Department of Primary Industries and Regional Development

GOVERNMENT OF WESTERN AUSTRALIA

ORIA STAGE II EXPANSION KEEP RIVER

FIRST POST-DEVELOPMENT AQUATIC FAUNA & TARGETED SAWFISH SURVEY - 2020

Final Report

WRM
Wetland Research & Management

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ORIA Stage II Expansion – Keep River

First Post-Development Aquatic Fauna & Targeted Sawfish Survey September/October 2020

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Frontispiece: (top) juvenile freshwater sawfish (*Pristis pristis*) at site K3-5; *(bottom)* Policemans' Waterhole (KR2) (photos by WRM ©).

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EXECUTIVE SUMMARY

In 2008 the Ord Irrigation Expansion Project was approved by the Western Australian Government to develop irrigated agriculture on the Weaber Plain and surrounding areas. The expansion, referred to as greater Ord Stage 2 included land along the lower Ord (Packsaddle, West Bank, Carlton Station and Mantinea), the Cockatoo Sands, as well as the Weaber, Keep River and Knox Creek Plains as suitable for development. Construction of the M2 supply channel connecting the Ord River Irrigation Area and Weaber Plain, and the final period of irrigation design, environmental management and related approval processes, commenced in 2010. Approximately 7,400 ha were granted to develop the Weaber Plain, now referred to as Goomig farmlands, requiring 120 GL irrigation supply from Lake Argyle. The farm design in the development is based on the use of an irrigation tail-water management system, with irrigation runoff from irrigated land to be reused on farms (GHD 2010).

Wetland Research & Management (WRM) were commissioned by LandCorp to survey macroinvertebrate and fish assemblages to establish baseline ecological condition, as well as occurrence of listed species, including targeted sampling for sawfish and *Glyphis* sharks. WRM were then commissioned to undertake three pre-development baseline surveys of the Keep River, with surveys completed in 2011, 2012 and 2013. Part of baseline data collection was to also provide data on sediment and water quality that were used to develop interim local surface water trigger values for assessing effects of any discharge to the Keep River. WRM applied standardised methodology across all three baseline surveys (2011, 2012 & 2013) and thereby developed a robust baseline to allow detection of any future impacts from the ORIA Stage 2.

Project Conditions require three-post-development surveys to assess changes to listed species and ecosystem health as a result of the development. WRM were commissioned to conduct the first of these post-development surveys, with the same four main river pools, three estuary and five reference sites re-visited in September 2020, with sampling conducted using identical methods to baseline sampling.

Findings from the 2020 survey

Sediment

- Many metals in sediment samples taken in 2020 exceeded the maximum values recorded in baseline surveys. These included Al, B, Cr, Cu, Fe, Ga, Li, Ni, Pb, Se, Ti, U, V and Zn.
- High levels of Total-N and in particular nitrate (NO_3) were detected most notably between pool K3 and K1.
- No detectable levels of the herbicide atrazine (ATZ) were found in any sediment taken on the Keep River.

Water Quality

- Increasing levels of Total-N and in particular nitrate (NO_3) were detected most notably between pool K3 and K1 in both the sediment samples and the water quality readings.
- Water quality analysis also found total-P was significantly higher in 2020 than all previous baseline years and significantly higher in estuary sites than the Keep river pools or reference sites.
- There appears to be a steady significant trend of increasing total nitrogen in the system since 2011.
- The increase in nitrogen is most prominent between K3, K2 and K1 where the values are all exceeding or close to the maximum levels recorded during baseline whereas the total-P increases are further downstream.
- High dissolved oxygen was recorded at all sites across the system. It is possible that the increase in nutrients is creating ideal conditions for photosynthetic material (algae) to increase and in turn are contributing to the increase of daytime dissolved oxygen.

Macroinvertebrates

- Richness and abundance, aquatic macroinvertebrate assemblages recorded during 2020 were found to be statistically similar to most baseline years across all sites.
- The exception being a significant increase in diversity compared to 2013 at sites K1 and K2 which were notably low in richness likely due to algal blooms at both sites that year.
- Species composition continues to be driven by water quality at each site but remains similar in 2020 when compared to baseline years.

Fish Species

- The total number of sawfish caught in 2020 (14 individuals) was comparable to baseline years 2011 (14 individuals), 2012 (22 individuals) and 2013 (6 individuals).
- No *Glyphis* sharks were recorded in 2020.
- Fish species richness was found to be significantly higher overall in 2020 than in the previous survey 2013, however it was not significantly different from 2011 or 2012.
- Species richness, abundance and biomass was not significantly different between all pools sampled in 2020.
- Keep River pools continue to support high diversity of fish species, supporting at least 40 of the 46 species known from the Keep River caught during the combined surveys.

The distinct increase in nutrient and metal levels between pools K3 and K1 are of some concern as they are directly below the Border Creek confluence with the Keep River and as such could be attributed to the effects of the tailwater discharge down Border Creek. However, these changes do not appear to be system wide, as the non-exposed site K4 did not exhibit altered sediment composition between years.

Other factors that correlate with the exceedances downstream of pool K4 include:

- major earthworks, upgrade and bituminising of the Legune Road,
- operation of a gravel pit to the west of the Keep River, close to Border Creek, with various points of wet season run-off to the Keep River
- construction of a major bridge across the Keep between pools K3 and K4,
- release of irrigation return water down Border Creek,
- release of M2 flushing water down Border Creek into the Keep River between pools K4 and K3 and,
- two consecutive years of below-average rainfall preceding the current survey.

Further sampling and investigation would be required to identify if any of the above activities were responsible for the observed changes.

Based on the 2020 monitoring it is recommended that:

i) Given the discharge of tailwater and M2 flushing water down Border Creek, two sites situated on Border Creek that were sampled during baseline years should be added during the next round of post-development surveys. Sampling should include water and sediment quality, as well as macroinvertebrates and fish. WRM has baseline data for Border Creek and it would be invaluable to discern the source of any adverse effects of releases down Border Creek.

ii) Future sampling should continue to use the standardised current methods, locations and season to collect additional post-development monitoring data to allow direct comparison with existing pre-development data. By repeating the univariate and multivariate analyses presented here, as well as targeted analyses of subsets of the data to assess spatial and temporal changes in individual species and assemblages, it will be possible to detect any future changes in water quality and aquatic fauna, and differentiate natural changes from any effects of the Goomig development.

1 INTRODUCTION

1.1 Background

In 2008 the Ord Irrigation Expansion Project was approved by the Western Australian Government to develop irrigated agriculture on the Weaber Plain and surrounding areas. The expansion, referred to as greater Ord Stage 2 included land along the lower Ord (Packsaddle, West Bank, Carlton Station and Mantinea), the Cockatoo Sands, as well as the Weaber, Keep River and Knox Creek Plains as suitable for development.

Construction of the M2 supply channel connecting the Ord River Irrigation Area and Weaber Plain, and the final period of irrigation design, environmental management and related approval processes, commenced in 2010. Approximately 7,400 ha were granted to develop the Goomig farmlands requiring 120 GL irrigation supply from Lake Argyle. The farm design in the Weaber Plains development is based on the use of an irrigation tail-water management system, with irrigation runoff from irrigated land to be reused on farms (GHD 2010).

In June 2010, the Australian Federal Government determined that the project required approval under the EPBC Act, as the proposal was considered to have the potential to impact on a number of matters of National Environmental Significance. The proposal was assessed and has been approved, subject to twenty EPBC conditions, issued on 13 September 2011. Condition 10 of EPBC Act Approval 2010/5491 required the preparation of an Aquatic Fauna Management Plan in order to protect listed threatened aquatic fauna species in the Keep River. Those specifically mentioned in the condition include:

- the critically endangered Speartooth Shark (*Glyphis glyphis*),
- the endangered Northern River Shark (*Glyphis garricki*),
- the vulnerable Dwarf Sawfish (*Pristis clavata*), and
- the vulnerable Freshwater Sawfish (*Pristis microdon*; now referred to as *P. pristis*[1], Largetooth Sawfish).

Sub-conditions 10A to 10H detail specific protective and monitoring measures to be implemented for the protection of the listed species, and require approval from the Minister for Sustainability, Environment, Water, Population and Communities (recently renamed to Department of Environment) prior to the clearance of farm lots. Particular concerns related to the number of listed species present in pools in the lower Keep River, the size of their populations, how the pools are used (*i.e.* by adults or as nursery habitat for juveniles), and how the proposed development may affect the listed species, both directly (*i.e.* water quality) and indirectly (*i.e.* through changes to habitat and the food chain). Condition 10 also specified that a baseline survey program was conducted over a period of three years, and developed in consultation with the Independent Review Group (IRG). The IRG oversee hydrological aspects of the project and associated impacts on EPBC Act listed threatened species. The group consists of independent scientific and technical experts appointed under Condition 9 of EPBC Act Approval 2010/5491.

The Aquatic Fauna Management Plan (WRM 2012, Strategen 2012c) was formulated to meet each requirement of the EPBC Act Approval. The Plan requires:

- a targeted, non-lethal baseline survey for listed species likely to occur in the Keep River,

[1] *Pristis microdon* has recently undergone taxonomic revision due to results of genetic analyses. Faria *et al*. (2013) used mDNA to determine that the previously classified *P. pristis*, *P. microdon* and *P. perotteti* are all, in fact, the same species. Classification of the freshwater sawfish into a single circum-tropical species is also supported by common morphological features, including the robust rostrum, origin of first dorsal fin anterior to origin of pelvic fins, and presence of a caudal-fin lower lobe. Therefore, *P. microdon* and *P. perotteti* have been synonymised with *Pristis pristis* (largetooth sawfish). As such, this species will be referred to as *Pristis pristis* throughout this document.

- measures to maintain water quality in Keep River pools, and
- a targeted aquatic fauna monitoring program to measure the success of management, and to inform an adaptive management approach.

Wetland Research & Management (WRM) were commissioned by LandCorp to design the current monitoring program, including selection of appropriate sampling methods (WRM, 2012) for the baseline surveys of the Keep River for the ORIA Stage II Expansion Aquatic Fauna Management Plan. The aim was to survey macroinvertebrate and fish assemblages to establish baseline ecological condition, as well as occurrence of listed species, including targeted sampling for sawfish and *Glyphis* sharks. WRM were then commissioned to undertake three pre-development baseline surveys of the Keep River, with surveys completed in 2011 (WRM 2013a), 2012 (WRM 2013b) and 2013 (WRM, 2014). The baseline macroinvertebrate surveys were also used to satisfy Condition 11F of the Stormwater and Groundwater Discharge Management Plan (SEWPAC 2011), which requires development of AusRivAS (Australian River Assessment System) trigger levels for aquatic macroinvertebrates[2].

Part of baseline data collection was to also provide data on sediment and water quality that were used to develop surface water trigger values for assessing effects of any discharge to the Keep River. WRM applied standardised methodology across all three baseline surveys (2011, 2012 & 2013) and thereby developed a robust baseline to allow detection of any future impacts from the ORIA Stage 2.

As part of the Approval process, Conditions require three post-development surveys to test for any adverse effects of the Goomig development on Listed Species. In mid-2020, WRM were contracted by DPIRD, acting as proponent for the development, to undertake the first of the post-development surveys in September/October 2020. As per the current RFQ, the programs included:

i) Sediment Sampling - in potentially impacted (exposed) pools;
ii) Targeted Sawfish and Shark Survey - to ascertain distribution and population size within the potentially affected area;
iii) Aquatic Fauna Ecological Health Assessment - general macroinvertebrate, fish and water quality sampling in potentially exposed and reference (control) pools.

[2] Following development of the AusRivAS Trigger Values, they were deemed inappropriate for assessing adverse changes in brackish, estuarine pools, as these habitats were beyond the bounds of the models, and the Approval was amended to change the wording of Condition 11F to remove reference to AusRivAS trigger values, with wording changed to "Use of best practice multivariate analyses on species level macro-invertebrate and fish assemblage data, within an adequate experimental design (as defined in the Aquatic Fauna Management Plan required under condition 10), using multiple indices of 'ecological condition' and a 'weight of evidence' approach, to assess any change in ecological health of Keep River pools (K1, K2 & K3) relative to baseline and upstream reference sites".

1.2 Scope of Work

The scope of work for the 2020 surveys was to repeat the sampling programs conducted for the 2011, 2012 and 2013 surveys, in order to compare to the baseline data and to allow detection of any future impacts from the ORIA Stage 2. Programs included:

i) Sediment Sampling - in potentially impacted (exposed) pools;
ii) Targeted Sawfish and Shark Survey - to ascertain distribution and population size within the potentially affected area;
iii) Aquatic Fauna Ecological Health Assessment - general macroinvertebrate, fish and water quality sampling in potentially exposed and reference (control) pools.

Rationale and methods used have been previously described in reports for the 2011, 2012, 2013 baseline surveys (WRM 2013ab, WRM 2014) but, for completeness, are reproduced in the following sections for each program.

Field sampling was undertaken under appropriate licences and permits pertaining to each State and Territory as follows:

- Western Australian Department of Biodiversity, Conservation and Attractions Regulation 27 Permit BA27000295.
- Western Australian Department of Fisheries Exemption for Scientific Purposes EXEM3130.
- Northern Territory Department of Primary Industries Special Permit No. S17/3275.

1.3 System changes since pre-development baseline surveys

As part of developing the Goomig irrigation area, but also in preparation for expansion of the current irrigation area and proposed aquaculture development into the Northern Territory, a series of changes and developments have taken place since the last of three baseline surveys were completed in October 2013 that are directly relevant to the study area. These changes have the potential to adversely affect listed species and the ecological health of the Keep River downstream of the project area.

The changes include construction and sealing (bituminising) of the Legune Road associated with the Seafarms prawn aquaculture project on Legune station, construction of a major bridge over the Keep River at the old Legune Road Crossing, and operation of a gravel pit immediately to the west of the Legune Road Crossing for road construction material (Figure 1, Plate 1). Further changes also include the release of tailwater and M2 supply water down Border Creek and into the Keep River, and two consecutive years (2018, 2019) of poor wet season rainfall prior to the survey. Unfortunately, all of these activities occur between the K4 and K3 pools on the Keep River, and although not all are directly related to the expansion of the Ord Irrigation area, if any individual activity has an adverse effect on the river system, it may not be possible to separate the relative effects of any one activity.

During the 2020 survey, the potential influence of all the above activities on the river system were observed.

Plate 1. The newly constructed Legune crossing bridge between the K3 and K4 pools and upstream of the Border Creek confluence with the Keep River. **A.** 26 Sept 2020 **B**. 26 Nov 2020. Photo credit: Debra Pearce.

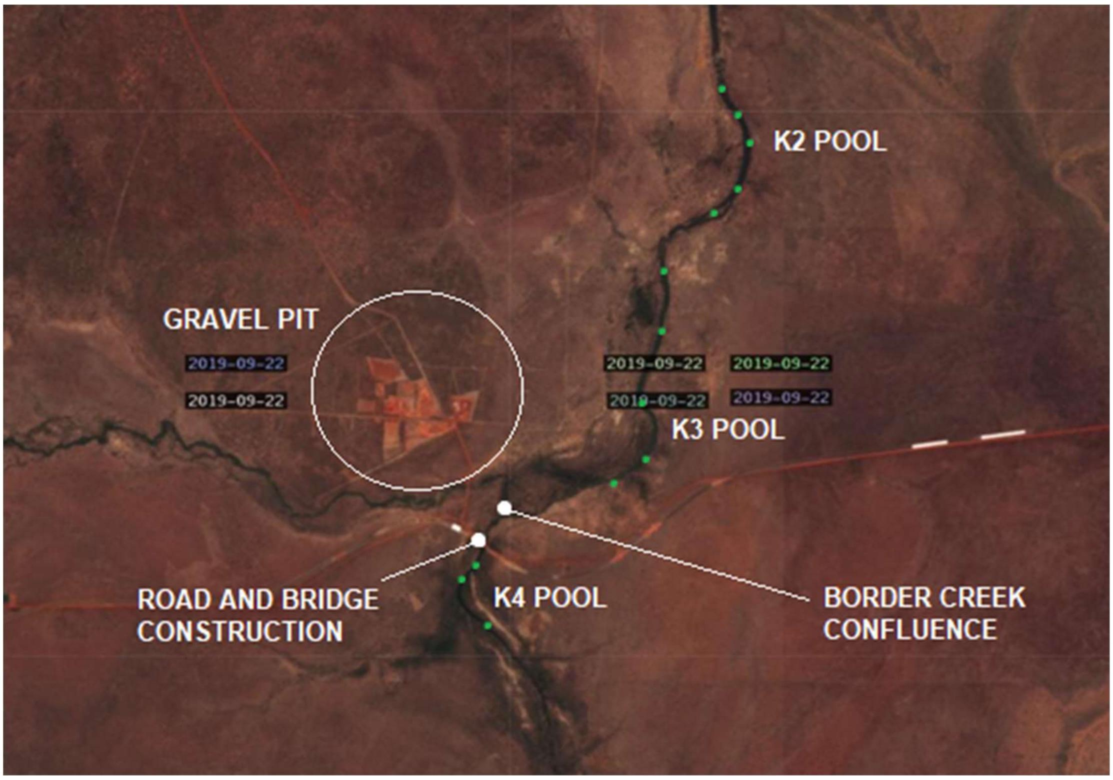


Figure 1. Keep river pool sites and their location relevant to various recent changes in the area occurring since pre-development baseline surveys.

Wet season (November to April) rainfall data from the Legune weather monitoring station (14803) is presented in Figure 2. Below average wet season rainfall was recorded in both 2018 and 2019 prior to the 2020 sampling (Sept 2020). The wet season is an important period of ecosystem productivity, dispersal and connectivity for northern Australian rivers as it facilitates freshwater-fish spawning and recruitment and poor wet seasons may result in reductions in abundance of fish species (King *et al.* 2020). Low rainfall may also reduce water levels in pool habitats and subsequently increase concentrations of dissolved nutrients and metals. Early wet season build-up and afternoon thunderstorms and rainfall prior to and during the current survey resulted in surface run-off from areas adjacent to the river which may also have influenced sampling results.

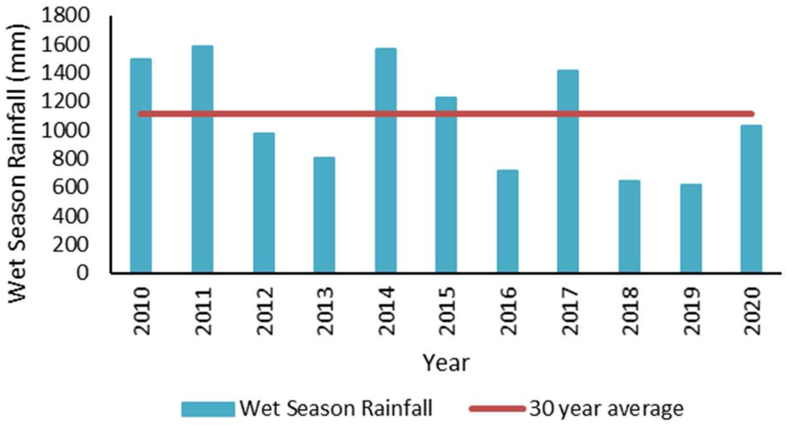


Figure 2. Total wet season rainfall (November to April) for the time period 2010 to 2020 recorded at the Legune gauging station (14803).

It is understood (R George, DPIRD, pers. com.) that an ongoing challenge for the Goomig development is that a component of irrigation drainage water from Ord Stage 1 flows through the Goomig development and is released down Border Creek. This drainage water then enters the Keep River immediately upstream of pool K3. As per the operational requirements of the Goomig development, and although this tailwater is not from the Goomig development *per se*, M2 supply water has been released down Border Creek and into the Keep to provide a flushing/dilution flow. During the 2020 survey Border Creek was flowing at various stages, with up to 50 – 100 L/sec of turbid water flowing under the Keep River estuary access track, with flows varying throughout the survey period. This water was assumed to be a mixture of tailwater and M2 supply water.

In addition to observed flows down Border Creek during the 2020 survey, a gravel pit close to Border Creek, and immediately west of the Keep River was in operation during the survey period, with gravel haulage occurring to provide construction material for the Legune Road to the east of the Keep River (Figure 1). Afternoon rainfall resulted in highly turbid run-off from the unsealed access road into creeklines feeding the Keep River. In addition, although not observed, there appeared to be dewatering activities from the gravel pit area, with small creeklines flowing with highly turbid water after rainfall events, and after other creeklines had dried. Again, this turbid water was reaching the Keep River.

Finally, activities associated with the construction and bituminising of the Legune Road to the east and west of the Keep River, and also construction of a substantial bridge over the Keep River (Plate 1), although all completed prior to the September 2020 survey, had the potential to affect the Keep River through increased siltation, potential hydrocarbon spills/releases, and run-off of chemicals from the newly laid bitumen.

Any changes observed in sediment or surface water quality in pools downstream of the Legune Road crossing, and Border Creek could reflect any of these activities.

2 SAMPLING SITES

A total of 26 sites were sampled between 19 September and 4 October 2020 (Table 1 & Figure 33 - Figure 4). Not all sites however, were sampled for all programs (refer to each specific section for further detail of sites sampled under that program). Site photographs are provided in Appendix 1.

Table 1. List of sampling sites and their corresponding GPS location (WGS84; degrees, decimal minutes). Type refers to whether the site is a potentially exposed (PE) or reference (R) site. Y = sampled.

CODE	DESCRIPTION	REP. CODE	LATITUDE	LONGITUDE	TYPE	SAMPLING PROGRAMS		
						Sediment	Sawfish & Sharks	Aquatic Fauna Ecological Health
EST01	Keep River estuary near end of airstrip	EST01	15° 19.583’	129° 07.087’	PE	Y	Y	
EST02	Keep River estuary mid-way between EST01 and EST03	EST02	15° 15.483’	129° 07.010’	PE	Y	Y	
EST03	Keep River estuary – mid estuary near old NRETAS gauging station	EST03	15° 13.792’	129° 07.314’	PE	Y	Y	
K1	Lower reach tidal pool	K1-1	15° 19.540’	129° 05.301’	PE	Y		Y
		K1-2	15° 20.038’	129° 05.764’	PE	Y		Y
		K1-3	15° 20.691’	129° 04.949’	PE	Y	Y	Y
		K1-4	15° 21.129’	129° 05.067’	PE	Y		Y
		K1-5	15° 21.659’	129° 05.025’	PE	Y		Y
K2	Middle reach brackish pool	K2-1	15° 22.122’	129° 05.114’	PE	Y		Y
		K2-2	15° 22.123’	129° 05.175’	PE	Y		Y
		K2-3	15° 22.358’	129° 05.186’	PE	Y	Y	Y
		K2-4	15° 22.531’	129° 05.120’	PE	Y		Y
		K2-5	15° 22.599’	129° 05.034’	PE	Y		Y
K3	Upper reach freshwater-brackish pool	K3-1	15° 22.865’	129° 04.782’	PE	Y		Y
		K3-2	15° 23.204’	129° 04.759’	PE	Y		Y
		K3-3	15° 23.503’	129° 04.684’	PE	Y	Y	Y
		K3-4	15° 23.767’	129° 04.669’	PE	Y		Y
		K3-5	15° 23.864’	129° 04.547’	PE	Y		Y
K4	Keep River freshwater pool upstream of Legune Road Crossing	K4-1	15° 24.284’	129° 03.854'	PE	Y		Y
		K4-2	15° 24.505’	129° 03.872'	PE	Y	Y	Y
		K4-3	15° 24.855’	129° 04.187'	PE	Y		Y
KE1	Milligan’s Lagoon, Keep R.	KE1	15° 37.069’	129° 00.388’	R			Y
KR1	Alligator Hole, Keep R.	KR1	15° 41.333’	129° 02.217’	R			Y
KR2	Policeman’s Waterhole, Keep R.	KR2	15° 44.450’	129° 04.400’	R			Y
SR4	Augustus Hole, Sandy Creek	SR4	15° 31.517’	129° 19.200’	R			Y
DR1	Dunham River at Sugarloaf Hill	DR1	16° 02.786’	128° 26.605’	R			Y

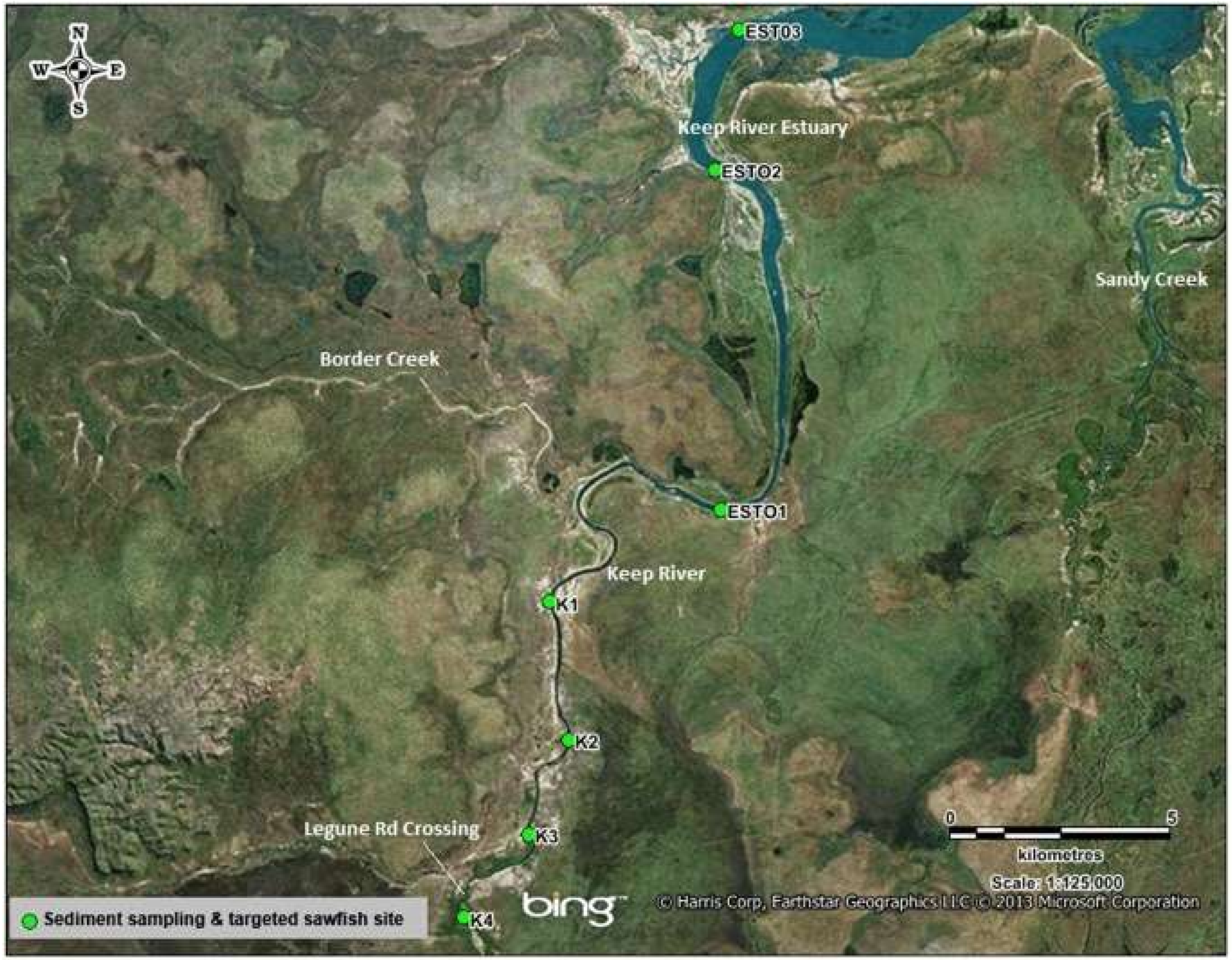


Figure 3. Location of sediment sampling and targeted sawfish and shark survey sites in the Keep River (pools and estuary sites).

