GBR. COTs outbreaks, which may be linked to nutrient enrichment from terrestrial run-off (Brodie et al. 2005) are rare at PCB with the exception of Clack and Corbett Reefs, the two reefs most frequently inundated by Normanby River floodwater (Figure 3). The Fabricius et al. (2005) study examined reefs and water quality in the far northern section of PCB, where only the largest Normanby plumes are likely to reach.

Discharge to PCB during the three flood events sampled by Howley et al. (in prep) was calculated from the gauging station at Kalpowar Crossing (105107A), which is situated approximately 70 km upstream from the mouth of the Normanby River (Figure 1). The Kalpowar guage captures less than 50% of Normanby Basin discharge and does not include discharge from the extensive coastal floodplains (Wallace et al 2012, Brooks et al 2013). The March 2012 flood event was a moderate flood (total event discharge 544 GL) preceded by several smaller events. The freshwater flood plume extended approximately 22 kms into Princess Charlotte Bay three days after peak discharge, covering approximately 350 km^2. The larger January 2013 flood (total event discharge 860 GL) associated with ex-tropical cyclone Oswald, was the first flood event in the catchment for the 2013 water year. The 2013 flood plume travelled over 60 km, first inundating Corbett Reef and then flowing east past Clack Reef to the outer GBR, covering at least 1400 km^2. The freshwater plume was approximately 1.5 m thick 4 km from the mouth of the Normanby (Oubelkheir et al. 2013). In April 2014, the passage of Cyclone Ita across the southeastern catchment created a 1-in-20 year flood event in the upper catchment, resulting in a total event discharge of 1,082 GL at Kalpowar Crossing. Numerous smaller events preceded this flood event. The flood plume extended 18 km north from the Kennedy River and 10.5 km from the Normanby River on the date of sampling. In the following days, strong southeasterly winds pushed the plume to the west, flowing north along the coast for at least 50 km, covering a minimum area of 1100 km^2.

During each of the flood events, SS measured at the Kalpowar Crossing gauge (105107) ranged from 10% to 30% of the concentrations measured in the upper catchment. SS concentrations at the Normanby, Kennedy and Bizant River mouths during the 3 flood events ranged from 26 mg L^{-1} to 125 mg L^{-1}. SS within the plume ranged from 0.8 mg/L to 150 mg/L, with a combined plume mean of 21.3 ± 30.3 mg/L. SS at the river mouths was strongly correlated with total event discharge ($rs = 0.879$, $p<0.001$). SS showed a rapid decrease within the 0 - 5 ppt zone for all events; beyond 6 km offshore all SS concentrations were <10 mg/L (Howley et al., in prep).

TN concentrations within the flood plumes ranged from 8.64 µM to 39.05 µM (mean 23.33 µM) while the mean concentration outside the visible plume was 7.972 µM. DON and PN comprised 50% and 34% respectively of TN at the river mouths. DON accounted for between 51% (2013) to 73% (2014) of TN within the flood plume, while PN comprised an average of 24% of all flood plume TN. A maximum NO_X concentration of 6.64 µM was detected at the river mouths while a mean of 1.84 µM was recorded within the plumes. NH_4 concentrations were significantly higher at the lower estuary (mean 2.473 µM) than at mid- and upper catchment sites, indicating that there is a source of NH_4 in the coastal region (similar to the Annan River flood; Davies and Eyre 2005). Maximum estuarine NH_4 concentrations (7.568 µM) were detected adjacent to Normanby River intertidal mudflats, potentially indicating that the mudflats were a significant source of nutrients, as has been shown for supra-tidal mudflats in the Norman River to the southwest (Burford et al., in press).

Mean TP was 1.99 µM in the estuary during the three flood events. TP concentrations within the plume ranged from 0.16 µM to 3.55 µM (mean 0.72 µM) compared to a mean of 0.16 µM outside the flood plume. Particulate phosphorus (PP) comprised on average 49%, 75% and 83% of estuarine TP in 2012, 2013 and 2014 respectively. FRP comprised 30%, 19% and 7% of estuarine TP in 2012, 2013 and 2014. PP accounted for an average of 58% of plume TP in 2014 compared to 20% in 2012 and 19% in 2013. DOP accounted for an average of 44%, 36%, and 22% of TP in 2012, 2013 and 2014 respectively.

TN, TP and PP concentrations exhibited strong positive correlations ($r_s>0.6$) with TSS ($p<0.001$). All nutrient species with the exception of NOx and FRP were negatively correlated ($p<0.01$) with salinity. NOx was strongly negatively correlated with total event discharge.

Silica samples were collected during the 2013 flood plume only. Concentrations ranged from 199.5 mg/L in the estuary to 1.7 outside of the flood plume at PCB, with a mean flood plume concentration of 74.9. Si exhibited conservative behavior (r^2= 0.89) as has been observed in other flood plumes (Boyle 1974).

Chlorophyll-a concentrations within the three PCB flood plumes ranged from 0.25 µg/L to 8.82 µg L^{-1} (mean 1.70 ± 1.86 µg L^{-1}). Concentrations outside of the flood plume ranged from 0.20 µg L^{-1} to 0.87 µg L^{-1} (Table 3). Maximum phytoplankton densities occurred during the 2013 plume, with densities ranging from 32,400 cells/L to 4,140,800 cells/L, compared to 18,300 cells/L to 35,900 cells/L outside of the freshwater plume. Diatomacea was the dominant species group all years, comprising up to 97% of phytoplankton. *Skeletonema sp.* were the most prevalent species in 2013, comprising over 50% of most samples, with a count of 3,892,000 cells/L in one sample. *Skeletonema sp.* were not detected in PCB samples outside of the freshwater plume and were not recorded in 2012 or 2014 samples.

Both Dagg et al (2004) and Turner et al (1990) have identified a suspended sediment threshold of 10mg/L, above which there is insufficient light for phytoplankton growth. In the PCB plume study, chlorophyll concentrations as high as 5.34 ug/L were detected at SS 20 mg/L. However, mid-salinity increases in chlorophyll and/or phytoplankton densities were observed in in all three flood plumes as suspended sediments decreased to less than 10mg/L.

Although significant volumes of sediment and nutrients are discharged into PCB during flood events, turbidity in PCB is also strongly influenced by wind-driven sediment re-suspension and/or tide-driven coastal and bank erosion. PCB is frequently turbid during the windy dry season, particularly in the shallow coastal zone (Howley 2010). Alongi et al (2005) describe sediment cores taken off PCB that reveal sedimentary facies characterized by "near-surface bioturbation and haphazardly oriented clay clasts and shell debris" indicating that the facies are subjected to scouring, re-suspension and rapid re-deposition. In-shore reefs (such as those at the Flinders Isles group) and coastal seagrass meadows are regularly exposed to turbid waters. It is not known how terrestrial sediment discharged into the Bay may alter the levels of re-suspended sediments.

2.2.2 Coastal Upwelling

Lush Halimeda sp. corraline algal meadows cover approximately 2000 km^2 along a narrow strip just landward of the outer barrier reefs between the Ribbon Reefs off Cooktown to the Blackwell Channel off the northern CYP region (Drew & Abel 1985). These meadows occur at 30 – 45m depths and are believed to be supported by upwelling of nutrients from the adjacent Coral Sea. Increased concentrations of nitrate and phosphate associated with upwelling caused by tidal suction at reef passages have been identified in the ribbon reef region off Cooktown. These upwelled nutrients appeared to remain primarily at depth in the region of the Halimeda meadows and are not available to coral reefs (Wolanski et al 1988). Negative correlations between temperature and chlorophyll-a detected along transects in the outer reef regions east of Cooktown (southern CYP) and northeast from Lockhart River (northern CYP) indicate that nutrient-rich colder upwelled waters are also fuelling phytoplankton growth (Liston et al 1992). Vertical mixing may bring chlorophyll enriched sub-surface water to the surface, however upwelled nutrients may be depleted by benthic macrolgae and phytoplankton (Liston et al, 1992). Brinnkman et al (2001) observed cross-shelf (onshore) flow in the Lizard Island region, which may circulate upwelled nutrients westerly over the GBR shelf, where they may be transported northerly along the dominant northerly currents.

2.3 Comparison of Cape York Flood Event Discharge with other GBR Rivers

A number of factors can complicate comparisons of flood plume concentrations from different rivers, including annual variations associated flood magnitude, antecedent rainfall, timing of sampling, and the location of sampling across the plume. Event loads and specific yields may be more appropriate metrics for comparison between rivers and flood events, when there is sufficient end of system discharge and water quality monitoring data to calculate empirical loads or to calibrate models for loads calculations. (A separate report underway as part of the CYWQIP will include empirical loads calculations for Cape York Rivers where sufficient data exists.) Despite the limitations, SS and nutrient concentrations and the dominant nutrient fractions may provide some indication of the level of disturbance within the catchments and potential impacts on discharge to the GBR. The Annan and Normanby flood plume concentrations are compared here against flood plumes from the three largest GBR catchments; the Burdekin, Fitzroy and Burnett Rivers, which, like the Normanby are dominated by grazing, as well as the Herbert and Tully Rivers, which have similar mean annual discharge to the Normanby but are dominated by sugarcane in the lower catchments (Table 1). Mean plume concentrations were not available for the Annan plume.

In the comparison of published concentrations of suspended sediments and nutrients discharged to the GBR lagoon during flood events, the Jardine River, which flows west from eastern CYP in the far northern region (Figure 1), had the lowest recorded end of system SS values, with concentrations remaining below 20 mg/L during one major flood event (Eyre &

Balls 1999). In contrast, SS concentrations near the mouth of the Annan River ranged from 15 mg/L – 105 mg/L during a minor flood event (Davies and Eyre 2005), and concentrations at the mouth of the Normanby ranged from 26 mg/L to 125 mg/L with a mean of 52.5 mg/L (Howley et al. in prep). The Herbert River, with a similar mean annual discharge to the Normanby but much smaller catchment size, recorded maximum TSS in the estuary close to 400mg/L and a mean flood event SS concentration of 156 mg/L (Mitchell et al 1997). The Burdekin River, with a catchment 5 times larger than the Normanby Basin and more than three times greater mean annual discharge, recorded SS as high as 1600 mg/L in the estuary during flood events, and a mean SS of 290 mg/L during one event (Brodie et al 2010 & Bainbridge et al, 2012). Concentrations of NOx discharged to the GBR during flood events reached a maximum 5 µM from the Annan River and 6.6 µM (mean of 3.2 µM) at the Normanby river mouth. The Herbert River estuary had a mean NOx concentration of 15 µM during one flood event (Mitchell et al 1997) and the Burdekin recorded concentrations between 9 µM to 32 µM near the mouth during flood events (Brodie et al, 2010).

Within the flood plumes, suspended sediments and particulate nutrients rapidly settle out, while increased light availability combined with elevated nutrient concentrations result in phytoplankton blooms. Mean plume transect concentrations can be biased towards higher particulate concentrations when samples are collected at low salinities, or higher chlorophyll and dissolved organic nutrients at higher salinities. The timing of sampling in relation to the flood peak also can have a significant influence on the measured concentrations. The 2014 Normanby flood plume, which had the largest discharge of the 3 PCB events monitored, had significantly lower chlorophyll-a concentrations and phytoplankton densities than the slightly smaller 2013 event (Howley et al in prep). While maximum SS concentrations were captured by sampling early in the flood event, it is likely that chlorophyll-a concentrations increased in the following week and are not accurately represented by the sampling results. The mean salinity for each of the flood plume datasets (Table 1) provides some indication of the degree of low salinity versus high salinity sampling that is represented by the mean plume values. The mean salinity value in the Normanby dataset is 18.0, representing approximately equal distribution of samples collected close to the river mouth compared to the outer plume. The mean salinity for the Burdekin dataset compared here is 5.9, indicating that a higher number of samples were collected closer to the mouth where higher mean SS and particulate nutrient, but lower chlorophyll-a concentrations would be expected (Table 1).

Mean SS concentrations within the plumes were highest at the Burdekin, followed by the Fitzroy and Normanby Rivers (Table 1). High mean SS in the Normanby plume may be factor of higher discharge but is also likely to reflect the high levels of erosion documented across the catchment (Brooks et al, 2013). Although mean concentrations were not available for the Annan River flood plume, SS concentrations detected during the 1995 flood event were amongst the highest concentrations of all the plumes, ranging from 20-110 mg/L within the plume (Davies & Eyre 2005).

