Port of Rockhampton Water Quality Monitoring Program

2019 Annual Report

Gladstone Ports Corporation (GPC)

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Acronyms

ALS	Australian Laboratory Services
ANOVA	Analysis of Variance
APHA	American Public Health Association
AWQG	Australian Water Quality Guidelines
BOM	Bureau of Meteorology
DEHP	Department of Environment and Heritage Protection (now DES)
DES	Department of Environment and Science
DOC	Dissolved organic carbon
DSITIA	Department of Science, Information Technology, Innovation and the Arts, Queensland
FB	Field Blank
FRP	Filterable Reactive Phosphorus
GPC	Gladstone Ports Corporation Ltd
LOR	Limit of Reporting
LSD	Least Significant Difference
LTMDMP	Long Term Maintenance Dredging Management Plan
NMI	National Measurement Institute
PAR	Photosynthetically Active Radiation
PCIMP	Port Curtis Integrated Monitoring Program
PCO	Principal Coordinates Ordination
PoG	Port of Gladstone
PoR	Port of Rockhampton
QA/QC	Quality Assurance/Quality Control
QWQG	Queensland Water Quality Guidelines
SE	Standard error
TOC	Total organic carbon
TSS	Total Suspended Solids
VE	Vision Environment
WQG	Water Quality Guidelines
WQO	Water Quality Objectives

1 INTRODUCTION

Gladstone Ports Corporation Ltd (GPC) is responsible for maintenance dredging at the Port of Rockhampton (PoR). Dredging is undertaken infrequently, with the most recent dredging campaign conducted in 2011. The estimated mean future dredging volume per campaign for PoR is 30,000 m^3 with a predicted frequency of five years. Under the Long Term Maintenance Dredging Management Plan (LMDMP) for the PoR, GPC undertake ambient monitoring of key environmental parameters which are used to inform impact assessments. During maintenance dredging, real time and impact monitoring is also proposed to be undertaken.

Ambient water quality monitoring at PoR sites (Figure 1) has been undertaken since 2014 (Vision Environment, 2016, 2017, 2018, 2019a), and will be used to establish a valid ambient dataset for comparison during future dredging campaigns. Quarterly water quality monitoring at PoR coincides with Port Curtis Integrated Monitoring Program (PCIMP) monitoring at 54 sites in Gladstone harbour (Figure 2), with methodologies aligning to provide easy comparisons of both current and historical data.

The PoR sites are located in a shallow (~ 4 to 10 m) mangrove dominated upper estuary, which is influenced mainly by tidal flows due to large tidal runs (~ 0.4 m/s). The Department of Science, Information Technology, Innovation and the Arts, Queensland (DSITIA, 2014) classified the lower estuarine areas of the Fitzroy River as moderately disturbed.

This report provides details of the methodology and results of the monitoring undertaken by Vision Environment (VE) for this project during 2019, in addition to providing a comparison with 2019 PCIMP data from adjacent and reference zones (Figure 3).

2 METHODOLOGY

2.1 Sites

During 2019, water quality monitoring for PoR was undertaken by VE on four occasions (Vision Environment, 2019b, c, d, e) aligning with PCIMP monitoring in Gladstone (March, June, August and November 2019).

PCIMP zones adjacent to and/or similar in ambient conditions to the PoR include the Narrows (six sites NW10 to NW60) and Western Basin (six sites WB10 to WB60, Figure 3). Reference sites for comparison include the Colosseum Inlet (four sites RCI0 to RCI40) and Rodds Bay (three sites RB10 to RB30, Figure 3).

2.2 Physicochemical Depth Profiling

During each monitoring occasion, depth-profiling of physicochemical parameters (temperature, conductivity, pH, turbidity and dissolved oxygen) was undertaken at 0.5 to 1 m depth intervals using a multiparameter water quality meter (YSI ProDSS), which was calibrated and tested prior to sampling. Triplicate sub-surface readings (0.5 m depth) were recorded at each site.

Light penetration through the water column was also examined at each site concurrently with physicochemical parameters by measuring down-welling photosynthetically active radiation (PAR: 400 – 700 nm) at 0.5 m intervals using a LI-COR LI192SA Underwater Quantum Sensor in a lowering frame and LI-1500 Quantum Radiometer Photometer until light was <10 µmol/s/m^2 or at least five readings have been recorded or the benthos has been reached.

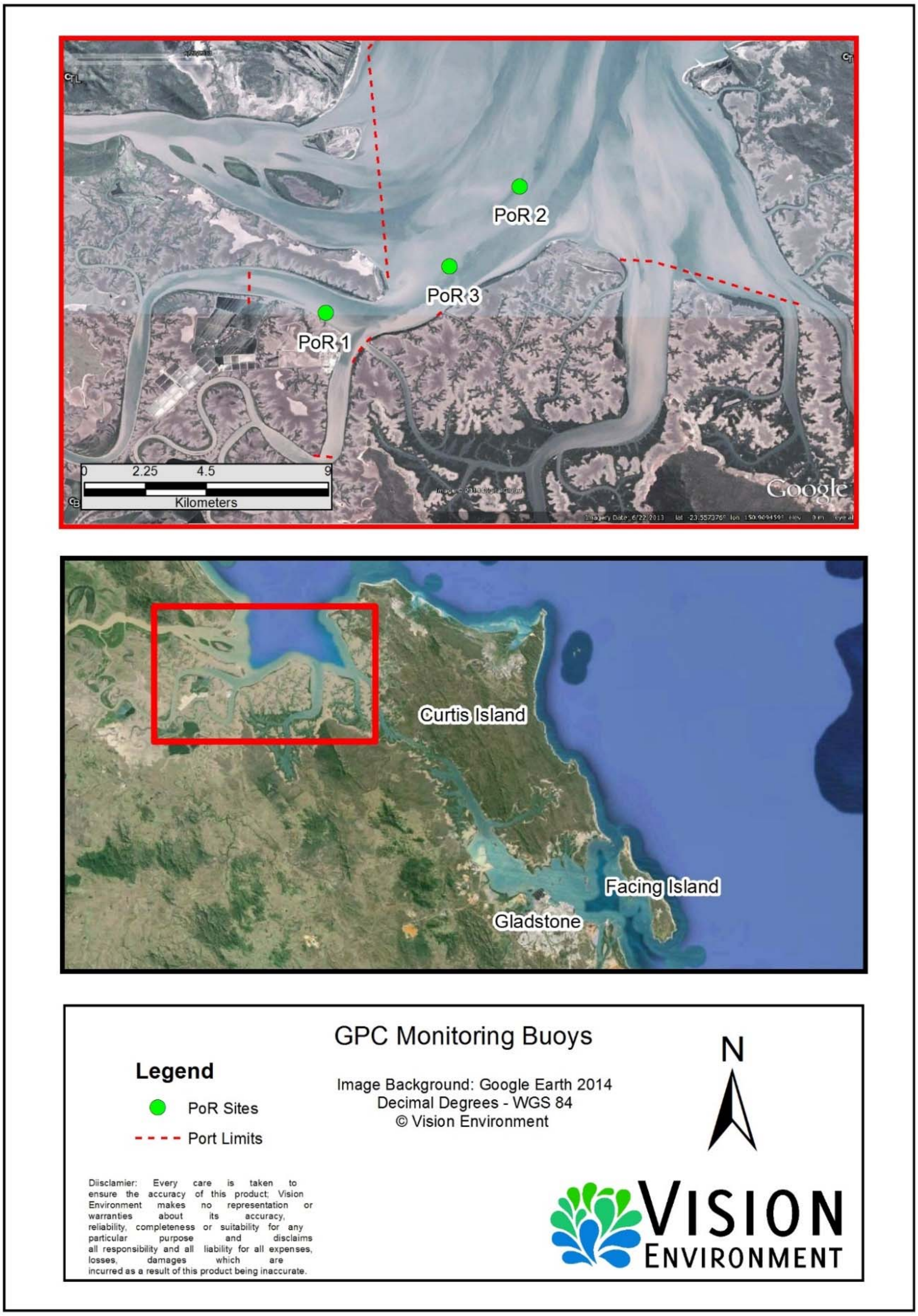

Figure 1 Location of the three monitoring sites for GPC PoR Water Quality monitoring.

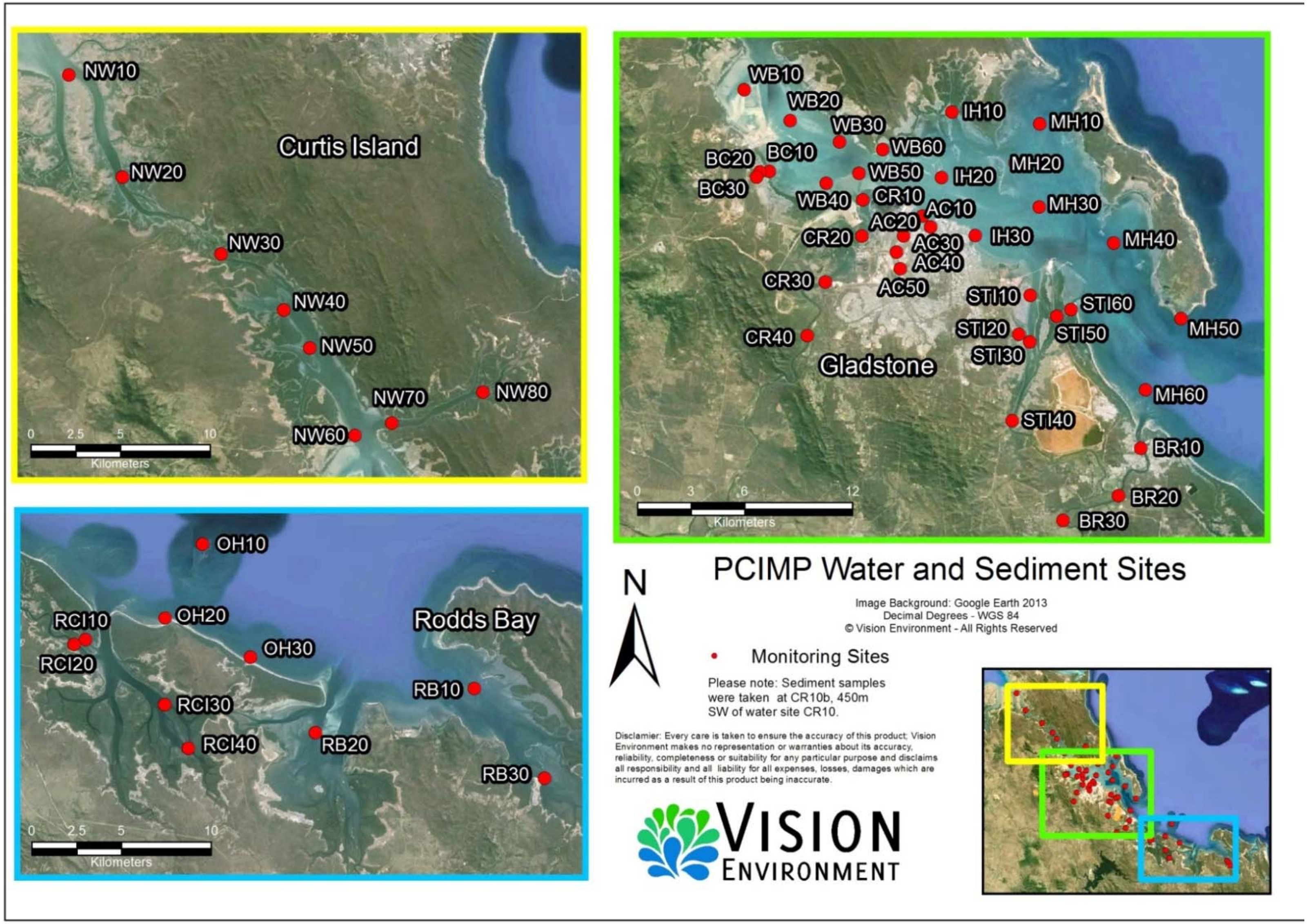

Figure 2 Location of PCIMP water quality monitoring sites in 2019.

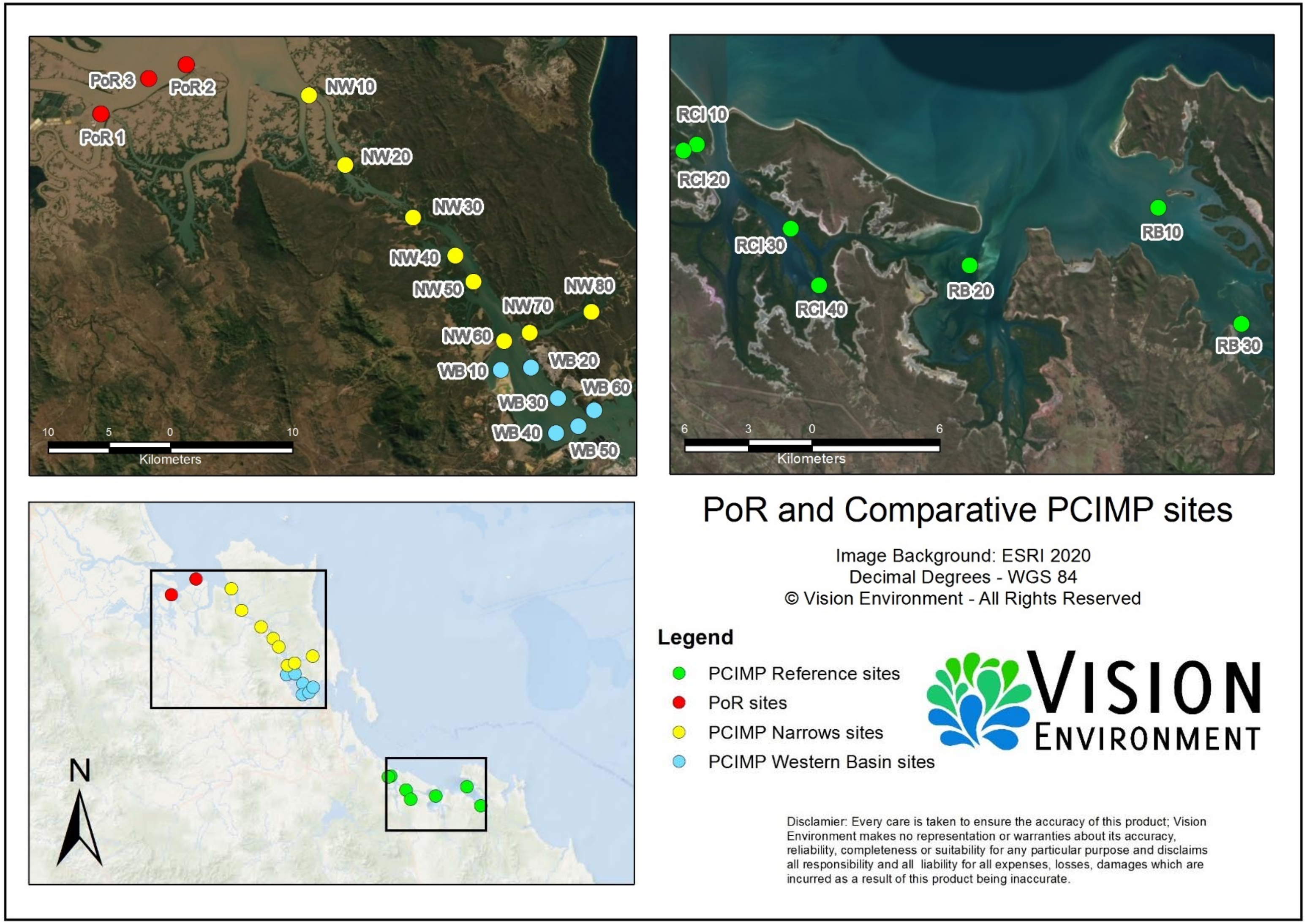

Figure 3 Location of PoR sites in comparison with sites in adjacent PCIMP zones (Narrows and Western Basin) and PCIMP reference sites (Colosseum Inlet and Rodds Bay).

In order to calculate light attenuation, the natural logarithm of the recorded PAR was plotted against depth, and the coefficient gained from the linear regression analysis of this relationship. The vertical light attenuation co-efficient (K_d) is another measure of water clarity, with lower co-efficient values indicating clearer water (less attenuation of light with depth).

2.3 Water Sample Collection

Water sampling was undertaken in accordance with standard protocols derived from worldwide authorities including:

- Australian and New Zealand Standards for water quality sampling (AS/NZS, 1998a, b, c, d);
- American Public Health Association Standard Methods for the Examination of Water and Wastewater (APHA, 2005);
- Australian and New Zealand Water Quality Guidelines (ANZECC, 1992, 1998, ANZECC/ARMCANZ, 2000, ANZG, 2018);
- Queensland Water Quality Guidelines (DERM, 2009); and
- Department of Environment and Science Monitoring and Sampling Manual (DES, 2018)

Samples were collected at the sub-surface (0.5 m depth) using pre-acid washed Nalgene bottles (triple rinsed in Milli-Q and site water) in a Perspex pole sampler. Powder free gloves were worn to avoid contamination.

Six separate laboratory provided sample bottles were required for each site, with different treatment and preservation requirements for each bottle (Table 1). The preservation requirements for each are detailed in Table 1 below, as are the specific analytical laboratories for each sample. All bottles were placed on ice on the research vessel, prior to being stored as per Table 1 at the VE laboratory.

Table 1 Summary of sample containers, treatment and preservation requirements.