Figure 4. Location of the aquatic fauna ecological health survey sites, showing potentially exposed Keep River pool sites and the five reference sites.

3 SEDIMENT SAMPLING

3.1 Rationale

Sediments are important, both as a source and as a sink of dissolved contaminants. Condition of sediments can influence water quality and represent a source of bioavailable contaminants to benthic biota, and ultimately the entire food chain. The ANZG (2018) guidelines suggest that "it is desirable to define situations in which contaminants associated with sediments represent a likely threat to ecosystem health". As such, sediment sampling was a requirement as part of the Commonwealth Conditions placed on the development. A sediment sampling program was undertaken at potentially exposed sites to establish baseline sediment quality prior to development. The sampling design was intended to characterise spatial variability in baseline sediment quality within each pool, with sampling to be repeated in following years to characterise temporal variability at the same locations. Data collected here will complement data collected by DAFWA (2011) and WRM (2013ab, WRM 2014) to establish baseline conditions and system-specific sediment quality trigger values for assessing the impacts of any discharge events, as specified in the Stormwater and Groundwater Discharge management plans (Strategen 2012 a,b).

3.2 Methods

3.2.1 Sampling sites

Sediment sampling was conducted at potentially exposed locations, being the estuary sites (EST01, EST02 and EST03) and the four major pools on the lower Keep River (K1, K2, K3, K4) to characterise spatial and temporal variability in sediment quality (Figure 3 & Table 1). Five replicate locations were sampled within each of the K1, K2 and K3 pools. These locations corresponded with those previously designated by KBR (2006) and sampled for water quality by WRM (2010a, 2011). However, as the K4 pool was much smaller in size, only three replicate locations were sampled. One sample was collected from each of the estuary sites, and each estuary site treated as a replicate for statistical comparison of spatio-temporal variability.

3.2.2 Field methods

Sediment samples were collected using an Eckman-Birge grab sampler. Separate sediment samples were taken from the left bank, mid-channel and right bank at each estuary site, and similarly from each replicate location within river sites (**Error! Reference source not found.**). Sediment samples were delivered to the ChemCentre, Bentley, Western Australia (a NATA-accredited laboratory), and analysed for a comprehensive suite of analytes including: pH and EC, S-SO4, Cl, HCO3, N-total, total organic carbon (TOC), Ag, Al, As, B, Ba, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Sb, Se, Sn, V and Zn. Atrazine was added to the suite in 2020 given the discharge of irrigation return water into the Keep via Border Creek, with atrazine measured in the "middle" location of the most upstream and most downstream site in each pool, and from the middle location at each estuary site.

Table 2. Number and type of sediment samples collected from each site (LB refers to samples collected from the Left Bank, M = middle, and RB = right bank).

Location	Sites	Replicates	Area collected LB	M	RB	Total # samples
Keep River	K1	5	1	1	1	**15**
	K2	5	1	1	1	**15**
	K3	5	1	1	1	**15**
	K4	3	1	1	1	**9**
Keep River Estuary	EST01	1	1	1	1	**3**
	EST02	1	1	1	1	**3**
	EST03	1	1	1	1	**3**

Limit of reporting (LOR) was sufficiently low for comparison against most recent Australian and New Zealand default guideline values for toxicants in sediments (ANZG DGVs; 2018 revision). These guidelines are an update to the previous ANZECC/ARMCANZ (2000) interim sediment quality guidelines (ISQGs). The revision, based partly on Simpson et al. (2013), includes guidance for use of a weight of evidence (WOE) approach to improve assessment of the potential impacts of contaminated sediments. This approach emphasises that the DGVs are not to be used simply on a pass/fail basis. The DGVs provide two values, the default guideline value (DGV), which is the threshold for effects, but metals are not necessarily bioavailable at this level, and guideline value-high (GV-High) which is the median value at which toxic effects are already likely to be observed; i.e. high probability of effects. Each analyte was compared against its respective ANZG (2018) GV-high and DGV (note: not all analytes currently have a GV-high or DGV set). Any analyte which exceeded a GV-high or a DGV was flagged as a Potential Contaminant of Concern (PCoC), unless DGVs were also exceeded at reference sites, in which case naturally high background levels are implied. In cases where there was an absence of toxicant guidelines set by ANZG (2018), analytes were compared against natural background (reference) condition. Any analyte with a concentration that exceeded the highest concentration recorded among reference sites by a factor of two or more was also flagged as a PCoC. A full list of ANZG (2018) analytes and corresponding sediment DG values is provided in Appendix 2 ANZG (2018) Default Guideline Values for toxicants in sediment.

3.2.3 Data analysis

Univariate

Box plots were produced to visualise spatial variation in concentrations of sediment analytes. Two-way ANOVA (IBM SPSS Statistics v22) was then used to test for significant differences in sediment quality amongst *a priori* groups, *i.e.* sites (K1, K2, K3, K4, Estuary) and years (2011, 2012, 2013 & 2020). For each analyte, the average of the three samples from each replicate within a site (i.e. left, centre and right bank) was calculated and used in analyses. Estuary sites were used as replicates in this case. Tukey's *post-hoc* tests were used to locate significant reach and/or year differences. For the purposes of analyses, concentrations below detection limits were reported as half the corresponding detection limit for that parameter. Where necessary, concentrations were $\log_{10}(x+1)$ transformed to conform to ANOVA's assumption of homogeneous variances. Spearman rank correlation (ρ) analysis was used to test for significant linear relationships between metal concentrations and total organic carbon content of sediments, as organic carbon content is known to influence sediment metal levels.

Multivariate

Multivariate analyses were performed using PRIMER v7 (Clarke & Gorley 2006) to investigate differences in sediment quality amongst *a priori* groupings, *i.e.* sites (K1, K2, K3, K4, EST01, EST02, EST03) and years (2011, 2012, 2013 & 2020). As for univariate analyses, left, centre and right bank samples were averaged for each site. Analyses were based on Euclidean distance matrices generated in PRIMER. Two-way permutational multivariate analysis of variance (PERMANOVA) add-in for PRIMER was used to test for statistically significant differences in the suite of sediment variables amongst *a priori* groups (Anderson 2001a, b, McArdle &Anderson 2001, Anderson & ter Braak 2003, Anderson *et al.* 2008). Canonical analysis of principal coordinates (CAP) was used to graphically represent *a priori* group differences as two dimensional ordination plots. Vector overlay of Spearman rank correlations of individual variables with the ordination were used to help characterise differences among groups. Where necessary, sediment data were $\log_{10}$ transformed prior to analysis to meet assumptions of the test. Unless indicated, default values or procedures otherwise recommended by Clarke and Gorley (2006) were employed for all PRIMER routines.

3.3 Results and Discussion

Summary statistics for sediment data collected from the Keep River and Estuary sites in 2020 with comparison to guideline values and baseline data are provided in Table 3 and Table **5**6. There were exceedances of ANZG (2018) default sediment guideline values (DGVs) for only one analyte, nickel (Ni), however multiple analytes exceeded the maximum values recorded during baseline surveys. Comparison of significant differences in analyte concentrations between sites and years can be found in Table 4 and Table 5. Detailed statistics for baseline data can be found in Appendix 3 Baseline Sediment Dataincluding minimum, maximum, median, mean, 20%ile and 80%ile values for the combined 2011-2013 data set for each site. A brief description of major sediment parameters is given below.

Total organic carbon (TOC)

Spatial variation in total organic carbon (TOC) content of sediments in 2020 is illustrated in Figure 5. Mean TOC ranged from 0.16% (median 0.14%) at EST02, to 2.32% (median 0.82%) at K3, with values for individual replicates ranging from <0.05% at K2, to 5.43% at K3. There were no significant differences in total organic carbon content between years (two-way ANOVA df = 3, F = 0.721, p = 0.54) or in the interaction between site and year (two-way ANOVA; df = 12, F = 1.495, *p* = 0.127) (Table 3, Figure 5).

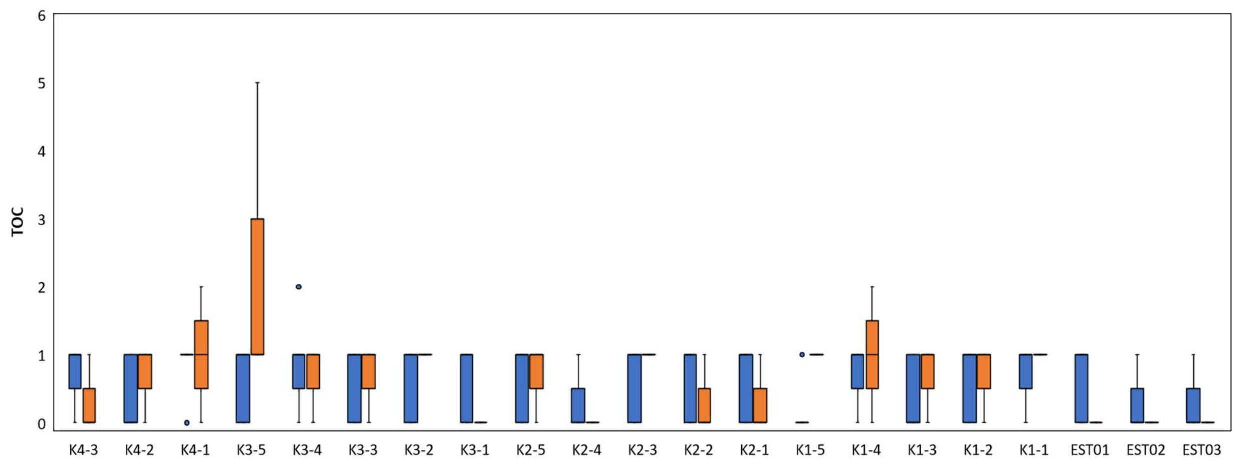


Figure 5. Box plots summarising combined baseline data (blue) and 2020 survey data (orange) of %TOC within sediments of the Keep River and Keep River Estuary. Plots show minimum, 20%ile, median (50%ile), 80%ile, maximum, outlier (O = greater than 1.5x the upper or lower percentile) for each replicate site.

Major ions

In 2020, calcium (Ca) was the dominant cation in both the Keep River and Estuary, with magnesium (Mg) subdominant, and chloride (Cl) the dominant anion, with sulphate (SO_4) subdominant (Table 3). Concentrations of all major ions differed significantly amongst sites (two-way ANOVAs, Table 4). Ionic composition of sediments reflected the salinity of the overlying water, with relatively higher concentrations of chloride and sodium (Na) at estuary sites and lower at Keep River pools (Table 4) reflecting tidal/marine influence. Longitudinal patterns were evident with lowest ionic concentrations recorded from the most upstream Keep River pool K4 (Figure 6).

Values for Mg, Na and SO_4 in 2020 at EST01 exceeded the maximum baseline values (Table 3) possibly due to the concentrating effects of the tidal influence downstream and the rock barrier at the upstream end of the site.

Within-site variability was high, particularly at the upper Keep River sites. For example, Mg at K4-3 ranged from 390 mg/kg dry weight in left bank sediments to 4200 mg/kg dry weight in right channel sediments.

There were significant temporal differences in concentration of Na, K, Cl, and SO_4 (Table 3). In particular, average potassium (K) concentration was significantly higher in 2020 than in all previous years. Potassium at sites K1, K2 and EST01 were particularly high compared to baseline samples (mean values at >3000 mg/kg).

Nutrients (N & P)

Spatial variation in nutrient content of Keep River sediments in 2020 is summarised in Table 3 and illustrated in Figure 7. There were no significant differences in total nitrogen between any of the Keep River sites (K1-K4), however there was a significant difference between the estuary sites and the Keep River sites (one-way ANOVA $p < 0.001$) (Table 3, Figure 7). Total nitrogen nutrients were highest at K3, with a maximum total nitrogen (N-total) concentration of 2400 mg/kg at K3-5. The maximum ammonium-nitrogen (NH_4-N) concentration of 32 mg/kg dry weight was recorded at K2-3. There were slight longitudinal gradients in N-total and NH_4-N, with concentrations decreasing with increasing distance downstream from K4 (Figure 7), and significantly lower concentrations in estuary sediments than in Keep River sediments (Table 3, Figure 7). Mean N-total concentrations ranged from 700 mg/kg (median 600 mg/kg) at K2 to 0.01 mg/kg (median 0.01 mg/kg) at EST02 and EST03 (Table 3). Mean NH_4-N concentrations ranged from 8.33 mg/kg (median 8 mg/kg) at K3 to 2.33 mg/kg at EST01 and EST02.

Mean nitrate concentrations exceeded the maximum baseline records for sites K1, K2 and EST02 (Table 3, Figure 7). This increase in nitrate appears to be most prevalent between sites K3-1 and K2-5 with some high spot readings at K1-4 and EST02 (Table 3). N-total values and nitrate (NO_3-N) concentrations were statistically significantly different between sites (two-way ANOVA df = 4 p = <0.009) and also statistically lower in the baseline studies compared to the post-development study (two-way ANOVA df = 3, P = <0.001) (Table 4, Figure 7). A two-way ANOVA also found that 2013 had significantly higher NH_4 values than all other years (df = 3, p = 0.001) (Table 4).

In contrast to nitrogen nutrients, total phosphorus (P-total) in sediments was significantly higher in the estuary than the river sites K4, K2 and K3 (Table 3, Figure 7). Site means ranged from 70.89 mg/kg (median 73.44 mg/kg) at K2 to 233 mg/kg (median 210 mg/kg) at EST03 (Table 3). There were significant differences in P-total concentrations amongst years, with the greatest difference being between baseline year 2013 and all other years (Table 4). 2020 values for phosphorus do appear to be exceeding the baseline variability for sediments aside from a single spot measure at K2-1 (Table 3, Figure 7).

Atrazine (ATZ)

Atrazine is a commonly used herbicide in Australia used to control weeds in grain crops as well as pastures and golf courses. It is a common contaminant in Australian waterways occurring through a number of pathways from direct discharge from wastewater treatment plants to run-off and wastewaters from treated agricultural areas (CSIRO 2007). Studies have shown exposure to high levels of Atrazine can cause reduced reproductive ability and metabolism in mice (Cook *et al*. 2019) and to alter hormone levels in certain frog species (Hayes et al. 2002).

One sediment sample from site K4, EST01, EST02 and EST03 and two samples from K1, K2 and K3 were tested for Atrazine during the current study and all readings were recorded as below the limit of detection (<0.01 mg/kg).

Table 3. Benthic sediment quality data for major ions and nutrients from 7 sites on the Keep River in 2020. Yellow highlight indicates data above the sediment default guideline value (DGV), orange highlight indicates data greater than the guideline value high (GV-High), blue highlight indicates data that are elevated relative to baseline condition (above the maximum value recorded at each site during the 2011, 2012 and 2013 baseline surveys).

Location	Site code	Replicate	Analyte	Ca	Cl_S	K	Mg	N	N-Total	NH4-N	NO3-N	P	SO4	OrgC	Na
			Units	mg/kg	mg/L	mg/kg	mg/kg	%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	%	mg/kg
			DGV	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
			GV-High	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
Keep River	K4	K4-1	Left	2600	18	1400	3400	0.07	670	13	1	94	300	1.52	280
			Middle	9000	9	610	2000	0.02	150	2	1	40	5	0.22	230
			Right	2200	15	1200	2900	0.04	400	5	1	84	200	0.59	210
		K4-2	Left	3800	5	1200	4700	0.04	440	19	1	62	20	0.76	190
			Middle	13000	15	1200	4500	0.03	320	5	1	76	10	0.37	310
			Right	2000	20	1200	3100	0.06	620	15	1	85	200	0.75	270
		K4-3	Left	430	5	190	370	0.05	480	2	1	18	30	0.07	38
			Middle	2000	12	860	1900	0.03	320	6	1	59	200	0.40	170
			Right	2700	32	1500	4200	0.06	610	8	1	120	200	0.60	380
	K3	K3-1	Left	2900	40	2400	8000	0.034	340	11	1	94	400	0.4	1500
			Middle	19000	16	1600	3500	0.041	410	5	1	99	30	0.46	310
			Right	2400	7	1500	4800	0.026	260	8	2	79	30	0.21	230
		K3-2	Left	3500	7	2100	6300	0.057	570	11	1	120	300	0.73	340
			Middle	19000	20	2000	5300	0.053	530	7	1	110	5	0.5	390
			Right	3500	11	2400	5900	0.067	670	15	1	150	200	0.71	500
		K3-3	Left	3300	6	1900	5200	0.06	600	11	1	120	70	0.83	330
			Middle	2800	18	1800	4100	0.04	400	8	1	110	400	0.49	360
			Right	5000	15	2100	4600	0.046	460	6	1	120	6	0.55	410
		K3-4	Left	3400	14	2000	5400	0.057	570	5	1	120	300	0.95	370
			Middle	3500	26	1800	4900	0.063	630	8	1	120	20	0.93	320
			Right	4500	28	2200	8900	0.041	410	8	1	120	100	0.42	570
		K3-5	Left	6800	10	1700	5000	0.24	2400	12	1	170	400	5.43	340
			Middle	5900	22	1400	3700	0.062	620	5	1	97	5	0.82	300
			Right	3100	8	1300	3500	0.04	400	5	1	84	50	0.71	230
	K2	K2-1	Left	2200	18	170	590	0.005	50	2	1	21	5	0.05	220
			Middle	3600	132	3100	10000	0.039	390	4	1	110	90	0.34	1600
			Right	26000	113	1800	4300	0.064	640	3	7	220	5	0.52	1200
		K2-2	Left	960	42	450	1100	0.017	170	2	1	30	30	0.13	170
			Middle	36000	85	1400	3700	0.025	250	2	2	90	5	0.34	8400
			Right	3300	242	4000	8900	0.023	230	16	1	120	900	0.57	1700
		K2-3	Left	2800	99	1700	3300	0.053	530	9	1	86	230	0.5	520
			Middle	2900	175	2500	5100	0.093	930	32	1	130	400	0.69	900
			Right	20000	312	2800	6400	0.103	1030	7	2	150	410	0.77	1400
		K2-4	Left	2500	32	1400	2800	0.036	360	4	2	66	30	0.46	300
			Middle	1700	46	950	2100	0.027	270	3	2	53	30	0.34	280
			Right	3900	81	1300	2700	0.034	340	3	1	67	5	0.34	430
		K2-5	Left	3200	240	2600	6800	0.069	690	5	1	120	440	1.17	1500
			Middle	2800	23	2200	6000	0.068	680	8	1	110	70	0.7	590
			Right	1700	7	1100	2800	0.022	220	4	3	58	30	0.31	170
	K1	K1-1	Left	27000	1710	3700	8900	0.04	400	3	1	180	2000	0.55	5900
			Middle	18000	3310	4800	12000	0.059	590	3	1	210	3000	0.59	11000
			Right	9700	2600	3200	7900	0.05	500	3	1	130	2000	0.55	8100
		K1-2	Left	4300	1520	2700	6100	0.051	510	5	1	100	1000	0.46	5000
			Middle	11000	2740	4500	11000	0.06	600	3	1	170	3000	0.76	9700
			Right	14000	3520	4600	12000	0.055	550	3	1	190	3000	0.65	12000
		K1-3	Left	1900	718	790	1300	0.018	180	2	1	32	480	0.2	2000
			Middle	11000	4850	3800	8100	0.169	1690	18	1	160	2000	1.31	14000
			Right	3200	2820	3800	8200	0.09	900	6	1	150	3000	1.34	10000
		K1-4	Left	4300	1740	1700	3100	0.055	550	2	2	63	1000	0.37	4800
			Middle	4600	4340	3700	7900	0.14	1400	6	1	160	5000	1.52	13000
			Right	2400	2710	3000	7600	0.103	1030	6	1	130	2000	0.97	9500
		K1-5	Left	2500	1920	2300	5500	0.086	860	9	1	110	2000	0.91	6200
			Middle	7000	1840	2000	4200	0.075	750	9	1	89	2000	0.7	5700
			Right	7300	1070	1900	4600	0.054	540	10	1	91	490	0.54	4000
Estuary	EST01	EST01	Left	26000	3520	4300	11000	0.043	430	3	1	210	3000	0.48	10000
			Middle	31000	3230	3400	9300	0.029	290	2	1	190	2000	0.38	10000
			Right	31000	2840	4100	9600	0.03	300	2	1	200	2000	0.38	8600
	EST02	EST02	Left	46000	2010	2600	7800	0.017	170	2	2	220	2000	0.23	7000
			Middle	74000	2650	2600	8400	0.015	150	2	2	250	2000	0.25	7800
			Right	53000	1670	2000	6500	0.012	120	3	3	200	1000	0.19	5100
	EST03	EST03	Left	42000	2230	2300	6900	0.016	160	3	1	200	2000	0.21	7100
			Middle	55000	1830	1600	5800	0.006	60	3	1	200	1000	0.14	6100
			Right	50000	1830	1400	5600	0.006	60	3	1	200	1000	0.14	5900

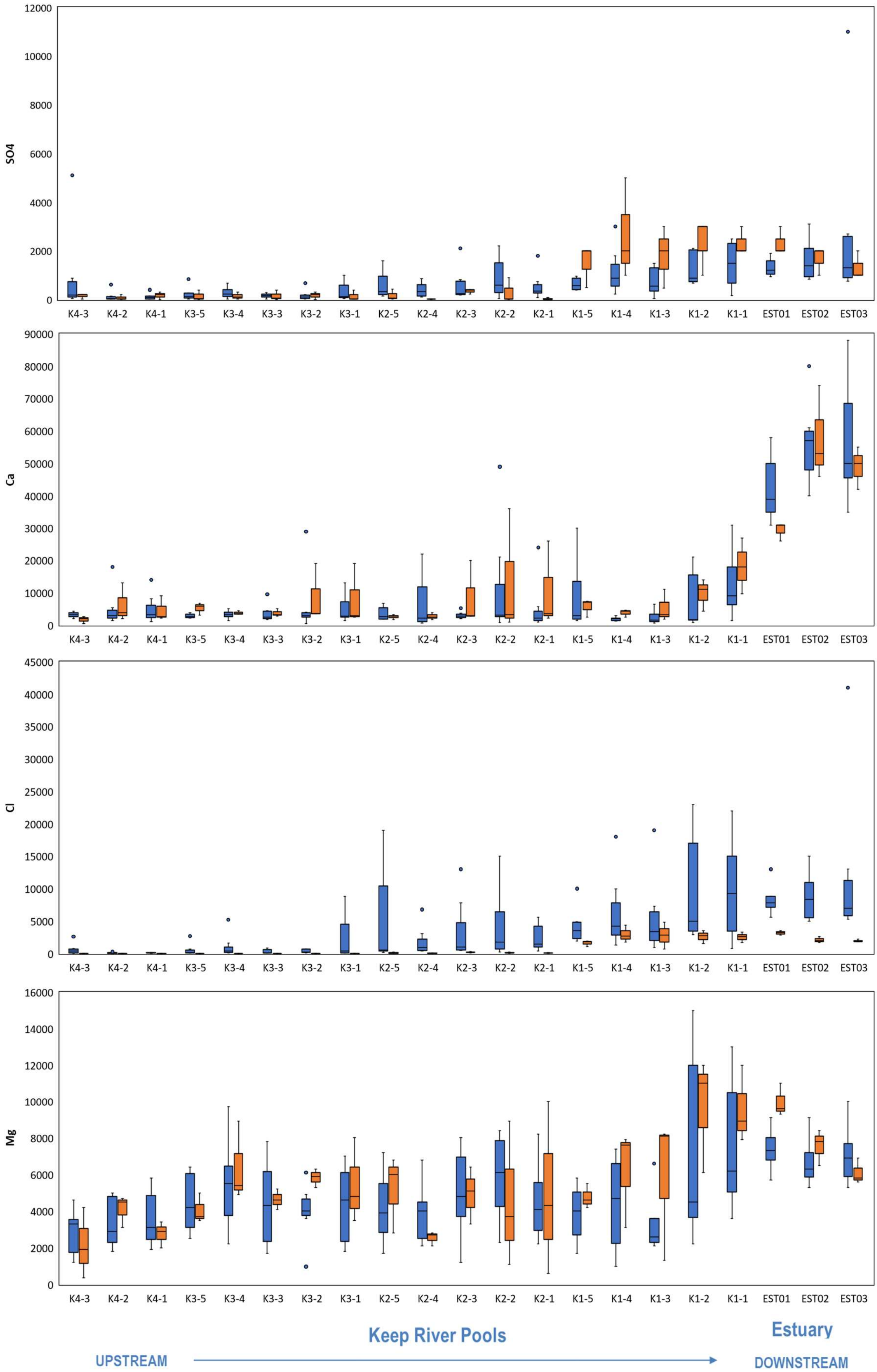


Figure 6. Box plots summarising combined baseline data (blue) and 2020 survey data (orange) on concentrations of dominant cations and anions (mg/kg dry weight) within sediments of the Keep River and Keep River Estuary. Plots show minimum, 20%ile, median (50%ile), 80%ile, maximum.