Mean TN concentrations are higher in the Normanby than the other GBR catchments (Table 1), despite the low levels of horticulture and cropping in the upper Normanby (<1%). Of the TN in the Normanby, mean DON was higher than the other plumes, with the exception of the Fitzroy river plume. PN concentrations were second only to the Burnett River, and similar to mean PN from the Fitzroy. High DON:TN ratios are indicative of a less anthropogenically disturbed catchment (Harris 2001) and may partially explain why the Normanby has the highest mean TN concentrations of the dataset. PN and PP concentrations are highest in the catchments with the largest discharge volumes, with the exception of the Burdekin. Mean NOx concentrations were the third highest in the Normanby plume, and exceeded mean concentrations in the Tully where horticulture and cropping covers 15% of the catchment, including coastal sugarcane. However a separate study presenting mean concentrations from MMP flood plume monitoring (Devlin et al 2012) showed the mean 2007 – 2011 Tully flood plume DIN concentration (3.69±4.18 uM/L) slightly exceeding the mean Normanby DIN (3.4 ± 2.2 µM). Mean DIP concentrations in the Normanby are amongst the lowest of all the river plumes. When the results from the three Normanby flood plume are compared against GBR-wide flood plume concentrations (Devlin 2012), the mean SS, TN, DIN, PN, DON, DOP and chlorophyll-a concentrations exceed the mean GBR concentrations (Table 1).

2.4 Herbicides, Pesticides, and PAHs

Horticulture in CYP is largely limited to the upper catchment of the Normanby River (Lakeland) and the Endeavour River catchment. Although pesticides are considered to be a critical pollutant to the GBR, the results from water and sediment sampling in the Normanby catchment (Howley 2010) and Endeavour River (Howley 2012) suggested that the current levels of herbicides & pesticides in these rivers are unlikely to impact aquatic ecosystems downstream at the Great Barrier Reef. Diuron (1.4 – 6.9 ng/L), simazine (1.8 ng/L) and atrazine (4.8 ng/L) were detected in passive samplers in the Endeavour River estuary during the 2008 and 2009 wet season (Howley 2012). No herbicides were detected in water samples collected at Kalpowar Crossing or the Normanby estuary during the 2007, 2008, 2009 and 2010 wet seasons (Howley 2010). However, passive samplers deployed in 2004 (dry season) and 2005 (wet season) off Hannah Island in northern PCB detected diuron (maximum 13 ng/L), atrazine (5.4 ng/L), simazine (1.3 ng/L) and hexazinone (0.7 ng/L) (Shaw et al. 2010). Diuron was detected in both the wet and dry season samplers; the remaining herbicides were detected by a sampler deployed during a major flood event in the Normanby River. The source of these herbicides is uncertain as they were not detected in passive samplers deployed in the lower reaches of the Normanby River in later years (Howley 2010). Herbicides may be used to fight weeds in the Stewart or other smaller catchments closer to Hannah Island.

The banned organochlorine (OC) insecticide trans-chlordane has been detected in one Normanby River crab sample (Negri et al. 2009). Historical use of this chemical may have resulted in the settlement of chlordane into Normanby River sediments, where it can bio-accumulate in animal tissues. Although no naphthalene or other poly-aromatic hydrocarbons (PAHs) were detected in Normanby estuary crab tissues by Negri et al. (2009), van Oosteron et al (2010) detected napthalene metabolite concentrations in crabs from the Normanby River. Metabolites for the highly toxic PAH benzo-a-pyrene were also present in Normanby River crab tissues (van Oosterom et al. 2010). These results indicate that biota in the Normanby River are exposed to PAHs (most likely from boating activity in the estuary), however the PAH exposure is minimal compared to other GBR rivers.

3 Data Review

Datasets from the AIMS Long-term Chlorophyll-a monitoring programme (AIMS 2015), AIMS Long-Term GBR Water Quality Monitoring Programme, GBRMPA Marine Monitoring Program (PCB flood plumes; Howley et al, in prep) and the CSIRO eReefs program (1 dry season and 1 wet season monitoring trip up the coast of Cape York; Oubelkheir et al, unpublished) are combined and evaluated for this report. This combined dataset comprises a total of 2080 monitoring points including 809 total suspended sediment (TSS) samples, 2075 chlorophyll-a samples, 561 total nitrogen and 592 total phosphorus samples, 1011 ammonium samples, 783 nitrogen oxide samples, 1000 dissolved inorganic phosphorus samples, 557 particulate nitrogen and 586 particulate phosphorus samples, and 866 and 850 dissolved organic nitrogen and phosphorus samples, and 896 silica samples.

The combined dataset has been divided into three regions, north, mid (PCB) and south (Figure 3), and assessed for variations between regions in the dry season (May to November) and wet season (December to April). The northern region is influenced by discharge from the Jackey-Jackey, Olive-Pascoe and Lockhart Rivers. The central (PCB) region is influenced primarily by the inter-connected Normanby and Kennedy Rivers and the Stewart River. The major rivers in the southern region are the Bloomfield, Annan, Endeavour and the Jeannie Rivers. Data from each region has also been divided into enclosed coastal, open coastal, mid-shelf and outer shelf zones as per the divisions established by the GBRMPA. Annual wet and dry season means are compared with the Great Barrier Reef Water Quality Guidelines (2010) (Table 2). The dry season and wet season 20th, 50th and 80th percentiles and mean values SS (TSS), chlorophyll-a, nitrogen and phosphorus fractions and silica from each zone within each region are presented in Tables 3 to 8. The sample locations and spatial variations of TSS, chlorophyll-a, NOx, NH4, DIP, PN and PP in eastern CYP waters are displayed in Figures 4 to 10. Box plots comparing TSS, chlorophyll-a, PN and PP dry season and wet season concentrations for each region and zone are presented in Figures 11 - 14.

3.1 Dry Season

During the dry season, mean SS was almost twice as high in the central (PCB) region than in the south or north region (Table 2). Median SS concentrations in the PCB open coastal and offshore zones and the north open coastal zone exceeded the GBR water quality guidelines (Figure 10, Table 3). Mean NH_4 and NOx were highest in the PCB region for all zones combined (Table 2); however mean open coastal and mid-shelf NH_4 concentrations were highest in the north (Tables 3 and 5) while offshore NH_4 was highest in the south region (Table 7). Offshore NOx values were highest in the north and decreased to the south (Table 7). DON and DOP were highest in the PCB region for the open coastal and mid-shelf zones, while dissolved organics (particularly DOP) in the south region and central offshore zones were elevated above northern region offshore concentrations. Median DIP concentrations in the PCB open coastal and midshelf zones were elevated above north and south region concentrations (Tables 3 and 5). Median and mean PN concentrations in all open coastal and midshelf zones and the PCB offshore zone exceeded the GBR guidelines (Figure 13; Tables 3, 5 and 7). Median and/or mean PP concentrations in the PCB open coastal and mid-shelf zones and the north and south offshore zones slightly exceeded the GBR guidelines (Figure 14; Tables 3, 5 and 7).

Mean chlorophyll-a concentrations were highest in the central region for the combined zones (Table 2); however mean values in the open coastal zone were highest in the north region and slightly exceeded the GBR guidelines (Table 3). Median and mean dry season chlorophyll-a concentrations for all other regions and zones remained below the GBR guidelines. Maximum chlorophyll-a concentrations were detected in the south enclosed coastal zone during both the dry and wet seasons (Figure 12).

3.2 Wet Season

Wet season variations for the combined dataset (Table 2, Figures 4 - 10) are biased towards higher SS and nutrient concentrations in the PCB region due to the intensive monitoring of three flood plumes in this region (Howley et al, in prep) while only opportunistic flood data exists from the south region from the JCU/CSIRO eReefs program trip in January 2013 and limited (if any) flood data exists from the northern region. For this reason, PCB flood monitoring data were removed from the wet season dataset presented in Tables 4, 6 and 8 and Figures 11 to 14 (boxplots). With the removal of PCB flood plume data, wet season SS did not vary significantly between the regions for the open coastal and mid-shelf zones, and median concentrations remained below the GBR guideline (Tables 4 and 6). However, median and mean PCB offshore SS values exceeded the GBR guideline (Table 8).

Median open coastal NH4 values for the wet season were highest in the south region, while NOx concentrations were highest in the north (Table 4). In the mid-shelf zone, median and mean NH4 concentrations were significantly higher in the north (Table 6). In the offshore zone, median NH4 and NOx values were highest in the PCB region, although mean NH4 values were highest in the north region (Table 8). Median DIP concentrations in the open coastal and mid-shelf zones were highest in the PCB region, while median and mean concentrations in the offshore zone were highest in the north region (Tables 4, 6 and 8).

Similar to the dry season, open coastal and mid-shelf zone DON and DOP concentrations were highest in the PCB region (Tables 4 and 6), while offshore DON and DOP median and/or mean concentrations were highest in the southern region (Table 8).

Median and mean PN concentrations in the northern open coastal and offshore zones slightly exceeded the GBR wet season water quality guidelines (Figure 13; Tables 4 and 8). Median PP concentrations in the open coastal and mid-shelf zones were below the GBR guidelines, however median and mean northern and PCB offshore PP concentrations exceeded the guidelines (Figure 14; Tables 4, 6 and 8).

Median wet season chlorophyll-a values were below the GBR guidelines for all regions and zones except for the north offshore zone (Figure 12). Concentrations in the open coastal, mid-shelf and offshore zones were highest in the north (Tables 4, 6 and 8). Maximum chlorophyll-a concentrations were detected in the south enclosed coastal zone (Figure 12). Limited data was available from the north or PCB enclosed coastal zones for comparison.

3.3 Discussion:

Water quality varies significantly between the three CYP regions and between the dry and wet seasons. This is likely to be a result of differences in both catchment land use and geological features as well as other sources (such as upwelling) and factors (wind, currents, water temperature) within the lagoon which may influence water quality. Spatial variations from the combined datasets could also result from sampling biases. Without a monitoring programme specifically designed to compare water quality between the three regions, it is difficult to draw conclusions regarding regional variations observed in the current dataset.

Elevated SS and nutrient concentrations in the central region coastal and mid-shelf zones are expected due to the presence of the Normanby catchment which has the largest catchment area of the eastern CYP rivers and the largest discharge to the GBR lagoon. Significant land-use disturbances have also been documented in this central region (Howley et al. 2013). Although significantly elevated SS concentrations in the PCB region were not evident from the current wet season and dry season data sets, DON, DOP and DIP were elevated in the PCB coastal and mid-shelf regions compared to the north and south regions. High DON and DOP concentrations were also detected in PCB flood plumes relative to other GBR rivers (Table 1). However, due to the lack of more intensive flood plume sampling from the south and north CYP regions, it is difficult to accurately compare water quality variations resulting from river discharge.

Regional and seasonal variations in dissolved inorganic nitrogen and phosphorus suggest that the sources of DIN differ between the regions, and/or that the conditions influencing nitrification and other nutrient cycling processes vary between the regions. These variations are also likely to influence chlorophyll-a concentrations. Wet season river discharge is likely to contribute to regional variations in coastal nutrient and chlorophyll-a concentrations, while upwelling may significantly influence these parameters in the offshore zone. Upwelling has been documented in both the southern and northern CYP regions, however regional variations and the extent of influence on nutrient budgets is unknown.

Limited data exists from the enclosed coastal zones, with the exception of flood plume samples collected from PCB. Additional monitoring of enclosed coastal zone regions is recommended to document the current condition and potential impacts on coastal ecosystems including fringing and inshore reefs and coastal seagrass meadows.

4 Conclusion

This report presents a synthesis of the existing water quality data and publications from Cape York Peninsula, and a comparison of the data from the north, central and southern CYP regions with GBR water quality guidelines. While CYP rivers are largely considered to have better water quality than other GBR regions, flood plume monitoring from the Annan and Normanby rivers indicate that high concentrations of sediments are discharged to the marine environment. In the case of the Annan and Endeavour Rivers, these flood plumes are known to regularly influence inshore reefs and seagrass meadows. Additional monitoring of flood events from the southern and northern CYP regions is recommended in order to better document regional variations in nutrient and sediment concentrations and loads and potential impacts on coastal ecosystems.