Bottle	Parameters	Field Treatment	Preservation	Analytical Laboratory
100 ml Plastic	Total metals	-	Acidified with HNO_3 to pH 2, stored at 4ºC.	NMI
100 ml Plastic	Dissolved metals	Filtered	Acidified with HNO_3 to pH 2, stored at 4ºC.	
500 ml Plastic	TSS	-	Stored at 4ºC	
250 ml Plastic	Total nutrients	-	Frozen prior to transport to laboratory.	Queensland Health
125 ml Plastic	Dissolved nutrients	Filtered	Frozen prior to transport to laboratory.	
1 L Plastic	Chlorophyll *a*	-	Filtered at VE lab, filter paper frozen prior transport to laboratory.	ALS

For samples which did not require filtration (total suspended solids [TSS]), total metals, total nutrients and chlorophyll *a*), water samples were decanted from Nalgene bottles directly into the laboratory provided sample bottles. Samples that required filtration (dissolved metals and nutrients) were filtered through a 0.45 µm sterile cellulose acetate membrane syringe filter (Minisart 16555K) into their respective sample bottles provided by the analysing laboratory. Each syringe and filter were pre-rinsed in site water prior to filling sample bottles, with filters were pre-packaged from the supplier. Cellulose acetate membrane pre-filters with a pore size of 1.2 µm (Minisart 17593k) were also attached to syringes at turbid sites, to assist in filtration.

Field blanks (FB) have been collected regularly during the surveys. FB are created by taking a complete set of sample bottles into the field each day, along with a supply of Milli-Q water in acid washed Nalgene bottles. The Milli-Q water is treated as if it was a field collected sample and placed into the laboratory sample bottles by directly decanting (or filtering as required) for each parameter, thus undergoing identical field processes as the field samples. If contamination is present in these samples it indicates that contamination has been sourced from field processes, the Milli-Q water or sample bottles.

In order to extend holding periods for chlorophyll *a*, samples were pre-processed at VE (within 24 h of collection) through 0.45 µm glass fiber filters, using a manifold and vacuum pump, with the volume of water passed through the filter recorded (500 ml). Filter papers were folded, placed in airtight plastic bags then frozen to extend the holding period of these samples to 28 days, in accordance with APHA method 12000H (APHA, 2005). All chlorophyll *a* samples were analysed at ALS.

2.4 Water Quality Objectives

Historically, monitoring data from the Queensland Central Coast has been compared to Queensland Water Quality Guidelines (QWQG) and Australian Water Quality Guidelines (AWQG) (ANZG, 2018, DERM, 2009). However, DSITIA and Department of Environment and Heritage Protection (DEHP, now Department of Environment and Science) also developed local water quality guidelines (WQG)/water quality objectives (WQO) for the Capricorn-Curtis Coast Region (DEHP, 2014, DSITIA, 2014). Where there are no local WQO provided by DSITIA, the QWQG and AWQG should be used as a default (DSITIA, 2014).

For PoR, no local WQO have been derived for the Fitzroy River mid and lower estuarine waters (including the delta) due to insufficient data having been collected (DEHP, 2014, DSITIA, 2014). Therefore, QWQG are used as a default. The appropriate QWQG for comparison to these sites are those derived for the Central Coast Queensland Region – 'Mid-Estuarine and Tidal Canals, Constructed Estuaries, Marinas and Boat Harbours'. DSITIA (2014) classify the lower estuarine areas of the Fitzroy River as moderately disturbed.

The comparative PCIMP zones are named the same as their WQO zone, and thus varying WQO apply to each. DEHP classified the Narrows, Colosseum Inlet and Rodds Bay as slightly disturbed, with the Western Basin classified as moderately disturbed (DEHP, 2014). WQOs have been derived for both base flow and event flow in Port Curtis and the Narrows. The WQOs that the results have been compared against in this report apply to base flow conditions only, as no event monitoring (when base flow conditions were exceeded at Castlehope gauging station in the Calliope River Basin) was undertaken during 2019.

At all sites, metal concentrations were compared to the AWQG (ANZG, 2018). For metals, trigger levels for varying levels of ecosystem protection (99%, 95%, 90% and 80% of species) have been derived. These guidelines refer to dissolved metals, which are those which pass through a 0.45 µm membrane filter (APHA, 2005), as these are considered to be the potential bioavailable fraction (ANZECC/ARMCANZ, 2000 (ANZG, 2018)). Total metals are the concentration of metals determined in an unfiltered sample (those bound to sediments or colloidal particles). DSITIA (2014) state that water quality zones which are designated as moderately disturbed (such as PoR and Western Basin) are proposed to meet the 95% AWQG trigger value, while zones classified as slightly disturbed (such as Narrows, Colosseum Inlet and Rodds Bay) are proposed to meet the 99% AWQG trigger value.

2.5 Data Analysis

Data for each site was collated for each survey, and means and standard errors calculated for each physicochemical, and water parameter for each site and zone during each survey. Results were tabulated and plotted.

Along with the relevant PCIMP data, two-way analyses of variance (ANOVA) were undertaken to determine whether there were any significant differences in parameters between zones (spatial variation) or across 2019 surveys (temporal variation). Data were tested for homogeneity of variance and normality. Significance levels were increased ($P < 0.01$, 99% confidence intervals) where data did not meet that criterion (O'Neill, 2000, Underwood, 1997). In order to determine where significant differences existed, Fisher's Least Significant Difference (LSD) *Post hoc* tests were used.

Multivariate analyses were undertaken for each component separately (physicochemistry, water nutrients and water metal(loid)s). Using Primer 6 (Clarke, 1993), data were normalised, averaged across 2019 for each survey/zone, and transformed into a similarity matrix using Euclidian distances. Principal Coordinates Ordination (PCO) was then used to determine dissimilarities (differences) among the surveys/zones, producing ordination plots. The larger the amount of variation in parameters between the zones/surveys, the greater the separation on the plot. The parameters driving the variation among the surveys/zones were overlaid as vectors on each plot. A Hierarchical Cluster Analysis was also performed on the similarity matrix data and was overlaid to indicate the level of similarity between surveys/zones.

3 RESULTS & DISCUSSION

3.1 Meteorological Conditions

Table 3 outlines the climatic conditions experienced during each water quality survey at PoR sites. Minimal rainfall (< 5 mm) at Rockhampton was recorded during all surveys, while wind conditions during sampling ranged between 24 to 43 km/h. Sampling was conducted at high tide during all surveys. The March and June 2019 surveys were carried out during spring tide periods, while the August and November surveys were carried out during neap tide periods.

Table 2 Summary of climatic conditions during the 2019 PoR surveys.
Rainfall includes amount recorded during the sampling day and one week prior at each site. Wind refers to the maximum wind gusts recorded during the sample day as recorded at the Rockhampton Aero Station 039083 (BOM, 2019). Tidal range measurements specified for Port Alma.

2019 Survey dates	Rainfall (mm)	Wind Gusts (km/h)	Tides
6 March	1.4	33	Spring tide with new moon on 7 March. Highest tidal range during sampling = 4.05 m
6 June	2.2	43	Spring tide after new moon on 3 June. Highest tidal range during sampling = 4.50 m
7 August	3.0	24	Neap tide with first quarter moon on 8 August. Highest tidal range during sampling = 3.33 m
19 November	0.2	31	Neap tide with last quarter moon on 20 November. Highest tidal range during sampling = 3.01 m

3.2 Physicochemical Parameters

Sub-surface (0.5 m depth) means for each physicochemical parameter across the four surveys are exhibited in Table 3, while depth-profiled plots are displayed in the Appendix (Figure 22). The results, in addition to concurrent PCIMP results at adjacent (Narrows and Western Basin) and Reference (Colosseum Inlet and Rodds Bay) zones, are presented in Figures 4 and 5 as well as Table 6 within the Appendix. Two-way ANOVA results table can be found in the Appendix (Table 9), while multivariate analysis results are presented in Figures 6 and 7. During each survey, physicochemical parameters were similar across the PoR sites (Table 3). While most physicochemical parameters were consistent within the water column, turbidity occasionally increased with water depth (see Figure 22 in Appendix). The sub-surface pH remained within the recommended QWQG range of 7.0 to 8.4 at all sites during all surveys. Dissolved oxygen concentrations also remained within the QWQG range (85 to 100 % saturation) during all surveys, apart from PoR2 in November 2019 (102 % saturation), indicating well-oxygenated waters.

In contrast, sub-surface turbidity exceeded the QWQG (8 NTU) at all PoR sites during each survey, except for PoR2 during November (7.2 NTU). On other occasions, turbidity ranged from 12 to 66 NTU. Lowest turbidity across the surveys was evident in November (7.2 to 17 NTU), during the neap-tide sampling. Higher tidal ranges associated with spring tides permit a higher level of mixing and resuspension of particles within the water column. When tidal ranges are lower, the turbidity levels tend to decrease accordingly. Light attenuation paralleled these results with higher water clarity (lower light attenuation) in November compared to the remaining surveys.

Comparison with PCIMP Monitoring Results

Physiochemical results from PoR were compared to the adjacent PCIMP monitoring zones of the Narrows and Western Basin, as well as the PCIMP Reference zones of Colosseum Inlet and Rodds Bay. Both the univariate and multivariate analyses indicated significant temporal and spatial variation in physicochemical parameters (Figures 4 to 7).

As expected, temperatures across all zones were significantly higher ($P < 0.05$) during the wet season months (March and November), with the PCO (Figure 6) showing the temperature vector pointing towards the March and November datapoints, indicating higher temperatures during these surveys. Temperatures at the PoR sites were similar to the Narrows and Western Basin zones, which were often higher than temperatures in Rodds Bay and Colosseum Inlet (Figure 4).

Conductivity did not vary significantly across the surveys, most likely due to the low rainfall experienced prior to each survey. However, conductivity was overall significantly ($P < 0.05$) lower in PoR (annual mean of 54.7 mS/cm) than in the other zones (55.9 to 57.7 mS/cm), most likely due to freshwater inputs from the Fitzroy River (Figure 4). Note the conductivity vector is directed away from the PoR datapoint in Figure 7. In contrast, the pH at PoR was significantly ($P < 0.05$) higher (annual mean of 8.1) than in the other zones (7.9 to 8.0).

All zones exhibited turbidity values which were significantly ($P < 0.05$) lower during November 2019, than during the other surveys (Figure 4), attributable to sampling during a neap tide period. While the August survey was also undertaken during a neap tide, turbidity was elevated. This may be due to the higher tidal range experienced in August (3.33 m) than November (3.01 m).

Table 3 Mean subsurface physicochemical parameters at individual PoR sites during 2019 surveys.
Values are means ± se (n = 3). Green shading indicates exceedances of the QWQG value. Note that K_d is the vertical light attenuation co-efficient, with lower values indicating clearer water.

Parameter	March 2019			June 2019			August 2019			November 2019			QWQG
	PoR1	PoR2	PoR3	PoR1	PoR2	PoR3	PoR1	PoR2	PoR3	PoR1	PoR2	PoR3	
Temperature (°C)	25.6 ± 0.0	25.6 ± 0.0	25.7 ± 0.0	19.0 ± 0.0	19.3 ± 0.0	19.5 ± 0.0	19.8 ± 0.0	19.9 ± 0.0	19.7 ± 0.0	27.0 ± 0.0	27.2 ± 0.0	26.8 ± 0.0	-
Conductivity (mS/cm)	53.7 ± 0.0	54.9 ± 0.0	55.4 ± 0.0	52.9 ± 0.0	53.4 ± 0.0	53.7 ± 0.0	54.1 ± 0.0	54.3 ± 0.0	54.3 ± 0.0	56.4 ± 0.0	56.2 ± 0.0	56.1 ± 0.0	-
pH	8.0 ± 0.0	8.0 ± 0.0	8.1 ± 0.0	8.1 ± 0.0	8.1 ± 0.0	8.1 ± 0.0	8.0 ± 0.0	8.1 ± 0.0	8.1 ± 0.0	8.0 ± 0.0	8.0 ± 0.0	8.0 ± 0.0	7.0 - 8.4
Dissolved oxygen (% sat.)	96 ± 0	97 ± 0	98 ± 0	96 ± 0	96 ± 0	97 ± 0	96 ± 0	96 ± 0	97 ± 0	100 ± 0	102 ± 0	100 ± 0	85 - 100
Turbidity (NTU)	59 ± 3	20 ± 1	12 ± 0	41 ± 1	65 ± 2	33 ± 0	38 ± 2	48 ± 1	66 ± 1	13 ± 0	7.2 ± 0.1	17 ± 0	8
K_d	3.8 ± 0.1	1.7 ± 0.0	1.6 ± 0.0	4.6 ± 1.0	6.3 ± 0.7	5.9 ± 1.7	3.6 ± 0.0	6.0 ± 1.0	7.1 ± 1.1	0.5 ± 0.0	0.2 ± 0.1	0.5 ± 0.0	-

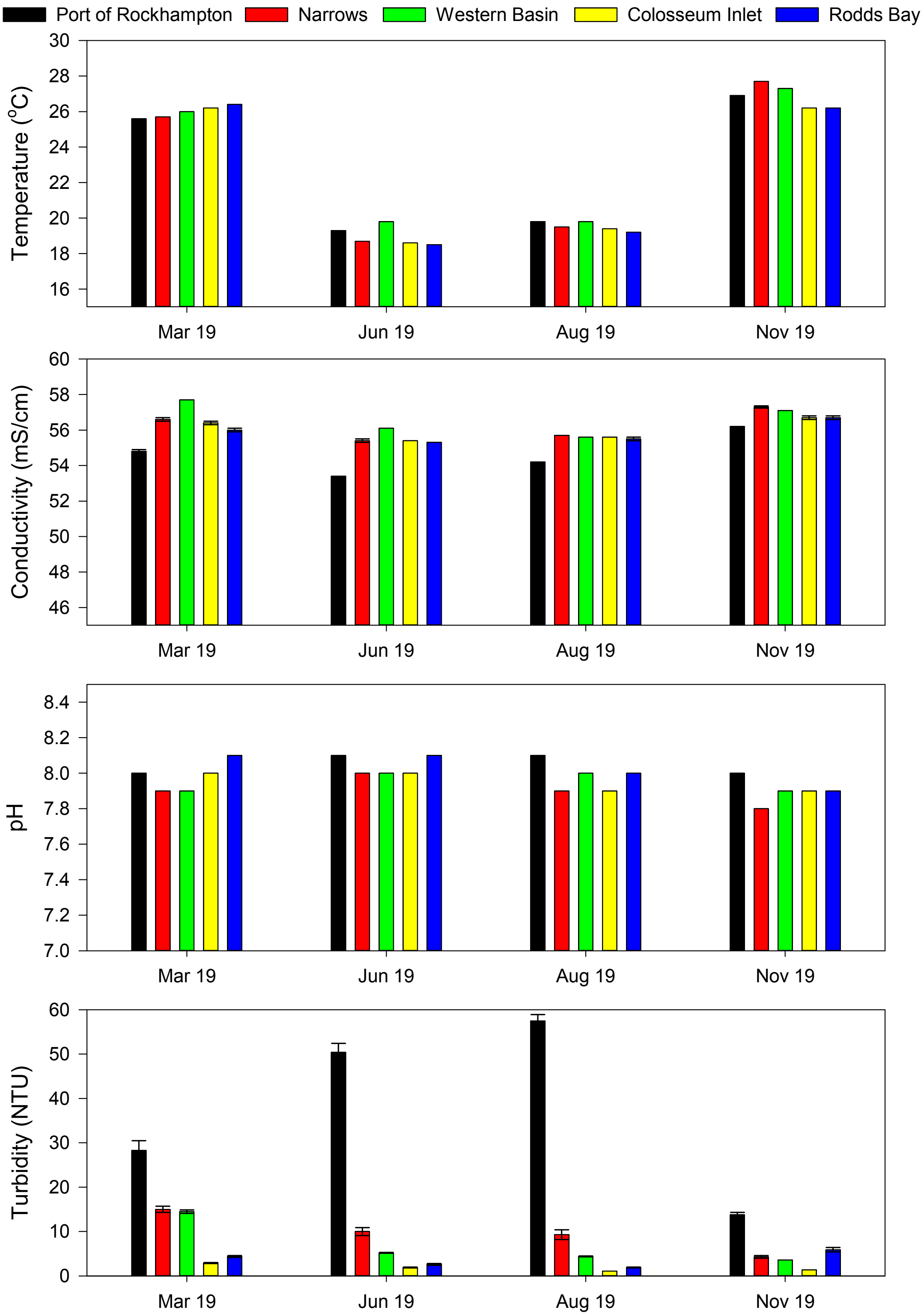

Figure 4 Subsurface temperature, conductivity, pH and turbidity at PoR, and adjacent and reference PCIMP zones.
Values are means ± se (n =64 to 153)

Overall, turbidity at PoR (annual mean of 37 NTU) was significantly higher than all other zones (Figure 4), with second highest turbidity recorded in the Narrows (annual mean of 9.6 NTU). Lowest turbidity was evident in Rodds Bay and Colosseum Inlet (annual mean of 1.8 to 3.7 NTU).

Dissolved oxygen was significantly (P < 0.05) higher in November (survey mean of 98% saturation) than during March (96% saturation). Significantly (P < 0.05) lower oxygen was evident in Colosseum Inlet (annual mean of 94% saturation) than all other zones (96 to 97% saturation, Figure 5).