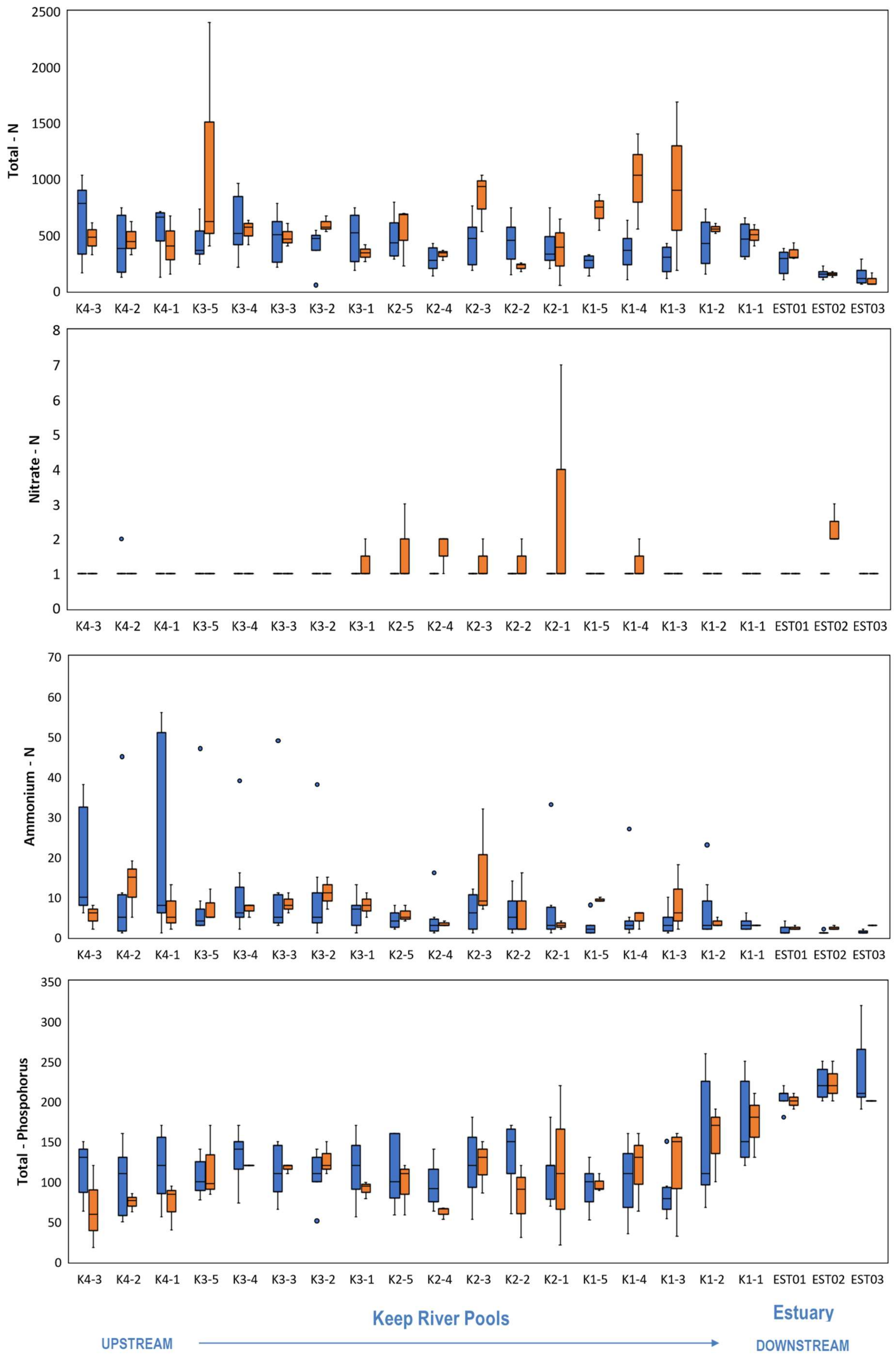


Figure 7. Box plots summarising combined baseline data (blue) and 2020 survey data (orange) on nutrient concentrations (mg/kg dry weight) within sediments of the Keep River and Keep River Estuary. Plots show minimum, 20%ile, median (50%ile), 80%ile, maximum.

Table 4. Two-way ANOVA and Tukey's post hoc testing for significant differences in sediment Ions and nutrient between years and sites at Keep River pools and Estuary sites. Average values for untransformed data are provided in brackets. Sampling locations joined by a common line are not significantly different ($p < 0.05$). Sampling locations are arranged in order of ascending average value, left-to right.

Major Ion	Source	ANOVA df	F	*p*	Tukey's *post hoc* tests				
Ca	Site	4	226.891	0.001	K4 (4195)	K3 (4474)	K2 (5967)	K1 (6932)	EST (49722)
	Year	3	0.419	0.74	2011 (11439)	2013 (11482)	2012 (12113)	2020 (12318)	
	Site*Year	12	2.193	0.013					
	Corrected Total	251							
Cl	Site	4	33.298	0.001	K4 (204)	K3 (643)	K2 (2544)	K1 (5693)	EST (7667)
	Year	3	22.256	0.001	2020 (972)	2012 (2260)	2011 (3321)	2013 (6401)	
	Site*Year	12	2.437	0.005					
	Corrected Total	251							
K	Site	4	24.623	0.001	K4 (882)	K3 (1300)	K2 (1523)	EST (2038)	K1 (2232)
	Year	3	14.8	0.001	2011 (1250)	2012 (1426)	2013 (1651)	2020 (2156)	
	Site*Year	12	1.524	0.116					
	Corrected Total	251							
SO4	Site	4	30.185	0.001	K3 (212)	K4 (298)	K2 (472)	K1 (1332)	EST01 (1796)
	Year	3	6.517	0.001	2012 (509)	2011 (620)	2020 (859)	2013 (1131)	
	Site*Year	12	2.098	0.018					
	Corrected Total	251							
Mg	Site	4	19.061	0.001	K4 (3204)	K2 (4583)	K3 (4696)	K1 (5648)	EST (7239)
	Year	3	9.009	0.001	2011 (3994)	2012 (4732)	2020 (5588)	2013 (5871)	
	Site*Year	12	1.415	0.16					
	Corrected Total	251							
Total - N	Site	4	12.931	0.001	EST(182)	K2 (413)	K1 (450)	K3 (509)	K4 (513)
	Year	3	4.06	0.008	2011 (349)	2012 (413)	213 (420)	2020 (521)	
	Site*Year	12	2.5	0.004					
	Corrected Total	251							
N - NO3	Site	4	3.484	0.009	K1 (0.91)	K4 (0.96)	K3 (1.0)	EST (1.1)	K2 (1.18)
	Year	3	10.731	0.001					
	Site*Year	12	2.295	0.009	2012 (0.82)	2013 (1.0)	2011 (1.02)	2020 (1.29)	
	Corrected Total	251							
N - NH4	Site	4	17.533	0.001	EST (1.57)	K1 (4.62)	K2 (5.85)	K3 (8.98)	K4 (14.64)
	Year	3	807.03	0.001	2012 (3.94)	2011 (5.76)	2020 (6.59)	2013 (11.49)	
	Site*Year	12	300	0.001					
	Corrected Total	251							
Total - P	Site	4	58.228	0.001	K4 (101)	K2 (110)	K3 (115)	K1 (123)	EST (217)
	Year	3	6.222	0.001	2011 (119)	2020 (212)	2012 (127)	2013 (146)	
	Site*Year	12	1.665	0.076					
	Corrected Total	251							
TOC	Site	4	4.228	0.003	EST (0.36)	K2 (0.54)	K1 (0.59)	K4 (0.65)	K3 (0.71)
	Year	3	0.721	0.54	2013 (0.53)	2011 (0.55)	2012 (0.61)	2020 (0.64)	
	Site*Year	12	1.495	0.127					
	Corrected Total	251							

Metals

Sediment concentrations for most metals in 2020 were well below the ANZG (2018) default guideline values (DGVs) (Table 5), However, there were exceedances of the DGV for nickel at K3, K2 and K1. A number of sites also recorded a number of metals elevated above the maximum values recorded during baseline (Table 5).

Concentrations of Ni equal to or in excess of the DGV (21 mg/kg dry weight) were recorded on 18 occasions; K3-1 (25mg/kg), K3-2 (22,23,24), K3-4 (25), K3-5 (23), K2-1 (27,33), K2-2 (26,36), K2-3 (22,29), K2-5 (22,23), K1-3 (24,25), K1-4 (22,23) (Table 5, Figure 8). Although Ni is known to be an essential element in some aquatic biota, including cyanobacteria, algae and aquatic plants (Muyssen *et al.* 2004), elevated concentrations are harmful (Ali & Fishar 2005). In a study conducted in Port Curtis, Queensland, Ni was found to be enriched in oysters where concentrations were elevated in sediments (Jones *et al.* 2005). Bioconcentration of Ni has been reported for a wide variety of aquatic organisms ranging from bacteria, algae, and invertebrates to fish (Riley & Roth 1971, Wilson 1983, Zaroogian & Johnson 1984, Alikhan *et al*. 1990, Azeez & Banerjee 1991, Wong *et al*. 2000). However, Watras *et al.* (1985) suggested very limited uptake of Ni *via* the diet, suggesting that elevated Ni is of greater concern in surface waters than sediments. Mobilisation of metals from sediments is generally dependent on changes in pH, redox, salinity and dissolved organic carbon. The potential for mobilisation of Ni from Keep River sediments is unknown. WRM (2014) previously reported nickel exceedances of DGV at site replicates of K1, K2 and K3 in baseline surveys in 2012 and 2013, so it would appear that Ni is naturally elevated, with the exceedances pre-dating the Goomig development.

Barium (Ba), cobalt (Co), copper (Cu), chromium (Cr), and iron (Fe) all showed significantly lower mean values in estuary sediments than in the upstream river sediments (Table 5, Table 6). Alternately, boron (B) and arsenic (As) were significantly higher at the estuary sites compared to the upstream river sites K2, K3 and K4 (Table 5, Figure 9).

Estuary site EST01 had maximum baseline value exceedances in the greatest number of metals including; aluminium (Al), arsenic (As), boron (B), barium (Ba) beryllium (Be), bismuth (Bi), Cobalt (Co), chromium (Cr), iron (Fe), gallium (Ga), lanthanum (La), lithium (Li), nickel (Ni), lead (Pb), antimony (Sb), selenium (Se), silicon (Si), tin (Sn) and vanadium (V) (Table 5).

Site K-4 had only one exceedance of the maximum baseline values for lead (Pb) and two exceedances of the maximum baseline values of silicon (Si).

Majority of metals, with the exception of mercury (Hg), in the current survey (2020) were statically higher than at least one of the baseline surveys (2011, 2012, 2013) (Table 4) (Two-way ANOVA $p = <0.05$).

The most notable increase was seen in the average nickel (Ni) level which has been significantly steadily increasing from 2011 (9.45) to 2020 (17.13). During baseline surveys concentrations of nickel (Ni) equal to or in excess of the DGV value (21 mg/kg dry weight) were recorded at eight sites; K1-3 (2012), K2-2 (2012, 2013), K2-3 (2013), K3-1 (2013), K3-3 (2013) and K3-4 (2012, 2013). In the current study there were exceedances at 10 sites K1-3, K1-4, K2-5, K2-3, K2-2, K2-1, K3-4, K3-5, K3-2, K3-1.

Lithium (Li), lead (Pb), iron (Fe) and chromium (Cr) were all slightly, but significantly higher on average in 2020 than all baseline mean values. Mean values for aluminium (Al) and titanium (Ti) were significantly higher than baseline values, with both analytes at least double the previous highest mean. Interestingly mercury (Hg) was the only metal with lower mean values than all previous years. There were no DGV exceedances after having multiple records of exceedances of DGV-high values in all previous years.

Table 5. Benthic sediment quality data for metals from 7 sites on the Keep River in 2020. Yellow highlight indicates data above the sediment default guideline value (DGV), orange highlight indicates data greater than the guideline value high (GV-High), blue highlight indicates data that are elevated relative to baseline condition (above the maximum value recorded at each site during the 2011, 2012 and 2013 baseline surveys).

Location	Site code	Replicate	Analyte	Ag	Al	As	B	Ba	Be	Bi	Cd	Co	Cr	Cu	Fe	Ga	Hg	La	Li	Mg	Mn	Mo	Na	Ni	Pb	Sb	Se	Si	Sn	Ti	U	V	Zn
			Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
			DGV	1	NP	20	NP	NP	NP	NP	1.5	NP	80	65	NP	NP	0.15	NP	NP	NP	NP	NP	NP	21	50	2	NP	NP	9	NP	NP	NP	200
			GV-High	4	NP	70	NP	NP	NP	NP	10	NP	370	270	NP	NP	1	NP	NP	NP	NP	NP	NP	52	220	25	NP	NP	70	NP	NP	NP	410
Keep River	K4	K4-1	Left	0.05	19800	1.70	5	140.00	0.58	0.13	0.05	19.00	24.00	15.00	28000	6.70	0.02	15.00	8.00	3400	580	0.15	280	14.00	9.80	0.09	0.13	180	0.90	210	0.81	67	20
			Middle	0.05	7790	2.80	5	430.00	0.36	0.07	0.05	39.00	15.00	9.10	18000	4.60	0.02	21.00	3.00	2000	2700	0.26	230	15.00	16.00	0.17	0.15	320	0.50	130	0.59	57	10
			Right	0.05	15600	1.40	5	100.00	0.49	0.11	0.05	16.00	21.00	13.00	23000	5.40	0.02	13.00	6.20	2900	630	0.11	210	11.00	8.20	0.08	0.10	210	0.80	200	0.67	58	17
		K4-2	Left	0.05	20000	1.90	5	140.00	0.63	0.15	0.05	20.00	30.00	18.00	32000	7.20	0.02	18.00	6.80	4700	650	0.12	190	17.00	12.00	0.06	0.11	160	1.00	140	0.79	76	23
			Middle	0.05	16400	2.50	5	350.00	0.61	0.13	0.05	40.00	25.00	17.00	31000	6.90	0.02	26.00	6.10	4500	3200	0.23	310	21.00	12.00	0.11	0.14	180	0.90	120	0.91	77	20
			Right	0.05	16600	1.60	5	130.00	0.53	0.14	0.05	20.00	20.00	15.00	27000	6.00	0.02	14.00	6.00	3100	400	0.14	270	13.00	9.30	0.08	0.10	170	0.80	100	0.75	62	19
		K4-3	Left	0.05	1950	0.40	5	23.00	0.08	0.05	0.05	4.40	5.00	2.10	3900	0.79	0.02	2.70	0.80	370	110	0.05	38	2.40	2.30	0.05	0.05	270	0.50	46	0.11	13	5
			Middle	0.05	12200	1.20	5	110.00	0.35	0.09	0.05	16.00	15.00	11.00	18000	4.00	0.02	10.00	4.40	1900	500	0.10	170	9.10	6.90	0.06	0.07	200	0.60	130	0.50	43	14
			Right	0.05	23300	2.00	5	170.00	0.70	0.16	0.05	25.00	27.00	18.00	34000	7.90	0.02	18.00	9.90	4200	950	0.15	380	16.00	11.00	0.08	0.13	190	1.10	170	0.91	79	24
	K3	K3-1	Left	0.05	44700	2.00	10	170.00	0.98	0.23	0.05	20.00	46.00	28.00	49000	13.00	0.02	21.00	16.00	8000	670	0.13	1500	25	13	0.08	0.11	130	2	210	1.4	96	44
			Middle	0.05	21500	1.60	5	150.00	0.46	0.11	0.06	18.00	25.00	14.00	27000	6.60	0.11	17.00	8.30	3500	1100	0.15	310	14	8.3	0.1	0.11	140	1	230	0.71	59	20
			Right	0.05	21100	2.80	5	81.00	0.78	0.18	0.05	18.00	40.00	22.00	45000	8.60	0.02	24.00	8.40	4800	530	0.2	230	21	13	0.13	0.1	120	1.3	370	1.3	100	45
		K3-2	Left	0.05	35600	2.10	7	150.00	0.81	0.20	0.05	23.00	40.00	25.00	41000	11.00	0.02	22.00	14.00	6300	480	0.17	340	23	14	0.12	0.15	120	1.6	400	1.2	90	39
			Middle	0.05	33800	2.20	6	290.00	0.75	0.16	0.05	26.00	36.00	21.00	38000	10.00	0.02	26.00	13.00	5300	1700	0.21	390	22	13	0.11	0.14	120	1.5	210	1.1	83	33
			Right	0.05	43000	2.20	7	210.00	0.90	0.21	0.05	24.00	44.00	26.00	46000	12.00	0.02	22.00	17.00	5900	660	0.2	500	24	14	0.11	0.17	130	1.8	330	1.1	99	42
		K3-3	Left	0.05	34400	2.00	7	160.00	0.81	0.19	0.05	21.00	36.00	22.00	38000	10.00	0.02	22.00	14.00	5200	470	0.19	330	21	13	0.12	0.15	130	1.5	360	1.2	85	34
			Middle	0.05	31600	1.90	6	150.00	0.67	0.16	0.05	19.00	33.00	19.00	34000	9.20	0.02	18.00	12.00	4100	450	0.15	360	18	12	0.09	0.14	140	1.4	260	0.9	72	29
			Right	0.05	35200	2.00	7	220.00	0.78	0.17	0.05	23.00	37.00	21.00	37000	10.00	0.02	20.00	14.00	4600	730	0.17	410	20	13	0.09	0.15	150	1.5	250	0.97	80	32
		K3-4	Left	0.05	36400	2.40	7	170.00	0.85	0.19	0.05	18.00	40.00	24.00	42000	11.00	0.02	20.00	14.00	5400	460	0.21	370	20	13	0.07	0.18	140	1.6	270	1.1	92	37
			Middle	0.05	32500	2.40	5	160.00	0.84	0.19	0.05	20.00	39.00	22.00	41000	10.00	0.02	19.00	12.00	4900	370	0.26	320	20	14	0.11	0.2	140	1.5	270	1.1	88	34
			Right	0.05	40500	2.80	8	170.00	1.00	0.25	0.05	22.00	54.00	32.00	54000	13.00	0.02	24.00	16.00	8900	670	0.18	570	25	15	0.09	0.15	150	1.9	320	1.4	110	52
		K3-5	Left	0.05	31200	2.70	7	160.00	0.86	0.18	0.05	23.00	38.00	25.00	40000	11.00	0.02	25.00	12.00	5000	410	0.32	340	23	14	0.13	0.25	180	1.5	280	1.7	94	35
			Middle	0.05	20700	2.00	5	150.00	0.59	0.14	0.05	19.00	28.00	17.00	30000	7.30	0.02	16.00	7.00	3700	610	0.19	300	16	11	0.09	0.13	190	1	140	0.84	68	23
			Right	0.05	19400	1.90	5	120.00	0.53	0.13	0.05	16.00	28.00	15.00	28000	6.70	0.02	14.00	7.20	3500	490	0.18	230	14	10	0.08	0.12	200	1	240	0.81	69	21
	K2	K2-1	Left	0.05	1560	1.20	5	450.00	0.13	0.05	0.05	29.00	5.10	4.60	6100	1.90	0.02	18.00	0.70	590	2500	0.12	220	11	10	0.08	0.05	200	0.5	49	0.28	37	4.8
			Middle	0.05	52800	2.40	14	130.00	1.10	0.25	0.05	20.00	55.00	33.00	55000	15.00	0.02	24.00	22.00	10000	610	0.13	1600	27	14	0.11	0.12	130	2.2	340	1.6	100	56
			Right	0.05	25300	8.30	7	1200.00	0.92	0.17	0.11	67.00	58.00	26.00	62000	11.00	0.02	58.00	9.80	4300	6400	0.82	1200	33	22	0.36	0.27	170	1.3	260	2.3	200	35
		K2-2	Left	0.05	5340	0.70	5	37.00	0.13	0.05	0.05	5.90	9.60	4.10	8300	1.80	0.02	5.20	2.10	1100	350	0.06	170	4.3	3.5	0.05	0.05	210	0.5	120	0.24	23	6.8
			Middle	0.05	14200	4.10	5	1200.00	0.51	0.09	0.11	92.00	20.00	16.00	25000	8.90	0.02	67.00	6.20	3700	890	0.44	8400	36	23	0.23	0.23	150	0.6	210	1.9	99	16
			Right	0.05	58500	2.80	16	180.00	1.10	0.27	0.05	24.00	52.00	34.00	54000	16.00	0.02	25.00	23.00	8900	450	0.11	1700	26	16	0.08	0.16	78	2.4	390	1.7	96	51
		K2-3	Left	0.05	24500	1.50	6	110.00	0.49	0.12	0.05	15.00	26.00	13.00	25000	6.70	0.02	14.00	10.00	3300	440	0.12	520	14	8.8	0.07	0.1	150	1	280	0.74	59	20
			Middle	0.05	39700	2.20	9	180.00	0.81	0.18	0.05	22.00	39.00	22.00	38000	11.00	0.02	19.00	16.00	5100	640	0.2	900	22	13	0.12	0.15	97	1.7	300	0.99	88	35
			Right	0.05	41900	3.10	10	540.00	0.89	0.19	0.08	52.00	39.00	24.00	43000	13.00	0.02	39.00	17.00	6400	3800	0.27	1400	29	16	0.13	0.19	160	1.7	300	1.5	100	38
		K2-4	Left	0.05	16900	1.40	5	110.00	0.37	0.12	0.05	14.00	20.00	11.00	19000	5.20	0.02	13.00	7.00	2800	620	0.12	300	12	8	0.08	0.08	190	0.8	300	0.59	50	16
			Middle	0.05	11300	1.10	5	66.00	0.26	0.08	0.05	11.00	17.00	8.20	16000	3.60	0.02	8.90	4.50	2100	480	0.1	280	8.7	6.5	0.08	0.05	190	0.5	220	0.44	40	13
			Right	0.05	16100	1.50	5	150.00	0.36	0.09	0.05	17.00	20.00	11.00	20000	5.20	0.02	13.00	6.60	2700	930	0.14	430	12	7.9	0.09	0.08	170	0.7	220	0.64	49	16
		K2-5	Left	0.05	44200	2.20	11	180.00	0.90	0.19	0.05	20.00	42.00	24.00	44000	12.00	0.02	20.00	18.00	6800	980	0.17	1500	23	12	0.06	0.14	97	1.8	270	1.1	93	40
			Middle	0.05	35300	2.20	8	140.00	0.75	0.19	0.05	21.00	38.00	23.00	39000	10.00	0.02	21.00	14.00	6000	610	0.18	590	22	13	0.12	0.13	130	1.5	370	1.1	87	36
			Right	0.05	13200	1.20	5	68.00	0.30	0.09	0.05	11.00	20.00	10.00	20000	4.40	0.02	11.00	5.30	2800	350	0.1	170	11	7.6	0.08	0.06	160	0.7	330	0.56	52	16
	K1	K1-1	Left	0.05	26200	4.00	27	38.00	0.48	0.13	0.05	12.00	30.00	13.00	27000	7.40	0.02	17.00	18.00	8900	320	0.2	5900	16	8.2	0.08	0.1	150	1.1	470	0.78	49	25
			Middle	0.05	33000	4.40	39	42.00	0.68	0.19	0.05	16.00	40.00	18.00	35000	9.40	0.02	17.00	25.00	12000	350	0.23	11000	20	11	0.07	0.13	110	1.3	370	0.87	62	38
			Right	0.05	25200	2.90	24	48.00	0.54	0.15	0.05	13.00	32.00	15.00	29000	7.40	0.02	14.00	16.00	7900	320	0.19	8100	16	8.9	0.06	0.1	130	1.1	280	0.73	56	25
		K1-2	Left	0.05	23100	2.50	18	65.00	0.50	0.14	0.05	12.00	28.00	14.00	26000	6.70	0.02	14.00	14.00	6100	510	0.23	5000	14	8.7	0.09	0.1	150	1	320	0.74	56	22
			Middle	0.05	35100	4.50	34	80.00	0.71	0.19	0.05	18.00	42.00	21.00	38000	10.00	0.02	19.00	24.00	11000	550	0.37	9700	21	11	0.11	0.15	110	1.4	390	1.1	74	40
			Right	0.05	33300	4.30	37	54.00	0.69	0.20	0.05	16.00	41.00	19.00	36000	9.70	0.02	17.00	23.00	12000	500	0.24	12000	21	11	0.09	0.13	120	1.4	370	1	65	38
		K1-3	Left	0.05	5970	0.90	5	41.00	0.16	0.05	0.05	9.80	9.30	4.40	8200	2.10	0.02	6.60	2.80	1300	550	0.1	2000	5.5	5.4	0.05	0.05	190	0.5	110	0.34	23	7
			Middle	0.05	37900	3.30	23	99.00	0.82	0.19	0.05	26.00	39.00	23.00	42000	11.00	0.02	26.00	18.00	8100	2800	0.54	14000	24	13	0.15	0.19	100	1.6	280	1.3	88	40
			Right	0.05	43200	3.40	23	95.00	0.90	0.22	0.05	25.00	44.00	26.00	47000	12.00	0.02	22.00	22.00	8200	1400	0.81	10000	25	14	0.14	0.23	120	1.8	340	1.4	95	42
		K1-4	Left	0.05	15700	1.60	9	100.00	0.34	0.09	0.05	16.00	18.00	9.70	19000	5.00	0.02	14.00	6.90	3100	1000	0.19	4800	11	8.5	0.09	0.08	150	0.7	240	0.6	44	14
			Middle	0.05	39700	3.00	21	97.00	0.82	0.20	0.05	26.00	41.00	24.00	46000	11.00	0.02	22.00	18.00	7900	2600	0.98	13000	23	13	0.14	0.2	120	1.7	280	1.3	93	41
			Right	0.05	35400	2.50	16	100.00	0.80	0.20	0.05	21.00	41.00	25.00	44000	11.00	0.02	21.00	15.00	7600	590	0.36	9500	22	13	0.09	0.14	130	1.6	230	1.1	91	40
		K1-5	Left	0.05	22700	1.80	11	74.00	0.57	0.16	0.05	20.00	29.00	18.00	31000	7.40	0.02	16.00	9.70	5500	720	0.3	6200	17	11	0.09	0.12	130	1.1	230	1	69	26
			Middle	0.05	17200	2.10	11	250.00	0.43	0.10	0.05	28.00	21.00	13.00	24000	6.10	0.02	21.00	8.30	4200	2200	0.43	5700	17	9.7	0.11	0.11	160	0.8	220	0.79	62	18
			Right	0.05	19200	2.10	9	220.00	0.47	0.13	0.05	26.00	26.00	16.00	28000	6.50	0.02	21.00	8.60	4600	1900	0.28	4000	18	13	0.13	0.1	170	0.9	290	0.94	70	21
Estuary	EST01	EST01	Left	0.05	22800	4.80	40	23.00	0.59	0.16	0.05	13.00	31.00	13.00	28000	7.10	0.02	14.00	19.00	11000	330	0.23	10000	16	8.6	0.08	0.1	180	1	380	0.73	47	27
			Middle	0.05	18200	3.90	36	20.00	0.43	0.12	0.05	10.00	24.00	10.00	22000	5.80	0.02	14.00	15.00	9300	290	0.19	10000	13	7	0.07	0.08	210	0.8	460	0.67	38	22
			Right	0.05	21900	4.40	36	25.00	0.44	0.14	0.05	11.00	27.00	11.00	23000	6.90	0.02	15.00	18.00	9600	310	0.19	8600	14	7.6	0.07	0.09	160	1	480	0.72	43	24
	EST02	EST02	Left	0.05	10700	5.00	25	15.00	0.25	0.08	0.05	8.40	18.00	6.40	16000	3.80	0.02	13.00	11.00	7800	330	0.17	7000	9.6	5.3	0.05	0.06	220	0.5	360	0.53	33	16
			Middle	0.05	10000	7.60	25	34.00	0.26	0.08	0.05	9.00	16.00	5.90	18000	4.00	0.02	15.00	9.20	8400	510	0.22	7800	9.7	6.1	0.07	0.07	220	0.5	340	0.55	34	15
			Right	0.05	8250	4.90	19	11.00	0.20	0.06	0.05	7.50	13.00	4.80	14000	3.20	0.02	12.00	7.60	6500	320	0.16	5100	8.2	4.6	0.06	0.05	270	0.5	350	0.51	27	13
	EST03	EST03	Left	0.05	10100	4.40	24	12.00	0.24	0.08	0.05	7.90	16.00	5.80	16000	3.60	0.02	11.00	9.10	6900	290	0.15	7100	8.9	4.9	0.05	0.06	220	0.5	340	0.52	29	15
			Middle	0.05	5080	4.90	15	8.70	0.14	0.05	0.05	6.70	10.00	3.30	12000	2.40	0.02	11.00	5.30	5800	330	0.15	6100	6.7	3.9	0.05	0.05	270	0.5	300	0.45	24	12
			Right	0.05	4400	6.30	15	8.30	0.13	0.05	0.05	7.20	9.60	3.30	12000	2.40	0.02	11.00	4.80	5600	370	0.17	5900	6.8	4.2	0.07	0.05	300	0.5	320	0.48	26	12

Table 6. Two-way ANOVA and Tukey's post hoc testing for significant differences in metal levels among sediment sampling events. Average values for untransformed data are provided in brackets. Sampling events joined by a common line are not significantly different ($p < 0.05$). Sampling events are arranged in order of ascending average value, left-to right.