Tables 3 through 8 present an overview of the condition* of water quality parameters within CYP northern, central and southern regions and the open coastal, mid-shelf and offshore zones for each of these regions. (**The combined dataset includes data collected between 1991 to present.*) Significant variations were identified between the north, south and central CYP marine water quality zones; however some of these variations may be a factor of sampling design (due to the nature of the combined dataset). A more thorough statistical analysis of the data, and/or specifically designed sampling programme, would be necessary to draw conclusions regarding the nature of regional and seasonal variations. In general, low SS and chlorophyll-a concentrations across the regions indicate that ambient water quality in the open coastal, mid-shelf and offshore zones remains in relatively good condition. However, insufficient data exists from the enclosed coastal zone to assess the current condition in that area. In addition, median SS in the PCB offshore zone (wet season only) and both PN and PP in a range of regions and zones (Figures 13 and 14) exceeded the GBR water quality guidelines. Wind-driven sediment resuspension may contribute to these exceedances. It should also be noted that the influence of shipping on sediment re-suspension has not been quantitatively documented in any of the existing datasets but is likely to have a significant localised impact on water quality across the shipping zones.

Despite the importance of the CYP region of the GBR for maintaining relatively good coral condition, intact seagrass meadows and healthy populations of dugongs, turtles and fish, there is currently no regular monitoring of ambient or flood plume water quality in the CYP region. Monitoring of both ambient and flood water quality is necessary to identify any changes in water quality resulting from on-going and expanding anthropogenic activities such as grazing, horticulture, road development, shipping and mining.

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Appendix 1: Figures

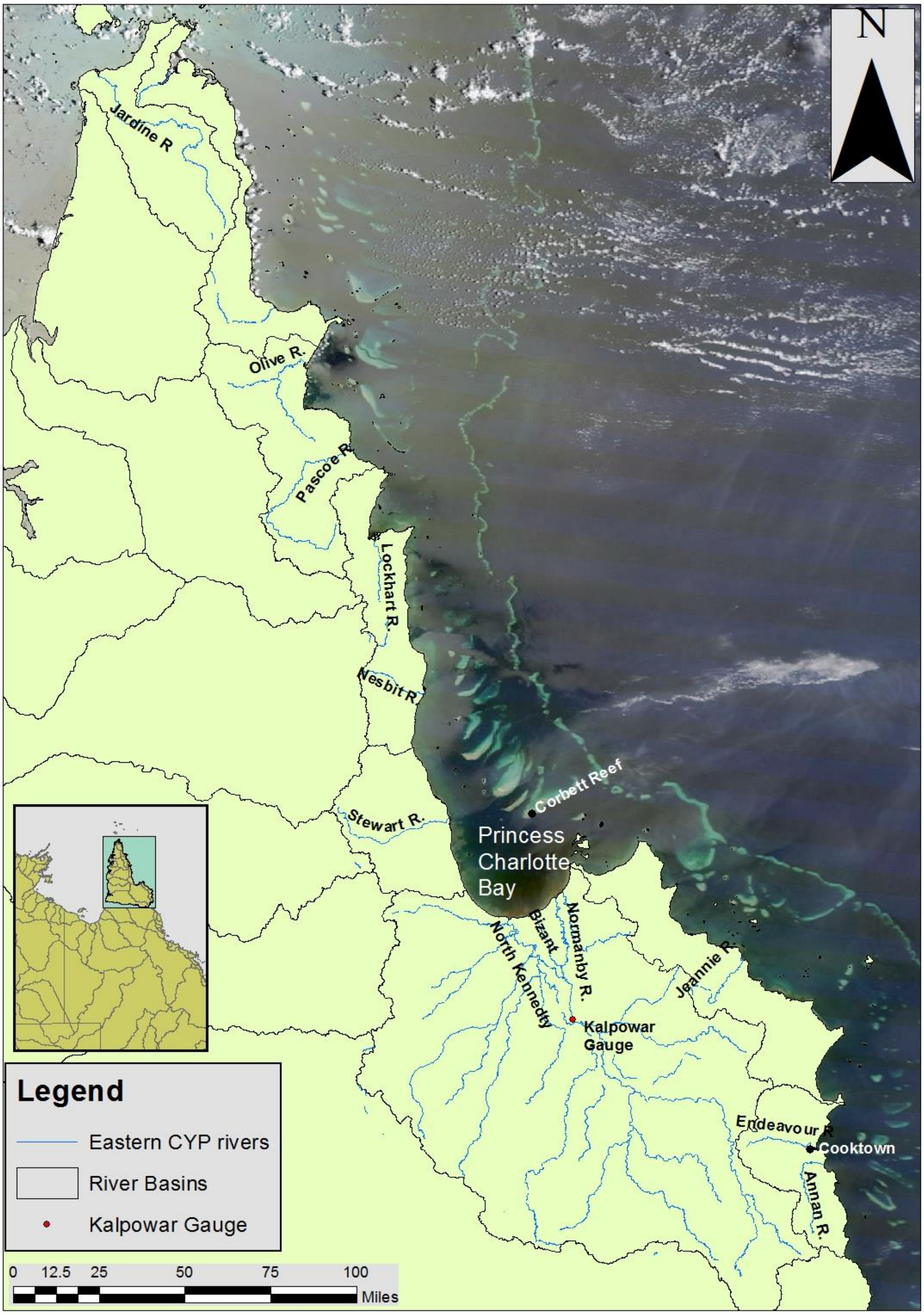

Figure 1: Major Eastern Cape York Rivers and the Normanby River Kalpowar Gauge site

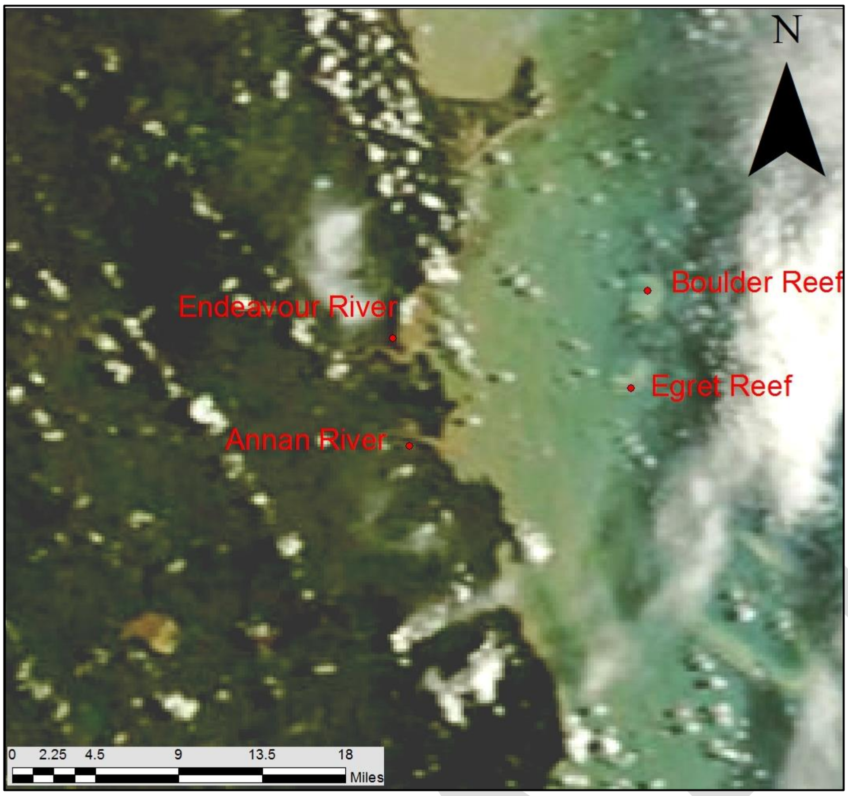

Figure 2: 15th March 2015 (post cyclone Nathan) flood plume from Annan and Endeavour River showing turbid water reaching Boulder and Egret Reef

Figure 3: Princess Charlotte Bay Flood Plume (February 2007)

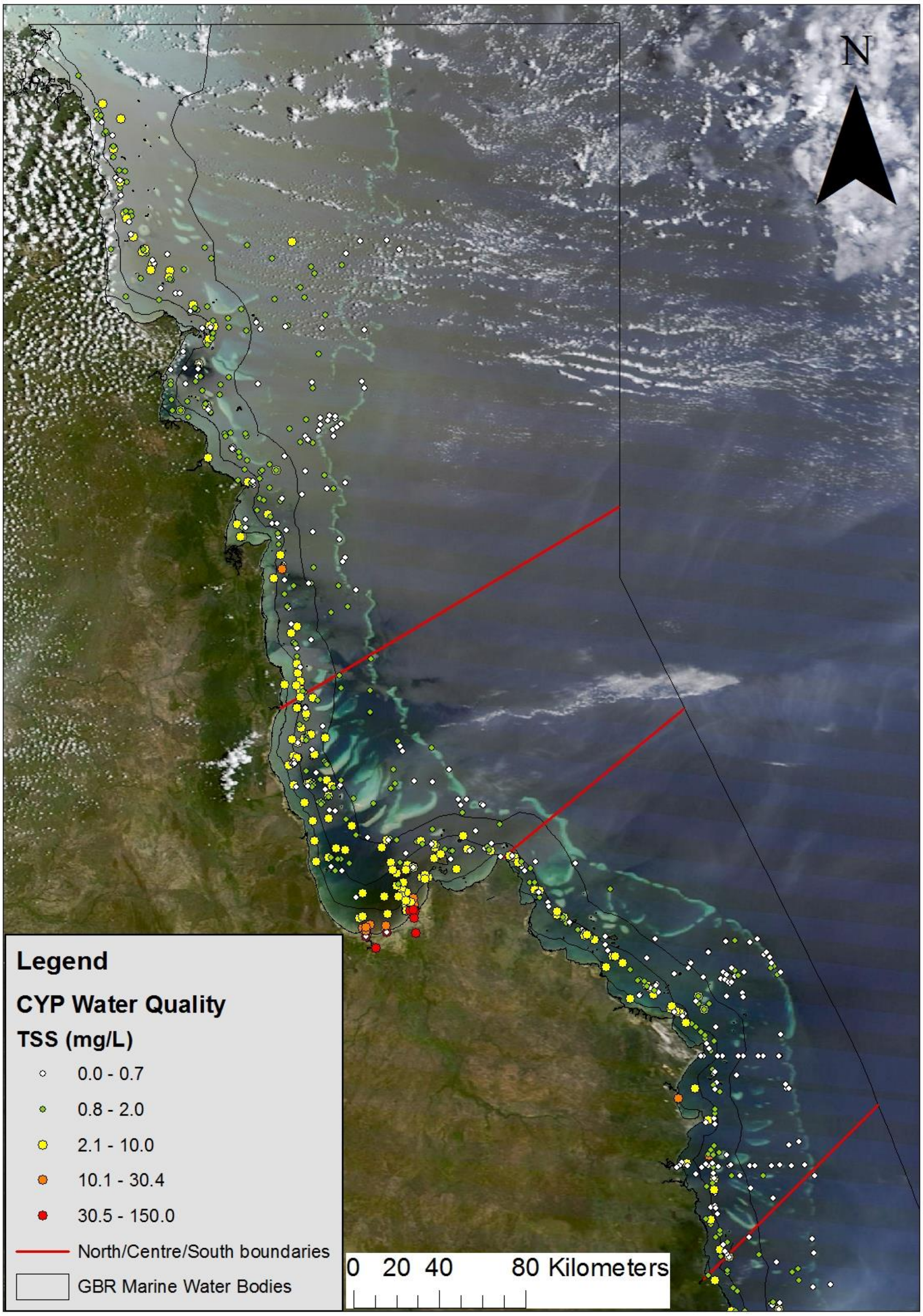

Figure 4: TSS Concentration Distribution for CYP Region of the GBR (data from AIMS Long Term Chlorophyll-a and Water Quality Monitoring Programme, CSIRO eReefs program, and Reef Trust MMP (Howley & Devlin) Flood Plume Monitoring at PCB)