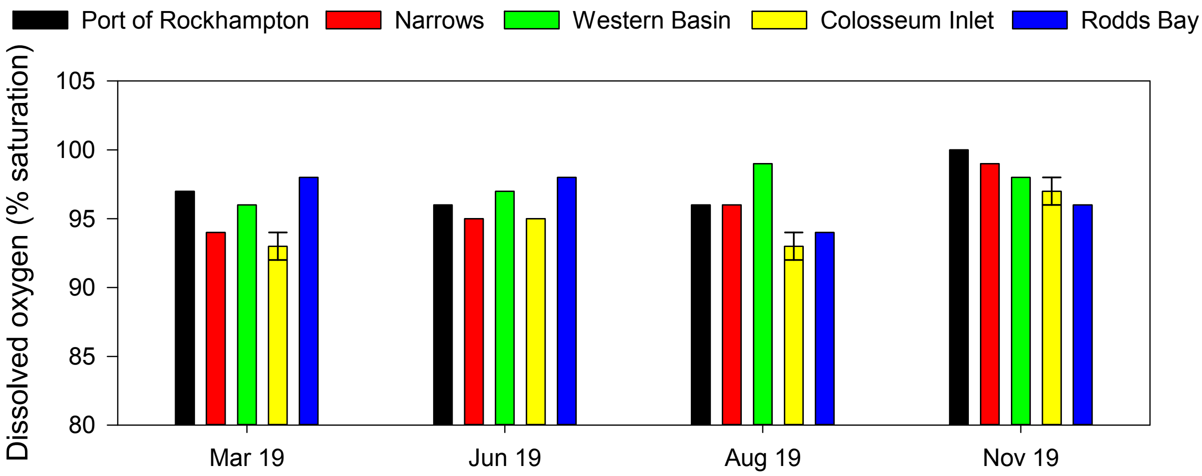

Figure 5 Subsurface dissolved oxygen at PoR, and adjacent and reference PCIMP zones.
Values are means ± se (n =64 to 153)

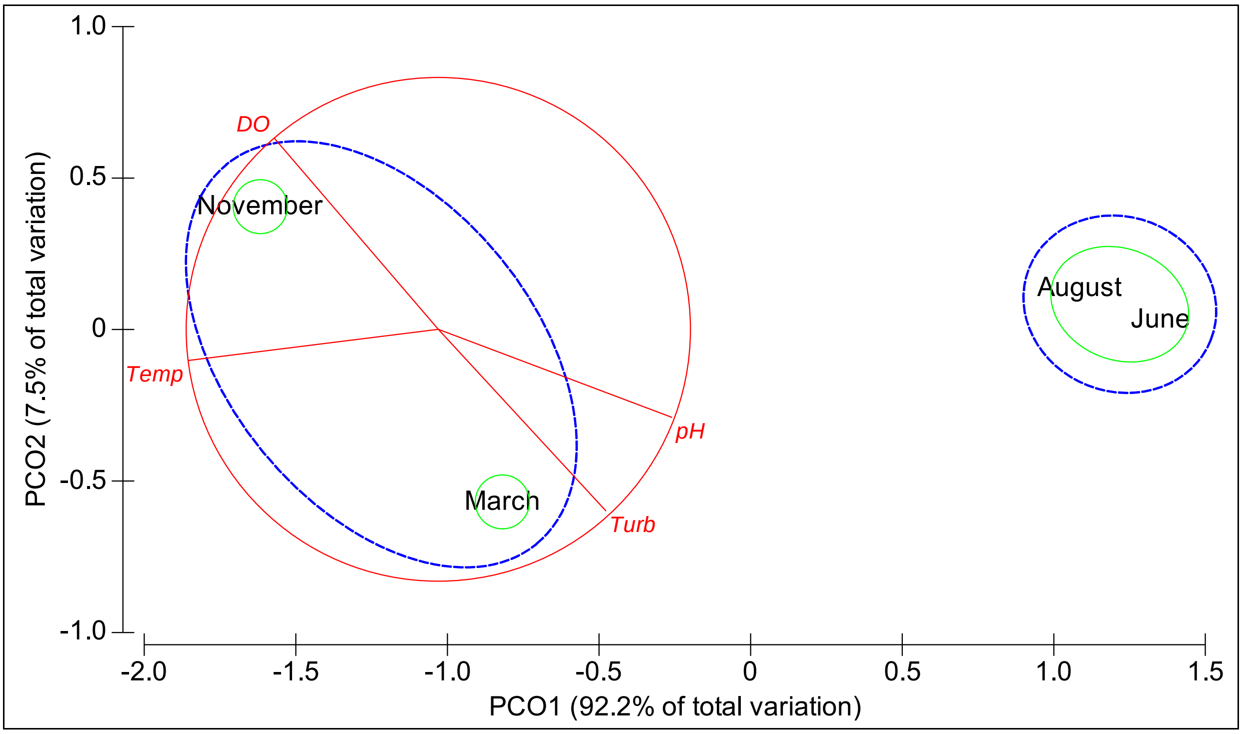

Figure 6 Principal Co-ordinates Ordination (PCO) of PoR physicochemical parameters during 2019 surveys.
Physicochemical parameters were overlaid as vectors (in red) to determine the specific parameters driving the temporal variation. The closer the end of the vector to the circle, the stronger the correlation between the parameter and the survey to which the line is directed. A Hierarchical Cluster Analysis was also performed and overlaid (green =1 and blue 2) to indicate the level of similarity between the surveys. The lower the 'Euclidean distance' number, the more similar the surveys were regarding physicochemical parameters.

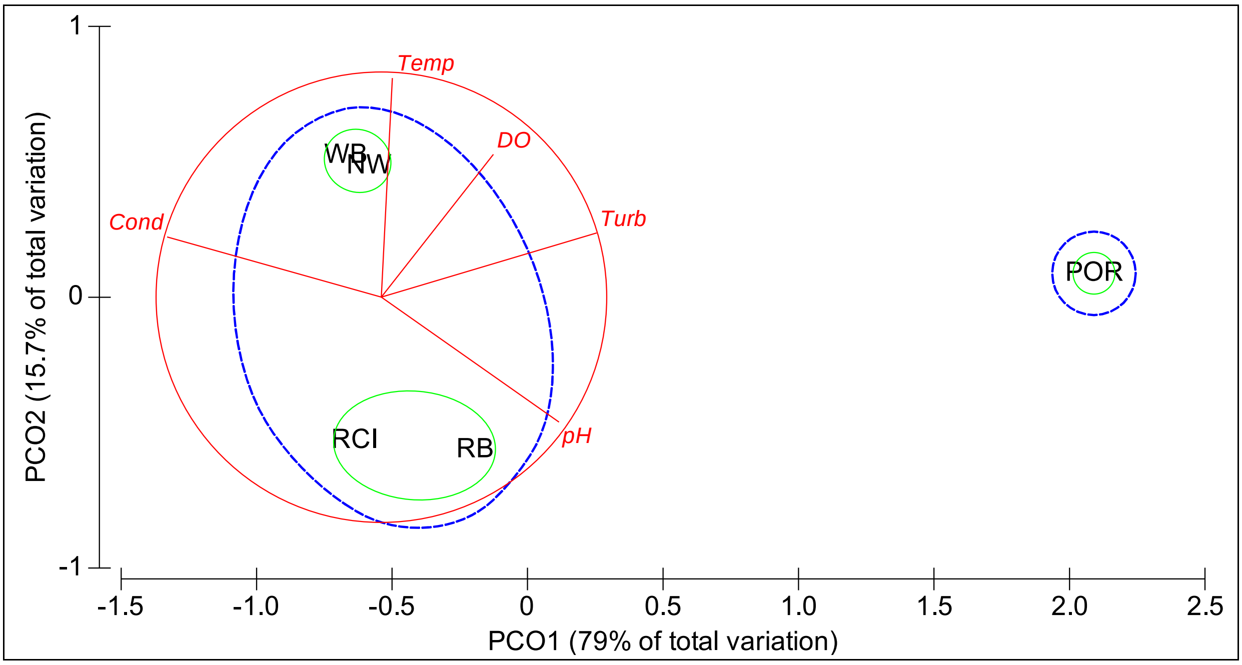

Figure 7 Principal Co-ordinates Ordination (PCO) of PoR physicochemical parameters across zones. *Physicochemical parameters were overlaid as vectors (in red) to determine the specific parameters driving the spatial variation. The closer the end of the vector to the circle, the stronger the correlation between the parameter and the zone to which the line is directed. A Hierarchical Cluster Analysis was also performed and overlaid (green =1 and blue =2) to indicate the level of similarity between the zones. The lower the 'Euclidean distance' number, the more similar the zones were regarding physicochemical parameters.*

3.3 Chlorophyll a, Nutrients and TSS

Tabulated nutrient, chlorophyll *a* and TSS results for 2019 can be found in Table 4. The results, in addition to concurrent PCIMP sampling at adjacent and reference zones, are presented in Figures 8 to 10, and Table 7 within the Appendix. Two-way ANOVA results table can be found in the Appendix (Table 9), while multivariate analysis results are presented in Figures 11 and 12.

Total phosphorus at all three sites exceeded the QWQG of 25 µg/L on most sampling occasions. Concentrations over 90 µg/L were recorded at one or more sites during March and June. Lowest concentrations (21 to 28 µg/L) were evident during November 2019. Naturally occurring geological deposits of phosphorous in the area (Donchak and Holmes, 1991) are thought to contribute to total phosphorus concentrations (Vision Environment, 2009, 2017, 2018, 2019a).

Filterable reactive phosphorus (FRP) concentrations were lower than total concentrations, ranging from 2 to 11 µg/L (Table 4). The QWQG of 8 µg/L was slightly exceeded within at least one site during the March, June and August surveys.

Total nitrogen includes both organic and inorganic forms. Concentrations during 2019 ranged from 170 to 300 µg/L, with no exceedances of the QWQG (300 µg/L) recorded. Ammonia (a readily bioavailable form) ranged from <2 to 20 µg/L. Concentrations at all three sites during August 2019, exceeded the QWQG of 10 µg/L (Table 4). This is typically a period of low demand for nutrients by algal populations, which tend to bloom utilizing nutrients in the warmer months, as confirmed by chlorophyll *a* concentrations.

Table 4 Chlorophyll *a*, nutrient and TSS concentrations at PoR during 2019 surveys.
N = 1. Green shading indicates exceedances of the QWQG value

Parameter (µg/L)	March 2019			June 2019			August 2019			November 2019			QWQG
	PoR1	PoR2	PoR3	PoR1	PoR2	PoR3	PoR1	PoR2	PoR3	PoR1	PoR2	PoR3	
Total Phosphorus	93	39	20	77	96	54	47	60	69	25	21	28	25
Filterable Reactive Phosphorus	11	5	2	10	9	4	10	9	6	8	7	7	8
Total Nitrogen	300	170	120	240	280	170	210	230	280	170	170	180	300
Ammonia	7	2	2	3	8	3	21	20	20	<2	<2	<2	10
Nitrogen oxides	19	7	<2	16	13	7	39	23	18	16	17	17	10
Chlorophyll a	1.7	1.7	1.1	0.30	0.41	0.38	0.14	0.56	0.55	0.76	0.78	0.37	4
TOC (mg/L)	2.0	1.0	<1	2.0	2.0	2.0	2.0	3.0	4.0	2.0	1.0	2.0	-
DOC (mg/L)	1.1	0.9	0.8	1.0	1.0	0.9	1.0	0.9	0.8	1.2	1.1	1.1	-
TSS (mg/L)	130	46	26	130	120	67	110	120	330	25	21	27	20

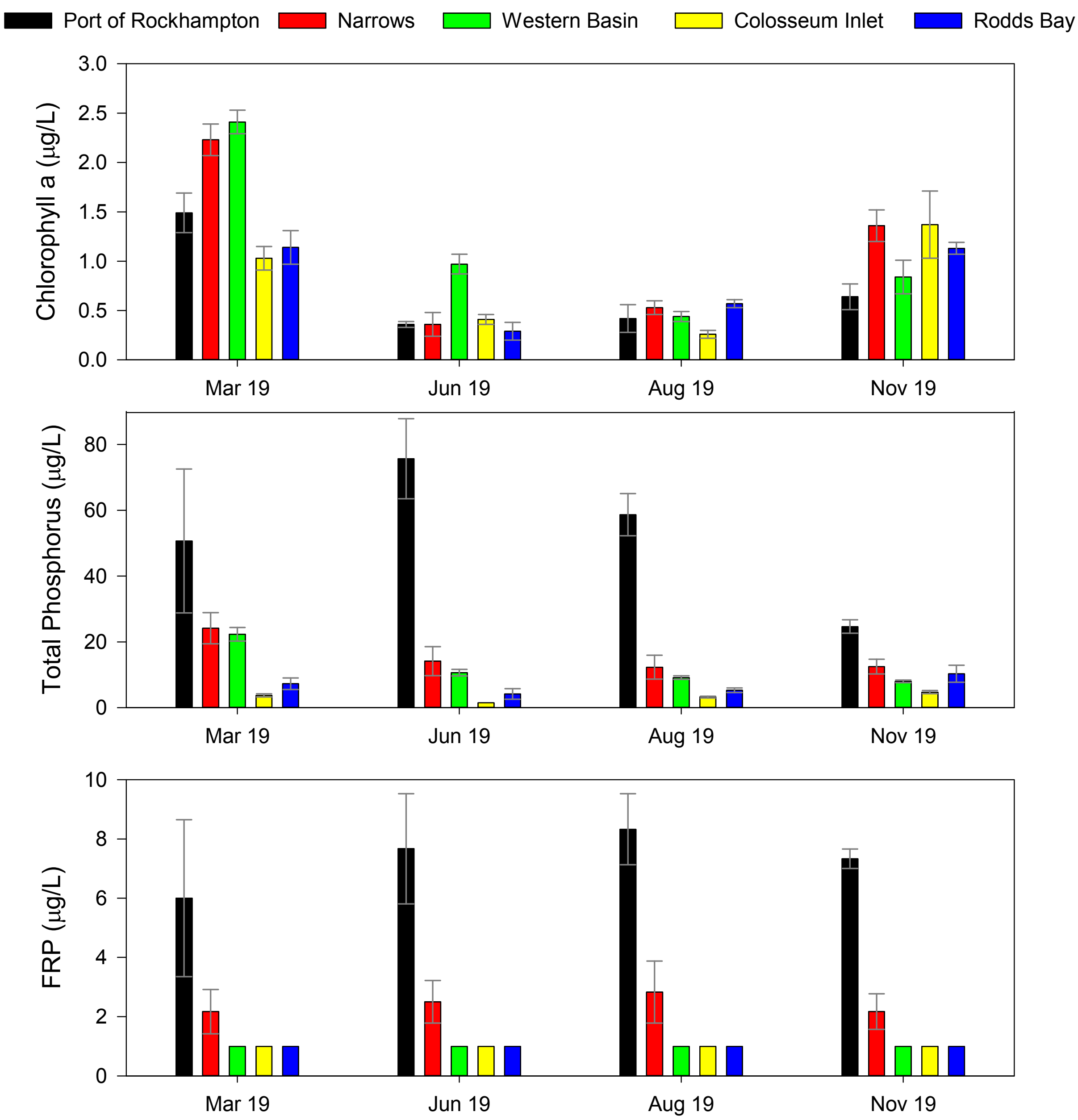

Figure 8 Concentrations of chlorophyll *a*, total phosphorus and filterable reactive phosphorus at adjacent and reference PCIMP zones.
Values are means ± se (n = 3 to 6). For concentrations below LOR, half the LOR was used in the plots.

In contrast, nitrogen oxides (nitrate + nitrite or NOx) which are also readily bioavailable, exceeded the QWQG (10 µg/L) at PoR1 during all four surveys (16 to 39 µg/L), and exceeded at PoR2 and PoR3 during August and November (17 to 23 µg/L). Chlorophyll *a* concentrations were more elevated in the warmer months but below QWQG (4 µg/L) at all sites during all surveys.

Total organic carbon (TOC) concentrations were slightly higher during the August survey (2.0 to 4.0 mg/L), than during the remaining three surveys (<1 to 2.0 mg/L). Dissolved organic carbon (DOC) concentrations were lower than TOC as expected, and ranged from 0.8 to 1.2 mg/L.