Analyte	Source	ANOVA df	F	*p*	Tukey's *post hoc* tests				
Ni	Site	4	21.14	0.001	EST(7.33)	K4 (12.51)	K1 (13.81)	K2 (15.37)	K3 (15.4)
	Year	3	22.85	0.001	2011 (9.45)	2012 (13.31)	2013 (13.9)	2020 (17.13)	
	Site*Year	12	2.246	0.011					
	Corrected Total	251							
As	Site	4	46.91	0.001	K4 (1.72)	K3 (1.75)	K2 (1.91)	K1 (2.31)	EST (4.5)
	Year	3	16	0.001	2011 (1.72)	2013 (2.01)	2012 (2.74)	2020 (2.76)	
	Site*Year	12	3.734	0.001					
	Corrected Total	251							
B	Site	4	98.35	0.001	K4 (4.38)	K3 (4.82)	K2 (5.73)	K1 (12.57)	EST (21.31)
	Year	3	17.66	0.001	2011 (1250)	2012 (1426)	2013 (1651)	2020 (2156)	
	Site*Year	12	3.831	0.001					
	Corrected Total	251							
Cr	Site	4	17.01	0.001	EST (14.7)	K4 (18.46)	K1 (23.64)	K2 (24.1)	K3 (26.41)
	Year	3	28.74	0.001	2011 (15.64)	2012 (20.82)	2013 (23.71)	2020 (29.41)	
	Site*Year	12	2.603	0.003					
	Corrected Total	251							
Ti	Site	4	79	0.001	K4 (63.94)	K2 (119.03)	K3 (128.50)	K1 (138.02)	EST (253.33)
	Year	3	199.8	0.001	2011 (74.60)	2013 (87.81)	2012 (114.73)	2020 (271.35)	
	Site*Year	12	3.033	0.001					
	Corrected Total	251							
Li	Site	4	8.612	0.001	K4 (4.05)	K2 (6.10)	K3 (6.40)	EST (7.22)	K1 (8.10)
	Year	3	52.23	0.001	2011 (3.75)	2012 (5.14)	2013 (5.63)	2020 (11.53)	
	Site*Year	12	2.49	0.004					
	Corrected Total	251							
Pb	Site	4	30.41	0.001	EST (4.66)	K1 (8.45)	K4 (9.14)	K2 (9.72)	K3 (9.83)
	Year	3	16.4	0.001	2011 (7.35)	2012 (8.25)	2013 (8.27)	2020 (10.65)	
	Site*Year	12	1.687	0.071					
	Corrected Total	251							
Cu	Site	4	29.67	0.001	EST (5.86)	K4 (12.27)	K1 (13.13)	K2 (14.75)	K3 (15.81)
	Year	3	18.8	0.001	2011 (10.22)	2012 (11.27)	2013 (14)	2020 (6.47)	
	Site*Year	12	2.531	0.004					
	Corrected Total	251							
Co	Site	4	11.55	0.001	EST (9.6)	K3 (18.8)	K1 (18.83)	K4 (22.04)	K2 (23.22)
	Year	3	0.482	0.695	2011 (18.03)	2013 (18.65)	2012 (18.77)	2020 (20.57)	
	Site*Year	12	0.403	0.961					
	Corrected Total	251							
Ba	Site	4	12.18	0.001	EST (13.99)	K1 (101.48)	K3 (130.77)	K4 (170.7)	K2 (191.77)
	Year	3	1.725	0.163	2012 (108.63)	2011 (114.41)	2013 (121.22)	2020 (165.16)	
	Site*Year	12	1.299	0.22					
	Corrected Total	251							
Al	Site	4	12.28	0.001	EST (8193)	K4 (11780)	K1 (15646.7)	K2 (16076.5)	K3 (17172.7)
	Year	3	49.02	0.001	2011 (8101.9)	2013 (12698.25)	2012 (12730.5)	2020 (24449.84)	
	Site*Year	12	3.473	0.001					
	Corrected Total	251							
Fe	Site	4	14.54	0.001	EST (15861.11)	K4 (22372.22)	K1 (24618.33)	K2 (26728.33)	K3 (28716.67)
	Year	3	17.55	0.001	2011 (18207.94)	2012 (23831.75)	2013 (25574.6)	2020 (30484.13)	
	Site*Year	12	2.052	0.021					
	Corrected Total	251							
Hg	Site	4	1.483	0.208	K3 (0.17)	K2 (0.20)	K1 (0.25)	K4 (0.26)	EST (0.31)
	Year	3	22.02	0.001	2020 (0.02)	2013 (0.15)	2012 (0.35)	2011 (0.40)	
	Site*Year	12	0.947	0.501					
	Corrected Total	251							

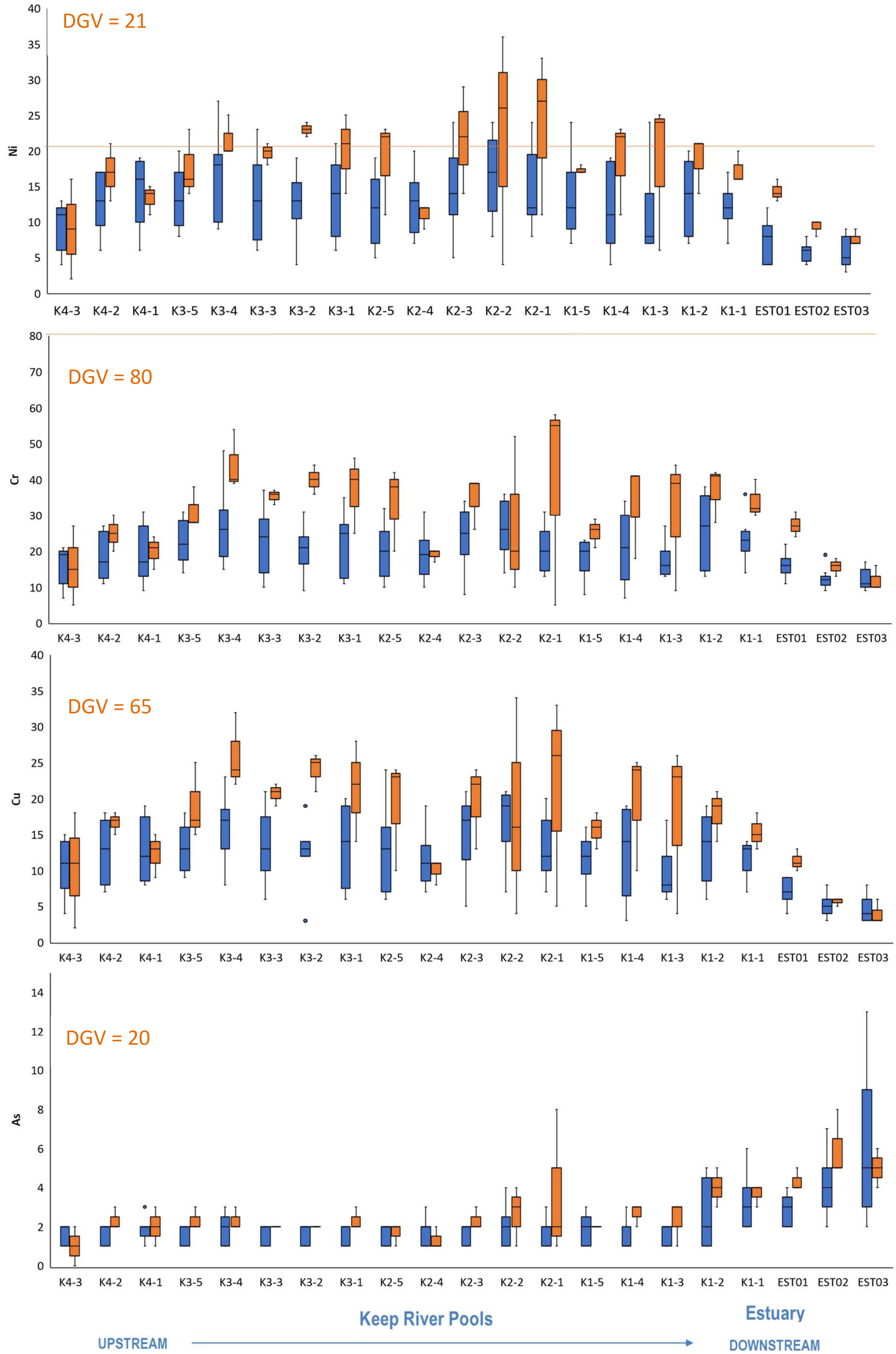


Figure 8. Box plots summarising recent survey data (2020; orange boxes) against baseline (2011, 2012 & 2013; blue boxes) for concentrations of select metals (mg/kg dry weight) within sediments of the Keep River and Keep River Estuary. Plots show minimum, 20%ile, median (50%ile), 80%ile, maximum.

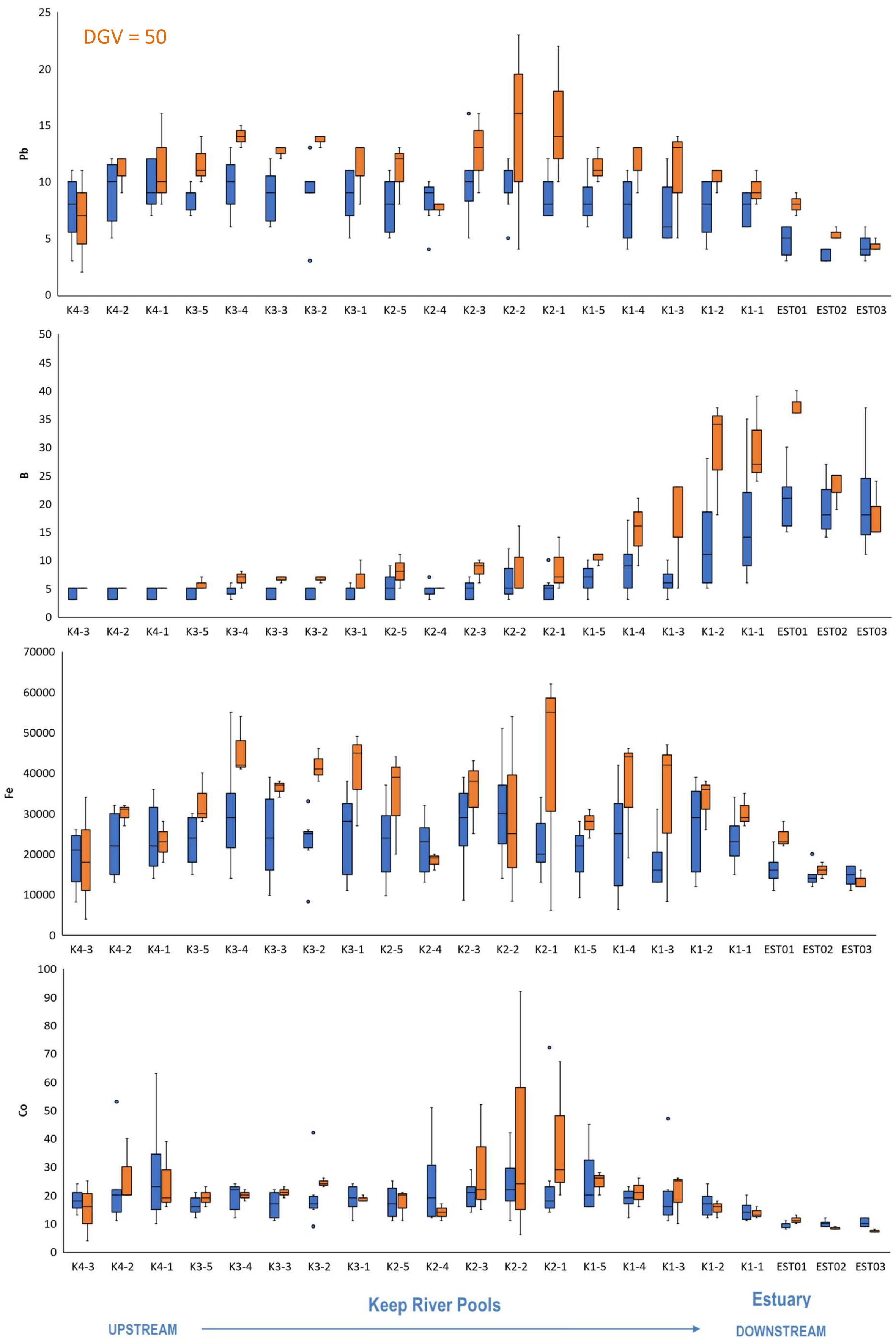
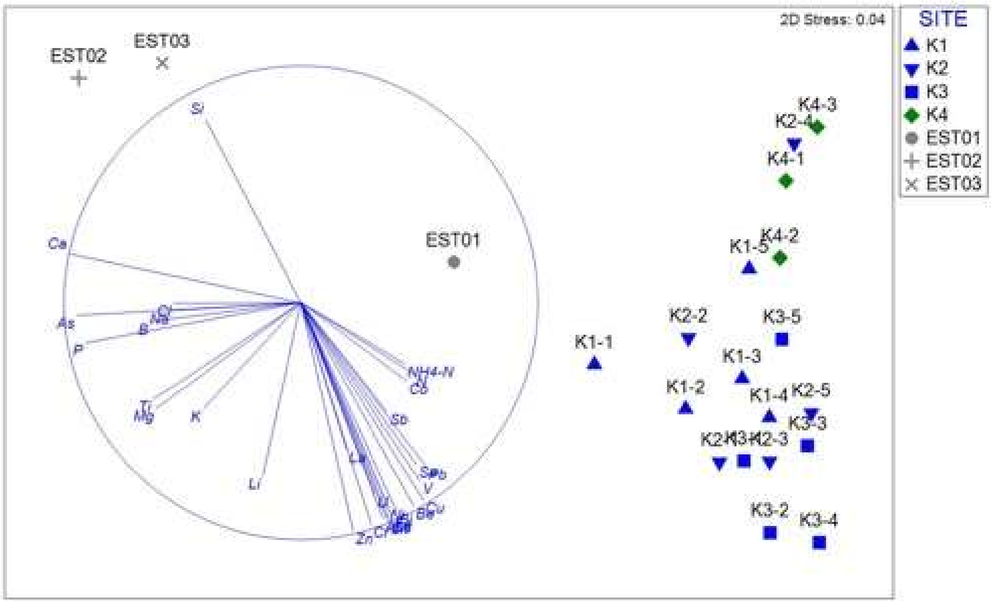


Figure 9. Box plots summarising recent survey data (2020; orange boxes) against baseline (2011, 2012 & 2013; blue boxes) for sediment concentrations of select metals (mg/kg dry weight) within sediments of the Keep River and Keep River Estuary. Plots show minimum, 20%ile, median (50%ile), 80%ile, maximum.

3.3.1 Multivariate patterns in the sediment data

One-way PERMANOVA on the suite of sediment data for Keep River indicated there was a significant difference between each individual Keep River Pool and the estuary sites ($P < 0.021$). K3 and K4 differed significantly from each other (t-stat = 4.2015 $P = 0.019$) and K1 differed significantly from K3 and K4 ($p < 0.031$). Pool K2 was not significantly different from any other pool. PERMANOVA pairwise comparisons of the baseline data showed that sites K3 and K4 were not significantly different ($t = 1.208$, $P = 0.252$) (WRM 2014). These differences are clearly discernible in the MDS ordinations for the Keep River 2020 sediments (Figure 10 A & B,). The differences between sites are primarily influenced by the combination of comparatively higher ionic concentrations in the estuary and greater proportion of NH_4 and metals in the sediments in the pools directly downstream of Border Creek.

A



B

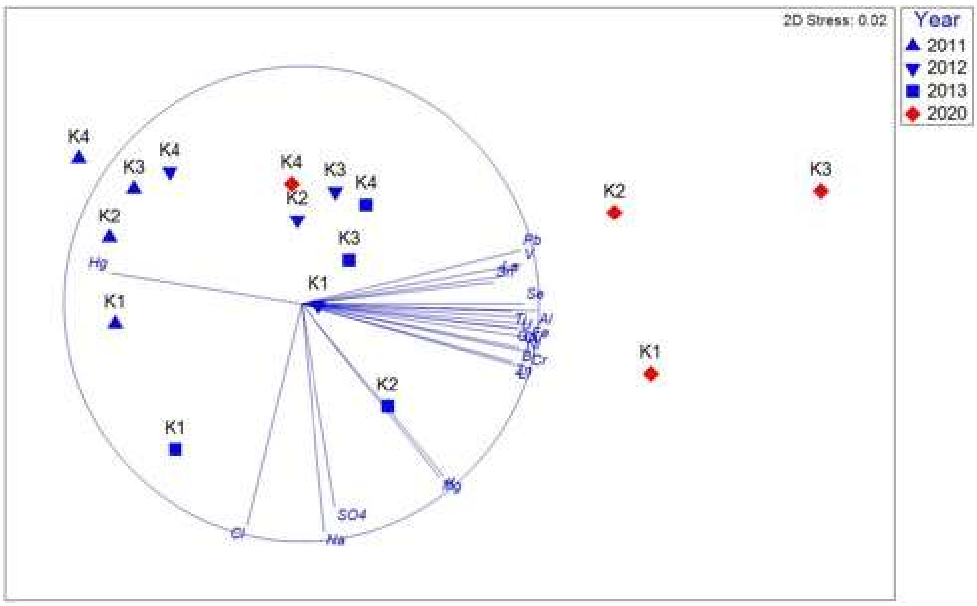


Figure 10. Two-dimensional (2D) plot of MDS ordinations on sediment data for Keep River sites for 2020 (A), and comparing the baseline data (blue) to the current study 2020 (B).

MDS ordinations comparing differences between sites and years show a clear distinction between the 2020 sites K1, K2 and K3 and all other pools previously sampled (Figure 10). K4, however, was similar in sediment composition overall to previous years. The increase in metals Al, Fe, Cr, Pb, Cr, Ti, Ni and B and the reduction of Hg appears to be driving the distinction of the sediments at these sites during the current study.

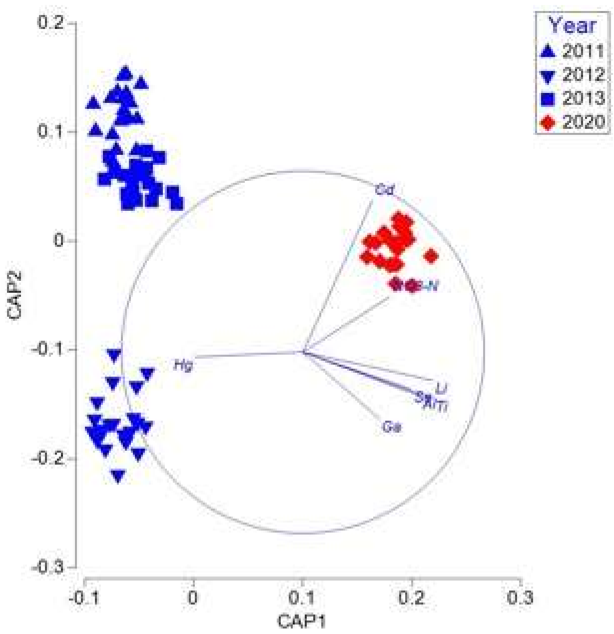
PERMANOVA also showed an overall significant difference between sampling occasions (pseudo F = 8.3735, p = 0.001) (Table 7). Pairwise comparisons indicated this was driven by significant differences between all years (p < 0.001). These differences were also clearly apparent in the CAP ordination plot (Figure 11 A, B).

The CAP ordination plots showed distinct clustering of sediment samples according to both site and year (Figure 11A, B, C). The first three canonical axes of each ordination had high canonical correlations (δ^2 >0.68) with the suite of sediment variables, explaining 48% of the total variation between sites and 63% of the variation between years (Figure 11 A, B, C).

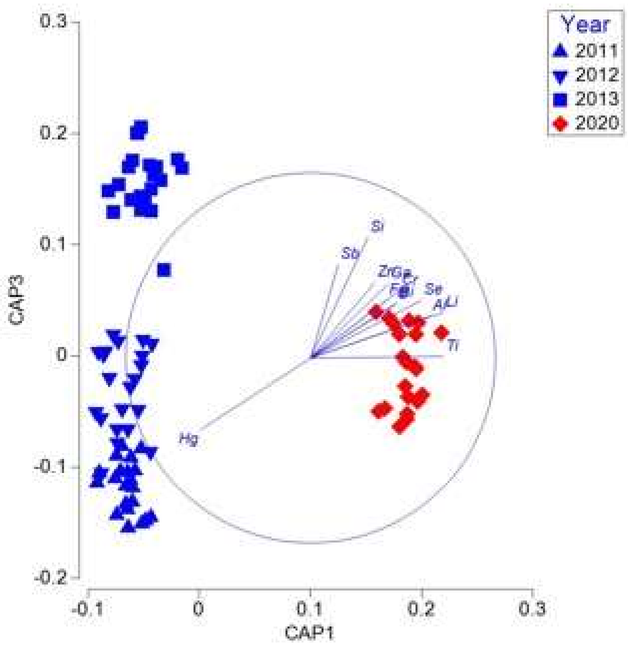
Amongst years (Figure 11 A, B), axis 1 and axis 2 distinctly separated the 2020 samples from prior years, while the 2011 and 2012 samples overlapped. The separation of years was best correlated with relatively higher concentrations of a number of metals in 2013 and 2020, compared to 2011/2012 and the distinct low levels of mercury (Hg) in 2020 compared to previous years (Figure 11B). Together, axes 1 and 2 accounted for 45.2% of inter-annual variation.

Combined data from all years showed that Keep River pools tended to cluster together and away from estuarine sites along axis 1 and axis 2 (Figure 11 C). Within the river sites, there was a distinct longitudinal pattern in overall sediment quality, whereby upstream sites separated from downstream sites along axis 2 (Figure 11 C). Vector overlay of analytes with Spearman rank correlation >0.5 indicated the separation of estuary sites from river sites was associated with higher concentrations of Na, Cl, SO4, K, B, Mg, As, P and Ti in the estuary but lower concentrations of N-total and NH_4-N and metals Ni, Cu, Cr, Pb, Ba, Be, U, and Ga and the reverse in the river sites (Figure 11C).

A.



B.



C.

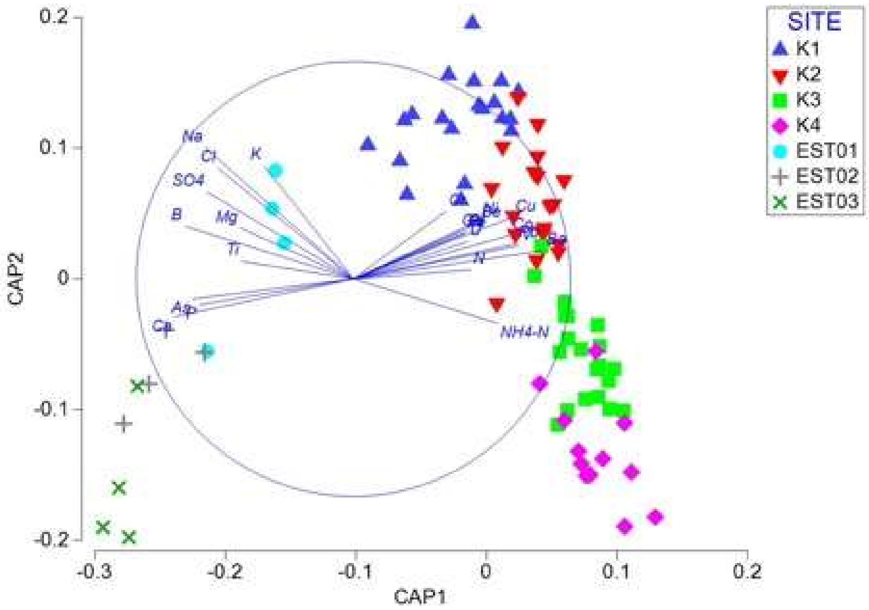


Figure 11. Results of constrained CAP analyses showing (A) axes 1 and 2, and (B) axes 1 and 3, that best discriminated sediment quality between years (baseline samples in blue, post development monitoring in red), and (C) axes 1 and 3 that best discriminated amongst sites among all years. Correlations of sediment variables ($\log_{10}(x+1)$ transformed) with the CAP axes are shown for variables with correlation > 0.5.

Table 7. Summary of (A) two-factor PERMANOVA results comparing sediment quality between site and year, and (B) PERMANOVA *post hoc* results showing t-values for all pairwise comparisons between years, and (C) between sites; all sites and years were significantly different (p <0.05).

A.

Source	df	MS	Pseudo-F	p
Site	6	197.7	13.073	0.001
Year	3	126.7	8.3735	0.001
Site*Year	18	21.67	1.4326	0.02
Residual	56	15.13		
Total	83			

B.

YEAR	t - statistic	*p* (perm)
2011, 2012	2.4094	0.001*
2011, 2013	2.5814	0.002*
2011, 2020	3.8404	0.001*
2012, 2013	2.4052	0.002*
2012, 2020	3.0937	0.001*
2013, 2020	2.6006	0.001*

C.

SITE	t - statistic	*p* (perm)
K1, K2	1.1936	0.267
K1, K3	2.3735	0.017*
K1, K4	3.1339	0.031*
K1, EST	4.6788	0.017*
K2, K3	1.4439	0.126
K2, K4	1.8248	0.119
K2, EST	4.0999	0.014*
K3, K4	4.2015	0.019*
K3, EST	5.6326	0.021*
K4, EST	3.9163	0.09*

3.4 Conclusions

Baseline data collected in 2011, 2012 and 2013 showed sediment quality and composition to be highly variable amongst sites and between years, and this was again evident in the 2020 data. Ionic composition of the sediments tended to reflect geographic location. Consistent with the baseline studies, estuary and lower Keep River sediments had higher concentrations of ions Na and Cl, due to tidal influence in these areas. Estuary sediments also had significantly higher concentrations of Ca, Mg, K and SO_4 than river sediments.

Concentrations of most metals in the 2020 study were well below ANZG (2018) default guideline values, with the exception of nickel. Concentrations of Ni in river sediments exceeded the DGV (21 mg/kg dry weight) at 10 sites K1-3, K1-4, K2-5, K2-3, K2-2, K2-1, K3-4, K3-5, K3-2, K3-1. Elevated Ni at these sites was also recorded in the pre- development baseline surveys. The source is unknown and likely represents natural background levels associated with surrounding geology. It is important that post-development monitoring continues in the river sediments to detect any future increases above the naturally high nickel levels detected during baseline.