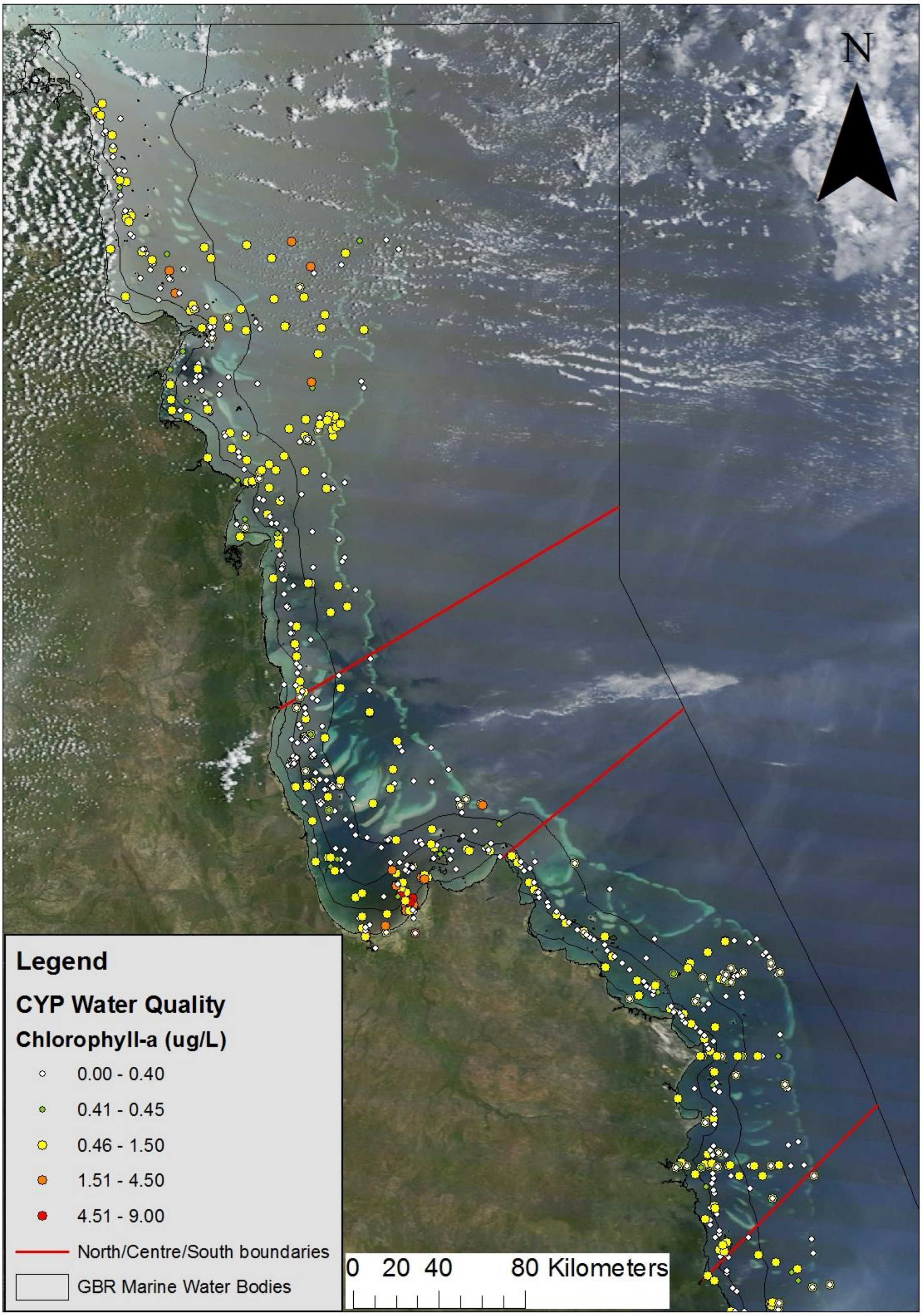

Figure 5: Chlorophyll-a Concentration Distribution for CYP Region of the GBR (data from AIMS Long Term Chlorophyll-a and Water Quality Monitoring Programme, CSIRO eReefs program, and Reef Trust MMP (Howley & Devlin) Flood Plume Monitoring at PCB)

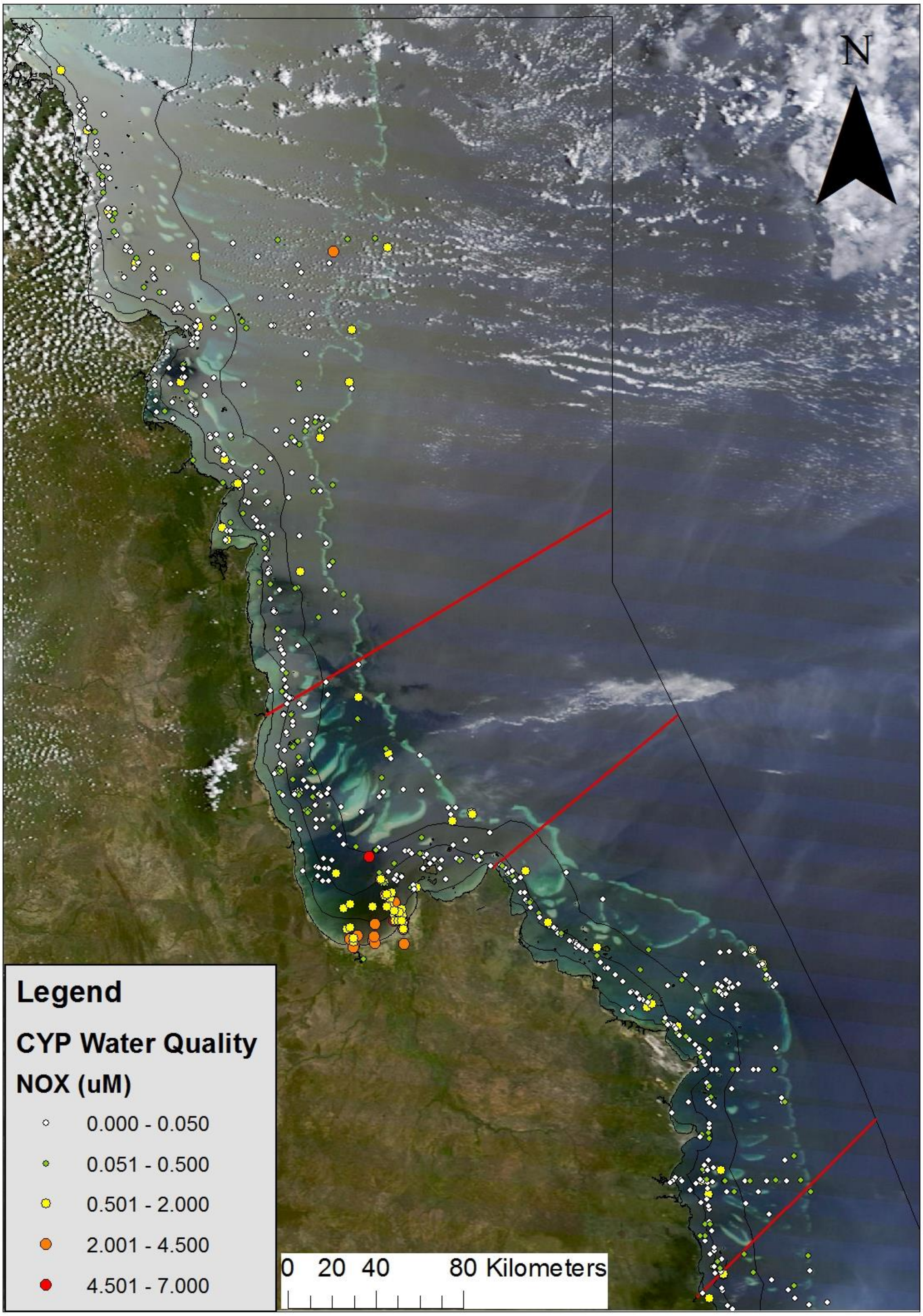

Figure 6: Nitrogen oxides (NOx) Concentration Distribution for CYP Region of the GBR (data from AIMS Long Term Water Quality Monitoring Programme, CSIRO eReefs program, and Reef Trust MMP (Howley & Devlin) Flood Plume Monitoring at PCB)

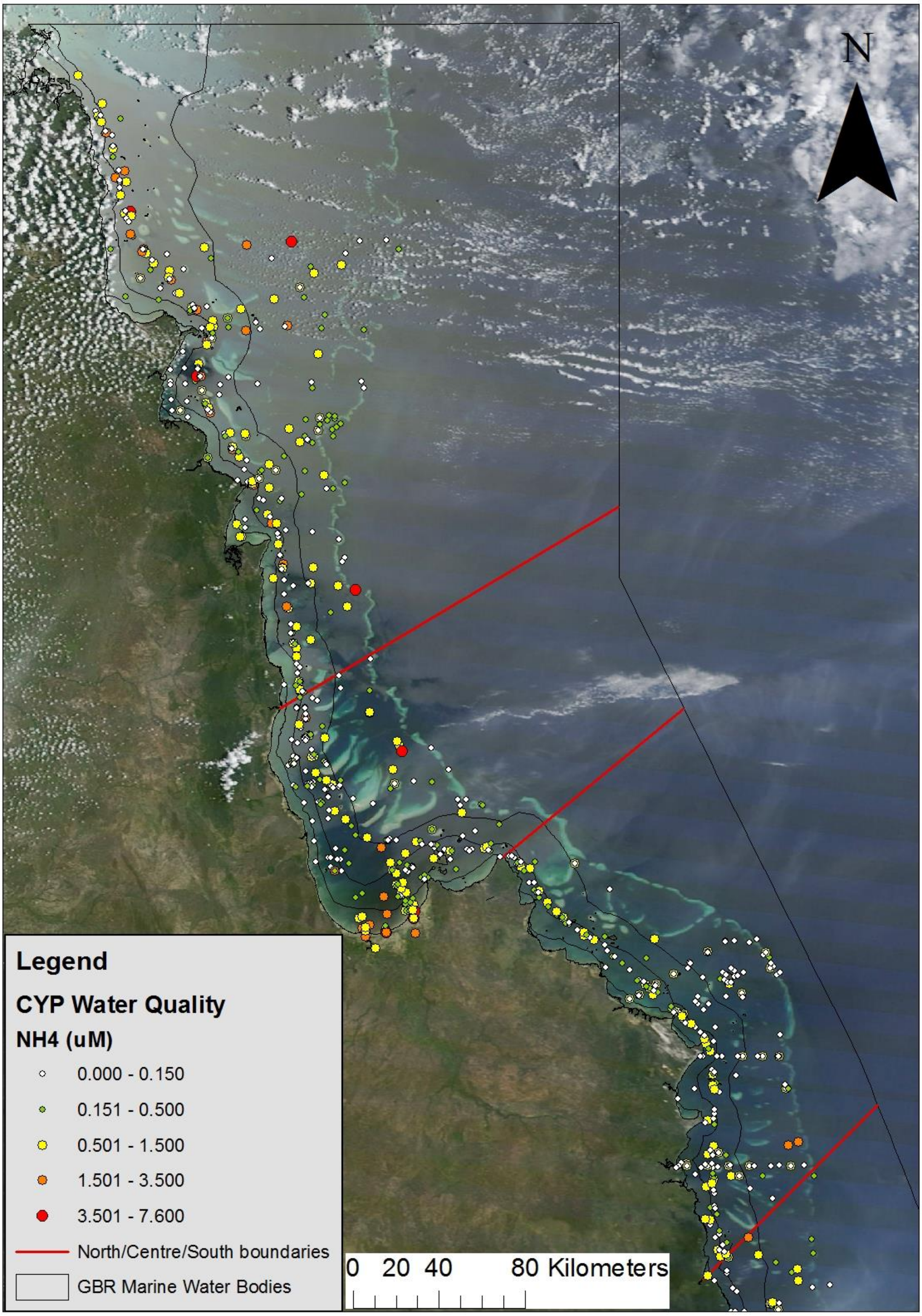

Figure 7: Ammonium (NH_4) Concentration Distribution for CYP Region of the GBR (data from AIMS Long Term Water Quality Monitoring Programme, CSIRO & JCU Monitoring trips, and Reef Trust MMP (Howley & Devlin) Flood Plume Monitoring at PCB)