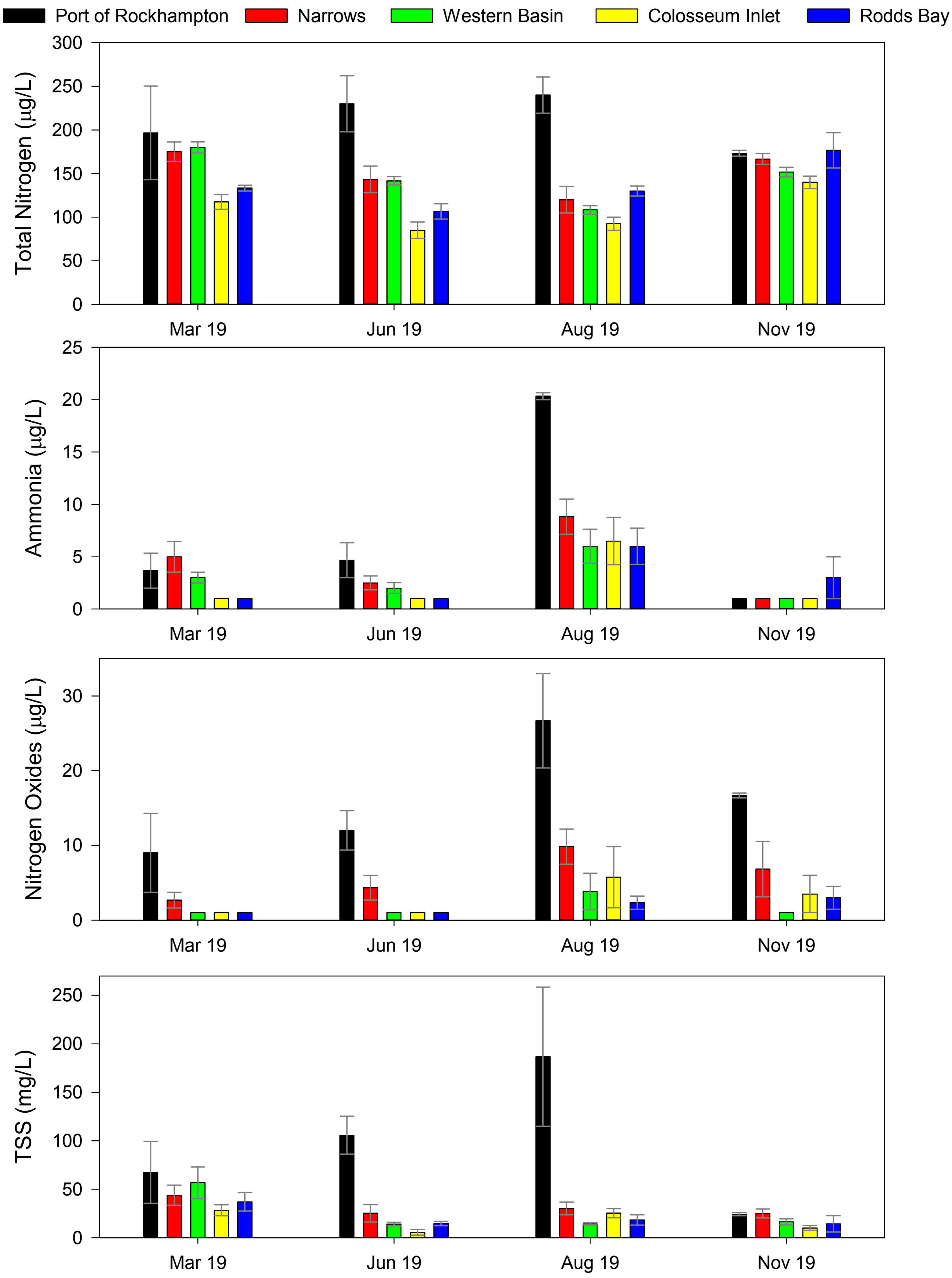

Figure 9 Concentrations of total nitrogen, ammonia, NOx and TSS at PoR, and adjacent and reference PCIMP zones.
Values are means ± se (n = 3 to 6). For concentrations below LOR, half the LOR is displayed in the plots.

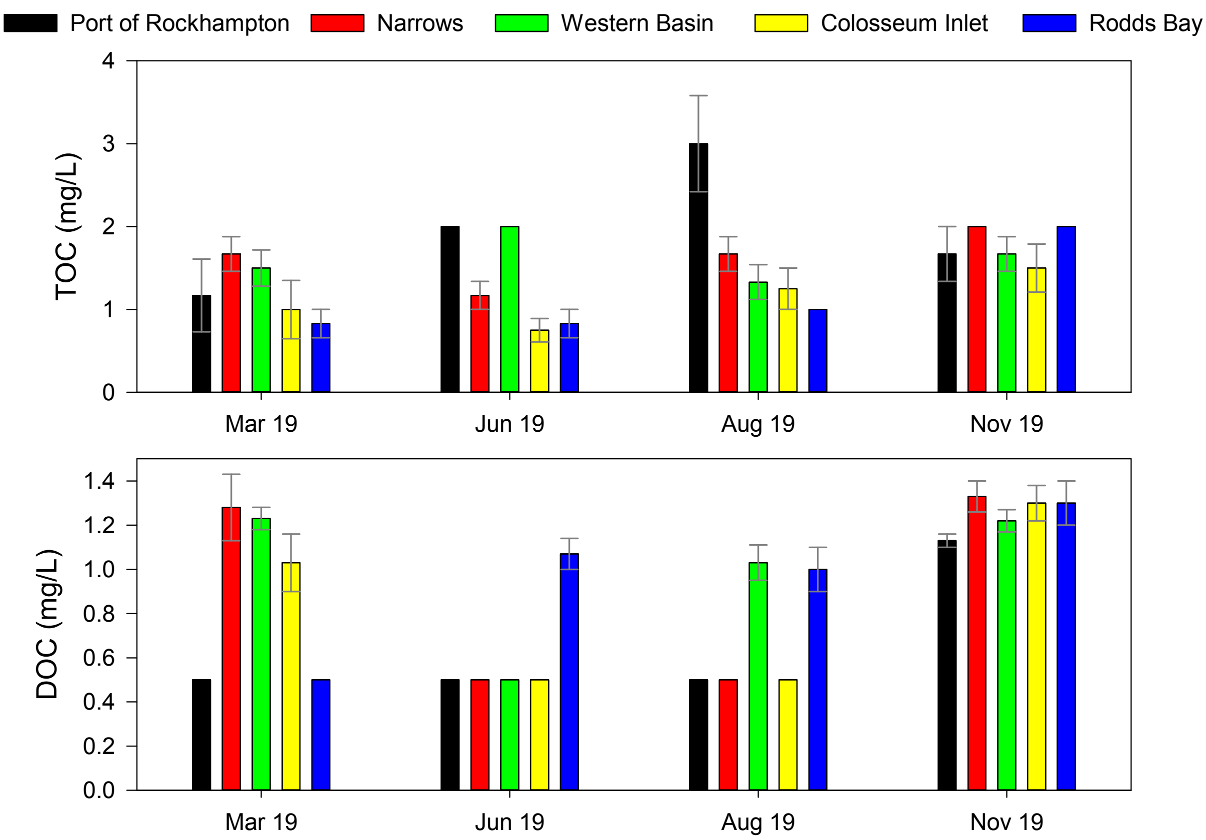

Figure 10 Concentrations total and dissolved organic carbon at PoR, and adjacent and reference PCIMP zones.
Values are means ± se (n = 3 to 6). For concentrations below LOR, half the LOR was used in the plots.

Total suspended solids (TSS) concentrations ranged from 21 to 330 mg/L, exceeding the QWQG of 20 mg/L at each site during every survey (Table 4). Concentrations were highest during August (110 to 330 mg/L) in comparison with the other three surveys (21 to 130 mg/L). This corresponds with the elevated turbidity recorded during this survey (Table 3).

Overall, concentrations of several nutrients were lower during the neap-tide November 2019 survey than during the other three surveys. Of note was the elevated concentrations of ammonia, NOx, TOC and TSS during the August survey, despite neap tide conditions prevailing at this time.

Comparison with PCIMP Monitoring Results

Both the univariate and multivariate analyses indicated the presence of significant temporal and spatial variation in nutrient concentrations during 2019. The univariate statistical analysis found significantly ($P < 0.05$) higher concentrations of total phosphorus, total nitrogen, TOC, DOC, TSS and chlorophyll *a* concentrations during the Wet Season months of March and November 2019 (Figures 8 to 10). In contrast, bioavailable nitrogen concentrations (ammonia and NOx) were significantly higher during August 2019, hence the separation of this survey from the others in the temporal PCO (Figure 11). Demand for bioavailable nutrients during the warmer months would lead to a depletion in November with a corresponding increase in chlorophyll *a*, representative of increased algal populations.

The univariate statistical analysis also found that significantly (P < 0.05) higher concentrations of TSS and all nutrients (except DOC) were found at PoR than in other zones, and this was supported by the separation of this datapoint in Figure 12. However, chlorophyll *a* concentrations were significantly higher in the Narrows and Western Basin than at PoR (Figure 8), indicating lower biological impact of elevated nutrients at PoR than would be expected. This may be due to the lower light availability at PoR as indicated by the turbidity and TSS. Chlorophyll *a* provides a measure of the microalgal biomass within the water column, which is generally stimulated by warmer temperatures and higher light availability (APHA, 2005). Low water clarity at PoR may have inhibited microalgal growth.

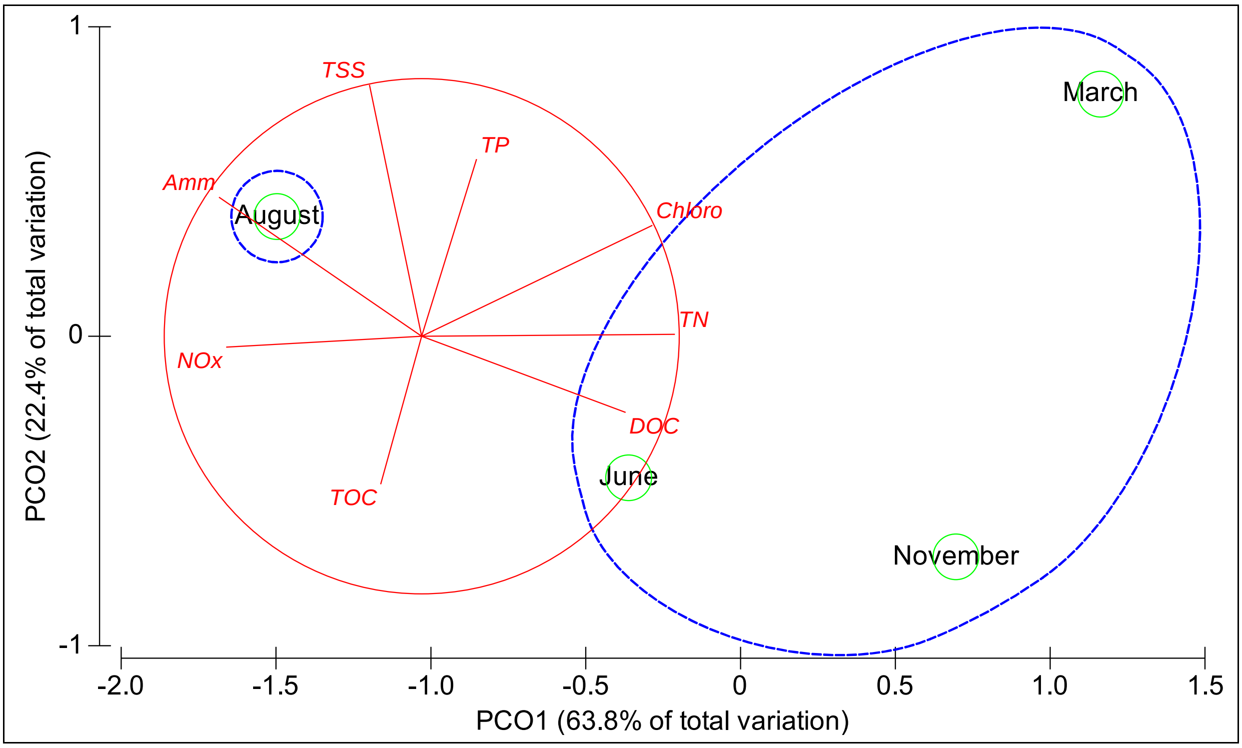

Figure 11 Principal Co-ordinates Ordination (PCO) of PoR nutrient concentrations during 2019 surveys.
Nutrients were overlaid as vectors (in red) to determine the specific parameters driving the temporal variation. The closer the end of the vector to the circle, the stronger the correlation between the parameter and the survey to which the line is directed. A Hierarchical Cluster Analysis was also performed and overlaid (green =1 and blue =2) to indicate the level of similarity between the surveys. The lower the 'Euclidean distance' number, the more similar the surveys were regarding nutrients.

As stated previously, exceedance of the QWQG was evident for total phosphorus, NOx and TSS at the PoR sites during most surveys. The WQO for the PCIMP zones vary from the QWQG and in different areas of Port Curtis, based on background data collected over several years. As such, WQO numerical values for the PCIMP zones are often lower than the QWQG applicable to the PoR sites.

Nonetheless, exceedance of the WQO was less frequent in the PCIMP zones. No exceedances of the total phosphorus WQO was exhibited in any PCIMP zone, while NOx WQO exceedances were recorded only in the Narrows and Colosseum Inlet during the August survey. The TSS QWQG was exceeded during all surveys in the Narrows (similar to PoR) and exceeded during March only at other PCIMP zones.

Concentrations of nutrients overall, were lower in the PCIMP zones, with lowest concentrations in Colosseum Inlet and Rodds Bay (Figures 8 to 10). It is likely that elevated nutrients in PoR compared to PoG adjacent zones are a result of differing anthropogenic activities (farming in comparison to industrial) between the two areas.

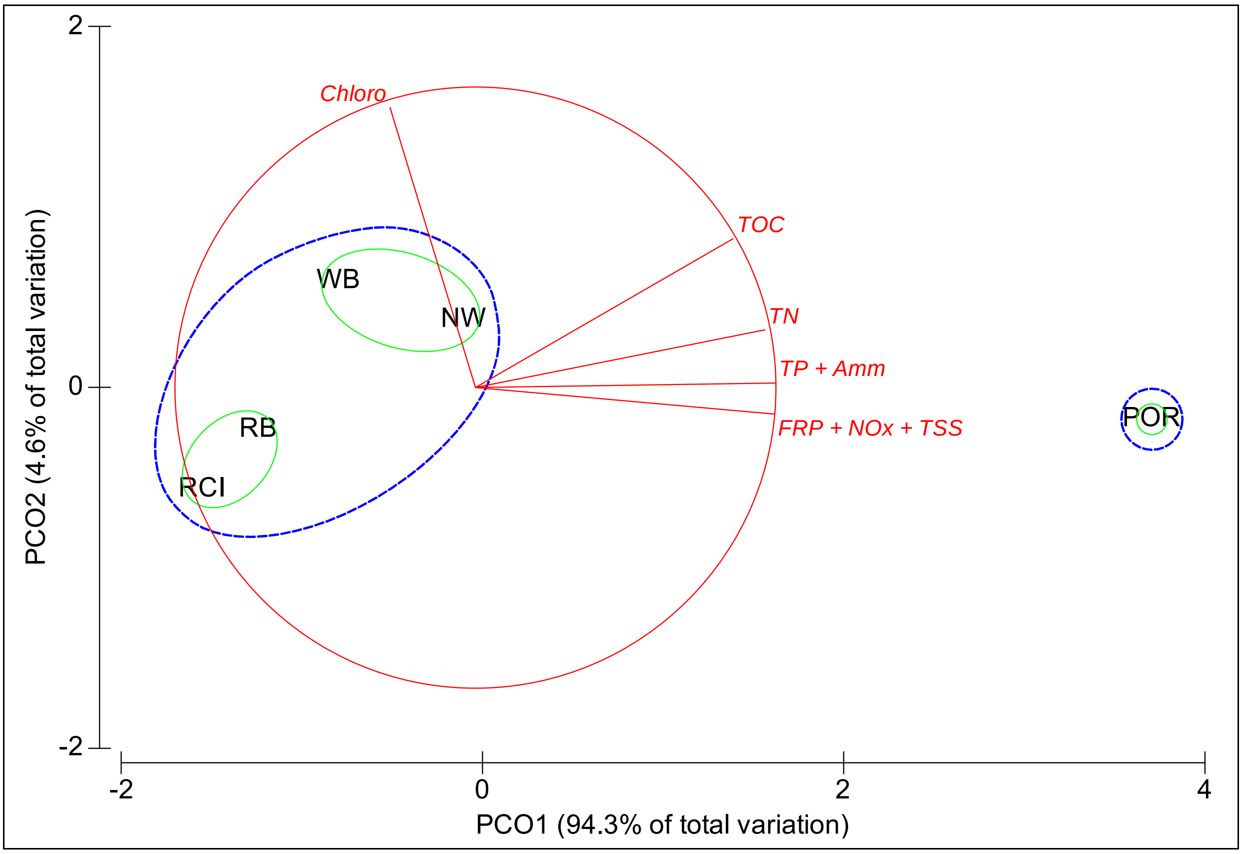

Figure 12 Principal Co-ordinates Ordination (PCO) of PoR nutrient concentrations across zones. *Nutrients were overlaid as vectors (in red) to determine the specific parameters driving the spatial variation. The closer the end of the vector to the circle, the stronger the correlation between the parameter and the survey to which the line is directed. A Hierarchical Cluster Analysis was also performed and overlaid (green =1 and blue =2) to indicate the level of similarity between the zones. The lower the 'Euclidean distance' number, the more similar the zones were regarding nutrients.*

3.4 Total and Dissolved Metals

Total and dissolved metal results for 2019 can be found in Table 5. These results, in addition to concurrent PCIMP sampling results at adjacent and reference zones, are presented in Figures 13 to 19, and Table 8 within the Appendix. Two-way ANOVA results can be found in the Appendix (Table 9), while multivariate analysis results are presented in Figures 20 and 21.

Many metals were below laboratory LOR at the PoR sites (Table 5). Total and dissolved cadmium, mercury, silver and tin were below LOR at each site during each survey, as were dissolved chromium, cobalt, copper, gallium, lead and nickel.

Concentrations of total and dissolved arsenic, molybdenum and vanadium, in addition to total aluminium, chromium, iron, manganese and nickel were detected at each site during all surveys. The remaining metals were detected intermittently throughout the four surveys.

Table 5 Total and dissolved metal concentrations at PoR during 2019 surveys.
N = 1. Orange shading indicates exceedances of the relevant AWQG value. Note that speciation measures have not been carried out on chromium, and thus these forms (Cr(III) and Cr(VI)) could potentially contribute to total concentrations.