Within the river sites, there was a distinct longitudinal pattern in overall sediment quality, whereby upstream sites separated from downstream sites. Multiple analytes in 2020 exceeded the maximum values recorded during baseline studies, most notably between the sites K3 and EST01. Increasing levels of Total-N and in particular nitrate (NO3) were detected in 2020, most notably between pool K3 and K1.

The data gathered during the course of the current study showed significant increases in some analytes compared to the baseline dataset. The baseline data provides three years of site-specific analyte measurements of which many metals in 2020 exceeded the maximum values recorded in baseline surveys. These included Al, B, Cr, Cu, Fe, Ga, Li, Ni, Pb, Se, Ti, U, V and Zn. Interestingly these exceedances occurred almost entirely downstream of pool K4, and appear to culminate the most at EST01 and occur all the way to the most downstream estuary site EST03. Factors that correlate with the exceedances downstream of pool K4 include:

- major earthworks, upgrade and bituminising of the Legune Road,
- operation of a gravel pit to the west of the Keep River, close to Border Creek, with various points of wet season run-off to the Keep River
- construction of a bridge across the Keep between pools K3 and K4,
- release of irrigation return water down Border Creek, and,
- release of M2 flushing water down Border Creek into the Keep River between pools K4 and K3.

Further sampling and investigation would be required to identify if any of the above activities were responsible for the observed changes.

The distinct increase in nutrient and metal levels between the pools K3 and K1 are of some concern as they are directly below the Border Creek confluence with the Keep River and as such could be attributed to releases down Border Creek, although the source of these metals is unknown. These changes don't appear to be system wide, as the non-exposed site K4 had no significant changes in sediment composition between years. However, though there were multiple measures above baseline values, only Ni was above the ANZG (2018) sediment default-guideline value and may pose a low risk to aquatic ecological values, however it is thought to be naturally elevated in the Keep River.

4 TARGETED SAWFISH (*PRISTIS*) AND SHARK (*GLYPHIS)* SURVEYS

4.1 Rationale

The current survey of the Keep River estuary sites and pools was undertaken to ascertain abundance, distribution, size and structure of Sawfish (*Pristis*) and river shark (*Glyphis)* populations in the Keep River downstream of the Project. Aquatic fauna surveys (Larson 1999, WRC 2003a, NCTWR 2005, WRM unpub. data) and incidental sightings provided early, pre-baseline records of *Pristis* sawfish from the Keep River, in areas downstream of potential effects from the ORIA Stage II development. Three *Pristis* species, *Pristis clavata, Pristis pristis* and *Pristis zijsron* are listed on state (DBCA threatened and priority list: P1, P3, VU), national (EPBC Act 1999: Vulnerable) and international conservation lists (IUCN Red List: Critically endangered). Another listed species, the speartooth shark *Glyphis* sp., may also occur in the lower Keep River and estuary, but have yet to be recorded, possibly because of their cryptic nature, or because they are absent due to lack of suitable habitat. Records of this species have occurred in the nearby Ord River estuary and to the north in the Daly River estuary (ALA 2020). Therefore, conditions imposed on the development by the Commonwealth government included a requirement for three years of targeted baseline sampling of *Pristis* sawfish and *Glyphis* sharks.

Baseline surveys subsequently documented the current occurrence, distribution, population size, and population structure of these listed species in the Keep River and Estuary, with sampling conducted annually for three years prior to commencement of irrigation to establish baseline conditions. WRM (2013a & b, 2014) conducted the required baseline surveys and confirmed the presence of populations of Dwarf sawfish (*P. clavata*), and presence of Largetooth sawfish, (*P. pristis*) in the Keep River estuary and freshwater reaches respectively, but absence of *Glyphis* sharks. The current survey aimed to repeat the sampling method conducted during baseline and assess any changes in distributions and populations of these listed species, and whether such changes, if present, may be attributed to the development.

4.2 Methods

4.2.1 Sampling sites

Sites targeted for sawfish and shark surveys included the four main pools on the lower Keep River (K1, K2, K3 and K4) and three sites in the inner Keep Estuary (EST01, EST02 and EST03), before the estuary expands to include additional rivers (Table 1 and Figure 3). Catch records from targeted sampling were also supplemented with incidental captures from the Aquatic Fauna Ecological Health surveys using multi-panel gill nets at all other sites (see section 5 below).

4.2.2 Field methods

Targeted sampling involved the use of large, single mesh gill nets (6” mesh x 30 m long x 2 m drop (Line 30 - 100 lbs) & 7” mesh x 30 m long x 2 m drop (Line 70 - 180 lbs)) deployed specifically to catch listed species. The nets were set perpendicular to the bank in the mid-reach of each pool/estuary location, and deployed for up to eight hours, with duration of deployment recorded for each site. Each net was checked regularly (at least every 30 mins) to remove captured listed species, as well as any by-catch. Sawfish caught in multi-panel gill nets deployed as part of ecological health monitoring (section 5), were also identified, measured, tagged and recorded.

Any listed species were identified and processed in the following manner:

- Measurements of total length (TL), Total rostrum length (TRL), Standard rostrum length (SRL), and left and right teeth counts were recorded;
- Sex was determined (based on presence of claspers);

- Condition of claspers was recorded (calcified or not);
- Each individual was tagged using Size 1 Supertags (45 mm by 20 mm tags) (Plate 1);
- A fin clip was taken, placed in 100% ethanol in the field and later stored at -4°C to provide tissue samples for DNA analyses.

Listed species were processed and returned to the water alive as rapidly as possible. Very young individuals were not tagged to avoid risk of harm through excessive stress from handling; air (+40C) and water (+30C) temperatures were very high for the duration of the survey.

By-catch were identified to species, total length recorded and individuals returned to the water alive. Nomenclature of by-catch followed Allen *et al.* (2002).

Plate 2. Example of tag attached to *Pristis pristis* from pool K2 (photos by WRM staff, 2011 ©).

4.2.3 Data analysis

<u>Catch per unit effort</u>

In addition to population estimates consistent with the baseline methodology, sampling in 2020 included Catch Per Unit Effort (CPUE) calculations, with the following data recorded:

a) Net specifications for each and every net set;
b) GPS location and soak time for each and every net set;
c) Set and retrieval times, both date and time of day set and retrieved;
d) Per net set:
   (i) Fish species names and numbers, and total length;
   (ii) Sex of individual elasmobranchs;
   (iii) Maturity status of male elasmobranchs based on clasper morphology.

Catch per unit effort was then calculated by dividing the number of sawfish caught at each location by the amount of time the net was set, then dividing by the area of the gill net set. This was then multiplied by 100 to give a CPUE value of sawfish per hour per 100m² of net. Catch CPUE survey data were then compared against equivalent CPUE data from baseline surveys.

<u>Population size estimates</u>

During baseline surveys, where sufficient individuals were captured at a site, sampling was repeated over consecutive days, such that mark-recapture techniques could be used to estimate population size. The Catch Mark Release Recapture (CMRR) methodology and the Ricker Equation (Ricker 1975) were used for this purpose. This approach is based on the premise that the population is closed to emigration, immigrations, births and deaths during the sampling period and that all individuals have the same probability of being caught in the second sample, regardless of whether they were previously caught (Krebs 1998).

At sites where tagged individuals were recaptured the following day, population size was estimated using the Ricker Equation (Ricker 1975). This equation is a slight variation of the Chapman (1951) modification of the Lincoln-Petersen Index (Lincoln 1930, Seber 1982; see Equation 1). Modifications were made to the Lincoln-Petersen Index to provide a statistically unbiased estimate for finite populations, such as those of inland waters (Ricker 1975).

Equation 1. **Ricker Equation.**

$$N = \frac{(M+1)(C+1)}{R+1}$$

where:

N = Estimate of population size,
M = Total number of animals captured during initial sampling
C = Total number of animals captured during subsequent days sampling
R = Total number of recaptures.

Sawfish movement

As with baseline surveys, the movement of sawfish was assessed by examining capture records and locations of recaptures of tagged sawfish by WRM staff and/or captures of tagged fish subsequently reported by recreational fishers.

4.3 Results and Discussion

4.3.1 Abundance and Species data

A total of 14 individuals, covering two species of *Pristis* sawfish were recorded during the 2020 survey (Table 8); the largetooth sawfish *Pristis pristis* (n = 5) and dwarf sawfish *Pristis clavata* (n =9). All sawfish captured were juveniles (<2500mm), with a size range of 875 - 2010 mm TL for *P. pristis*, and 930 - 2020 mm TL for *P. clavata*. One individual of the green sawfish *Pristis zijsron* (a female 1,905 mm TL) was recorded from the estuary (EST01) in 2011 during baseline surveys, but this species has not been recorded during any subsequent surveys or in post-development monitoring in 2020 (Appendix 4).

During the current survey five individuals of *P. pristis* were recorded, all from Keep River pools, whilst *P. clavata* was found only in the estuary, with a total of 9 individuals recorded (Table 8). Estuary site EST01 recorded the greatest number of *Pristis* individuals (4) at a single site. One *P. pristis* was caught at Policeman's Waterhole (KR2) in the Keep River National Park (Table 8), approximately 60 km upstream from the Keep Estuary (refer Figure 4). No previously tagged individuals were recaptured during the course of the current study, and apart from recaptures of sawfish tagged on the same day/net set, no recaptures were recorded or reported by recreational fishers subsequently.

No *Glyphis* sharks were captured during the 2020 survey, consistent with the baseline surveys and current available records. By catch recorded 5 bullsharks (*Carcharhinus leucas*) from Keep River pools, indicating the current methods catch sharks of equivalent size and dimensions to *Glyphis*, and so would catch *Glyphis* sharks if they were present at the monitoring sites.

Table 8. Details of *Pristis* individuals recorded during the targeted survey (TL = total length, TRL = total rostral length, SRL = standard rostral length). Values for ECond (mS/m EC), temperature °C, DO (%) and pH measured at the time of sampling are also provided.

Site	Date	Species	Tag#	Size		Teeth count		Sex	Water quality			
				TL	TRL	Left	Right		EC (µs/cm)	Temp (°C)	DO (%)	pH
Keep River												
K1-2	24/09/2020	*P. pristis*	24	2010	490	21	21	M	8000	32.4	151	8.02
K1-2	24/09/2020	*P. pristis*	25	1824	425	21	21	M	8000	32.4	151	8.02
K3-5	22/09/2020	*P. pristis*	*	880	221	20	20	M	353	30.51	129.5	7.54
K4-2	23/09/2020	*P. pristis*	*	875	231	17	19	F	832	31.47	102.9	7.31
KR2	2/10/2020	*P. pristis*	*	923	221	19	21	M	164	31.37	121.9	7.84
Keep Estuary												
ESTO1	27/09/2020	*P. clavata*	26	1920	370	21	20	M	8000	30.43	144.7	7.82
ESTO1	27/09/2020	*P. clavata*	27	2020	387	20	22	F	8000	30.43	144.7	7.82
ESTO1	27/09/2020	*P. clavata*	28	1720	331	22	19	M	8000	30.43	144.7	7.82
ESTO1	27/09/2020	*P. clavata*	*	1090	224	21	21	M	8000	30.43	144.7	7.82
ESTO2	28/09/2020	*P. clavata*	*	1030	209	21	21	M	8000	30.06	146.9	7.89
ESTO2	28/09/2020	*P. clavata*	*	980	208	22	22	F	8000	30.06	146.9	7.89
ESTO2	28/09/2020	*P. clavata*	*	930	197	22	23	F	8000	30.06	146.9	7.89
ESTO3	30/09/2020	*P. clavata*	29	1290	254	22	21	M	8000	30.07	136.8	7.71
ESTO3	30/09/2020	*P. clavata*	30	1535	313	21	22	M	8000	30.07	136.8	7.71

*Sawfish released prior to tagging due either to it being too juvenile or evidence of stress in the animal due to high water (+30 C) and air temperatures (+ 40 C)

4.3.2 Adjusted abundance data

Due to late afternoon thunderstorm activity across the survey dates, soak time at all estuary sites was not conducted for the standard 8 hours. Soak time however was recorded and sawfish catch data were adjusted to CPUE to be comparable to previous surveys and potential future monitoring studies (Table 9).

An adjusted total of 16.83 individuals of two species of *Pristis* sawfish were recorded during the 2020 survey, 5.63 *P. pristis* and 11.20 *P. clavata* (Table 9).

Catch per unit effort (CPUE) was calculated using the number of sawfish caught per hour per 100m² of gillnet (Table 9).

Table 9. Details of juvenile *Pristis* Sawfish species recorded during 2020. Sawfish numbers were adjusted to a standard 8-hour net set for the 6" and 7" net and a 2.5-hour multi-panel net set. Catch-per-unit-effort (CPUE) was calculated as the number of sawfish per hour per 100m² of gillnet.

Site	Date	Species	Net Type	Soak Time (hrs)	No. Sawfish	No. Sawfish Adjusted	CPUE (Sawfish per hr per 100m² net)
Keep River							
K1-2	24/09/2020	*P. pristis*	6" 7"	7:10	2	2.23	0.23
K3-5	22/09/2020	*P. pristis*	Multi B	2:20	1	1.07	0.71
K4-2	23/09/2020	*P. pristis*	Multi B	2:20	1	1.07	0.71
KR2	2/10/2020	*P. pristis*	Multi A	2:00	1	1.25	0.83
Total					**5**	**5.63**	**2.48**
Keep Estuary							
ESTO1	27/09/2020	*P. clavata*	6" 7"	6:45	4	4.74	0.49
ESTO2	28/09/2020	*P. clavata*	6" 7"	6:00	3	4.00	0.41
ESTO3	30/09/2020	*P. clavata*	6" 7"	6:30	2	2.46	0.26
Total					**9**	**11.20**	**1.16**
Total Sawfish					**14**	**16.83**	**3.64**

4.3.3 Sawfish sex ratio

Sex ratio data recorded during baseline surveys (2011, 2012 & 2013) indicated an equal sex ratio for riverine populations of *P. pristis* of 1 male : 1 female (Appendix 4). During the current survey 4 males were captured compared to only 1 female, making the ratio 4 males : 1 female. Baseline male size ranged in total length from 1,100 to 1,900 mm TL similar to the 2020 values of 923 – 2,010 mm. The single female specimen caught in 2020 was the smallest *P. pristis* captured during all surveys at 875mm outside of the baseline female range of 950 to 1,505 mm TL.

For *P. clavata* in the estuary, baseline sex ratio was 1.6 males : 1 female and in 2020 the ratio was 2 males : 1 female with 6 males caught compared to 3 females. Male *P. clavata* ranged in length from 840 to 2,260 mm TL during baseline and similarly in 2020 the total length ranged from 930 – 2,020 mm. *P. clavata* females ranged in length from 1,300 to 2,720 mm TL during baseline, and in 2020 two females were caught outside of this range measuring 930 and 980 mm respectively. The third female specimen measured 2,020 mm.

4.3.4 Sawfish population estimates

Insufficient numbers of individuals were recaptured during individual sampling events to enable accurate estimation of population size. Ricker (1975) stated that the probability of a systematic statistical bias in the population estimate was high for recapture number less than 5. For example, using the Ricker Equation on data gathered from EST01 in September 2012, estimated population size of *P. clavata* was 12 individuals, *i.e.*

$$N = \frac{(M+1)(C+1)}{R+1} = \frac{(11+1)(5+1)}{(5+1)} = 12$$

4.3.5 Sawfish movement

Available recapture records by recreational fishermen were limited to 2011. Combined with WRM data, these data indicated *P. clavata* move around the estuary (Appendix 5, Appendix 6). An individual caught and tagged in September 2011 at EST01 (tag# 314) was caught approximately 7 km downstream only five days later, while over the course of eight months another *P. clavata* (tag# 311) moved around 13 km downstream from its capture site (WRM 2013, Appendix 7).

A *P. pristis* individual (tag# 302) was initially tagged in 2011, and recaptured in September 2012 at the same location (Keep River pool K2) in which it was originally caught and tagged. This is not to say that the individual did not move at all over the course of the year, but it was recaptured at the exact location where it was originally caught.

No recaptures from previous surveys occurred during the current survey, and no recaptures of fish tagged in the current survey were subsequently reported. In previous years recaptures have tended to come from recreational fishers camping along the lower Keep River. Few fishers were present in 2020, and those encountered were on day trips from Kununurra, and not camping. This reflected the early wet season build-up and early rains, which likely discouraged recreational fishers, and this limited the opportunity for recaptures.

4.4 Conclusions

The total number of sawfish caught in 2020 (14 individuals) was comparable to baseline years 2012 (22 individuals) and 2011 (14 individuals). Total numbers caught in 2013 (6 individuals) were much lower than all other years and the reason for the low catch is unknown. Sampling effort and timing of surveys was comparable across years. It is postulated that shallow water depth in the upper estuary associated with very low tides at the time of sampling in 2013, may have restricted movement of sawfish around the estuary and influenced catch rates. For example, maximum water depth at EST02 was estimated to be <1 m.

Listed dwarf sawfish *Pristis clavata* are common in the Keep Estuary, while largetooth sawfish *P. pristis* are widely distributed along the freshwater reaches of the Keep River. *P. pristis* occurs at least as far upstream as ~60 km from the estuary, (Policeman's Waterhole in the Keep River National Park). All records of *P. clavata* are from the estuary, while all records of *P. pristis* are from the river (Larson 1999, WRC 2003, WRM 2011ab, WRM 2014, current study). The single record of a female green sawfish *P. zijsron* recorded from the upper Keep Estuary (EST01) remains the only record of this species among all surveys. Green sawfish are also a listed species. In Australia, green sawfish are now rarely encountered outside the Gulf of Carpentaria (Thorburn *et al.* 2004, Stevens *et al.* 2005, Field *et al.* 2008, DoE 2014c), although Morgan et al. (2016) identified the Ashburton River in the Pilbara Region as a regionally important pupping site for green sawfish, so the individual recorded at EST01 is likely to have been a vagrant.

Site EST01 in the upper estuary continues to support the greatest numbers of sawfish (7 in 2011, 11 in 2012, 0 in 2013, 4 in 2020). It is hypothesised that there is a gradual concentration of sawfish in this part of the estuary throughout the dry season, as a result of sawfish moving upstream chasing bait fish on the incoming tide. They negotiate a sand bar on the rising tide, and then become essentially landlocked in the upper estuary, not being able to re-negotiate the sandbar in a downstream direction due to falling water levels. The main rock bar between the Estuary and pool K1 then acts as a physical and behavioural barrier to upstream movement into pool K1. Lower salinities in pool K1 may also discourage further upstream movement. Continued sampling during the dry season would be required to test the hypothesis of a potential congregation area of a number of sawfish in the upper estuary. However, the presence of a relatively large number of sawfish, and what appears to be a high proportion of the population of *P. clavata* in the Keep Estuary could be potentially impacted should there be any adverse effects on the water quality of the lower pools and upper estuary.

To date, formal targeted surveys have not recorded any *Glyphis* sharks within the Keep River or Estuary. This includes the current post-development survey (2020), the annual (2011-2013) baseline surveys conducted by WRM, and historic surveys by Larson (1999), WRC (2003) and NCTWR (2005). This does not prove that *Glyphis* sp. never occur in these waters, but suggests that, at best, they seldom occur. The regular capture of bull sharks (*Carcharhinus leucas*) indicates the current methods would capture *Glyphis* sharks if they were present at the selected sampling sites.

5 AQUATIC FAUNA ECOLOGICAL HEALTH

5.1 Rationale

The aim of the aquatic fauna ecological health monitoring program is to monitor change in aquatic macroinvertebrate and fish species assemblages, especially changes in keystone species that may influence distribution and abundance of listed species (i.e. loss of important prey species). As well as being integral to aquatic food webs, macroinvertebrates and fish are both acknowledged as being sensitive to changes in water quality (and quantity), albeit at different spatial scales, and are accepted nationally and internationally for biological monitoring. In addition, aquatic macroinvertebrates and fish are an integral components of aquatic food webs.

Many surveys of macroinvertebrates and fish in northern Australia target recessional flows in the late wet season, to maximise the influence of run-off on aquatic fauna. Baseline surveys for the Keep River were conducted during the late dry season (Sept-Oct), as opposed to earlier in the year, to integrate any effects from discharge from the project area during the wet season and early dry season. Sampling at this time of year also enables a measure of the effectiveness of any mitigation strategies such as the use of discharge from the M2 channel to flush river pools of poorer quality water during the late wet/early dry. The long residence time and effects of evapo-concentration in river pools throughout the dry season is expected to pose the highest risk to ecological health, especially given the lower water levels and hence reduced capacity for dilution of contaminants, and reduced ability for fauna to move between pools and avoid water quality issues. Data collected by WRM for baseline (WRM, 2013 a & b, & 2014) established benchmark conditions at exposed sites as well as reference sites. The post-development survey uses the same design and methodology, and level of taxonomic resolution to discriminate changes resultant of the development from natural changes, such as climatic variability.

As required under Condition11F, WRM (2013c) developed biotic TVs for each Keep River pool (K1 to K4), based on the 20th percentile of AusRivAS O/E scores for macroinvertebrates recorded during the baseline surveys. The suitability of using AusRivAS for these pools was queried with the Commonwealth, with a request to vary the wording of Condition (11F). Issues raised by the IRG regarding the suitability of AusRivAS for this purpose included:

1. It was inappropriate to assess the ecological health of the tidally-influenced saline pools of the lower Keep River using AusRivAS models which are designed specifically for inland freshwaters
2. AusRivAS is not intended for setting trigger values
3. AusRivAS is not intended for assessing point-source impacts, and
4. The baseline dataset used to develop AusRivAS trigger values comprises only 3 years of data, in a naturally very variable region, which the IRG consider was an insufficient period to understand the natural variability seen in the ecosystems, making any potential impacts difficult to identify once the development starts.

The proposal to vary the Condition was approved by the Commonwealth, with amended Condition 11F now stating “Use of best practice multivariate analyses on species level macroinvertebrate and fish assemblage data, within an adequate experimental design (as defined in the Aquatic Fauna Management Plan required under condition 10), using multiple indices of ‘ecological condition’ and a ‘weight of evidence’ approach, to assess any change in ecological health of Keep River pools (K1, K2 & K3) relative to baseline and upstream reference sites”. As such, ecological health assessments of Keep River pools using AusRivAS is no longer required under Commonwealth conditions.

5.2 Methods

5.2.1 Sampling sites

Baseline sampling for aquatic macroinvertebrate and fish assemblages was conducted at potentially exposed sites in the Keep River, as well as reference sites to create a classic BACI design (Before/After: Control/Impact). Potentially exposed sites included the four main pools on the lower Keep River (K1, K2, K3 & K4), while reference sites included, KE1 (Milligan's Lagoon), KR1 (Alligator Waterhole), KR2 (Policeman's Waterhole), SR4 (Augustus Waterhole) and DR1 (Dunham River at Sugarloaf Hill) (Table 1 & Figure 4). KR1 (Alligator Waterhole) was not accessible by vehicle or boat in 2020 and due to this no fish sampling and depth profiles were not undertaken at this site. Similar to sediment sampling, five replicate sites were sampled within each of the K1, K2 and K3 pools on the lower Keep River (refer Table 1 & Figure 3). These sites corresponded with those previously designated by KBR (2006) and sampled for water quality by WRM (2010a, 2011). As the K4 pool is much smaller in size, only three replicates were sampled. For reference sites, one sample only was collected from each, with each site treated as a replicate for statistical comparisons of spatio-temporal variability. The same methods were used at the same sites under the current survey as used by WRM (2013a & b, 2014) to allow direct comparison with baseline data, and this includes the same species-level of taxonomic resolution, particularly for macroinvertebrates.

5.2.2 Water quality

In situ water quality parameters were measured at the time of sampling, and included pH, dissolved oxygen (DO), electrical conductivity (EC) and temperature. Dissolved oxygen and temperature profiles through the water column were taken at each exposed site, with measurements taken at the surface, and then at 0.5 m intervals until the bottom. Undisturbed water samples were collected for laboratory analysis of major ions, dissolved organic carbon (DOC) and nutrient concentrations. Nutrient samples were collected as 1-L gulp samples and kept cool on ice whilst in the field. All laboratory analyses were conducted by ChemCentre, Bentley, Western Australia (a NATA accredited laboratory). The collection method and suite of analytes were those selected and used by DAFWA (DAFWA 2011), to support the respective management plans (Strategen 2012a,b,c), and allow development of system-specific trigger values for analytes of concern (Bennett & George, 2014).

Concentrations were compared against default ANZG (2018) water quality trigger values (TVs) for the protection of northern tropical systems (see Appendix 5). Past monitoring has shown that some parameters exceed the default TVs (DAFWA 2011), and so current post-development water quality analysis will be compared to ANZG (2018) DGVs and system-specific baseline water quality collected in the previous surveys (WRM 2013ab, 2014). Bennett and George (2014) produced a technical report detailing baseline water quality in the lower Keep River in order to create site specific guideline values. This report included the same sites as sampled by WRM and was conducted during the period June 2010 to November 2013. Comparisons to these system-specific values was also conducted in conjunction with the WRM baseline data.

In addition, sampling for water quality was also conducted at Estuary sites EST01 to EST03 (Table 1 & Figure 3).

5.2.3 Macroinvertebrates

Edge habitats

Macroinvertebrates have previously been sampled from riverine sites associated with both Ord Stage 1 and Stage 2 projects, either as part of broader WA and NT agency AusRivAS programmes or specifically for assessment of impacts associated with Ord Stage 2 development (NCTWR 2005, Storey & Lynas 2007, WRM 2010a, 2011, WRM 2013ab, WRM 2014). In accordance with these previous surveys, macroinvertebrate surveys involved sampling the equivalent of 10 m of 'edge' habitat at each site using a 250 µm-mesh pond net. Edge habitat consisted of habitat along the banks of each pool, typically root mat, leaf litter/detritus, occasionally some submerged macrophytes or floating vegetation. Each sample was washed *in situ* through a 250 µm sieve to remove fine sediment, while leaf litter and other coarse debris were washed and removed by hand. Samples were preserved in 70% ethanol and transported to the WRM Perth laboratory for processing.

Riffle habitats

A series of wet seasons with above average rainfall since 1999, and subsequent recharge of the aquifer, have resulted in permanent flows in the lower reaches of the Keep River. Prior to 1999, the lower Keep (from pool K4 downstream) was seasonal, ceasing to flow in the early dry. However, following successive big wet seasons, the lower Keep developed a small baseflow (5 - 10 L/sec) that persisted throughout the dry season. During the baseline surveys, flows were present from pool K4 downstream, providing riffle habitat. Given that riffle zones are known to be biodiversity 'hotspots' (Brown & Brussock 1991, Barbour *et al.* 1999), these riffle habitats were also sampled for macroinvertebrate fauna, with riffles sampled just below the K4 pool and just upstream of the K3 pool (& downstream of the Border Creek confluence). It is anticipated that riffle fauna will be the first to show impacts of any changes in water quality. Riffle habitat was sampled from those reference sites where there was surface flow (*i.e.* Augustus Hole & Dunham River).