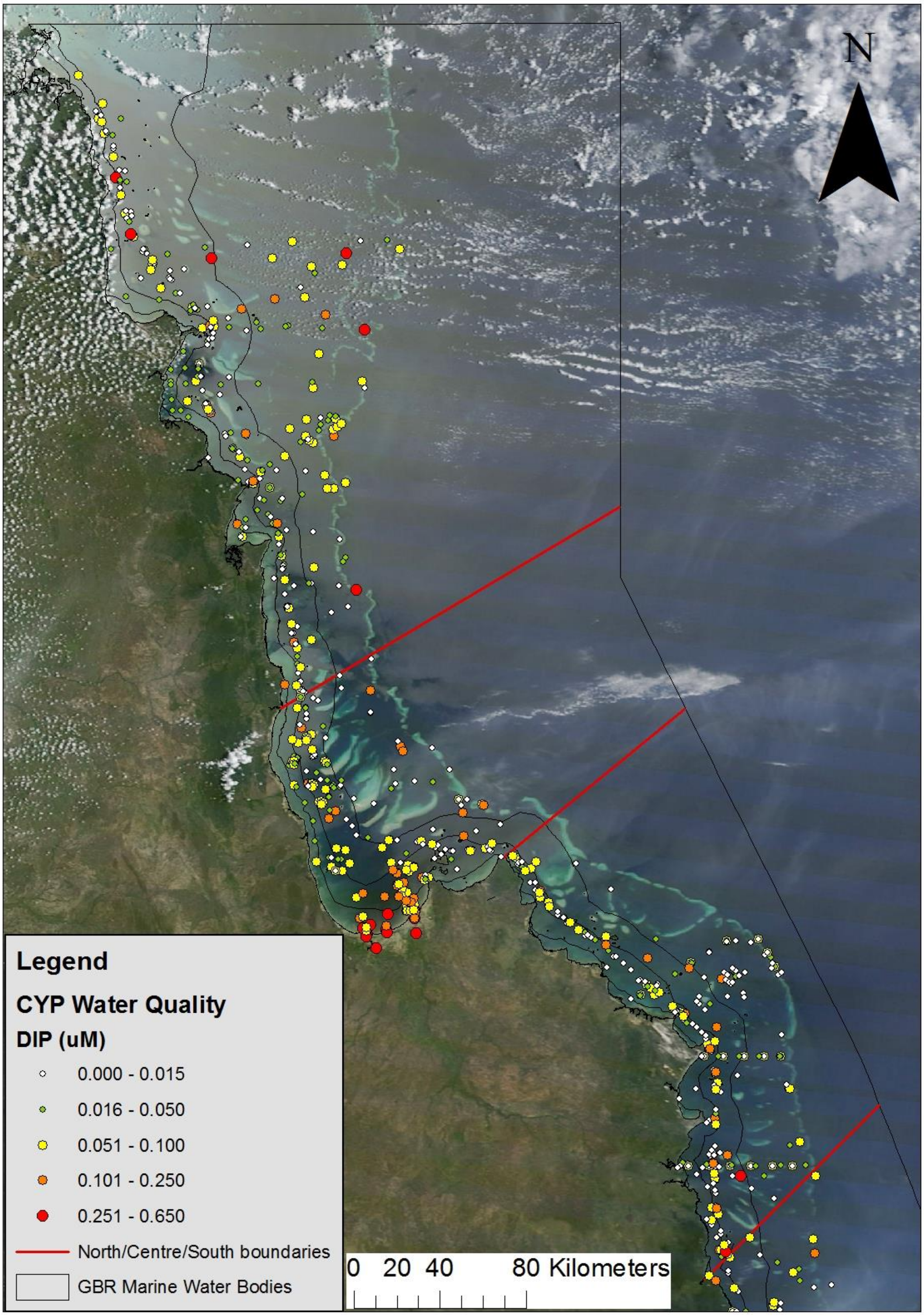

Figure 8: Dissolved Inorganic Phosphorus (DIP) Concentration Distribution for CYP Region of the GBR (data from AIMS Long Term Water Quality Monitoring Programme, CSIRO eReefs program, and Reef Trust MMP (Howley & Devlin) Flood Plume Monitoring at PCB)

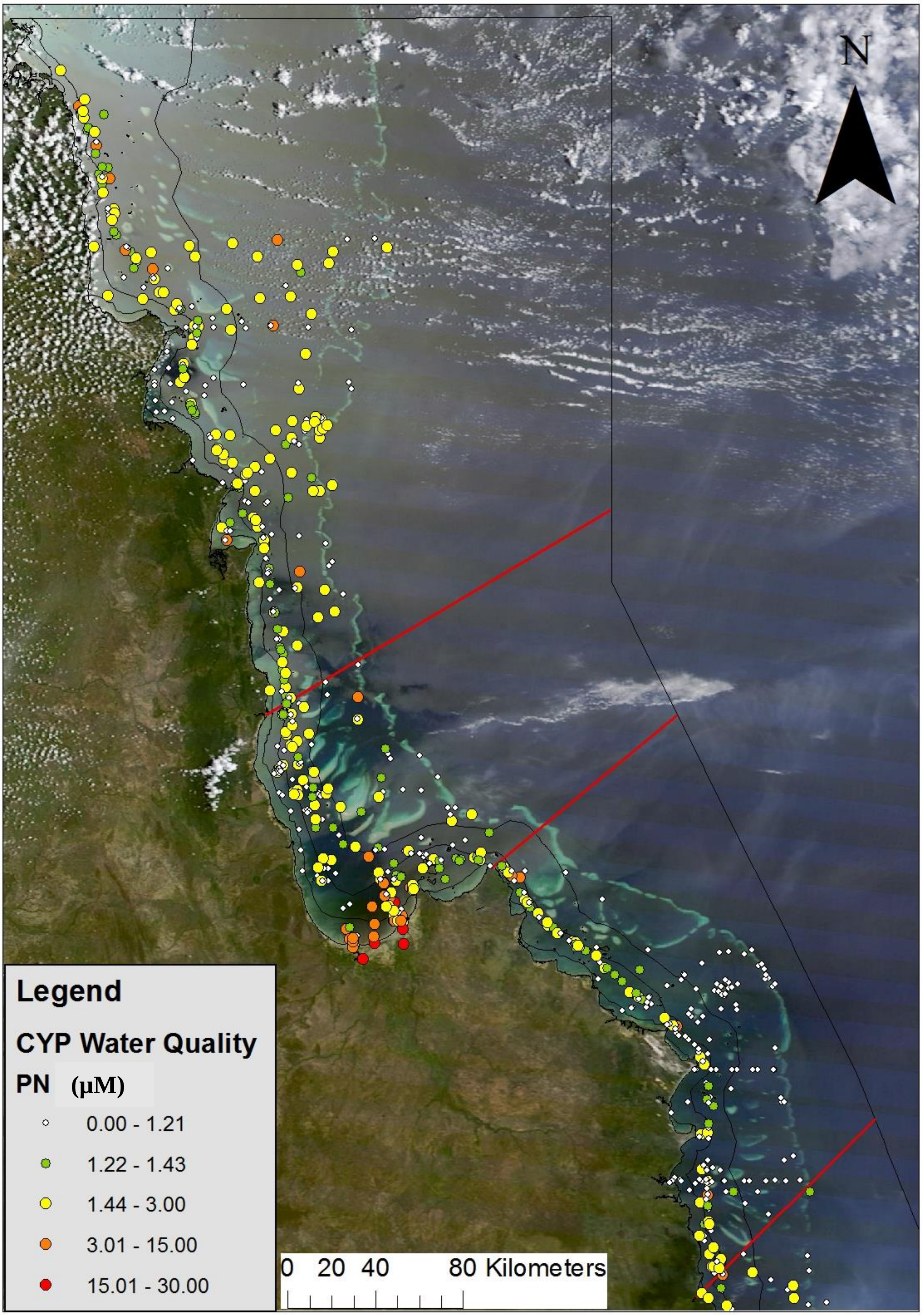

Figure 9: Particulate Nitrogen (PN) Concentration Distribution for CYP Region of the GBR (data from AIMS Long Term Water Quality Monitoring Programme, CSIRO eReefs program, and Reef Trust MMP (Howley & Devlin) Flood Plume Monitoring at PCB)

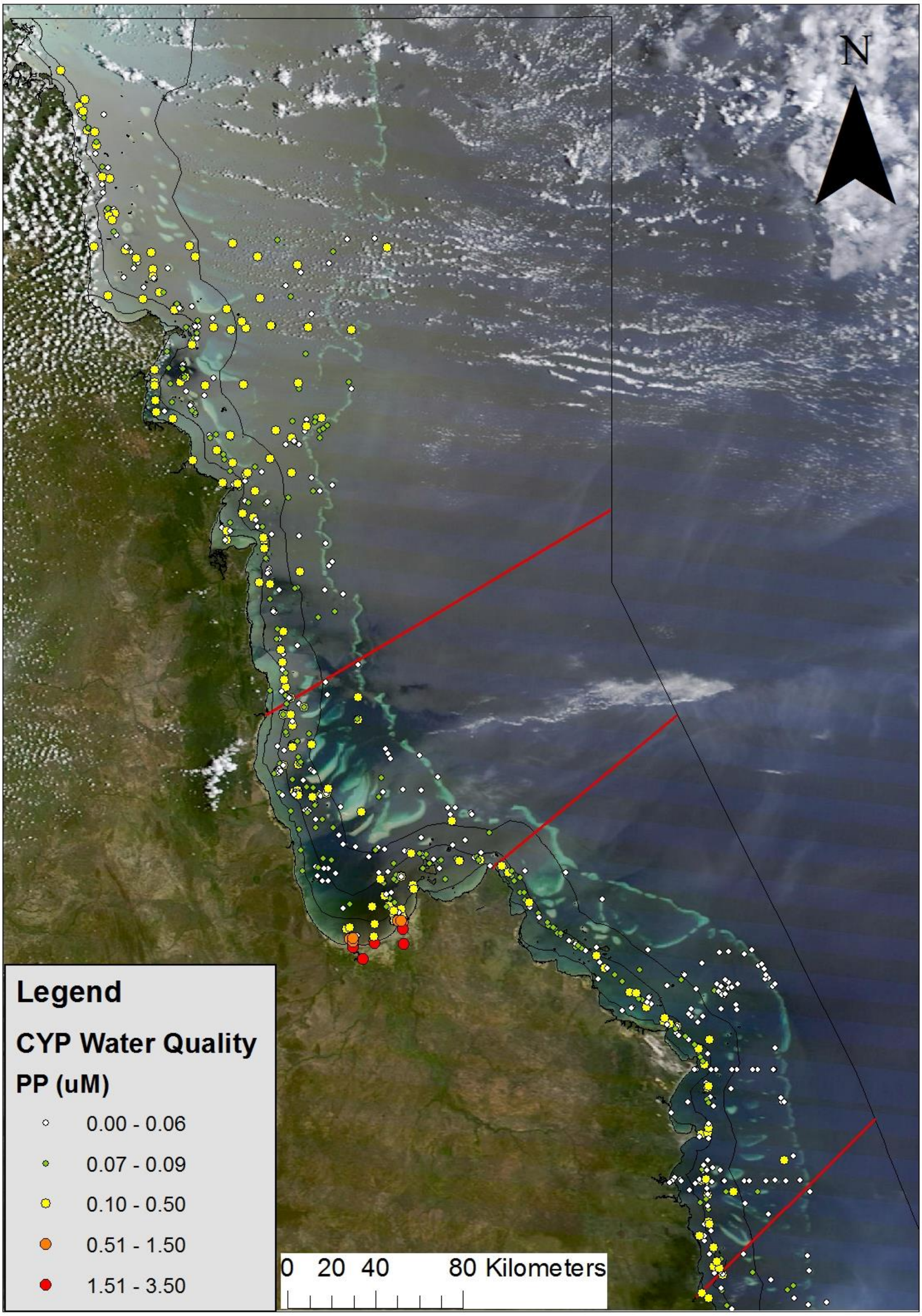

Figure 10: Particulate Phosphorus (PP) Concentration Distribution for CYP Region of the GBR (data from AIMS Long Term Water Quality Monitoring Programme, CSIRO eReefs program, and Reef Trust MMP (Howley & Devlin) Flood Plume Monitoring at PCB)