Metal (µg/L)		March 2019			June 2019			August 2019			November 2019			95% AWQG
		PoR1	PoR2	PoR3	PoR1	PoR2	PoR3	PoR1	PoR2	PoR3	PoR1	PoR2	PoR3	
Aluminium	Dissolved	14	8	10	<5	<5	9.9	<5	<5	<5	14	6.3	14	24
	Total	3480	1270	650	1680	3860	1750	860	910	1020	610	480	1190	
Arsenic	Dissolved	1.5	1.5	1.4	1.2	1.2	1.2	1.1	1.1	1.3	1.2	1.2	1.2	-
	Total	2.8	2.1	1.8	1.9	2.5	1.8	2	2.2	2.5	1.3	1.4	1.6	
Cadmium	Dissolved	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	5.5
	Total	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	
Chromium	Dissolved	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	Cr(III) 27.4 Cr(VI) 4.4
	Total	7.1	2.2	2.2	3.5	6.9	4.4	2.5	2.3	2.8	1.4	1.3	2.8	
Cobalt	Dissolved	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	1
	Total	1.7	<1	<1	1	1.6	<1	<1	1.2	1.4	<1	<1	<1	
Copper	Dissolved	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	1.3
	Total	2.4	<1	<1	1	1.9	1.1	2.1	2.2	2.2	1.1	<1	1.3	
Gallium	Dissolved	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	-
	Total	1.2	<1	<1	<1	1.1	<1	<1	<1	<1	<1	<1	<1	
Iron	Dissolved	6.3	<5	<5	<5	<5	<5	<5	<5	<5	<5	8.1	<5	-
	Total	4180	1560	830	1770	3800	1680	1230	1440	1640	830	560	1370	
Lead	Dissolved	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	4.4
	Total	1.1	<1	<1	<1	1.3	<1	<1	1.2	1.4	<1	<1	<1	
Manganese	Dissolved	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	2	-
	Total	63	24	15	39	58	29	38	55	59	11	8.5	19	
Mercury	Dissolved	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.05	<0.05	<0.05	<0.1	<0.1	<0.1	0.4

Metal (µg/L)		March 2019			June 2019			August 2019			November 2019			95% AWQG
		PoR1	PoR2	PoR3	PoR1	PoR2	PoR3	PoR1	PoR2	PoR3	PoR1	PoR2	PoR3	
	Total	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.05	<0.05	<0.05	<0.1	<0.1	<0.1	
Molybdenum	Dissolved	11	11	12	10	11	11	10	10	10	9.4	9.9	10	-
	Total	11	12	12	11	11	10	11	9.4	9.9	11	11	11	
Nickel	Dissolved	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	70
	Total	5.6	1.9	1.2	2.3	4.6	3	3	2.7	2.7	1.7	1.4	2.2	
Silver	Dissolved	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	1.4
	Total	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	
Tin	Dissolved	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	-
	Total	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	
Vanadium	Dissolved	3.7	2.9	2.7	1.9	2.1	1.8	2.1	2	1.9	1.8	1.8	1.8	100
	Total	11	5.9	4.3	6.1	9.5	6.1	6.1	6.9	7.1	3.1	2.8	4.2	
Zinc	Dissolved	<1	<1	<1	<1	<1	<1	<1	1.8	1.8	3.2	<1	2.5	15
	Total	5.8	1.3	<1	<1	3.2	<1	2	3.9	3.9	1.9	<1	2	

Exceedances of the AWQG 95% trigger value (Golding *et al.*, 2015) were recorded for total aluminium (24 µg/L) at all PoR sites during each of the four surveys. However dissolved concentrations remained ≤ 14 µg/L, well below the trigger value.

Several exceedances of the 95% AWQG trigger for total chromium (CrVI 4.4 µg/L), total cobalt (1 µg/L) and total copper (1.3 µg/L) were also recorded. During March, exceedances for all three total metals were recorded at PoR1, with similar exceedances at PoR2 in June. However dissolved concentrations of these metals were all < LOR.

During August, exceedances of the cobalt 95% AWQG were evident at PoR2 and PoR3, while all three sites exhibited exceedances of the copper 95% AWQG. However, dissolved concentrations of chromium, cobalt and copper were < LOR during all surveys, indicating low bioavailability despite elevated total concentrations.

Overall, higher concentrations of most total metals were apparent during the March and June spring tide surveys. Dissolved concentrations tended to be more uniform across the surveys.

Comparison with PCIMP Monitoring Results

Univariate and multivariate analyses indicated significant temporal and spatial variation in total metal concentrations (Figures 13 to 21).

Concentrations of total aluminium, chromium, iron, manganese, nickel, vanadium and zinc were significantly ($P < 0.05$) higher in PoR than all other zones, with most of these metals significantly higher during the March and June surveys. In contrast, total nickel and zinc were significantly higher during August, while vanadium was highest in November, as indicated by the vectors in Figure 20.

Of note was the significantly higher total and dissolved molybdenum concentrations in the Western Basin, with total zinc concentrations in this zone second only to PoR. Overall, lowest metal concentrations were consistently recorded in Colosseum Inlet and Rodds Bay.

As stated previously, exceedances of the 95% AWQG trigger value were recorded for total aluminium, chromium, cobalt and copper at PoR during 2019. Only Western Basin metal concentrations were compared to the same 95% AWQG due to the classification of this zone as moderately disturbed. The Narrows, Colosseum Inlet and Rodds Bay are classified as slightly disturbed, and thus the more stringent 99% AWQG trigger values are applicable to metals in these zones.

Total aluminium concentrations at each PCIMP zone exceeded the applicable AWQG value during each survey. Dissolved aluminium concentrations in the Narrows, Colosseum Inlet and Rodds Bay exceeded the 99% AWQG (2.1 µg/L) during two or three surveys each in 2019.

Total chromium concentrations in the Narrows from March to August (1.1 to 3.3 µg/L) exceeded the 99% AWQG of 0.14 µg/L. However, dissolved concentrations were below LOR (< 1 µg/L). Similarly, Narrows total copper concentrations in August (1.1 µg/L) exceeded the 99% AWQG (0.3 µg/L), but dissolved concentrations were below LOR (< 1 µg/L). Note that these concentrations would not have exceeded the 95% AWQG trigger values, remaining lower than PoR concentrations.

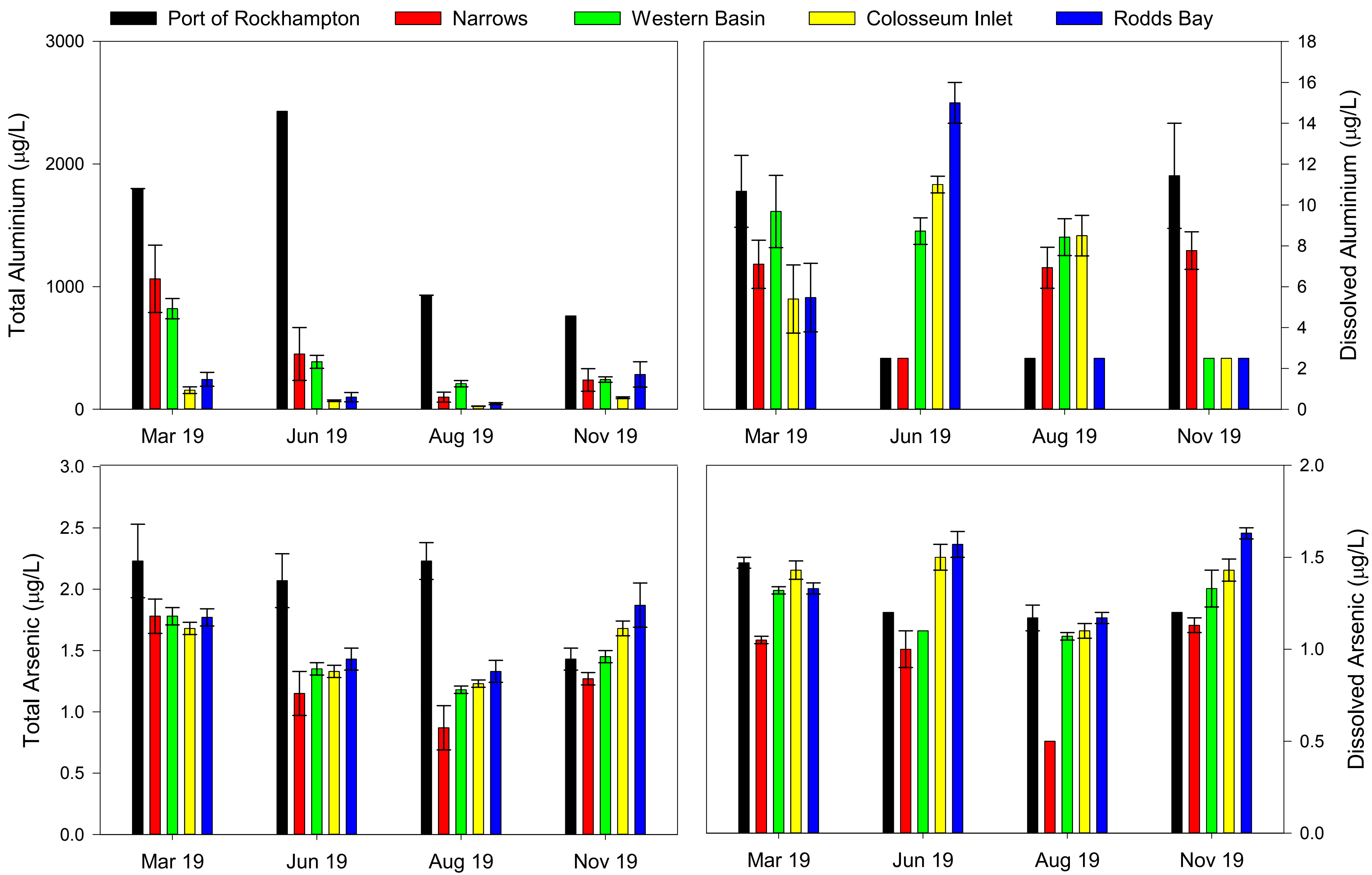

Figure 13 Concentrations of total and dissolved aluminium and arsenic at PoR, and adjacent and reference PCIMP zones.
Values are means ± se. For concentrations below LOR, half the LOR is displayed in the plots.

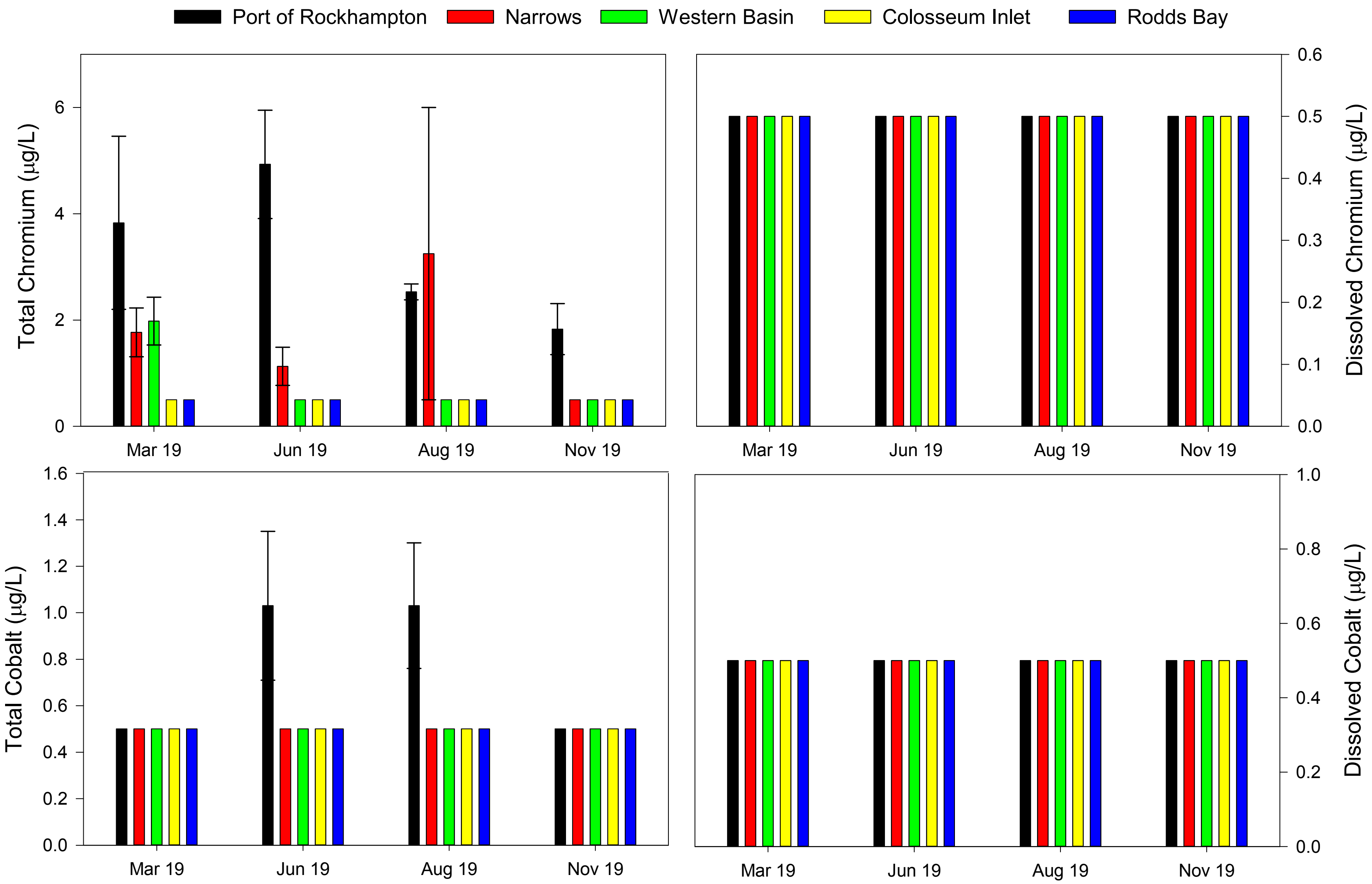

Figure 14 Concentrations of total and dissolved chromium and cobalt at PoR, and adjacent and reference PCIMP zones.
Values are means ± se. For concentrations below LOR, half the LOR is displayed in the plots.

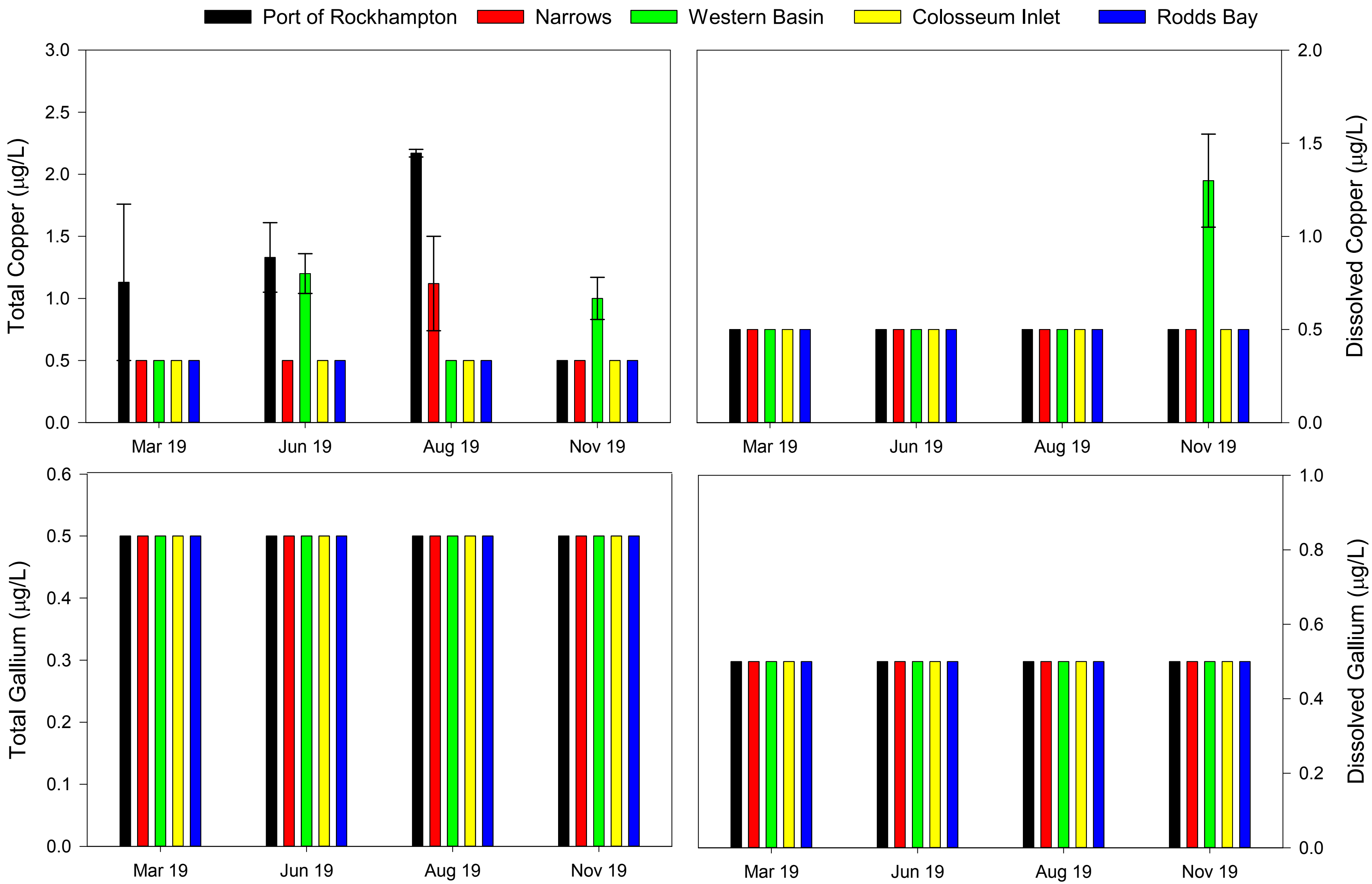

Figure 15 Concentrations of total and dissolved copper and gallium at PoR, and adjacent and reference PCIMP zones.
Values are means ± se. For concentrations below LOR, half the LOR is displayed in the plots.