Riffle samples were collected by 'kick-sampling' with a 250 µm-mesh pond net (Plate 2). As with the edge habitat samples, riffle samples were washed *in situ* through a 250 µm sieve to remove debris, preserved in 70% ethanol and transported to the WRM Perth laboratory. Riffle habitat is not commonly present during the dry season, and the design therefore has few sites and low replication for statistical analyses, however, this was unavoidable.

Plate 3. Macroinvertebrate sampling in a riffle upstream of K3.

Laboratory processing

In the laboratory, macroinvertebrates were removed from samples by sorting under a low power dissecting microscope. Collected specimens were then identified to the lowest possible level (genus or species level) and enumerated to log_{10} scale abundance classes (*i.e.* 1 = 1 individual, 2 = 2-10 individuals, 3 =11 - 100 individuals, 4 = 101-1000 individuals, 5 = >1000, *etc*.). In-house expertise was used to identify invertebrate taxa using available published keys and through reference to the established voucher collections held by WRM.

5.2.4 Fish

Fish were sampled using standard methodology that has been used extensively in the Northern Territory (Larson 1996, 1999) and Kimberley (Storey 2003, WRC 2003a). These methods have proven effective in providing standard catch per unit effort (CPUE) data from the Keep and adjacent Ord, Pentecost and

Dunham rivers. Sampling utilised duplicate (x2) 30 m multi-panel gill nets at each location, with each net consisting of 6 x 5 m panels, with 2 m drop, panels increasing in size from 1” to 6” stretched mesh size. The nets were set perpendicular to the bank, with the smallest mesh set against the bank, and the large mesh positioned into the channel with a float and weight to keep the net in place. At each replicate sampling location, duplicate nets were set for approximately 2.5 hours. Nets were checked frequently to avoid fish deaths. Catch from both nets were combined to form one replicate sample from each sampling location. Individual fish were identified to species and total length (mm) and weight (g) measured, before being released back into the water alive. Fish nomenclature followed Allen et al. (2002). Any listed species (e.g. *Pristis* sawfish or *Glyphis* sharks) were processed as outlined above (see section 4.2.2). Nets were deployed either in the morning or afternoon, allowing sufficient time to process the catch before nightfall.

The current survey continued the same method as employed by WRM (2013a & b, 2014), using the same nets as used for baseline surveys. Nets were deployed at the same locations, for the same duration, ensuring comparability of catch data to baseline data.

The following data were recorded to allow calculation of Catch Per Unit Effort (CPUE):

a) Net specifications for each and every net set;
b) GPS location and soak time for each and every net set;
c) set and retrieval times, both date and time of day set and retrieved;
d) Per net set:
    i) Fish species names and numbers, and total length;
    ii) Sex of individual elasmobranchs;
    iii) Maturity status of male elasmobranchs based on clasper morphology. This will allow comparison of post-development CPUE survey data against equivalent CPUE data from baseline surveys.

5.2.5 Data analysis

Univariate and multivariate analyses

All univariate analyses were performed using IBM SPSS Statistics (v22) software package. A significance level of $\alpha = 0.05$ was used in all univariate tests. Longitudinal gradients in environmental data were investigated using the regression analyses function in Microsoft Excel.

Average species richness in the Keep River was compared to data collected by WRM as part of baseline sampling (2011, 2012, 2013) and at the comparable regional sites to assess change over time. The regional sites were used here as reference sites, and included:

1. Milligans Lagoon (KE1)
2. Policemans Lagoon (KR2)
3. Alligator Waterhole (KR1)
4. Augustus Waterhole (SR4)
5. Dunham Pool (DR1)

One-way analysis of variance (ANOVA) was used to test for statistically significant differences in average species richness between Keep River and regional sites, between sites and between years. Prior to analyses, the assumptions of normality and homogeneity of sample variances were checked using a Levene’s test, and data transformed where appropriate. Where ANOVA indicated significant main effects, Tukey’s HSD post-hoc tests were performed to locate between-group differences.

Multivariate Analysis

Multivariate analyses were performed using the PRIMER package v7 to investigate differences in aquatic macroinvertebrate and fish fauna assemblages and environmental characteristics across sites and years. Relationships between faunal assemblages and environmental characteristics were also examined. Analyses applied to the data included some or all of the following:

1. Describing pattern amongst the fauna assemblage data using ordination techniques based on Bray-Curtis similarity matrices (Bray and Curtis 1957). The clustering technique uses a hierarchical agglomerative method where samples of similar assemblages are grouped and the groups themselves form clusters at lower levels of similarity. A group average linkage was used to derive a dendrogram, which was used for assisting in analysis but not included in this report. Ordination of data was by non-metric Multi-Dimensional Scaling (nMDS) (Clarke and Warwick 2001). Ordinations were depicted as two-dimensional plots based on the site by site similarity matrices. For water quality data, the Euclidean Distance Measure was used to create resemblances, habitat percentage cover data were arcsine transformed, and water quality data were log transformed (where necessary) and normalised. For clarity, ordinations were depicted as two-dimensional (2D) plots based on the site by site similarity matrices, with 'stress' for 2D and 3D plots provided where relevant.
2. Cluster analysis to produce SIMPROF results that were overlain on the ordination where necessary. The SIMPROF procedure tests for significant ($p>0.05$) *a posteriori* groups determined from the cluster analysis (40% similarity level);
3. The permutational multivariate analysis of variance (PERMANOVA) add-on to PRIMER v7 was used to test for significant ($p <0.05$) site effects on environmental variables or fauna assemblages (Anderson 2001a, b, McArdle and Anderson 2001, Anderson et al. 2008);
4. The relationship between the environmental variables and biotic data (macroinvertebrates) was assessed via the BIOENV routine in PRIMER. This was used to calculate the minimum suite of environmental variables that explained the greatest percentage of variation in the species data (i.e. the parameters which appeared best correlated with the species ordinations).

5.3 Results and Discussion

5.3.1 Water quality – univariate analyses

Major analyte parameters measured during the 2020 survey are summarised below in Tables 10 and 11. Water quality data are compared to both ANZG (2018) default water quality guidelines and the results of the three baseline surveys (2011, 2012, 2013) to support a robust analysis of changes between sites and over time. In addition, Table 12 also provides a comparison to Interim Local Trigger Values (ILTVs) developed for the Keep River pools by Bennett and George (2014).

Summary statistics for WRM baseline water quality data (2011, 2012, 2013) collected from the lower Keep River pools (K1 to K4 pools), Estuary and reference sites are provided in Appendix 6; including minimum, maximum, median, mean, 20%ile and 80%ile values for the combined 2011-2013 data set for each site. A brief description of major water quality parameters is given below.

General parameters – DO, pH, alkalinity, turbidity

In 2020 mean values of Keep River sites indicated the majority of sites were characterised by basic pH (7.29 - 8.07), moderate to high alkalinity (129- 146 mg/L $CaCO_3$) and hardness (95 - 1900 mg/L $CaCO_3$), low turbidity (1.9 – 5.1 NTU), and moderate to high daytime DO (85 – 151.9%). These results were mostly within the baseline range and ANZG (2018) guidelines with the exception of abnormally high DO% at pools K1, K2 and K3 (Table 10, Figure 12). DO also exceeded the baseline maximum values at all three estuary sites in 2020. DO (%) also exceeded the Bennett and George (2014) interim local trigger values (ILTVs) for Keep River sites K1, K2 and K3 (Table 12).

Spatial variation in selected general water quality parameters is illustrated in Figure 12; dissolved oxygen, pH, alkalinity and turbidity. DO and alkalinity showed statistically significant variation amongst sites and between years (two-way ANOVA, $p = 0.001$) but that these differences were independent of each other (two-way, ANVOA $p > 0.275$) (Table 13). pH, however, showed significant differences between sites and years (two-way ANOVA $p = 0.001$) and there was a significant interaction between these variables ($p = 0.001$). Average pH in 2020 (7.69) was the lowest recorded amongst all years and appears to be moving toward a more neutral pH since 2011 (8.07) when it was slightly more basic. This may reflect inter-basin transfer of M2 water from the Ord with lower pH. There was significant difference in turbidity between sites but not between years (two-way ANOVAs, $p = 0.001$, $p = 0.092$) (Table 10, Table 13). These water quality factors can be highly variable dependent on time of day, time of year and the weather at the time of sampling.

Previously low DO levels were recorded from the Keep River at K4 (Legune Rd crossing) in 2013 (31.8 - 42.4%), and from Milligan's Lagoon reference site KE1 in all baseline years (36.7 - 48.6%) which was theorised to be due to the extensive deposits of organic detritus and associated high microbial activity at these sites. In 2020 both these sites recorded values >100% DO (Figure 12).

Vertical profiles of DO are shown in Figure 13, and indicate some level of stratification at some Keep River sites (K2, K3), and reference site Milligan's Lagoon (KE1) in 2020. In baseline, stratification was strongest in Keep River pools K1 to K3 in 2013. In 2013, stratification was most pronounced in the mid reaches of the lowermost site K1 (K1-2, K1-3). Interestingly in 2020 these K1 sites appear to increase in DO% at depths between 1m and 2m before beginning to drop again at 2.5m depth. Though salinity profiles were not measured, the large increase in DO% at 1m depth at K1 sites may have been due to a halocline formation trapping a high amount of photosynthetic material around 1m below the surface level.

There was little evidence of strong thermocline development at any of the pools. Hypoxia (≤20% DO) prevailed in bottom waters at around 4m of depth at sites K4, K3 and Milligan's lagoon. The relatively shallow Estuary sites appeared to be well mixed and well oxygenated (Figure 13).

Table 10. Water Quality data from the lower Keep River sites on the Keep River 2020. Yellow highlight indicates data above the ANZG (2018) default guideline value (lower limit), orange highlight indicates data greater than the guideline value high (upper-limit), Dark blue highlight indicates data that are elevated relative to baseline condition, light blue highlight indicates data that are below the minimum recorded value during baseline sampling (recorded at each site during the 2011,2012 and 2013 baseline surveys).

						Keep River Sites																	
					Site	K4-3	K4-2	K4-1	K3-5	K3-4	K3-3	K3-2	K3-1	K2-5	K2-4	K2-3	K2-2	K2-1	K1-5	K1-4	K1-3	K1-2	K1-1
Analyte	Units	Baseline Min	Baseline Max	ANZG (2018) - Lower limit	ANZG (2018) - Upper Limit	2020																	
Acidity	mg/L	1	22			8	7	7	3	<2	2	<2	4	<2	<2	<2	<2	3	<2	<2	<2	<2	<2
Alkalin	mg/L	132	177			134	131	131	129	130	143	131	132	130	131	131	131	131	141	142	142	146	146
Ca	mg/L	31	395			41.3	38	37.6	18.1	18.1	18.1	18.6	19.8	21.3	19.6	20.2	19.5	19.9	83.2	84.4	87.5	130	136
Cl	mg/L	112	17600			156	151	151	22	22	22	27	46	43	43	47	47	56	3560	3460	3740	5930	6350
CO3	mg/L	1	24			<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	1	<1
DOC	mg/L	1.2	5.1			2	2	2.2	4.7	4.7	4.6	4.6	4.5	4.6	4.5	4.4	4.4	4.4	4.3	4.4	4.5	4.2	4.1
Econd	mS/m	81	4970	20	250	82.4	79.5	79.6	34	33.9	33.8	35.3	41.6	40.7	41.2	42	42	44.6	1050	1020	1100	1640	1750
F	mg/L	0.14	0.77			0.12	0.12	0.12	0.28	0.28	0.29	0.29	0.29	0.29	0.3	0.29	0.3	0.3	0.44	0.44	0.45	0.52	0.53
HCO3	mg/L	161	212			164	159	160	157	158	174	159	161	158	160	160	160	160	171	171	171	176	178
Hardness	mg/L	200	5700			210	200	200	95	97	96	98	110	120	100	110	100	110	1100	1100	1100	1800	1900
K	mg/L	4	313			3.9	3.6	3.5	3.6	3.6	3.6	3.6	3.9	4.2	3.9	4.1	3.9	4.1	70.7	76.1	77.4	128	133
Mg	mg/L	25	1130			26.6	26.7	26.6	12.2	12.5	12.4	12.4	13.8	15.2	13.3	14	13.4	14.2	209	209	219	351	375
N_NH3	mg/L	0.01	0.05			<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
N_NO2	mg/L	0.01	0.01			<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
N_NO3	mg/L	0.01	0.01			<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
N_NOx	mg/L	0.01	0.01	0.01		<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
N_org	mg/L	0.11	0.56			0.12	0.14	0.12	0.4	0.38	0.36	0.38	0.39	0.37	0.38	0.34	0.37	0.37	0.45	0.41	0.38	0.45	0.44
N_total	mg/L	0.07	0.58	0.2	0.3	0.12	0.15	0.12	0.4	0.38	0.36	0.38	0.39	0.37	0.4	0.36	0.37	0.37	0.45	0.41	0.38	0.45	0.44
N_totsol	mg/L	0.09	0.57			0.1	0.13	0.11	0.36	0.32	0.29	0.31	0.33	0.31	0.35	0.32	0.34	0.33	0.41	0.4	0.36	0.38	0.36
Na	mg/L	80	9230			69.2	68.3	68.6	29.7	30.3	30.1	31.7	40.7	43.9	39.3	42.1	40	44.5	1650	1660	1760	2850	3040
P_SR	mg/L	0.01	0.01			<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
P_TR	mg/L	0.01	0.01			<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
P_org	mg/L	0.01	0.01			<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	0.02	0.02	0.03	0.03
P_total	mg/L	0.005	0.02	0.01		0.008	0.007	0.007	0.01	0.011	0.008	0.007	0.009	0.007	0.009	0.007	0.007	0.006	0.022	0.018	0.017	0.025	0.028
P_totsol	mg/L	0.005	0.005			<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.009	0.01	0.009	0.015	0.015
SO4_S	mg/L	54	2460			53.7	54.3	54.2	10	10.3	10.1	10.3	12.3	13.8	12.1	13	12.4	13.6	431	427	446	714	763
TDS_calc	mg/L	520	27000			450	440	440	190	190	190	190	230	220	230	230	230	250	5800	5600	6000	9000	9600
TSS	mg/L	1	14			5	<3	<3	4	4	3	4	3	4	6	4	3	5	4	4	5	6	5
Turbidity	NTU	1.3	18	2	15	4.4	3	3.6	4.7	4	4.6	3.2	5.1	4.7	4.8	4.7	4.6	5.5	2.1	2.1	2.4	1.9	2.2
Temp	°C	23.2	33.7			30.03	31.47	29.31	30.51	30.2	29.81	29.09	28.62	30.94	30.64	30.47	29.09	28.9	30.85	30.83	30.11	32.43	29.96
pH		6.9	8.5	6	8	7.29	7.31	7.25	7.54	7.57	7.48	7.57	7.37	7.72	7.76	7.73	7.62	7.67	8.02	8.01	8.04	8.02	8.07
Redox	ORP					488	479	470	350	429	374	492	504	532.0	531	526	573	582.0	485	492	492	484	539
DO%	%	32	123	90	120	85.1	102.9	95.4	129.5	130.9	123.3	125.7	99	139.2	139.5	144.1	138.3	134.4	144.5	139.7	130.2	151.9	146.8
DO mg/L	mg/L					6.42	7.57	7.29	9.68	9.85	9.33	9.64	7.65	10.33	10.42	10.8	10.61	10.33	10.4	10.07	9.46	10.39	10.48

Table 11. Water Quality data from the reference sites and Keep River Estuary sites. Yellow highlight indicates data above the ANZG (2018) default guideline value (lower-limit), orange highlight indicates data greater than the guideline value high (upper-limit), Dark blue highlight indicates data that are elevated relative to baseline condition, light blue highlight indicates data that are below the minimum recorded value during baseline sampling (recorded at each site during the 2011,2012 and 2013 baseline surveys).

						Reference sites											Estuary		
						SR4	KE1	KR2	KR1	DR1							EST01	EST02	EST03
Analyte	Units	Baseline Min	Baseline High	ANZG (2018) - Lower limit	ANZG (2018) - Upper Limit	2020					Analyte	Units	Baseline Min	Baseline High	ANZG (2018) - Lower limit	ANZG (2018) - Upper Limit	2020		
Acidity	mg/L	1	10			<2	10	2	4	<2	Acidity	mg/L	5	18			<2	<2	6
Alkalin	mg/L	68	158			143	42	67	48	134	Alkalin	mg/L	133	195			148	150	135
Ca	mg/L	18	33			29.8	4.6	14.6	9.8	19.6	Ca	mg/L	376	482			288	337	425
Cl	mg/L	4	52			5	3	6	5	11	Cl	mg/L	16900	22900			14500	17000	21000
CO3	mg/L	1	4			<1	<1	<1	<1	1	CO3	mg/L	1	18			4	<1	<1
DOC	mg/L	1.7	12			2.7	10	3.9	5.9	5.3	DOC	mg/L	1.4	4.6			3	3.1	1.7
ECond	mS/m	20.3	45.9	20	250	29.3	9.3	15.7	11.3	27.5	ECond	mS/m	4520	6100			3810	4450	5710
F	mg/L	0.06	0.3			0.12	0.08	0.06	0.05	0.2	F	mg/L	0.68	1			0.79	0.85	1.1
HCO3	mg/L	83	233			175	52	82	58	160	HCO3	mg/L	131	238			173	183	165
Hardness	mg/L	75	170			160	31	65	45	110	Hardness	mg/L	5500	7300			4300	5100	6500
K	mg/L	2	14			3.8	4.2	2.7	3.6	3.4	K	mg/L	-	419			326	401	510
Mg	mg/L	0.01	27			19.8	4.7	7	4.9	15.9	Mg	mg/L	1110	1480			860	1030	1330
N_NH3	mg/L	0.01	0.04			<0.01	<0.01	<0.01	<0.01	<0.01	N_NH3	mg/L	0.01	0.07			<0.01	<0.01	<0.01
N_NO2	mg/L	0.01	0.01			<0.01	<0.01	<0.01	<0.01	<0.01	N_NO2	mg/L	0.01	0.01			<0.01	<0.01	<0.01
N_NO3	mg/L	0.01	0.01			<0.01	<0.01	<0.01	<0.01	<0.01	N_NO3	mg/L	0.01	0.01			<0.01	<0.01	0.01
N_NOx	mg/L	0.01	0.02	0.01		<0.01	<0.01	<0.01	<0.01	<0.01	N_NOx	mg/L	0.01	0.02	0.03		<0.01	<0.01	0.01
N_org	mg/L	0.15	0.98			0.16	0.94	0.31	0.4	0.35	N_org	mg/L	0.12	0.58			0.38	0.47	0.52
N_total	mg/L	0.15	1	0.2	0.3	0.16	0.94	0.31	0.4	0.35	N_total	mg/L	0.15	0.66	0.25		0.38	0.47	0.53
N_totsol	mg/L	0.14	0.83			0.13	0.63	0.21	0.32	0.26	N_totsol	mg/L	0.11	0.62			0.31	0.31	0.14
Na	mg/L	3	30			3.9	3.6	4.5	4.1	16.6	Na	mg/L		12200			7020	8570	11000
P_SR	mg/L	0.01	0.01			<0.005	<0.005	<0.005	<0.005	<0.005	P_SR	mg/L					<0.005	<0.005	0.008
P_TR	mg/L	0.01	0.01			<0.01	<0.01	<0.01	<0.01	<0.01	P_TR	mg/L	0.01	0.025			<0.01	<0.01	<0.01
P_org	mg/L	0.01	0.03			<0.01	0.07	0.02	0.02	0.02	P_org	mg/L	0.01	0.01			0.05	0.06	0.15
P_total	mg/L	0.005	0.03	0.01		<0.005	0.068	0.017	0.015	0.015	P_total	mg/L	0.005	0.05	0.02		0.046	0.062	0.15
P_totsol	mg/L	0.005	0.01			<0.005	0.024	0.006	0.006	0.005	P_totsol	mg/L	0.005	0.05			0.034	0.05	0.016
SO4_S	mg/L	0.6	44			6.3	0.6	3.5	3.6	1.1	SO4_S	mg/L		2970			1880	2210	2830
TDS_calc	mg/L	110	250			160	51	86	62	150	TDS_calc	mg/L	26000	34000			21000	24000	31000
TSS	mg/L	0.5	8			<3	15	4	4	5	TSS	mg/L	5	1100			12	27	810
Turbidit	NTU	0.6	30	2	15	0.8	13	7.2	3.6	4.3	Turbidit	NTU	12	1000	1	20	5.6	13	620
Temp	°C	25.2	32.1			30.87	31.98	31.37	30.46	33.23	Temp	°C	22.7	33.2			30.43	30.06	30.07
pH		7.1	8.3	6	8	7.81	7.26	7.84	7.46	8.13	pH		8	8.3	7	8.5	7.82	7.89	7.71
Redox	ORP					481	447	425	461	469	Redox	ORP					586	560	542
DO%	%	37	100	90	120	107.7	114.5	121.9	99.7	135.3	DO%	%	86	125	80	120	144.7	146.9	136.8
DO mg/L	mg/L					8	8.33	9.01	7.45	9.69	DO mg/L	mg/L					9.42	9.38	8.27

Table 12. Interim Local Trigger Values (ILTVs) for aquatic environmental stressors and toxicants in the lower Keep River (Bennett and George 2014). Yellow highlight indicates an exceedance of the 80th percentile trigger value.

Parameter	K4 SSGV	K4-3	K4-2	K4-1
EC	85	82.4	79.5	79.6
NH3	0.03-032	<0.01	<0.01	<0.01
NOx/NO3	0.01-0.17	<0.01	0.01	<0.01
TN	0.44	0.12	0.15	0.12
SRP	0.004	<0.005	<0.005	<0.005
TP	0.04	0.008	0.007	0.007
TSS	62	5	<3	<3
Turb.	120	4.4	3	3.6
Temp	24–31	30.03	31.47	29.31
ph	6.0–8.0	7.29	7.31	7.25
DO	23–120	85.1	102.9	95.4

Parameter	K3 SSGV	K3-5	K3-4	K3-3	K3-2	K3-1
EC	434	34	33.9	33.8	35.3	41.6
NH3	0.02 - 0.32	<0.01	<0.01	<0.01	<0.01	<0.01
NOx/NO3	0.01-0.17	<0.01	<0.01	<0.01	<0.01	<0.01
TN	0.39	0.4	0.38	0.36	0.38	0.39
SRP	0.004	<0.005	<0.005	<0.005	<0.005	<0.005
TP	0.013	0.01		0.008	0.007	0.009
TSS	29	4	4	3	4	3
Turb.	17	4.7	4	4.6	3.2	5.1
Temp	24–31	30.51	30.2	29.81	29.09	28.62
ph	6.0–8.2	7.54	7.57	7.48	7.57	7.37
DO	22–120	129.5	130.9	123.3	125.7	99

Parameter	K2 SSGV	K2-5	K2-4	K2-3	K2-2	K2-1
EC	2158	40.7	41.2	42	42	44.6
NH3	0.01-0.32	<0.01	0.02	0.01	<0.01	<0.01
NOx/NO3	0.01-0.17	<0.01	<0.01	<0.01	<0.01	<0.01
TN	0.35	0.37	0.4	0.36	0.37	0.37
SRP	0.004	<0.005	<0.005	<0.005	<0.005	<0.005
TP	0.01	0.007	0.009	0.007	0.007	0.006
TSS	21	4	6	4	3	5
Turb.	15	4.7	4.8	4.7	4.6	5.5
Temp	26–32	30.94	30.64	30.47	29.09	28.9
ph	6.0–8.4	7.72	7.76	7.73	7.62	7.67
DO	35–120	139.2	139.5	144.1	138.3	134.4

Parameter	K1 SSGV	K1-5	K1-4	K1-3	K1-2	K1-1
EC	4166	1050	1020	1100	1640	1750
NH3	0.02-0.32	<0.01	<0.01	<0.01	<0.01	<0.01
NOx/NO3	0.01-0.17	<0.01	<0.01	<0.01	<0.01	<0.01
TN	0.4	0.45	0.41	0.38	0.45	0.44
SRP	<0.004	<0.005	<0.005	<0.005	<0.005	<0.005
TP	0.01	0.022	0.018	0.017	0.025	0.028
TSS	27	4	4	5	6	5
Turb.	15	2.1	2.1	2.4	1.9	2.2
Temp	25–33	30.85	30.83	30.11	32.43	29.96
ph	6.0 –8.4	8.02	8.01	8.04	8.02	8.07
DO	28–120	144.5	139.7	130.2	151.9	146.8

Table 13. Two-way ANOVA and Tukey's post hoc testing for significant differences in general water parameters among sampling events and between Keep River pools, reference sites and estuary sites. Average values for untransformed data are provided in brackets. Sampling events joined by a common line are not significantly different (p < 0.05). Sampling events are arranged in order of ascending average value, left-to right.