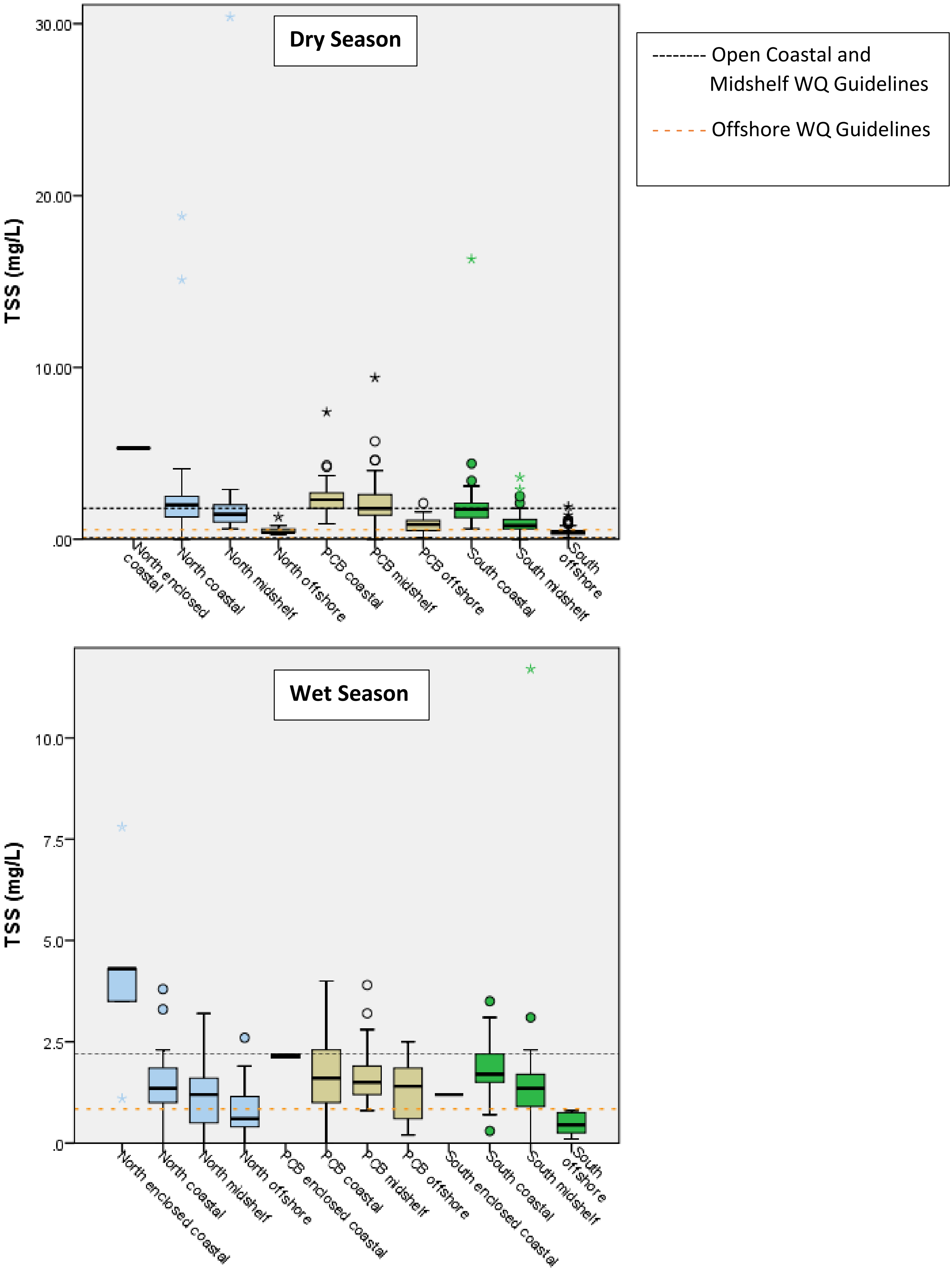

Figure 11: Dry Season and Wet Season TSS concentration box plots for the North, Central (PCB) and South Regions and the enclosed coastal, (open) coastal, midshelf and offshore zones, compared with the GBR Water Quality Guidelines (2010) for wet and dry seasons.

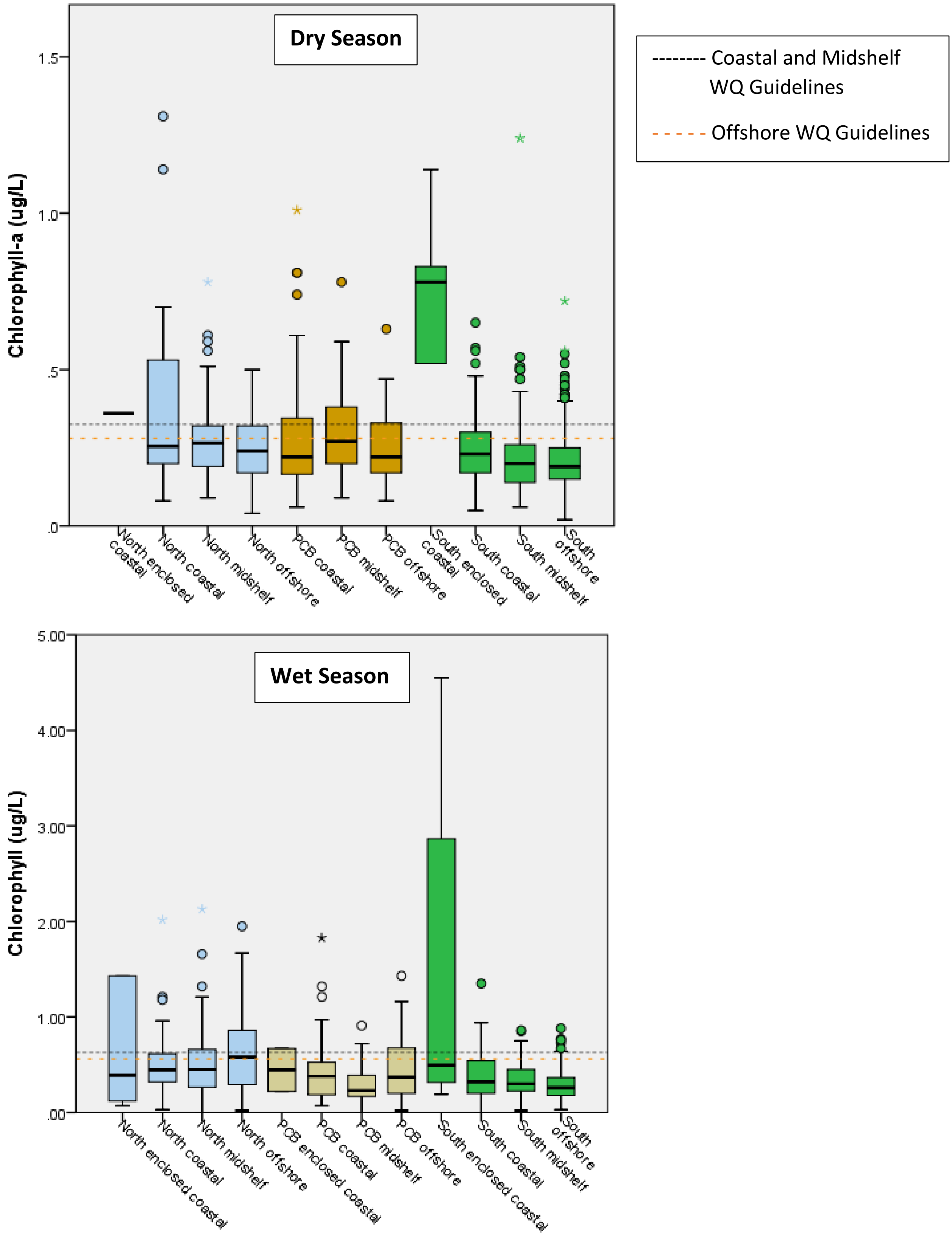

Figure 12: Dry Season and Wet Season Chlorophyll-a concentration box plots for the North, Central (PCB) and South Regions and the enclosed coastal, (open) coastal, midshelf and offshore zones, compared with the GBR Water Quality Guidelines (2010) for wet and dry seasons.

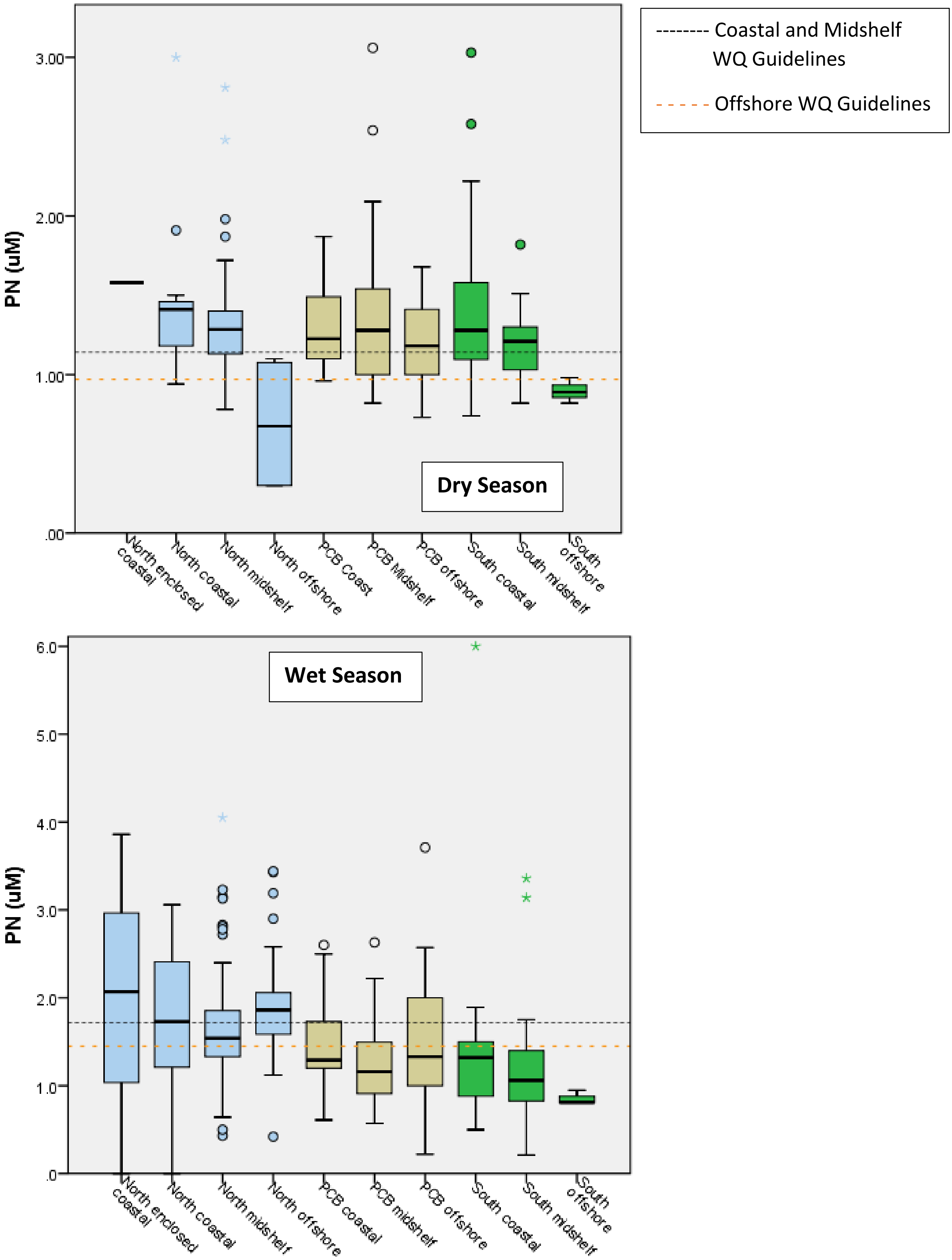

Figure 13: Dry Season and Wet Season PN concentration box plots for the North, Central (PCB) and South Regions and the enclosed coastal, (open) coastal, midshelf and offshore zones, compared with the GBR Water Quality Guidelines (2010) for wet and dry seasons.