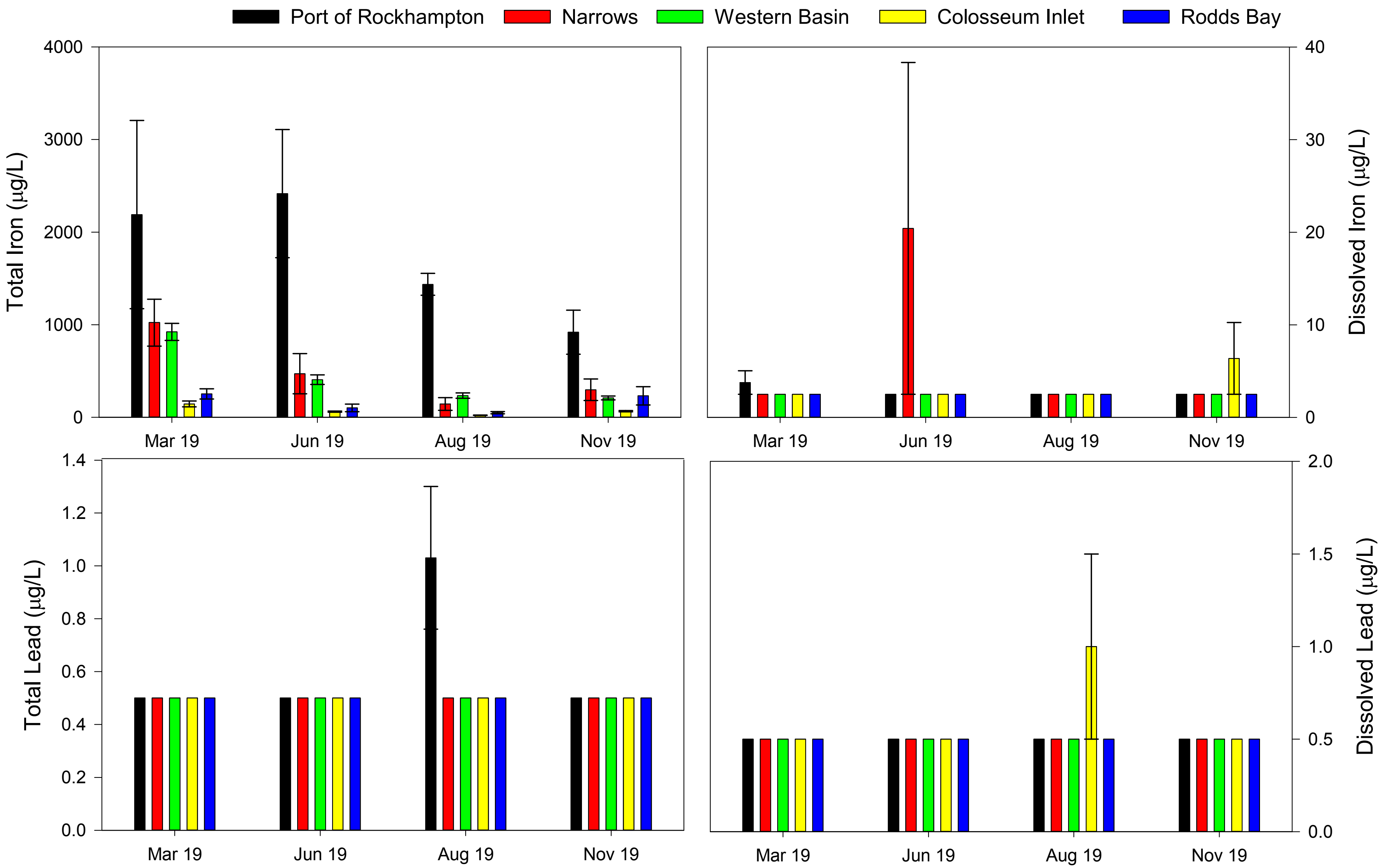

Figure 16 Concentrations of total and dissolved iron and lead at PoR, and adjacent and reference PCIMP zones.
Values are means ± se. For concentrations below LOR, half the LOR is displayed in the plots.

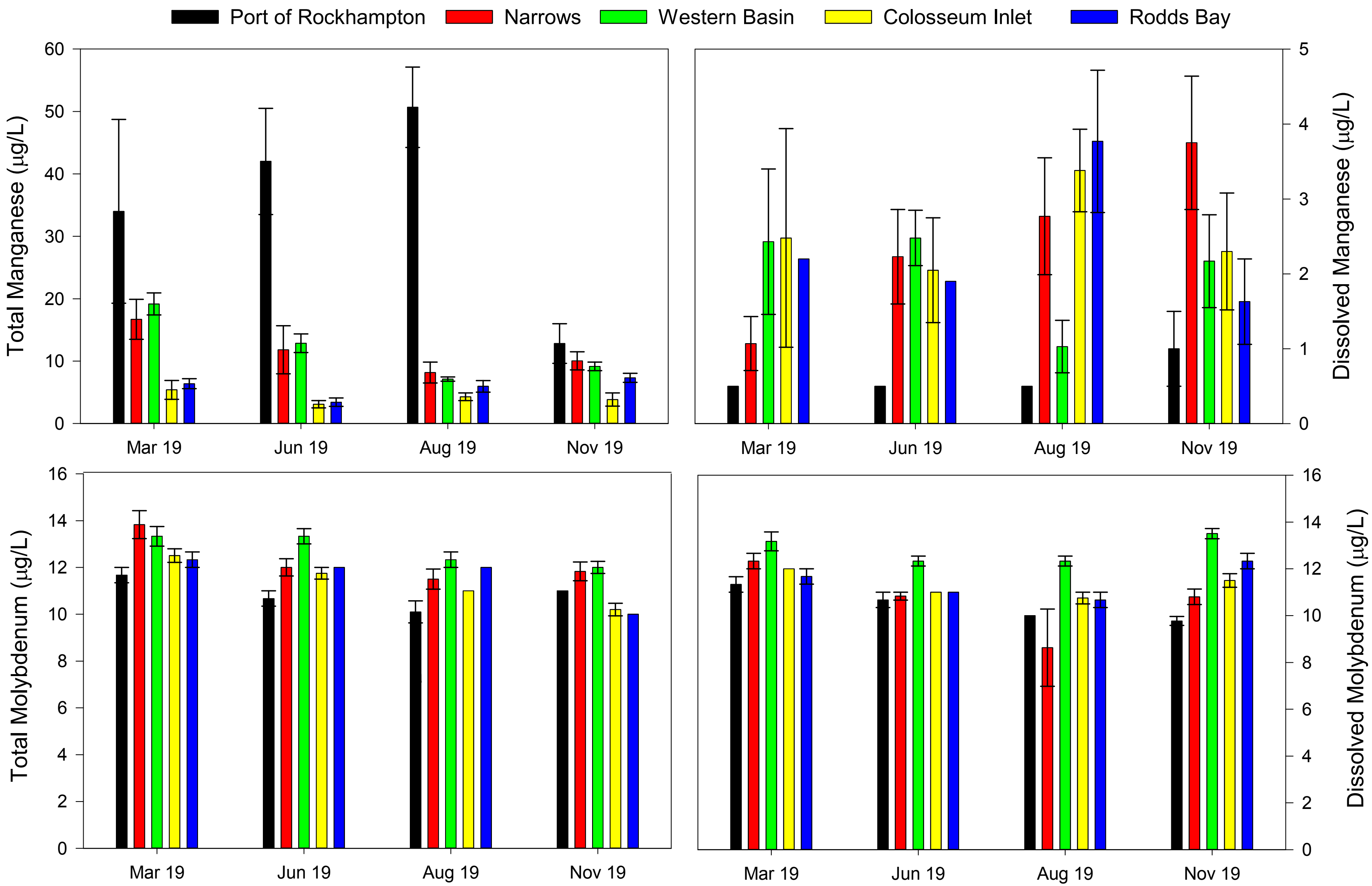

Figure 17 Concentrations of total and dissolved manganese and molybdenum at PoR, and adjacent and reference PCIMP zones.
Values are means ± se. For concentrations below LOR, half the LOR is displayed in the plots.

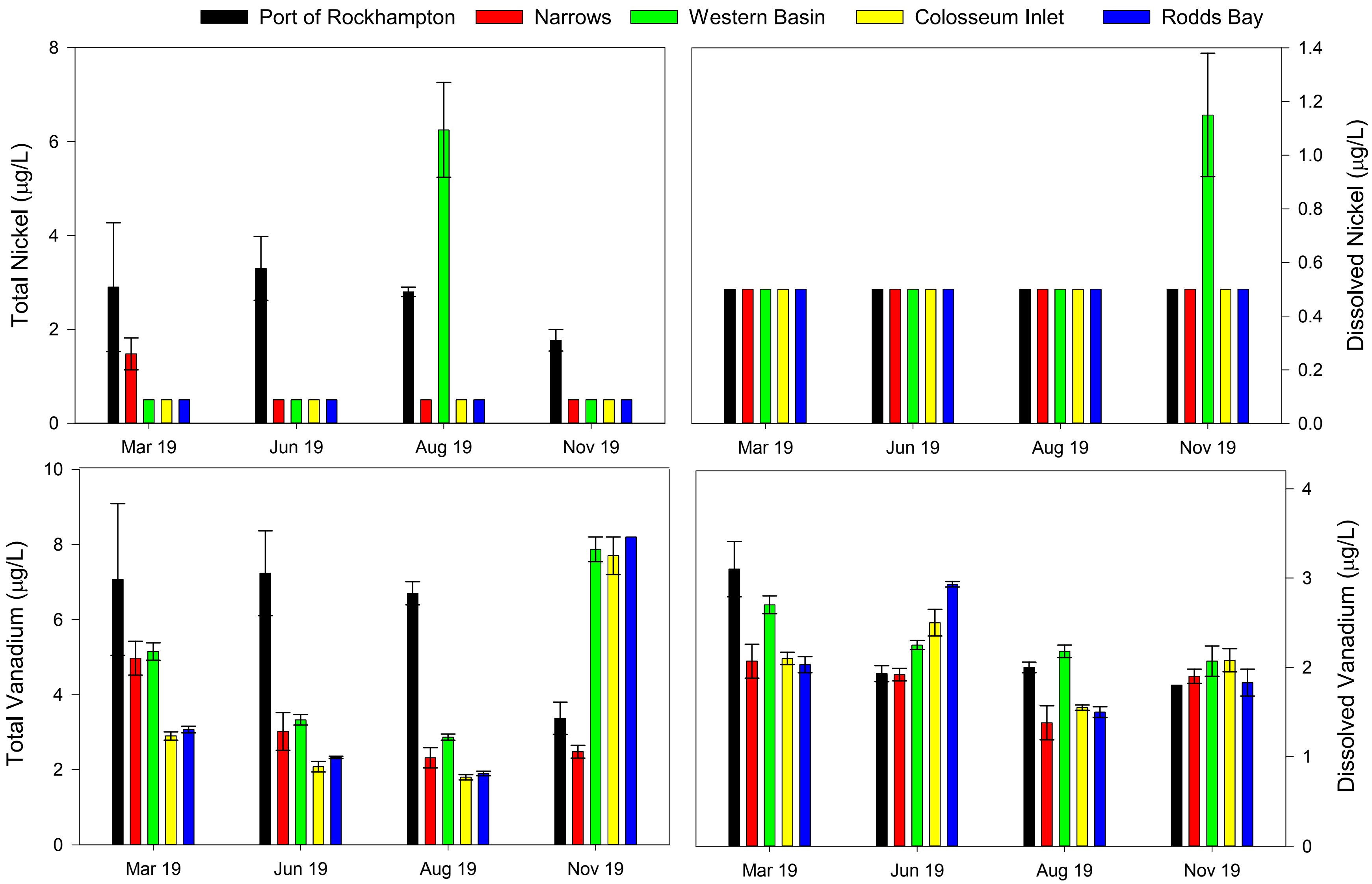

Figure 18 Concentrations of total and dissolved nickel and vanadium at PoR, and adjacent and reference PCIMP zones.
Values are means ± se. For concentrations below LOR, half the LOR is displayed in the plots.

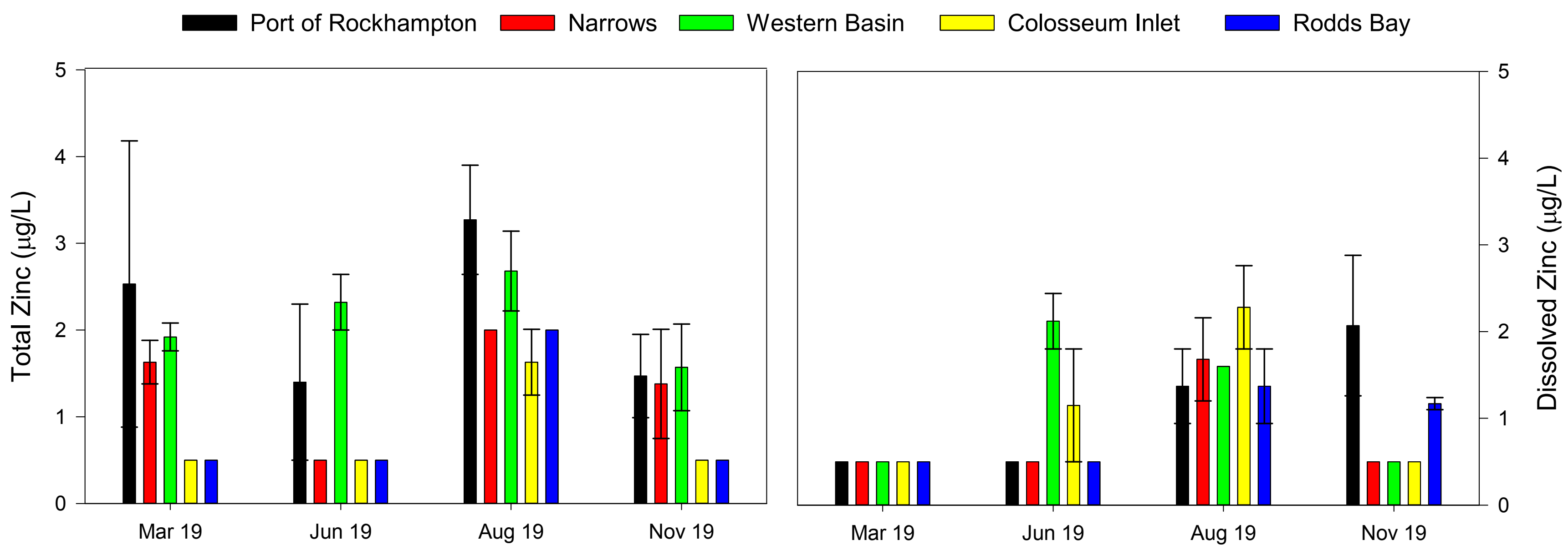

Figure 19 Concentrations of total and dissolved zinc at PoR, and adjacent and reference PCIMP zones.
Values are means ± se. For concentrations below LOR, half the LOR is displayed in the plots.