Analyte	Source	ANOVA			Tukey's *post hoc* tests					
		df	F	*p*						
pH	Site	5	1.841	0.001	K4 (7.22)	REF (7.75)	K3 (7.89)	EST (8.4)	K2 (8.10)	K1 (8.23)
	Year	3	26.086	0.001	2020 (7.69)	2012 (7.82)	2013 (8.06)	2011 (8.07)		
	Site*Year	15	3.47	0.001						
	Corrected Total	103								
DO	Site	5	39.48	0.001	K4 (63.20)	REF (84.75)	K3 (93.12)	EST (108.63)	K2 (110.57)	K1 (113.37)
	Year	3	79.043	0.001	2013 (80.51)	2012 (85.23)	2011 (95.44)	2020 (127.23)		
	Site*Year	15	1.219	0.275						
	Corrected Total	103								
Turb	Site	5	11.302	0.001	K1 (4.4)	REF (5.24)	K2 (6.91)	K3 (7.54)	K4 (7.56)	EST (247.47)
	Year	3	2.223	0.092	2011	2012	2020	2013		
	Site*Year	15	1.343	0.197						
	Corrected Total	103								
Alkalinity	Site	5	9.551	0.001	REF (121.1)	K4 (135.33)	K3 (141.5)	K2 (147.7)	EST (156.75)	K1 (160.4)
	Year	3	6.775	0.001	2020 (126.88)	2013 (146.73)	2012 (146.88)	2011 (153.31)		
	Site*Year	15	1.186	0.3						
	Corrected Total	103								

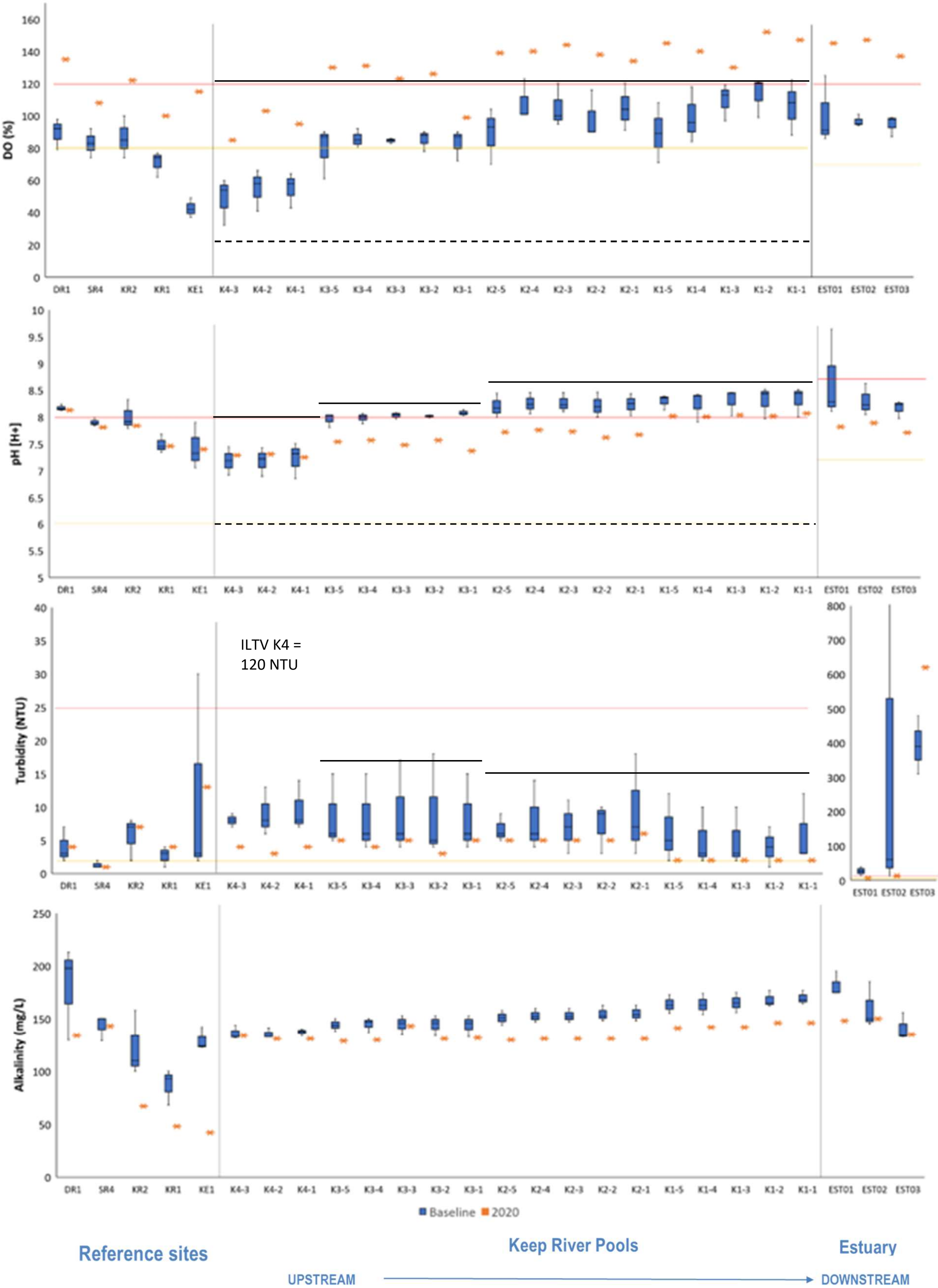


Figure 12. Box plots of general water quality parameters in 2020 within the Keep River, Keep River Estuary and reference sites. Plots show minimum and maximum values recorded during baseline sampling (—) for each region (reference, Keep River, and estuary sites) and 2020 recorded values at each site (*). ANZG (2018) upper limit (—) and lower limit (—) guideline values for fresh or estuarine waters (as appropriate) for protection of 95% of species, and ILTV for Keep River Pools high (—) and low (- - - -) are also indicated.

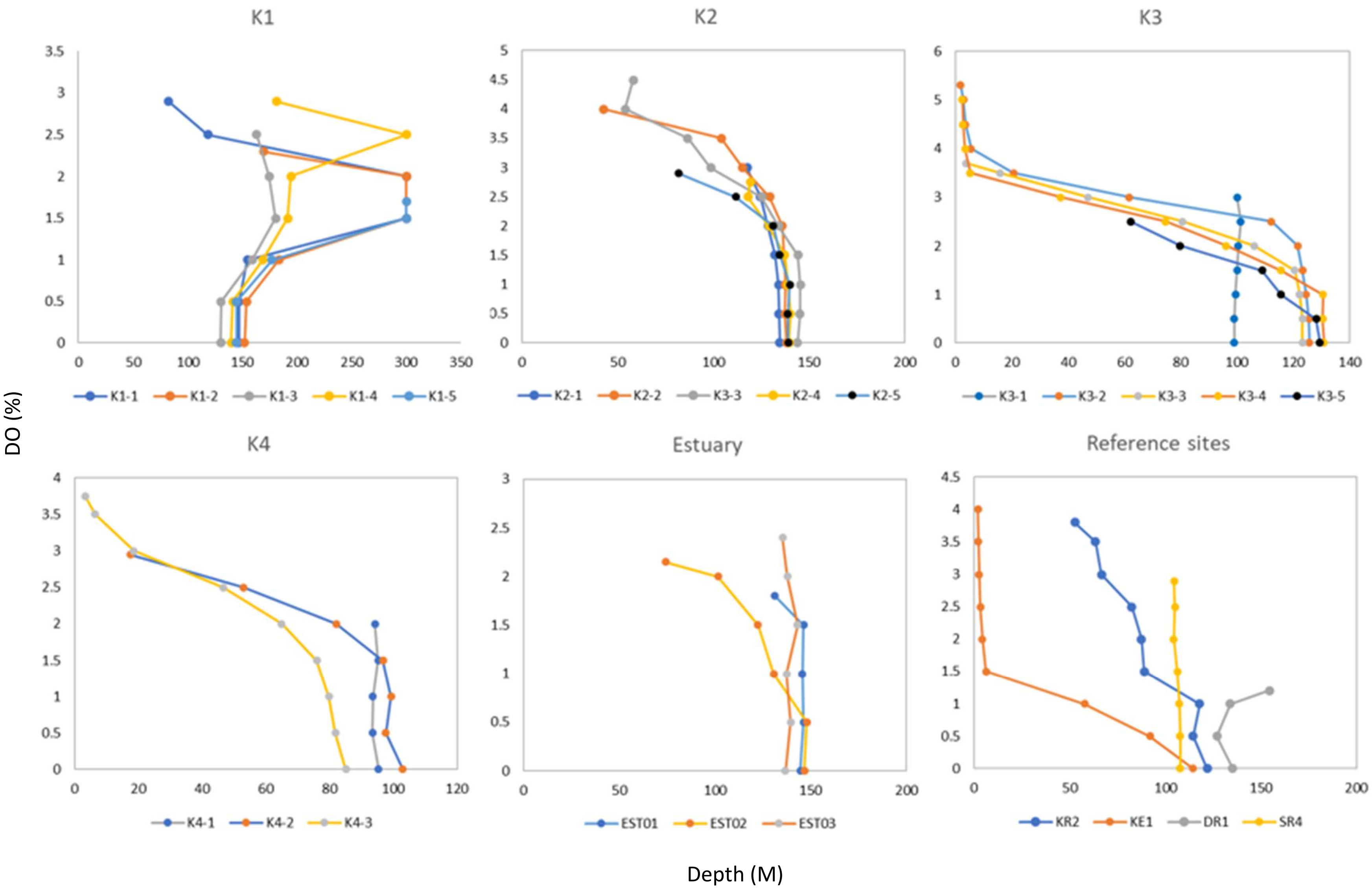


Figure 13. Changes in dissolved oxygen (% saturation) with depth at each Keep River, Estuary and reference site in 2020. Note depth profile was not measured at Alligator Waterhole (SR4).

Dissolved organic carbon (DOC) was mostly consistent between sites, however K4 and Estuary sites displayed significantly lower concentrations than reference sites (one-way ANOVA p = 0.012). There did not appear to be any longitudinal gradient in DOC in the Keep River and all DOC values were within the maximum and minimum values recorded during the baseline studies (Figure 14).

There is currently no guideline for DOC for the protection of aquatic biota. DOC is an important source of carbon and energy for aquatic foodwebs, and has an ameliorating effect on the toxicity of certain metals through complexation (Wetzel 1992, Winch *et al.* 2002, Baken *et al.* 2011). However, elevated levels are often coupled with increased mobilisation of metals into waterways and an increase in toxic potential. Continually high DOC also reduces light penetration and aquatic productivity. There were strong correlations found in baseline between DOC and nitrogen nutrient concentrations (total-N, total organic N & total soluble N) within the Keep River and reference sites however, no significant correlations between DOC and other water quality parameters, or sediment TOC.

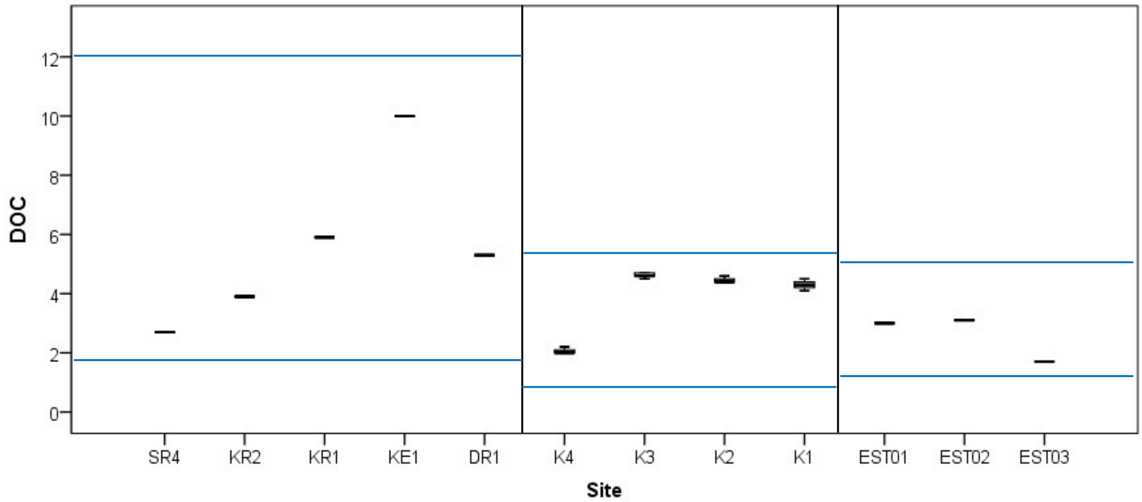


Figure 14. Box plots of dissolved organic carbon in 2020 within the Keep River, Keep River Estuary and reference sites. Plots show minimum and maximum values recorded during baseline sampling (—) for each region (reference, Keep River, and estuary sites).

Salinity and major ions

At all lower Keep River sites, salinity (as ECond) values exceeded the ANZG (2018) default GV of 20 mS/m (Figure 15). However, in exception to this were the Keep river reference sites KE1 (9.3), KR1 (15.7) and KR2 (11.3) which all recorded values below the DGV. In the lower Keep River, salinity ranged from 33.8 mS/cm at freshwater pool K3 (K3-3) to 1750 mS/m at the saline, tidally influenced K1 pool (K1-1). In baseline sampling a pronounced longitudinal gradient in salinity (and major ions) between K1 and K4 pools, with salinity increasing with increasing proximity to the Estuary was detected.

There was a significant difference in salinity between sites and years (two-way ANOVA p = 0.001) with the two factors having a statistically significant interaction (p = 0.001) (Table 14). Salinity in 2020 (817.45) was the lowest recorded, however, was not significantly different to 2011 (933.53). Interestingly in 2020 mean salinity was slightly higher at the K4 upstream site (80.5 mS/m) than at the lower pools K3 (35.7 mS/m) and K2 (42.1 mS/m) (Figure 15, Table 10). This was likely due to the influence of irrigation tailwater initially, and then M2 flushing water being released down Border Creek. This is also likely the reason 2020 average conductivity was low compared to baseline years.

A one-way ANOVA (p = 0.001) testing for differences between the 2020 site data found mean salinity at K4 (80.5), K3 (35.72), K2 (42.1) pools were all statistically similar to the mean for reference sites (18.62), but significantly lower than K1 (1312) and Estuary sites (4657).

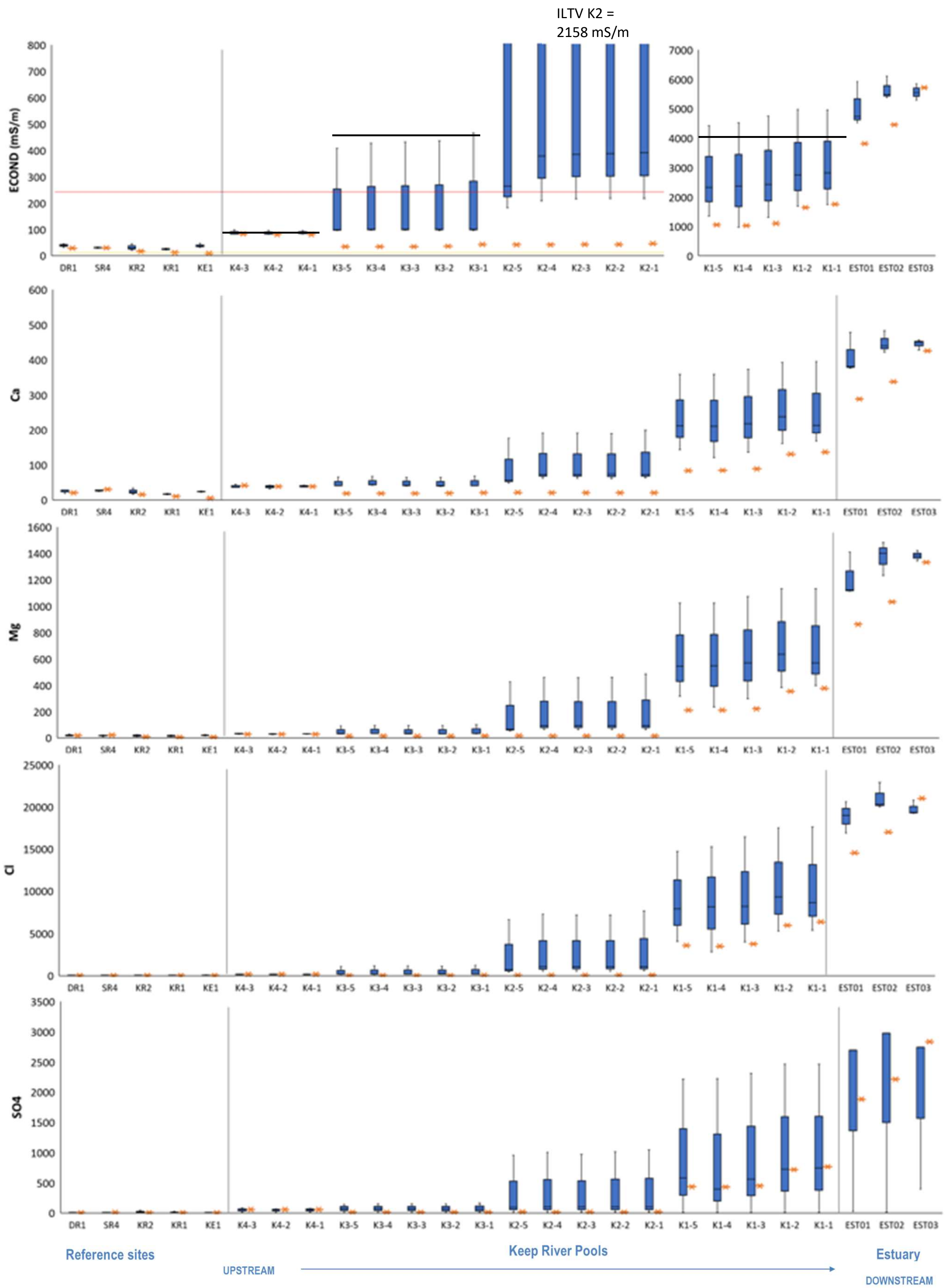


Figure 15. Box plots of salinity and major ion parameters in 2020 within the Keep River, Keep River Estuary and reference sites. Plots show minimum and maximum values recorded during baseline sampling (—) for each region (reference, Keep River, and estuary sites) and 2020 recorded values at each site (*). ANZG (2018) upper (—) and lower (—) guidelines for fresh or estuarine waters (as appropriate) for protection of 95% of species, and ILTV for Keep River Pools high (—) are also indicated.

In the Estuary, ionic dominance was consistent with seawater, with Na the dominant cation and Cl the dominant anion; *i.e.* Na>>Mg>>K : Cl>>SO_4>>HCO_3 (Table 15). In the Keep River, the influence of groundwater was apparent at upper pools, with Ca gradually replacing Mg as the subdominant cation, and HCO_3 replacing SO_4 as the subdominant anion (Table 14). Ionic dominance at most reference sites was strongly influenced by groundwater, with Ca the dominant or equally dominant cation and HCO_3 the dominant anion, *i.e.* Ca>Mg>K : HCO_3>>Cl>SO_4.

In 2020 concentrations of all major ions were not significantly different between sites K4, K3, K2 and the reference sites (one-way ANOVA $p > 0.773$) however K1 differed significantly from the upper sites and the estuary sites (one-way ANOVA $p = 0.001$). Longitudinal gradients in ions largely reflected gradients in conductivity (Figure 15).

Nutrients (N & P)

Phosphorus concentrations exceeded the baseline maximum values at sites K1-5, estuary sites EST01, EST02 and EST03 at reference site KE1. There were also exceedances of the ANZG (2018) guideline values at site K3-5, K3-4 and all sites in the K1 pool (Table 10 & 11, Figure 16). The Bennett and George (2014) ILTV for phosphorus also was exceeded at all K1 sites (Table 12). There was also a noticeable gradient of increasing phosphorus concentration from site K1 to EST03 (Figure 16). Total-P was significantly higher in 2020 than all previous baseline years (two-way ANOVA $p = 0.001$) and significantly higher in estuary sites than the Keep river pools or reference sites (one-way ANOVA $p = 0.001$) (Table 14).

Phosphorus (P) is an essential but often limiting nutrient in freshwater aquatic and terrestrial ecosystems. Tidal mixing of fresh and saltwater within estuaries can lead to localised resuspension of sediment and organic material. Combined with downstream transport in rivers, estuaries are vulnerable to nutrient pollution because dissolved inorganic P gets drawn out of sediment surfaces when anions in seawater compete with phosphate anions for binding sites, leading to P efflux. This can impair the critical function of estuaries and wetlands, which is to reduce nutrient loads before they reach coastal waters (Watson *et al.* 2018). Compared to baseline, the phosphorus values were much higher in the estuary than other sites during 2020, and were significantly higher than in baseline years exceeding the maximum baseline values and the ANZG (2018) value for P (Figure 16). This increase does not appear to be due to influence from border creek as K3 and K2 are within baseline and ANZG (2018) limits. It is more likely the tidal influence on the K1 pool is causing phosphorus in the sediment to become mobilised into the water column.

Total nitrogen (total-N) exceeded ANZG (2018) default GVs for eutrophication at almost every site with the exception of the K4 pool sites and the reference site Augustus Waterhole (SR4) (Table 10, Table 11, Figure 16). Average values for K1 and K2 also slightly exceeded the interim local trigger values (ILTVs) from Bennett and George (2014). Particularly elevated levels of total-N were recorded from Milligan's Lagoon reference site KE1 though this was consistent with baseline sampling and did not exceed the maximum values recorded during baseline. Total soluble nitrogen typically constituted >70% of total nitrogen at all sites. Inorganic nitrogen (NH_3-N, NO_2-N, NO_3-N) was generally low across all sites (Table 10, Table 11).

Statistically, there were significant differences in mean concentrations of nitrogen species between the sites and years (two-way ANOVA $p = 0.001$) however, there was no significant interaction between these factors ($p = 0.314$) (Table 14). 2020 (0.38) had a significantly higher mean nitrogen concentration than all previous years, however there has been significantly increasing total-N concentration each successive year since 2011 (Figure 16). The increase in total-N levels in 2020 from previous years appears most distinctly in the K2 and K3 pools as the K1 and estuary pools are higher on average but still within the baseline range of values. As K3 average values do not exceed the Bennett and George (2014) ILTV's but the K2 values do, it is difficult to speculate if the nitrogen increase is natural variation or due to the input of nutrient rich irrigation water from Border Creek. However, the systematic increase in nitrogen nutrients in Pools K3, K2 and K1, but not at pool K4 is coincident with discharge down Border Creek (Figure 16), and should be monitored in future years.

Table 14 Two-way ANOVA and Tukey's post hoc testing for significant differences in ionic and nutrient water quality parameters among sampling events and among Keep River pools. Average values for untransformed data are provided in brackets. Sampling events joined by a common line are not significantly different ($p < 0.05$). Sampling events are arranged in order of ascending average value, left-to right.

Analyte	Source	ANOVA			Tukey's *post hoc* tests					
		df	F	*p*						
Econd	Site	5	1140.473	0.001	REF (28.63)	K4 (85.11)	K3 (165.71)	K2 (702.38)	K1 (2493.7)	EST (5230)
	Year	3	140.887	0.001	2020 (817.45)	2011 (933.53)	2012 (1191.75)	2013 (2118.41)		
	Site*Year	15	37.084	0.001						
	Corrected Total	103								
Cl	Site	5	1228.644	0.001	REF (13.8)	K4 (146.58)	K3 (372.65)	K2 (2176.10)	K1 (8400)	EST (19291.67)
	Year	3	122.881	0.001	2020 (2938.58)	2011 (3216.15)	2012 (4025.46)	2013 (7224.04)		
	Site*Year	15	36.897	0.001						
	Corrected Total	103								
Ca	Site	5	1145.531	0.001	REF (21.03)	K4 (38.36)	K3 (41.26)	K2 (84.22)	K1 (210.66)	EST (413.25)
	Year	3	161.03	0.001	2020 (75.37)	2011 (103.70)	2012 (120.20)	2013 (183.9)		
	Site*Year	15	36.682	0.001						
	Corrected Total	103								
SO4	Site	5	535.701	0.001	REF (45.82)	K4 (152.51)	K3 (181.1)	K2 (721.15)	K1 (4321.55)	EST (7943.34)
	Year	3	987.799	0.001	2011 (157.01)	2020 (384.47)	2013 (1127.86)	2013 (6493.6)		
	Site*Year	15	103.323	0.001						
	Corrected Total	103								
Mg	Site	5	659.65	0.001	REF (15.04)	K4 (28.44)	K3 (41.96)	K2 (153.72)	K1 (560.20)	EST (1259.17)
	Year	3	390.595	0.001	2020 (186.48)	2011 (234.88)	2012 (283.57)	2013 (482.36)		
	Site*Year	15	108.851	0.001						
	Corrected Total	103								
N-Total	Site	5	7.257	0.001	K4 (0.14)	K3 (0.25)	K2 (0.28)	REF (0.37)	K1 (0.37)	EST (0.42)
	Year	3	5.712	0.001	2011 (0.20)	2012 (0.29)	2013 (0.36)	2020 (0.38)		
	Site*Year	15	1.168	0.314						
	Corrected Total	103								
P-Total	Site	5	6.412	0.001	K2 (0.01)	K3 (0.01)	K4 (0.01)	K1 (0.1)	REF (0.1)	EST (0.3)
	Year	3	16.488	0.001	2013 (0.01)	2011 (0.01)	2012 (0.01)	2020 (0.2)		
	Site*Year	15	6.196	0.001						
	Corrected Total	103								

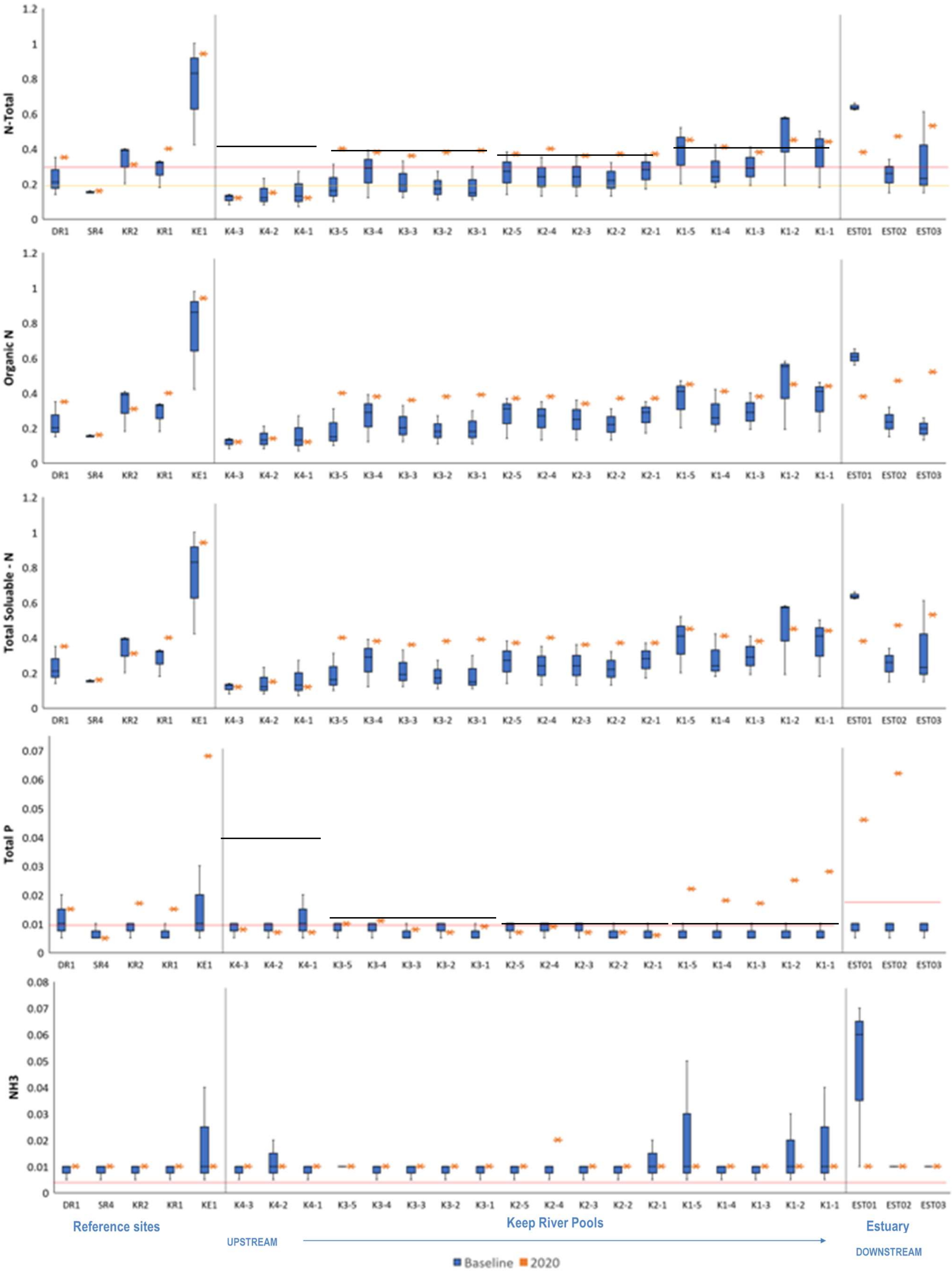


Figure 16. Box plots summarising 2020 data on nitrogen nutrients (mg/L) and total phosphorus (mg/L) in surface waters of the Keep River, Keep River Estuary and reference sites. Plots show minimum and maximum values recorded during baseline sampling (—) for each region (reference, Keep River, and estuary sites) and 2020 recorded values at each site (*). ANZG (2018) upper (—) and lower (—) guidelines for fresh or estuarine waters (as appropriate) for protection of 95% of species, and ILTV for Keep River Pools high (—) are also indicated.