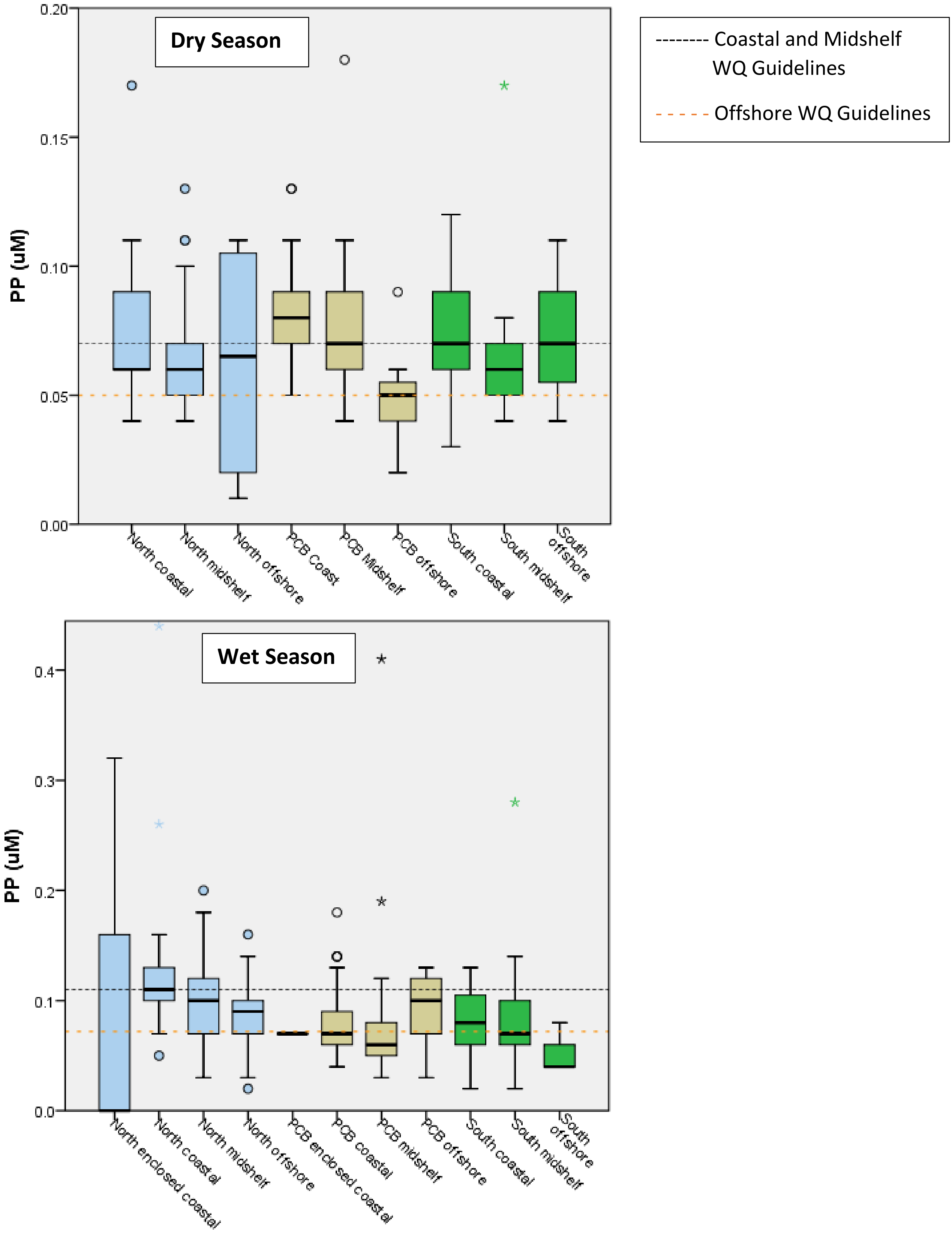

Figure 14: Dry Season and Wet Season PP concentration box plots for the North, Central (PCB) and South Regions and the enclosed coastal, (open) coastal, midshelf and offshore zones, compared with the GBR Water Quality Guidelines (2010) for wet and dry seasons.

Appendix 2: Tables

Table 1: Comparison of Mean Concentrations (±stdev) of Water Quality Parameters from the Normanby, Herbert, Tully, Burdekin, Fitzroy And Burnett River Flood Plumes

River	salinity	TSS_mg_l	TN_uM	NH4_uM	NOX_uM	PN_uM	DON_uM	TP_uM	DIP_uM	DOP_uM	PP_uM	Chl_ug_l
Normanby	18.0 ±11.4	21.3 ± 30.3	23.33 ± 10.19	1.26 ± 1.30	2.16 ±1.50	6.45 ± 7.01	13.64 ±6.28	0.85 ± 0.70	0.19 ± 0.11	0.43 ± 0.60	0.21 ± 0.14	1.5 ± 1.8
Burdekin[1]	5.9 ±12.2	28.9 ± 70.8	14.69 ± 14.11	1.47 ± 1.96	2.44 ± 3.52	2.87 ± 5.01	7.19 ± 6.83	0.63 ± 1.20	0.31 ± 0.35	0.17 ± 0.17	0.40 ± 1.01	0.7 ± 1.2
Burnett[1]	35.8 ± 2.4	5.1 ± 4.2	20.92 ± 12.76	1.89 ± 0.55	0.74 ± 0.40	6.85 ± 10.23	11.44 ± 7.60	0.93 ± 0.24	0.43 ± 0.08	0.33 ± 0.17	0.18 ± 0.20	1.6 ± 1.7
Fitzroy[1]	9.8 ± 15.1	19.9 ± 37.5	22.80 ± 16.34	1.12 ± 0.93	2.21 ± 2.22	5.35 ± 6.77	14.10 ± 10.58	1.22 ± 0.99	0.79 ± 0.69	0.29 ± 0.30	0.40 ± 0.56	2.0 ± 3.7
Fitzroy[2]		24.7±38.8		3.2±2.2		5.1±5.6	0.8±0.7		0.3 ± 0.3	0.4 ± 0.5	15.2±10.5	2.1±3.6
Herbert[1]	21.4 ± 13.7	10.1 ± 14.5	10.40 ± 10.53	0.56 ± 0.77	1.60 ± 2.62	1.08 ± 2.83	5.97 ± 6.09	0.26 ± 0.26	0.16 ± 0.18	0.14 ± 0.25	0.07 ± 0.16	1.3 ± 1.4
Herbert[2]		10.7±25.1		3.0±6.3		3.1±3.3	0.2±0.2		0.2 ± 0.2	0.2 ± 0.2	7.4 ± 4.2	1.2±1.0
Tully[1]	15.4 ± 15.2	6.9 ± 11.3	9.51 ± 9.31	0.64 ± 0.66	1.44 ± 2.57	1.63 ± 2.58	4.51 ± 4.30	0.48 ± 0.42	0.23 ± 0.22	0.16 ± 0.19	0.12 ± 0.18	0.9 ± 0.9
Tully[2]		10.89±11.59		3.69±4.18		3.94±5.14	9.25 ± 7.85		0.41 ± 0.41			1.77±2.57
GBR Mean[2]		13.6±29.3		2.8±3.1		3.4±4.7	8.8±7.1		0.4 ± 0.4	0.2±0.2	0.3±0.6	1.3±1.8

1 M.Devlin, 2012, James Cook University, Flood plume monitoring in the Great Barrier Reef, 1994 - 2012. (https://eresearch.jcu.edu.au/tdh/data/f31cbf35-2c03-4c6f-a312-2f621b1fc5b5)

2 Devlin et al 2012b: MMP 2011/2012 Report, Mean Concentrations 2007 – 2011 Flood Plume Monitoring

Table 2: Mean Wet and Dry Season Suspended Sediment, Chlorophyll-a and Nutrient Concentrations from South, Central and North Eastern Cape York Peninsula Plus Combined Annual Mean Concentrations for all zones & seasons, compared against the GBR Marine Park Water Quality Guidelines

Region	Season [1]	Stat	SS (mg/L)	Chl-a (µg/L)	TN (µM)	NH4 (µM)	NOx (µM)	PN (µM)	DON (µM)	TP (µM)	DIP (µM)	PP (µM)	DOP (µM)	n[2]
North	Dry	Mean	1.3	0.26	6.74	0.205	0.026	1.30	11.14	0.26	1.499	0.07	0.065	113-173
	Wet	Mean	1.2	0.65	7.28	0.414	0.078	1.85	--	0.21	2.843	0.10	--	77-115
Central/ PCB[3]	Dry	Mean	2.2	0.31	8.33	0.329	0.080	1.34	9.57	0.43	3.904	0.07	0.048	108-190
	Wet	Mean	8.8	0.73	14.18	0.598	0.786	3.18	13.71	0.60	3.966	0.23	0.207	180-207
South	Dry	Mean	1.0	0.23	7.27	0.233	0.066	1.50	9.59	0.28	3.232	0.08	0.052	63-915
	Wet	Mean	1.9	0.34	7.21	0.281	0.126	1.15	6.64	0.27	3.364	0.08	0.048	69-476
Combined regions annual mean			3.1	0.34	9.77	0.386	0.231	2.01	12.46	0.40	3.445	0.13	0.171	
GBR guidelines[4]	Open Coastal		2.0	0.45				1.43				0.09		
	Mid-Shelf		2.0	0.45				1.43				0.09		
	Offshore		0.7	0.40				1.21				0.06		

1 Dry Season = May to November Wet Season = December to April

2 n = number of samples (lower number refers to DON & DOP, higher number to Chlorophyll-a)

3 Means include flood plume samples from PCB, which increase wet season mean concentrations. No plume samples have been collected from North or South sections.

4 Great Barrier Reef Marine Park Water Quality Guidelines (2010) based on mean annual concentrations. SS, PN, and PP guideline values are adjusted by -20% for dry season and +20% for wet season. Chlorophyll-a is considered to be 40% higher in summer (wet) and 30% lower in winter (dry). Adjusted values are presented in Tables 3 to 8

Table 3: Dry Season Water Quality for the North, Central (PCB) and South Open Coastal Zone

Region and Zone	Season	Stats	TSS (mg/L)	Chlor (µg/L)	TN (µM)	NH4 (µM)	NOX (µM)	PN (µM)	DON (µM)	TP (µM)	DIP (µM)	PP (µM)	DOP (µM)	Si (µM)
North Open Coastal	**DRY**	**n**	**19**	**31**	**18**	**24**	**24**	**18**	**24**	**17**	**24**	**18**	**21**	**19**
		20th %ile	1.3	0.20	5.25	0.047	0.015	1.15	2.97	0.18	0.010	0.05	0.09	2.83
		50th %ile	2.0	0.27	6.40	0.154	0.020	1.41	3.54	0.26	0.020	0.06	0.15	3.59
		80th %ile	3.1	0.54	8.11	1.085	0.041	1.49	5.46	0.32	0.100	0.09	0.19	6.17
		mean	3.6	0.37	6.80	0.582	0.037	1.43	4.37	0.26	0.051	0.07	0.14	4.45
PCB Open Coastal	**DRY**	**n**	**29**	**47**	**30**	**34**	**34**	**30**	**36**	**27**	**34**	**27**	**36**	**31**
		20th %ile	1.8	0.16	6.46	0.057	0.010	1.08	5.23	0.18	0.001	0.07	0.16	1.86
		50th %ile	2.3	0.22	7.99	0.150	0.020	1.23	7.08	0.36	0.041	0.08	0.28	3.91
		80th %ile	2.9	0.36	9.42	0.227	0.045	1.50	7.79	0.71	0.070	0.09	0.61	4.84
		mean	2.5	0.29	8.12	0.169	0.047	1.29	6.80	0.45	0.039	0.08	0.37	3.73
South Open Coastal	**DRY**	**n**	**48**	**110**	**36**	**64**	**61**	**36**	**61**	**39**	**64**	**39**	**55**	**51**
		20th %ile	1.1	0.16	5.38	0.039	0.015	1.06	3.36	0.11	0.010	0.06	0.01	1.55
		50th %ile	1.8	0.24	6.21	0.103	0.025	1.28	4.48	0.25	0.018	0.07	0.08	3.09
		80th %ile	2.2	0.34	7.71	0.369	0.040	1.67	5.47	0.33	0.070	0.09	0.17	4.85
		mean	2.1	0.27	6.54	0.195	0.037	1.42	4.53	0.23	0.037	0.07	0.10	3.31
GBR Guideline Open Coastal	**DRY**		**1.8**	**0.33**				**1.14**				**0.07**		

Table 4: Wet Season Water Quality for the North, Central (PCB) and South Open Coastal Zone