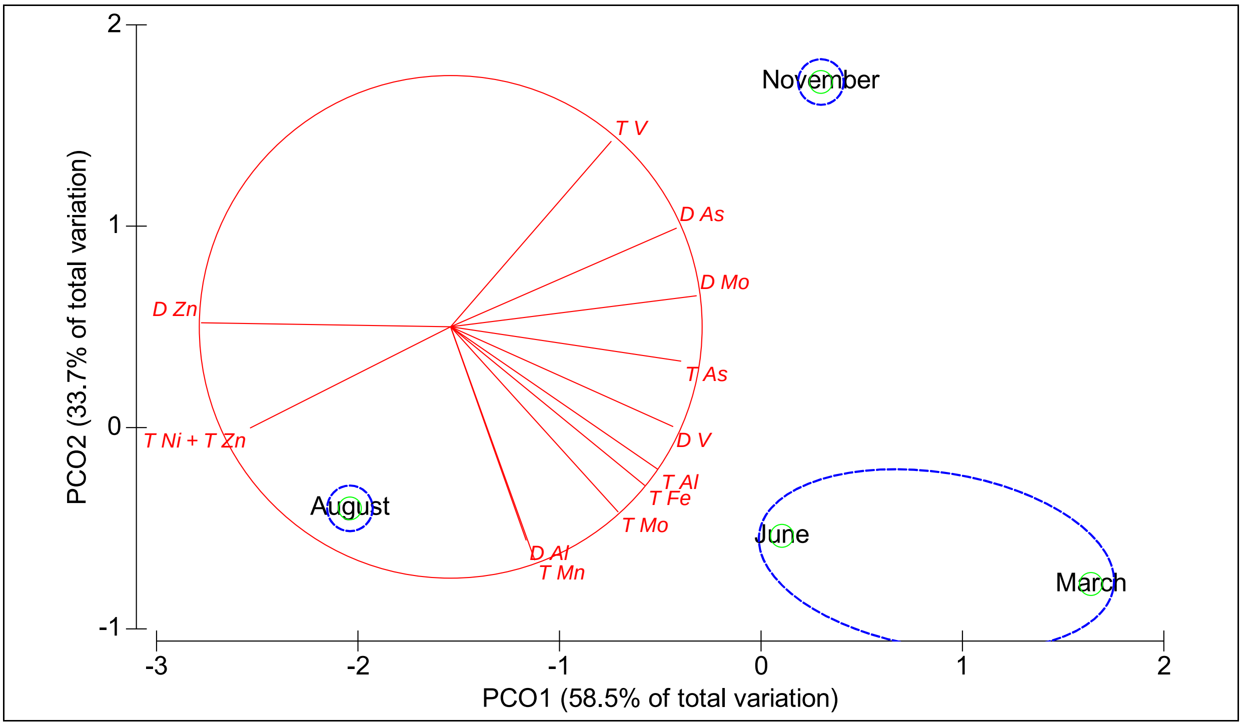

Figure 20 Principal Co-ordinates Ordination (PCO) of PoR metal concentrations during 2019 surveys. *Metals were overlaid as vectors (in red) to determine the specific parameters driving the temporal variation. The closer the end of the vector to the circle, the stronger the correlation between the parameter and the survey to which the line is directed. A Hierarchical Cluster Analysis was also performed and overlaid (green =1, blue = 2) to indicate the level of similarity between the surveys. The lower the 'Euclidean distance' number, the more similar the surveys were regarding metals.*

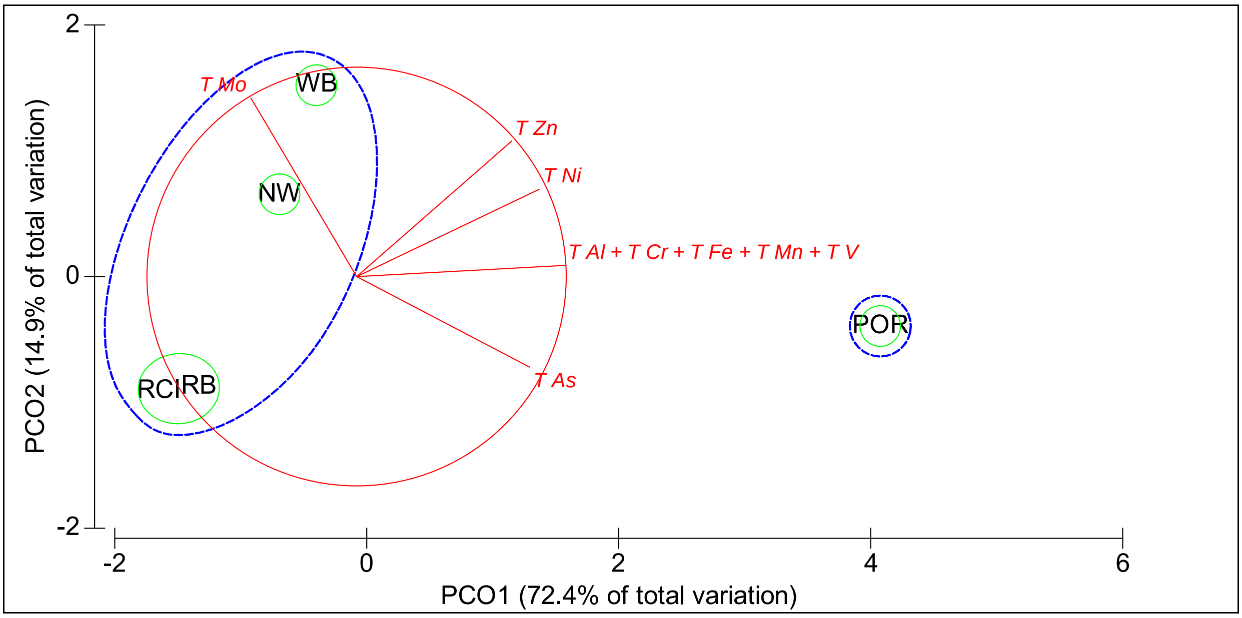

Figure 21 Principal Co-ordinates Ordination (PCO) of PoR metal concentrations across zones. *Metals were overlaid as vectors (in red) to determine the specific parameters driving the spatial variation. The closer the end of the vector to the circle, the stronger the correlation between the parameter and the survey to which the line is directed. A Hierarchical Cluster Analysis was also performed and overlaid (green =2 and blue =3) to indicate the level of similarity between the zones. The lower the 'Euclidean distance' number, the more similar the zones were regarding metals.*

4 Summary

Physicochemical characteristics at the three PoR monitoring sites were largely similar during each survey. Turbidity was highly influenced by prevailing tidal conditions, with higher levels during periods of higher tidal ranges. Lowest tidal ranges were evident during the November sampling, with turbidity and TSS also lowest during this survey, although QWQG were still exceeded. Significantly higher turbidity and TSS was recorded at PoR than at the adjacent and reference PCIMP zones as typically observed in this mangrove dominated estuary. In contrast conductivity was slightly lower, most likely due to freshwater inputs from the Fitzroy River into PoR.

Nutrient concentrations were also lower in PoR during the November survey mostly likely due to utilisation by reproducing algal populations moving into the warmer months. Concentrations of most nutrients were similar from March to August, except for elevated concentrations of ammonia, NOx and TOC during August, which is likely attributable to the high concentrations of TSS during this survey in addition to dormant algal populations. However, elevated ammonia and NOx was not restricted to PoR with adjacent and reference PCIMP zones also exhibiting high concentrations during August 2019, suggesting a regional seasonal phenomenon.

Concentrations off all nutrients (except DOC) were found to be significantly higher at PoR than the adjacent and reference PCIMP zones, similar to what has been reported from 2015 to 2018 (Vision Environment, 2016, 2017, 2018, 2019a). The higher nutrient concentrations in PoR may be associated with fertiliser runoff from farmland, which is more predominant in the Fitzroy River catchment area than in the PoG surroundings. However, elevated nutrients did not result in increased algal biomass, as chlorophyll *a* concentrations were significantly lower than adjacent PCIMP site concentrations. Low water clarity as a result of elevated turbidity and TSS and thus less light availability at PoR may have inhibited microalgal growth

Total metals in PoR were generally highest during the spring tide March and June surveys. Dissolved metals tended to remain reasonable consistent throughout 2019.

Concentrations of total aluminium, chromium, cobalt and copper were recorded above the 95% AWQG in at least one site during one or more surveys. However, dissolved concentrations of all four metals were low (often < LOR) during all surveys, indicating low bioavailability despite elevated total concentrations.

Similar to nutrients, concentrations of total aluminium, chromium, iron, manganese, nickel, vanadium and zinc were significantly higher in PoR than all other zones, consistent with what has been reported from 2015 to 2018 (Vision Environment, 2016, 2017, 2018, 2019a). The shallower PoR basin is likely to be conducive to the deposition of fine sediments (and therefore subsequent resuspension of sediment bound metals), in comparison to the deeper channels of the adjacent PCIMP zones.

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6 APPENDIX

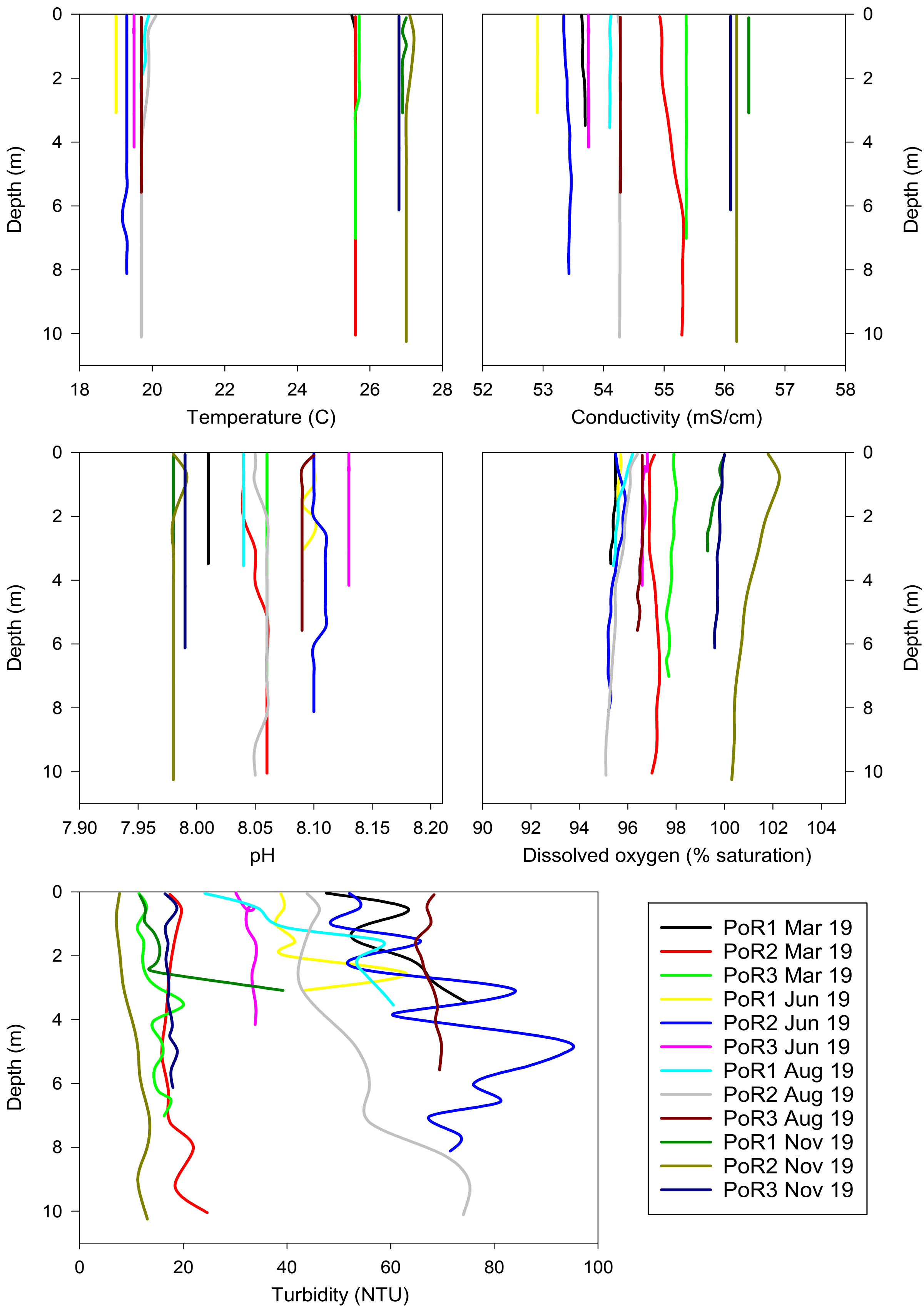

Figure 22 Depth-profiled physicochemical parameters at all Port of Rockhampton sites during 2019.

Table 6 Physicochemical parameters at PoR, and adjacent and reference PCIMP zones during 2019 surveys.
Values are means ± se (n = 64 to 153) of whole column. 20th to 80th WQO percentile ranges listed for pH and DO, with two 80th percentile trigger value for turbidity listed: Wet Season (March and November) and Dry Season (June and August). No WQO are available for PoR sites, so QWQG used (DERM, 2009).

Site	Survey	Temperature (ºC)	Conductivity (mS/cm)	pH	Turbidity (NTU)	Dissolved oxygen (% sat.)
PoR	Mar-19	25.6 ± 0.0	54.8 ± 0.1	8.0 ± 0.0	28 ± 2	97 ± 0
	Jun-19	19.3 ± 0.0	53.4 ± 0.0	8.1 ± 0.0	50 ± 2	96 ± 0
	Aug-19	19.8 ± 0.0	54.2 ± 0.0	8.1 ± 0.0	58 ± 1	96 ± 0
	Nov-19	26.9 ± 0.0	56.2 ± 0.0	8.0 ± 0.0	14 ± 1	100 ± 0
	QWQG	**-**	**-**	**7.0 – 8.4**	**8**	**85 - 100**
NW	Mar-19	25.7 ± 0.0	56.6 ± 0.1	7.9 ± 0.0	15 ± 1	94 ± 0
	Jun-19	18.7 ± 0.0	55.4 ± 0.2	8.0 ± 0.0	10 ± 1	95 ± 0
	Aug-19	19.5 ± 0.0	55.7 ± 0.0	7.9 ± 0.0	9.3 ± 1.1	96 ± 0
	Nov-19	27.7 ± 0.0	57.3 ± 0.0	7.8 ± 0.0	4.3 ± 0.3	99 ± 0
	WQO	**-**	**-**	**7.4 – 8.3**	**30, 12**	**87 - 95**
WB	Mar-19	26.0 ± 0.0	57.7 ± 0.0	7.9 ± 0.0	15 ± 0	96 ± 0
	Jun-19	19.8 ± 0.0	56.1 ± 0.0	8.0 ± 0.0	5.2 ± 0.1	97 ± 0
	Aug-19	19.8 ± 0.0	55.6 ± 0.0	8.0 ± 0.0	4.4 ± 0.1	99 ± 0
	Nov-19	27.3 ± 0.0	57.1 ± 0.0	7.9 ± 0.0	3.6 ± 0.0	98 ± 0
	WQO	**-**	**-**	**7.4 – 8.3**	**29, 17**	**91 - 100**
RCI	Mar-19	26.2 ± 0.0	56.4 ± 0.1	8.0 ± 0.0	2.9 ± 0.1	93 ± 1
	Jun-19	18.6 ± 0.0	55.4 ± 0.0	8.0 ± 0.0	1.9 ± 0.1	95 ± 0
	Aug-19	19.4 ± 0.0	55.6 ± 0.0	7.9 ± 0.0	1.1 ± 0.0	93 ± 1
	Nov-19	26.2 ± 0.0	56.7 ± 0.1	7.9 ± 0.0	1.4 ± 0.0	97 ± 1
	WQO	**-**	**-**	**7.4 – 8.3**	**14, 4**	**86 - 97**
RB	Mar-19	26.4 ± 0.0	56.0 ± 0.1	8.1 ± 0.0	4.4 ± 0.2	98 ± 1
	Jun-19	18.5 ± 0.0	55.3 ± 0.0	8.1 ± 0.0	2.6 ± 0.2	98 ± 0
	Aug-19	19.2 ± 0.0	55.5 ± 0.0	8.0 ± 0.0	1.9 ± 0.1	94 ± 0
	Nov-19	26.2 ± 0.0	56.7 ± 0.1	7.9 ± 0.0	5.9 ± 0.5	96 ± 0
	WQO	**-**	**-**	**7.4 – 8.3**	**12, 7**	**93 - 98**

Table 7 Chlorophyll *a*, nutrient and TSS concentrations at PoR, and adjacent and reference PCIMP zones during 2019 surveys. *Values are means ± se (n = 3 to 6). WQG are the 80th percentile WQO as per EHP (2014). No WQO are available for the PoR sites, so QWQG for Central Coast Queensland Region – 'Mid-Estuarine and Tidal Canals, Constructed Estuaries, Marinas and Boat Harbours' have been used (DERM, 2009). Additionally, no WQO is available for TSS, so the QWQG are used instead. Values exceeding WQO or QWQG are highlighted in green.*

Site	Survey	Chlorophyll *a* (µg/L)	Phosphorous (µg/L)	Orthophosphate (µg/L)	Nitrogen (µg/L)	Ammonia (µg/L)	NOx (µg/L)	TOC (mg/L)	DOC (mg/L)	TSS (mg/L)
PoR	Mar-19	1.5 ± 0.2	51 ± 22	6 ± 3	197 ± 54	4 ± 2	9 ± 5	1.2 ± 0.4	<1	67 ± 32
	Jun-19	0.4 ± 0.0	76 ± 12	8 ± 2	230 ± 32	5 ± 2	12 ± 3	2.0 ± 0.0	<1	106 ± 20
	Aug-19	0.4 ± 0.1	59 ± 6	8 ± 1	240 ± 21	20 ± 0	27 ± 6	3.0 ± 0.6	<1	187 ± 72
	Nov-19	0.6 ± 0.1	25 ± 2	7 ± 0	173 ± 3	<2	17 ± 0	1.7 ± 0.3	1.1 ± 0.0	24 ± 2
	WQG	**4.0**	**25**	**8**	**300**	**10**	**10**	**-**	**-**	**20**
NW	Mar-19	2.2 ± 0.2	24 ± 5	2 ± 1	175 ± 11	5 ± 1	3 ± 1	1.7 ± 0.2	1.3 ± 0.2	44 ± 10
	Jun-19	0.4 ± 0.1	14 ± 4	3 ± 1	143 ± 15	3 ± 1	4 ± 2	1.2 ± 0.2	<1	25 ± 9
	Aug-19	0.5 ± 0.1	12 ± 4	3 ± 1	120 ± 15	9 ± 2	10 ± 2	1.7 ± 0.2	<1	30 ± 6
	Nov-19	1.4 ± 0.2	13 ± 2	2 ± 1	167 ± 6	<2	7 ± 4	2.0 ± 0.0	1.3 ± 0.1	25 ± 5
	WQG	**2.0**	**29**	**7**	**220**	**10**	**9**	**-**	**-**	**20**
WB	Mar-19	2.4 ± 0.1	22 ± 2	<2	180 ± 6	3 ± 1	<2	1.5 ± 0.2	1.2 ± 0.0	57 ± 16
	Jun-19	1.0 ± 0.1	11 ± 1	<2	142 ± 5	2 ± 1	<2	2.0 ± 0.0	<1	14 ± 2
	Aug-19	0.4 ± 0.0	9 ± 1	<2	108 ± 5	6 ± 2	4 ± 2	1.3 ± 0.2	1.0 ± 0.1	14 ± 1
	Nov-19	0.8 ± 0.2	8 ± 0	<2	152 ± 5	<2	<2	1.7 ± 0.2	1.2 ± 0.1	16 ± 3
	WQG	**2.0**	**29**	**7**	**210**	**8**	**16**	**-**	**-**	**20**
RCI	Mar-19	1.0 ± 0.1	4 ± 0	<2	118 ± 9	<2	<2	1.0 ± 0.4	1.0 ± 0.1	28 ± 6
	Jun-19	0.4 ± 0.1	<3	<2	85 ± **10**	<2	<2	0.8 ± 0.1	<1	6 ± 3
	Aug-19	0.3 ± 0.0	3 ± 0	<2	93 ± 8	7 ± 2	6 ± 4	1.3 ± 0.3	<1	25 ± 5
	Nov-19	1.4 ± 0.3	5 ± 0	<2	140 ± 7	<2	4 ± 3	1.5 ± 0.3	1.3 ± 0.1	10 ± 3
	WQG	**1.4**	**15**	**3**	**180**	**15**	**5**	**-**	**-**	**20**
RB	Mar-19	1.1 ± 0.2	7 ± 2	<2	133 ± 3	<2	<2	0.8 ± 0.2	<1	37 ± 10
	Jun-19	0.3 ± 0.1	4 ± 2	<2	107 ± 9	<2	<2	0.8 ± 0.2	1.1 ± 0.1	15 ± 2