Region and Zone	Season	Stats	TSS (mg/L)	Chlor (µg/L)	TN (µM)	NH4 (µM)	NOX (µM)	PN (µM)	DON (µM)	TP (µM)	DIP (µM)	PP (µM)	DOP (µM)	Si (µM)
North Open Coastal	**WET**	**n**	**38**	**42**	**16**	**36**	**37**	**17**	**33**	**24**	**38**	**25**	**33**	**29**
		20th %ile	1.0	0.32	6.07	0.080	0.030	1.13	4.26	0.16	0.00	0.09	0.02	1.05
		50th %ile	1.4	0.45	6.33	0.216	0.040	1.73	4.99	0.20	0.02	0.11	0.06	2.59
		80th %ile	2.0	0.63	9.75	0.643	0.096	2.67	6.81	0.27	0.04	0.13	0.19	6.80
		mean	1.5	0.54	8.32	0.344	0.135	1.75	5.62	0.23	0.03	0.13	0.09	5.89
PCB Open Coastal	**WET**	**n**	**43**	**49**	**33**	**45**	**37**	**33**	**36**	**41**	**45**	**41**	**45**	**45**
		20th %ile	0.9	0.17	6.25	0.022	0.019	1.16	4.06	0.26	0.001	0.06	0.16	2.49
		50th %ile	1.6	0.38	10.09	0.140	0.038	1.29	6.92	0.49	0.030	0.07	0.37	4.72
		80th %ile	2.4	0.68	12.52	0.347	0.152	1.92	10.02	0.87	0.053	0.09	0.78	7.67
		mean	1.7	0.45	10.49	0.242	0.091	1.47	8.03	0.75	0.030	0.08	0.62	5.56
South Open Coastal	**WET**	**n**	**38**	**109**	**39**	**69**	**69**	**38**	**43**	**37**	**68**	**36**	**35**	**67**
		20th %ile	1.2	0.19	5.27	0.023	0.020	0.87	3.91	0.08	0.001	0.04	0.03	1.09
		50th %ile	1.7	0.33	6.50	0.360	0.030	1.32	4.98	0.23	0.011	0.08	0.10	3.02
		80th %ile	2.3	0.57	9.26	0.605	0.079	1.52	7.43	0.28	0.038	0.11	0.16	6.30
		mean	1.8	0.46	7.53	0.344	0.094	1.34	5.80	0.20	0.030	0.08	0.10	4.95
GBR Guideline Open Coastal	**WET**		**2.2**	**0.63**				**1.72**				**0.11**		

Table 5: Dry Season Water Quality for the North, Central (PCB) and South Mid-Shelf Zone

Region and Zone	Season	Stats	TSS (mg/L)	Chlor (µg/L)	TN (µM)	NH4 (µM)	NOX (µM)	PN (µM)	DON (µM)	TP (µM)	DIP (µM)	PP (µM)	DOP (µM)	Si (µM)
North Mid-shelf	**DRY**	**n**	**68**	**98**	**58**	**80**	**78**	**58**	**76**	**59**	**80**	**58**	**75**	**62**
		20th %ile	0.9	0.19	4.88	0.040	0.015	1.05	3.09	0.12	0.01	0.05	0.01	1.42
		50th %ile	1.5	0.27	6.71	0.133	0.020	1.29	4.25	0.24	0.02	0.06	0.10	2.17
		80th %ile	2.1	0.35	8.57	0.866	0.030	1.45	5.69	0.33	0.05	0.07	0.21	3.62
		mean	1.9	0.28	6.96	0.600	0.025	1.31	4.51	0.26	0.03	0.07	0.13	2.69
PCB Mid-shelf	**DRY**	**n**	**38**	**54**	**38**	**42**	**40**	**38**	**39**	**38**	**42**	**38**	**44**	**38**
		20th %ile	1.3	0.17	5.68	0.056	0.005	0.97	3.91	0.24	0.010	0.06	0.08	2.14
		50th %ile	1.8	0.27	7.19	0.121	0.015	1.28	5.24	0.36	0.031	0.07	0.23	2.61
		80th %ile	3.2	0.38	9.33	0.215	0.037	1.61	7.24	0.71	0.071	0.09	0.60	4.40
		mean	2.3	0.41	7.76	0.242	0.026	1.37	5.87	0.46	0.045	0.08	0.34	3.21
South Mid-shelf	**DRY**	**n**	**51**	**139**	**13**	**62**	**60**	**13**	**59**	**19**	**59**	**18**	**56**	**54**
		20th %ile	0.60	0.14	4.02	0.030	0.013	1.02	2.79	0.10	0.005	0.05	0.02	1.41
		50th %ile	0.80	0.20	6.13	0.127	0.020	1.21	4.17	0.21	0.010	0.06	0.08	2.52
		80th %ile	1.30	0.27	6.84	0.334	0.037	1.33	5.25	0.32	0.031	0.07	0.17	7.25
		mean	0.97	0.22	5.71	0.191	0.047	1.21	4.14	0.22	0.023	0.07	0.09	4.11
GBR Guideline Mid-shelf	**DRY**		**1.8**	**0.33**				**1.14**				**0.07**		

Table 6: Wet Season Water Quality for the North, Central (PCB) and South Mid-shelf Zone

Region and Zone	Season	Stats	TSS (mg/L)	Chlor (µg/L)	TN (µM)	NH4 (µM)	NOX (µM)	PN (µM)	DON (µM)	TP (µM)	DIP (µM)	PP (µM)	DOP (µM)	Si (µM)
North Mid-Shelf	**WET**	**n**	**91**	**91**	**63**	**87**	**87**	**63**	**85**	**70**	**87**	**68**	**85**	**80**
		20th %ile	0.4	0.23	5.48	0.061	0.020	1.24	3.93	0.14	0.00	0.07	0.03	1.29
		50th %ile	1.2	0.45	7.54	0.470	0.040	1.54	5.19	0.23	0.02	0.10	0.11	2.25
		80th %ile	1.7	0.75	9.88	0.713	0.101	2.15	6.95	0.29	0.06	0.13	0.16	4.39
		mean	1.1	0.51	7.87	0.476	0.139	1.69	5.54	0.23	0.04	0.10	0.10	3.47
PCB Mid-Shelf	**WET**	**n**	**62**	**77**	**60**	**72**	**68**	**60**	**67**	**63**	**72**	**63**	**71**	**71**
		20th %ile	1.1	0.15	7.47	0.035	0.017	0.89	5.72	0.23	0.003	0.04	0.14	1.85
		50th %ile	1.5	0.23	9.00	0.133	0.045	1.16	7.52	0.39	0.030	0.06	0.27	2.92
		80th %ile	2.0	0.44	11.45	0.309	0.161	1.81	9.93	0.56	0.059	0.09	0.44	5.20
		mean	1.6	0.29	9.65	0.262	0.102	1.27	8.02	0.43	0.033	0.07	0.32	3.99
South Mid-Shelf	**WET**	**n**	**20**	**120**	**30**	**57**	**55**	**27**	**32**	**30**	**55**	**27**	**31**	**53**
		20th %ile	0.8	0.21	5.60	0.058	0.020	0.77	3.86	0.16	0.005	0.05	0.03	1.42
		50th %ile	1.4	0.30	7.06	0.165	0.045	1.06	5.18	0.26	0.015	0.07	0.10	2.86
		80th %ile	1.9	0.46	10.03	0.571	0.352	1.50	7.81	0.33	0.097	0.12	0.15	6.97
		mean	1.8	0.34	7.56	0.307	0.201	1.20	5.80	0.25	0.042	0.08	0.10	4.99
GBR Guideline Mid-shelf	**WET**		**2.2**	**0.63**				**1.72**				**0.11**		

Table 7: Dry Season Water Quality for the North, Central (PCB) and South Offshore Zone

Region and Zone	Season	Stats	TSS (mg/L)	Chlor (µg/L)	TN (µM)	NH4 (µM)	NOX (µM)	PN (µM)	DON (µM)	TP (µM)	DIP (µM)	PP (µM)	DOP (µM)	Si (µM)
North Offshore	**DRY**	**n**	**14**	**33**	**0**	**18**	**18**	**4**	**14**	**0**	**18**	**4**	**14**	**14**
		20th %ile	0.4	0.16		0.027	0.017	0.30	3.05		0.01	0.02	0.01	0.25
		50th %ile	0.4	0.24		0.045	0.043	0.68	3.92		0.02	0.07	0.04	1.06
		80th %ile	0.6	0.33		0.060	0.105	1.07	4.40		0.03	0.10	0.13	2.11
		mean	0.5	0.25		0.080	0.086	0.69	4.06		0.02	0.06	0.06	1.65
PCB Offshore	**DRY**	**n**	**16**	**27**	**12**	**14**	**14**	**7**	**14**	**7**	**14**	**7**	**14**	**11**
		20th %ile	0.4	0.16	0.00	0.025	0.012	0.90	2.76	0.12	0.005	0.04	0.02	0.13
		50th %ile	0.9	0.22	4.85	0.065	0.020	1.18	4.15	0.20	0.010	0.05	0.09	1.07
		80th %ile	1.1	0.36	7.12	0.321	0.050	1.52	6.01	0.34	0.041	0.06	0.17	2.40
		mean	0.9	0.25	3.93	0.496	0.070	1.20	4.42	0.23	0.025	0.05	0.10	2.12
South Offshore	**DRY**	**n**	**104**	**538**	**3**	**116**	**114**	**3**	**108**	**3**	**116**	**3**	**109**	**105**
		20th %ile	0.3	0.14	8.16	0.022	0.013	0.85	3.15	0.59	0.005	0.05	0.02	0.94
		50th %ile	0.4	0.19	9.16	0.084	0.028	0.89	4.22	1.08	0.010	0.07	0.09	1.72
		80th %ile	0.6	0.27	9.54	0.260	0.050	0.94	5.43	1.32	0.015	0.09	0.14	3.91
		mean	0.5	0.21	8.82	0.178	0.065	0.90	4.27	0.94	0.018	0.07	0.10	2.67
GBR Guideline Offshore	**DRY**		**0.6**	**0.28**				**0.97**				**0.05**		

Table 8: Wet Season Water Quality for the North, Central (PCB) and South Offshore Zone

Region and Zone	Season	Stats	TSS (mg/L)	Chlor (µg/L)	TN (µM)	NH4 (µM)	NOX (µM)	PN (µM)	DON (µM)	TP (µM)	DIP (µM)	PP (µM)	DOP (µM)	Si (µM)
North Offshore	**WET**	**n**	**52**	**57**	**39**	**53**	**53**	**39**	**53**	**45**	**46**	**46**	**39**	**53**
		20th %ile	0.4	0.26	5.68	0.174	0.020	1.52	3.60	0.15	0.01	0.07	0.02	0.17
		50th %ile	0.6	0.58	7.13	0.430	0.043	1.86	4.99	0.18	0.05	0.09	0.13	0.79
		80th %ile	1.2	0.89	8.59	0.720	0.153	2.16	6.03	0.28	0.07	0.10	0.19	2.01
		mean	0.8	0.63	7.51	0.628	0.193	1.90	4.94	0.21	0.05	0.09	0.11	1.26
PCB Offshore	**WET**	**n**	**16**	**24**	**13**	**17**	**16**	**13**	**16**	**13**	**17**	**13**	**17**	**17**
		20th %ile	0.6	0.18	4.62	0.370	0.037	0.70	2.71	0.22	0.001	0.07	0.07	0.59
		50th %ile	1.4	0.37	5.86	0.565	0.074	1.33	4.89	0.26	0.010	0.10	0.15	1.66
		80th %ile	1.9	0.74	13.64	0.615	0.255	2.25	5.97	0.29	0.066	0.13	0.19	1.97
		mean	1.3	0.47	8.24	0.479	0.282	1.49	5.13	0.28	0.035	0.09	0.14	1.67
South Offshore	**WET**	**n**	**8**	**371**	**3**	**63**	**63**	**3**	**12**	**3**	**63**	**3**	**13**	**63**
		20th %ile	0.2	0.17	7.13	0.030	0.020	0.81	4.23	0.80	0.010	0.04	0.12	0.90
		50th %ile	0.5	0.26	7.60	0.190	0.045	0.81	5.65	1.62	0.017	0.04	0.17	1.30
		80th %ile	0.8	0.40	8.72	0.518	0.097	0.89	7.40	2.02	0.034	0.06	0.27	1.87
		mean	0.5	0.29	7.96	0.286	0.066	0.86	5.70	1.39	0.025	0.05	0.42	2.08
GBR Guideline Offshore	**WET**		**0.84**	**0.56**				**1.45**				**0.07**		

Appendix 3: Cape York Peninsula Combined Marine Water Quality Dataset

- AIMS Long Term Chlorophyll-a Monitoring Programme (1997 – 2008)
    - Chlorophyll-a
- CSIRO eReefs Program (dry season 2012)
    - TSS, total and dissolved nutrients (N & P), chlorophyll-a
- CSIRO eReefs program & GBRMPA Marine Monitoring Program (flood event 2013)
    - TSS, total and dissolved nutrients (N & P), chlorophyll-a
- Howley & Devlin (in prep), PCB Flood Plume monitoring 2012-2014 (undertaken as part of the GBR Marine Monitoring Programme & Griffith University PhD)
    - SSC/TSS, total and dissolved nutrients (N & P), chlorophyll-a, phytoplankton, silica
- AIMS Long-Term Water Quality Monitoring Programme: 1991-2005
    - TSS, total and dissolved nutrients (N & P), chlorophyll-a, silica