Site	Survey	Chlorophyll *a* (µg/L)	Phosphorous (µg/L)	Orthophosphate (µg/L)	Nitrogen (µg/L)	Ammonia (µg/L)	NOx (µg/L)	TOC (mg/L)	DOC (mg/L)	TSS (mg/L)
	Aug-19	0.6 ± 0.0	5 ± 1	<2	130 ± 6	6 ± 2	2 ± 1	1.0 ± 0.0	1.0 ± 0.1	18 ± 5
	Nov-19	1.1 ± 0.1	10 ± 3	<2	177 ± 20	3 ± 2	3 ± 2	2.0 ± 0.0	1.3 ± 0.1	14 ± 8
	WQG	**2.2**	**21**	**3**	**200**	**4**	**9**	**-**	**-**	**20**

Table 8 Total and dissolved metal concentrations at PoR, and adjacent and reference PCIMP zones during 2019 surveys.
Values are means ± se (n = 2 to 6). Note the 99% AWQG applicable to the Narrows, Colosseum Inlet and Rodds Bay (DSITIA, 2014, EHP, 2014)

Site	Survey	Aluminium (µg/L)		Arsenic (µg/L)		Cadmium (µg/L)		Chromium (µg/L)		Cobalt (µg/L)		Copper (µg/L)	
		Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total
PoR	Mar 19	11 ± 2	1800 ± 859	1.5 ± 0.0	2.2 ± 0.3	<0.1	<0.1	<1	3.8 ± 1.6	<1	<1	<1	1.1 ± 0.6
	Jun 19	<5	2430 ± 715	1.2 ± 0.0	2.1 ± 0.2	<0.1	<0.1	<1	4.9 ± 1.0	<1	1.0 ± 0.3	<1	1.3 ± 0.3
	Aug 19	<5	930 ± 47	1.2 ± 0.1	2.2 ± 0.1	<0.1	<0.1	<1	2.5 ± 0.1	<1	1.0 ± 0.3	<1	2.2 ± 0.0
	Nov 19	11 ± 3	760 ± 218	1.2 ± 0.0	1.4 ± 0.1	<0.1	<0.1	<1	1.8 ± 0.5	<1	<1	<1	<1
NW	Mar 19	7 ± 1	1063 ± 275	1.1 ± 0.0	1.8 ± 0.1	<0.1	<0.1	<1	1.8 ± 0.5	<1	<1	<1	<1
	Jun 19	<5	450 ± 216	1.0 ± 0.1	1.2 ± 0.2	<0.1	<0.1	<1	1.1 ± 0.4	<1	<1	<1	<1
	Aug 19	7 ± 1	98 ± 41	<1	0.9 ± 0.2	<0.1	<0.1	<1	3.3 ± 2.8	<1	<1	<1	1.1 ± 0.4
	Nov 19	8 ± 1	238 ± 92	1.1 ± 0.0	1.3 ± 0.0	<0.1	<0.1	<1	<1	<1	<1	<1	<1
WB	Mar 19	10 ± 2	820 ± 83	1.3 ± 0.0	1.8 ± 0.1	<0.1	<0.1	<1	2.0 ± 0.5	<1	<1	<1	<1
	Jun 19	9 ± 1	387 ± 53	1.1 ± 0.0	1.4 ± 0.1	<0.1	<0.1	<1	<1	<1	<1	<1	1.2 ± 0.2
	Aug 19	8 ± 1	208 ± 25	1.1 ± 0.0	1.2 ± 0.0	<0.1	<0.1	<1	<1	<1	<1	<1	<1
	Nov 19	<5	242 ± 22	1.3 ± 0.1	1.5 ± 0.1	<0.1	<0.1	<1	<1	<1	<1	1.3 ± 0.3	1.0 ± 0.2
RCI	Mar 19	5 ± 2	155 ± 27	1.4 ± 0.0	1.7 ± 0.0	<0.1	<0.1	<1	<1	<1	<1	<1	<1
	Jun 19	11 ± 0	69 ± 7	1.5 ± 0.1	1.3 ± 0.0	<0.1	<0.1	<1	<1	<1	<1	<1	<1
	Aug 19	9 ± 1	25 ± 2	1.1 ± 0.0	1.2 ± 0.0	<0.1	<0.1	<1	<1	<1	<1	<1	<1
	Nov 19	<5	93 ± 7	1.4 ± 0.1	1.7 ± 0.1	<0.1	<0.1	<1	<1	<1	<1	<1	<1
RB	Mar 19	5 ± 2	243± 56	1.3 ± 0.0	1.8 ± 0.1	<0.1	<0.1	<1	<1	<1	<1	<1	<1
	Jun 19	15 ± 1	99 ± 38	1.6 ± 0.1	1.4 ± 0.1	<0.1	<0.1	<1	<1	<1	<1	<1	<1
	Aug 19	<5	45 ± 8	1.2 ± 0.0	1.3 ± 0.1	<0.1	<0.1	<1	<1	<1	<1	<1	<1
	Nov 19	<5	283 ± 103	1.6 ± 0.0	1.9 ± 0.2	<0.1	<0.1	<1	<1	<1	<1	<1	<1
95% AWQG		**24**		**-**		**5.5**		**Cr(III) 27.4, Cr(VI) 4.4**		**1**		**1.3**	
99% AWQG		**2.1**		**-**		**0.7**		**Cr(III) 7.7, Cr(VI) 0.14**		**0.005**		**0.3**	

Table cont.

Site	Survey	Gallium (µg/L)		Iron (µg/L)		Lead (µg/L)		Manganese (µg/L)		Mercury (µg/L)	
		Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total
PoR	Mar 18	<1	<1	<5	2190 ± 1017	<1	<1	<1	34 ± 15	<0.1	<0.1
	Jun 18	<1	<1	<5	2417 ± 692	<1	<1	<1	42 ± 9	<0.1	<0.1
	Aug 18	<1	<1	<5	1437 ± 118	<1	1.0 ± 0.3	<1	51 ± 6	<0.1	<0.1
	Nov 18	<1	<1	<5	920 ± 238	<1	<1	1.0 ± 0.5	13 ± 3	<0.1	<0.1
NW	Mar 18	<1	<1	<5	1023 ± 253	<1	<1	1.1 ± 0.4	17 ± 3	<0.1	<0.1
	Jun 18	<1	<1	20 ± 18	472 ± 216	<1	<1	2.2 ± 0.6	12 ± 4	<0.1	<0.1
	Aug 18	<1	<1	<5	145 ± 68	<1	<1	2.8 ± 0.8	8 ± 2	<0.1	<0.1
	Nov 18	<1	<1	<5	298 ± 117	<1	<1	3.8 ± 0.9	10 ± 1	<0.1	<0.1
WB	Mar 18	<1	<1	<5	923 ± 92	<1	<1	2.4 ± 1.0	19 ± 2	<0.1	<0.1
	Jun 18	<1	<1	<5	407 ± 53	<1	<1	2.5 ± 0.4	13 ± 1	<0.1	<0.1
	Aug 18	<1	<1	<5	235 ± 29	<1	<1	1.0 ± 0.3	7 ± 0	<0.1	<0.1
	Nov 18	<1	<1	<5	210 ± 20	<1	<1	2.2 ± 0.6	9 ± 1	<0.1	<0.1
RCI	Mar 18	<1	<1	<5	145 ± 31	<1	<1	2.5 ± 1.5	5 ± 2	<0.1	<0.1
	Jun 18	<1	<1	<5	62 ± 6	<1	<1	2.1 ± 0.7	3 ± 1	<0.1	<0.1
	Aug 18	<1	<1	<5	23 ± 2	1.0 ± 0.5	<1	3.4 ± 0.6	4 ± 1	<0.1	<0.1
	Nov 18	<1	<1	6 ± 4	67 ± 6	<1	<1	2.3 ± 0.8	4 ± 1	<0.1	<0.1
RB	Mar 18	<1	<1	<5	253 ± 55	<1	<1	2.2 ± 0.0	6 ± 1	<0.1	<0.1
	Jun 18	<1	<1	<5	102 ± 41	<1	<1	1.9 ± 0.0	3 ± 1	<0.1	<0.1
	Aug 18	<1	<1	<5	51 ± 12	<1	<1	3.8 ± 1.0	6 ± 1	<0.1	<0.1
	Nov 18	<1	<1	<5	233 ± 98	<1	<1	1.6 ± 0.6	7 ± 1	<0.1	<0.1
95% AWQG		**-**		**-**		**4.4**		**-**		**0.4**	
99% AWQG		**-**		**-**		**2.2**		**-**		**0.1**	

Table cont.

Site	Survey	Molybdenum (µg/L)		Nickel (µg/L)		Silver (µg/L)		Tin (µg/L)		Vanadium (µg/L)		Zinc (µg/L)	
		Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total
PoR	Mar 18	11 ± 0	12 ± 0	<1	2.9 ± 1.4	<1	<1	<1	<1	3.1 ± 0.3	7.1 ± 2.0	<1	2.5 ± 1.6
	Jun 18	11 ± 0	11 ± 0	<1	3.3 ± 0.7	<1	<1	<1	<1	1.9 ± 0.1	7.2 ± 1.1	<1	1.4 ± 0.9
	Aug 18	10 ± 0	10 ± 0	<1	2.8 ± 0.1	<1	<1	<1	<1	2.0 ± 0.1	6.7 ± 0.3	1.4 ± 0.4	3.3 ± 0.6
	Nov 18	10 ± 0	11 ± 0	<1	1.8 ± 0.2	<1	<1	<1	<1	1.8 ± 0.0	3.4 ± 0.4	2.1 ± 0.8	1.5 ± 0.5
NW	Mar 18	12 ± 0	14 ± 1	<1	1.5 ± 0.3	<1	<1	<1	<1	2.1 ± 0.2	5.0 ± 0.4	<1	1.6 ± 0.3
	Jun 18	11 ± 0	12 ± 0	<1	<1	<1	<1	<1	<1	1.9 ± 0.1	3.0 ± 0.5	<1	<1
	Aug 18	9 ± 2	12 ± 0	<1	<1	<1	<1	<1	<1	1.4 ± 0.2	2.3 ± 0.3	1.7 ± 0.5	2.0 ± 0.0
	Nov 18	11 ± 0	12 ± 0	<1	<1	<1	<1	<1	<1	1.9 ± 0.1	2.5 ± 0.2	<1	1.4 ± 0.6
WB	Mar 18	13 ± 0	13 ± 0	<1	<1	<1	<1	<1	<1	2.7 ± 0.1	5.2 ± 0.2	<1	1.9 ± 0.2
	Jun 18	12 ± 0	13 ± 0	<1	<1	<1	<1	<1	<1	2.3 ± 0.1	3.3 ± 0.1	2.1 ± 0.3	2.3 ± 0.3
	Aug 18	12 ± 0	12 ± 0	<1	6.3 ± 1.0	<1	<1	<1	<1	2.2 ± 0.1	2.9 ± 0.1	1.6 ± 0.0	2.7 ± 0.5
	Nov 18	14 ± 0	12 ± 0	1.2 ± 0.2	<1	<1	<1	<1	<1	2.1 ± 0.2	7.9 ± 0.3	<1	1.6 ± 0.5
RCI	Mar 18	12 ± 0	13 ± 0	<1	<1	<1	<1	<1	<1	2.1 ± 0.1	2.9 ± 0.1	<1	<1
	Jun 18	11 ± 0	12 ± 0	<1	<1	<1	<1	<1	<1	2.5 ± 0.1	2.1 ± 0.1	1.2 ± 0.7	<1
	Aug 18	11 ± 0	11 ± 0	<1	<1	<1	<1	<1	<1	1.6 ± 0.0	1.8 ± 0.1	2.3 ± 0.5	1.6 ± 0.4
	Nov 18	12 ± 0	10 ± 0	<1	<1	<1	<1	<1	<1	2.1 ± 0.1	7.7 ± 0.5	<1	<1
RB	Mar 18	12 ± 0	12 ± 0	<1	<1	<1	<1	<1	<1	2.0 ± 0.1	3.1 ± 0.1	<1	<1
	Jun 18	11 ± 0	12 ± 0	<1	<1	<1	<1	<1	<1	2.9 ± 0.0	2.3 ± 0.0	<1	<1
	Aug 18	11 ± 0	12 ± 0	<1	<1	<1	<1	<1	<1	1.5 ± 0.1	1.9 ± 0.1	1.4 ± 0.4	2.0 ± 0.0
	Nov 18	12 ± 0	10 ± 0	<1	<1	<1	<1	<1	<1	1.8 ± 0.1	8.2 ± 0.0	1.2 ± 0.1	<1
95% AWQG		**-**		**70**		**1.4**		**-**		**100**		**15**	
99% AWQG		**-**		**7**		**0.8**		**-**		**50**		**7**	

Table 9 Results of two-way ANOVAs for PoR statistical comparison with PCIMP zones.
Note no analyses able to be performed for, total and dissolved cadmium, dissolved chromium, total and dissolved cobalt, dissolved copper, total and dissolved gallium, dissolved iron, total and dissolved lead, total and dissolved mercury, dissolved nickel, dissolved and total silver, dissolved and total tin as site concentrations generally < LOR.

Parameter	Zone		Survey		Interaction		Comment
	P-value	F statistic	P-value	F statistic	P-value	F statistic	
Temperature	<0.01	385	<0.01	102770	<0.01	272	Lower temperatures in June and August than November and March. Temperatures in NW and WB higher than RB and RCI
Conductivity	0.05	9	<0.01	8	0.08	6	Conductivity lower in PoR than other zones
pH	<0.01	314	<0.01	268	<0.01	23	pH in June higher than November pH in PoR higher than NW and WB.
Turbidity	<0.01	1119	<0.01	129	<0.01	125	Turbidity in March higher than November Turbidity in PoR higher than other zones.
DO	<0.01	89	<0.01	103	<0.01	41	DO in November higher than March DO in RCI lower than other zones.
Chlorophyll *a*	<0.01	8.9	<0.01	74	<0.01	7	Chlorophyll highest in March, followed by November Chlorophyll higher in NW and WB
Phosphorus	<0.01	55	<0.01	5	<0.01	4	Phosphorus higher in March than November Phosphorus higher in POR than other zones. Lowest in RCI
FRP	<0.01	43	0.80	0.3	0.93	0.5	FRP highest in PoR, followed by NW
Nitrogen	<0.01	23	0.01	4	<0.01	3	Nitrogen highest in March and November Nitrogen highest in PoR
Ammonia	<0.01	9	<0.01	47	<0.01	5	Ammonia highest in August Ammonia highest in PoR
Nitrogen oxides	<0.01	20	<0.01	8	0.36	1	NOx highest in August NOx highest in PoR
TOC	<0.01	8	<0.01	6	<0.01	4	TOC higher in November than March and June TOC higher in PoR, NW and WB, than RB and RCI
DOC	0.49	1	<0.01	6	0.82	1	DOC higher in November and March than June and August.
TSS	<0.01	16	<0.01	6	<0.01	4	TSS in March higher than November TSS in PoR higher than other zones.
Dissolved Al	0.85	0	<0.01	5	<0.01	7	Higher Al in June than in November
Total Al	<0.01	22	<0.01	8	0.01	2	Higher Al in March and June than August and November Highest Al in PoR than other zones
Dissolved As	<0.01	40	<0.01	27	0.01	4	Lower As in August Lowest As in NW
Total As	<0.01	17	<0.01	13	<0.01	3	Highest As in March Highest As in PoR

Parameter	Zone		Survey		Interaction		Comment
	P-value	F statistic	P-value	F statistic	P-value	F statistic	
Total Cr	<0.01	4	0.51	1	0.72	1	Highest Cr in PoR
Total Cu	0.08	2	0.10	2	0.07	2	
Total Fe	<0.01	28	<0.01	7	0.11	2	Highest Fe in March Highest Fe in PoR
Dissolved Mn	<0.01	4	0.61	1	0.19	1	Lowest Mn in PoR
Total Mn	<0.01	41	<0.01	5	<0.01	4	Lowest Mn in November Highest Mn in PoR
Dissolved Mo	<0.01	12	<0.01	6	0.24	1	Lowest Mo in August Highest Mo in WB
Total Mo	<0.01	15	<0.01	17	0.05	2	Highest Mo in March Highest Mo in WB
Total Ni	<0.01	18	<0.01	8	<0.01	12	Highest Ni in August Highest Ni in PoR
Dissolved V	<0.01	10	<0.01	27	<0.01	6	Highest V in March and June Highest V in PoR and WB
Total V	<0.01	23	<0.01	35	<0.01	20	Highest V in November Highest V in PoR
Dissolved Zn	0.16	2	<0.01	12	<0.01	3	Highest Zn in August
Total Zn	<0.01	7	<0.01	7	0.83	1	Highest Zn in August Highest Zn in PoR and WB