5.3.2 Water quality - multivariate patterns

The CAP ordination plots showed distinct clustering of water quality samples according to year (Figure 17A-C). The first two canonical axes of the ordination examining differences amongst years had very high canonical correlations (δ^2 >0.83) with the suite of water quality variables, explaining 65.4% of the total variation amongst sites (Figure 17A). Similar to sediment quality, CAP analysis showed the 2020 values separated from baseline sites along axis 1 (Figure 17B). There was some overlap between the 2020 and 2012 sites and these were only distinguishable due to the unusually high dissolved oxygen at the Keep River pools recorded in 2020.

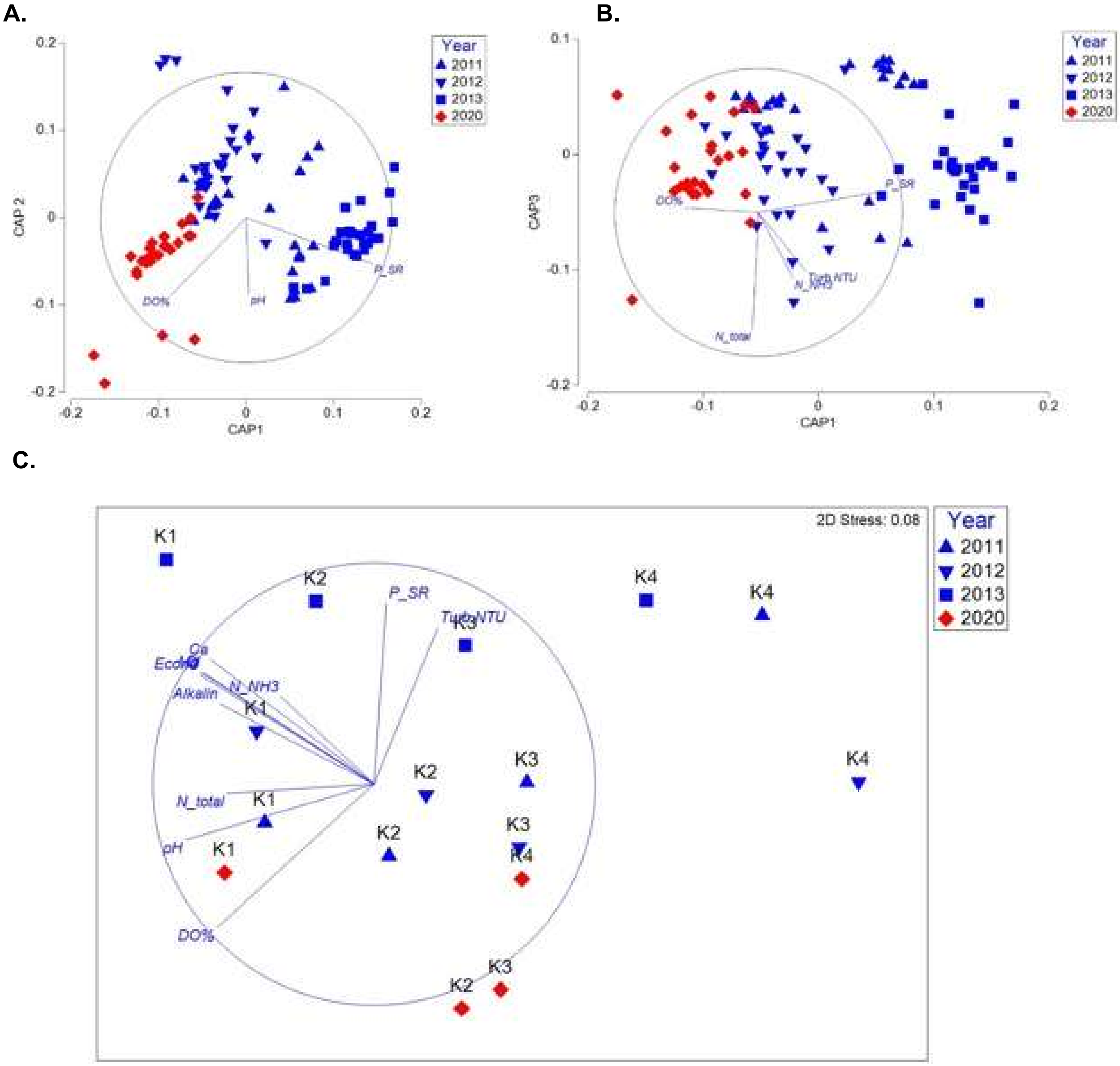


Figure 17. Results of constrained CAP analyses showing (A) axes 1 and 2, and (B) axes 1 and 3, that best discriminated surface water quality amongst years (baseline values in blue, post development in red), and (C) nMDS plot displaying the water quality variables best distinguishing the 2020 pools from each other. Correlations of water quality variables (untransformed) are shown for variables with correlation > 0.5.

nMDS analysis on the Keep River pools shows a shift from baseline to 2020 correlated strongly with the increase of DO% at all sites. K4 river sites tended to cluster together and away from other sites, and the K1 sites overall, with conductivity, DO% and ionic composition appearing to be the strongest distinguishing factors for separation (Figure 17C). The sites K2 and K3 in 2020 appeared to cluster together and away from previous years due much lower conductivity than previous years but much higher DO%.

The separation amongst baseline years was associated with generally higher water temperatures, TDS, Cl and turbidity in 2013, compared to 2012 and 2011 (Figure 17AB). Differences in water quality between 2020 and baseline years reflected the high daytime DO% levels and slight increases in total nitrogen. Two-factor PERMANOVA indicated that the multivariate suite of water quality parameters differed significantly between each of the K1 to K4 pools, and that each pool differed significantly from the group of reference sites, and from the Estuary ($p = 0.001$). Differences amongst all years were also statistically significant.

5.3.3 Macroinvertebrates – taxonomy and conservation significance

A total of 209 macroinvertebrate taxa ('species') were recorded from all sites and habitats sampled during September and October 2020 (Appendix 7). Including taxa recorded during baseline sampling, this makes a combined total of 417 macroinvertebrate 'species' collected from edge and riffle habitats in Keep River pools and reference sites. This list includes groups which could not be identified to species level due to life phase (*e.g*. larvae, early instars), sex (some taxonomic determinations are based on males only) and/or lack of suitable taxonomic keys (*i.e.* some Diptera families, some families of Coleoptera, *etc*.).

In 2020, Insects comprised 89% of taxa collected at all sites, predominantly two-winged flies (Diptera, 29%) and aquatic beetles (Coleoptera, 28%) (Table 15). Other species-rich faunal groups were true bugs (Hemiptera, 15%), mayflies (Ephemeroptera, 6%), caddis-flies (Trichoptera, 10%), dragonflies/damselflies (Odonata 9%) and aquatic caterpillars (Lepidoptera 3%). Approximately 14% of 'species' were recorded in only one sample (*i.e.* singletons), and approximately 15% in just two samples (*i.e.* doubletons). Singleton rates in riffle habitat were similar to those in edge habitats. On average each 'species' occurred in about 20% of samples. Most commonly collected species were the pygmy backswimmers *Paraplea* sp. (88% of samples), the beetle *Hydrochus* sp. (80%) and the non-biting midges *Larisia albiceps* (80% of samples) and *Cladotanytarsus* sp. (73% of samples) (Table 15, Appendix 7).

No species listed as rare or endangered under State or Commonwealth legislation were recorded. The majority of macroinvertebrates collected were common, ubiquitous species, with distributions extending throughout Australia, northern Australia or Australasia. Several taxa are however, currently considered to have restricted distributions, though this may be partly due to limited historical sampling effort in remote regions of Australia. Species include the dragonfly *Austrogomphus pusillus* (tiny hunter) and the mayflies *Wundacaenis dostini* and *Manggabora wapitja*.

The tiny hunter, *Austrogomphus pusillus,* is known only from the Kimberley region of Western Australia (Theischinger and Hawking 2006). It was recorded only once before in the SR4 riffle sample in 2012. The mayfly *Manggabora wapitja* is also restricted to the extreme northern Kimberley region and the Northern Territory (Dean & Suter 2004). It is previously known from Kakadu National Park, Litchfield National Park, Manggabor Creek (Arnhem Land) and the Alligator River in the Northern Territory and the King Edward River in the Kimberley, W.A. (Dean and Suter 2004). During the current study, *M. wapitja* was only recorded from the riffle habitat at Augustus Hole. During baseline surveys in 2012 and 2013 this species was also only present from this site. *Wundacaenis dostini* is an uncommon species found sporadically in the Kimberley and Pilbara regions of W.A. In 2020, *W. dostini* was found at all of the reference sites except for Milligans lagoon.

Table 15. Composition of macroinvertebrate fauna in edge and riffle habitats of the K1 to K4 pools and reference sites in 2020 compared to the baseline combined data. Values are total number of 'species' recorded from all replicate samples (*n*) from 2020 and the combined baseline surveys 2011, 2012 and 2013. Edge habitats were sampled from all 5 replicate locations within K1 to K3 pools, all 3 replicate locations within K4, and all references sites (DR1, KE1, KR1, KR2, SR4). Riffle habitats were only present at single locations within K3 and K4 sites, and at DR1 and SR4, however, in some years, some riffles were drowned out by high flows or dry and hence were not sampled.

Macroinvertebrate group	Common name	Edge habitats				Riffle habitats			
		2020 Survey		Baseline		2020 Survey		Baseline	
		K1 - K4 Pools (n = 18)	Ref. (n = 5)	K1 - K4 Pools (n = 54)	Ref. (n = 15)	K3 - K4 (n =2)	Ref. (n =1)	K3 - K4 (n = 6)	Ref. (n = 4)
Cnidaria	Freshwater hydra	1	0	1	1	0	0	1	1
Nemertea	Ribbon worms	0	0	1	1	0	0	1	0
Turbellaria	Flat worms	0	0	1	0	0	0	1	1
Nematoda	Round worms	1	0	1	1	0	0	0	0
Bivalvia	Mussel & clams	2	1	4	2	1	1	2	0
Gastropoda	Snails	3	7	5	8	2	0	3	1
Polychaeta	Aquatic bristle worms	1	0	3	0	0	0	1	1
Oligochaeta	Aquatic earthworms	1	1	4	4	1	1	3	2
Amphipoda	Amphipods	2	1	3	1	0	0	0	0
Decapoda	Crabs, prawns, shrimps	6	5	9	9	2	1	5	2
Arachnida	Aquatic mites	1	1	1	2	1	1	1	2
Collembola	Springtails	1	0	1	2	0	0	2	0
Ephemeroptera	Mayflies	7	7	17	18	5	6	12	17
Odonata	Dragonflies & damselflies	10	11	19	22	4	3	4	6
Hemiptera	True bugs	23	19	41	41	5	0	16	8
Coleoptera	Aquatic beetles	39	30	54	57	20	9	25	13
Diptera	Two-winged flies	36	33	48	63	22	19	42	44
Trichoptera	Caddis-flies	9	11	14	14	9	10	15	13
Lepidoptera	Moths with aquatic larva	0	1	1	0	4	3	5	5
	Total number of 'species'	***143***	***128***	***228***	***246***	***76***	***54***	***139***	***116***

5.3.4 Macroinvertebrates – univariate analyses

Spatial variation in species richness amongst sites sampled in 2020 is illustrated in Figure 18. Species richness varied between site and habitat, with minimum values recorded at K1-4 (14 species) and maximum values recorded from KR1 (63 species) edge habitats. There was a broad gradient in species richness in edge habitats along the Keep River, with richness tending to decrease with increasing proximity to the Estuary (Figure 19). This gradient was evident in each baseline sampling occasion with K1 having consistently lower species richness. This was considered to be due to the combination of higher salinity and lower habitat diversity at the K1 sites.

In 2020, average species richness in the downstream, saline K1 pool (21 species) was significantly lower than middle freshwater pools K2 (41.2) and K3 (48.33) and upper pool K4 (57.25) and combined reference sites (58). K2 was also significantly lower than the K4 and reference sites but statistically similar to the K3 pool and riffle site richness (one-way ANOVA, $P < 0.001$) (Table 16). Edge habitats in K4 pools supported significantly similar average species richness to similar habitats across reference sites, with an average 57 species compared to 58 species. Proportions of species in 2020 were generally similar to the baseline with the dominant species collected from both pools and riffles being from either Coleoptera or Diptera groups (Table 19).

Table 16 Two-way ANOVA and Tukey's post hoc testing for significant differences between Keep River pools and Reference sites macroinvertebrate species richness in 2020 and baseline years. Average values for untransformed data are provided in brackets. Sampling events joined by a common line are not significantly different (p < 0.05). Sampling events are arranged in order of ascending average value, left-to right.

Source		ANOVA df	F	*p*	Tukey's *post hoc* tests				
Richness	Site	4	93.662	0.001	K1 (17.15)	K2 (37.75)	K3 (42.8)	K4 (52.33)	REF (64.85)
	Year	3	1.61	0.195	2013 (38.26)	2012 (42.96)	2011 (43.7)	2020 (43.74)	
	Year*Site	12	3.659	0.001					

Table 17. One-way ANOVA and Tukey's post hoc testing for significant between-year differences macroinvertebrate species richness within each Keep River pool and Reference sites. Average values for untransformed data are provided in brackets. Sampling events joined by a common line are not significantly different (p < 0.05). Sampling events are arranged in order of ascending average value, left-to right.

Source	ANOVA df	MS	F	*p*	Tukey's *post hoc* tests			
K1	3	262.717	7.555	0.002	2013(7.6)	2012 (15.6)		
						2012 (15.6)	2020 (21.6)	2011 (23.8)
K2	3	542.45	9.618	0.001	2013 (22.6)			
						2012 (41)	2020 (41)	2011 (46.4)
K3	3	39	0.517	0.676	2011 (41)	2012(41.6)	2013 (41.6)	2020 (47)
K4	3	140.22	1.371	0.32	2011 (42.33)	2012 (53.66)	2020 (56)	2013 (57.33)
REF	3	128.58	1.719	0.203	2020 (58)	2011 (64.4)	2012 (67.2)	2013 (69.8)

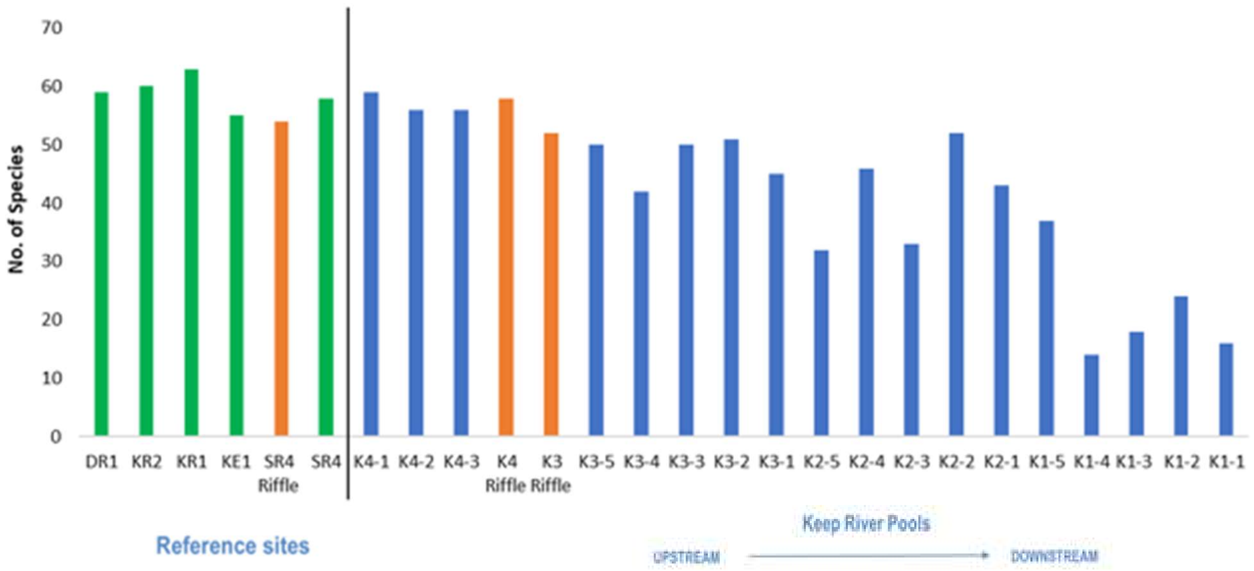


Figure 18. Histogram plot summarising 2020 macroinvertebrate species richness in edge (blue) and riffle habitats (orange) of the Keep River and reference sites (green).

There was no significant difference in macroinvertebrate richness between years (two-way ANOVA p = 0.195) but there were significant differences between sites (p= 0.001) (Table 16). There was also a significant interaction effect between these factors (p = 0.001). One-way ANOVA's found that K1 and K2 significantly separated from other years in 2013 reflecting the lower richness that year (one-way ANVOA p = <0.002) (Table 17). Average species richness increased at sites K1, K2 and K3 between 2013 to 2020, however average species richness at reference sites in 2020 decreased though not significantly (Table 17, Figure 19).

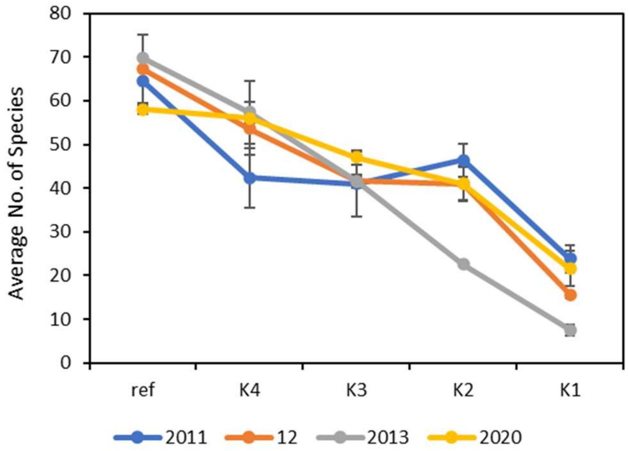


Figure 19. Temporal variability in average (±SE) species richness of macroinvertebrates at each of the Keep River and reference sites.

One possible explanation for the observed increase in species richness at K1 and K2 was the effect of algal blooms. In 2013, extensive blooms were observed throughout the K1 pool and along the lower half of the K2 pool. Oxygen depletion in the water column as the bloom decays would be expected to adversely affect macroinvertebrate survival and/or recruitment rates, especially if DO levels fell below 20% for extended periods; a strong possibility given the vertical stratification measured at these sites in 2013 (see section 5.3.1). Species richness in 2020 appears to have recovered as it was notably not significantly different from 2011 which recorded the previously highest average species richness.

In order to statistically compare riffle habitats in the Keep River with riffle habitats at reference sites, species richness data for K3 and K4 riffles were combined, and one-way ANOVA used to compare K3/K4 against the reference riffles at SR4 and DR1. In 2020 there was no significant difference between the K3/K4 riffles and the reference riffle at SR4 (one-way ANOVA p = 0.879).

Despite the greater number of species recorded at K3/K4 over time (*i.e.* 139 *cf* 116, Table 5), ANOVA indicated no significant difference in average species richness between K3/K4 riffles and reference riffles (df = 1, F = 0.640, p = 0.447); acknowledging low statistical power for small sample sizes. For statistical comparison between riffle and edge habitats, edge data from replicate samples were averaged for each of the K3 (K3-1 to 5) and K4 (K4-1 to 3) pools, and then combined (n = 4) for analysis against K3 and K4 riffle data (n = 2). One-way ANOVA indicated no significant difference in average species richness in 2020 between riffle and edge habitats (df = 1, F = 1.917 p = 0.238). There was also no significant difference between K3/K4 riffle habitats over time (df = 3, 0.660, P = 0.618).

5.3.5 Macroinvertebrates - multivariate patterns in species assemblages

The difference in macroinvertebrate assemblages between sampling events was due to small changes in abundance of a large number of species, each contributing < 2.5% to the total variation (SIMPER). For example, 47 species contributed to 50% of the total variation between the 2013 and 2020. The freshwater shrimp *Caridina 'nilotica'* spp., the aquatic beetle *Hydrochus* sp., immature mayfly Caenidae spp. and Chironomid species *Cladotanytarsus* sp. (ORC2), *Larsia albiceps* (ORT1) contributed the most to the dissimilarity between the 2020 sampling and previous years.

Average similarity between baseline samples was significantly different from similarity in 2020 at site K1, K2 and K3 (one-way ANOVA, P < 0.033) (Table 18). Similarity between replicate samples between sites was higher on average overall at all sites in 2020 (Figure 20). K4 similarity has not significantly changed between baseline and 2020 sampling (one- way ANOVA, p = 0.099).

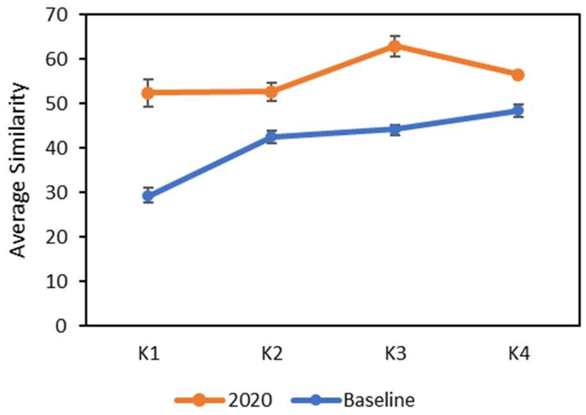


Figure 20. Temporal variability in average (±SE) site similarity of macroinvertebrates at each of the Keep River and reference sites.

Table 18. One-way ANOVA for significant differences between Keep River pools macroinvertebrate site similarity.

Similarity	Comparison	ANOVA df	F	*p*
K1	Baseline to 2020	1	13.204	0.001
K2	Baseline to 2020	1	4.674	0.033
K3	Baseline to 2020	1	25.587	0.001
K4	Baseline to 2020	1	2.867	0.099
Overall	Baseline to 2020	1	30.538	0.001

MDS ordination on macroinvertebrate data between all the Keep River sites show assemblage changes occurring between sampling events, *i.e.* 2011, 2012, 2013 and 2020 (Figure 21). PERMANOVA indicated this separation was statistically significant (pseudo-F = 14.84, *p* = 0.001), suggesting temporal shifts in species assemblage composition.

In 2020, water quality variables calcium (Ca) and chloride (Cl) were strongly correlated with the observed patterns in macroinvertebrate assemblages (BIOENV, rho ≤ 0.787, p ≤ 0.01). This reflects the observed reduction of diversity as salinity increased with distance downstream.

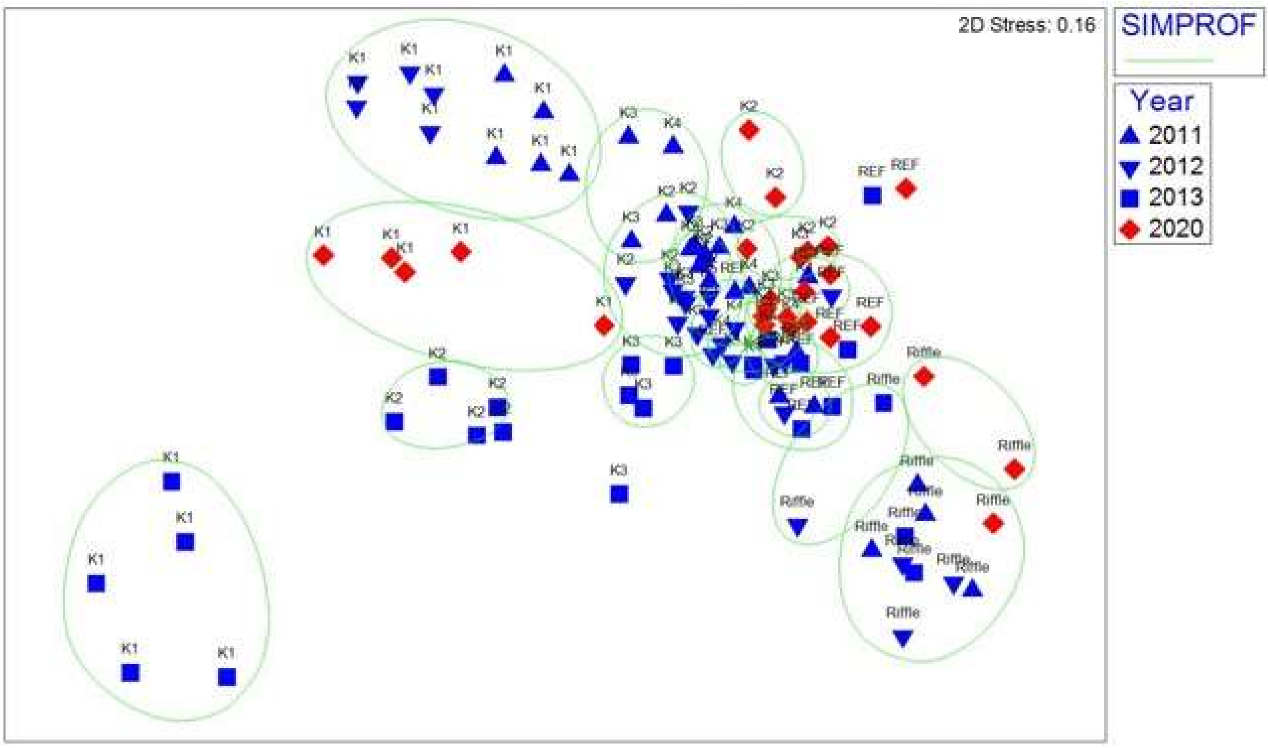


Figure 21. Two-dimensional (2D) plot of MDS ordination on macroinvertebrate assemblage data (log_{10} abundance class) for Keep River pools, reference sites and riffle samples comparing 2020 to baseline sampling. Green circles show site groupings with a Bray-Curtis similarity ≥40% (based on SIMPROF).

Not unsurprisingly the BIOENV routine on water quality analytes using all year's data indicated ECond, Ca, Cl and Mg were best correlated (correlation >0.802) with the groupings of species assemblages produced by the MDS ordination (Figure 21). All these water quality parameters were relatively higher in the saline K1 pool. Vector overlay of individual species on the ordination (not shown) indicated groupings were most strongly associated (correlation >0.7) with the higher abundance of estuarine species such as polychaetes (Nereididae sp.) and amphipods (Corophiidae sp.) in K1 samples. The separation of reference sites from the K2 to K4 pools was associated with higher abundances of juvenile caenid mayflies, the caddis-fly *Ecnomus* sp., and diptera (flies) species *larsia albiceps* and Tabanidae sp.

Comparison of the riffle habitats showed species assemblages in 2020 significantly differed from the previous years (one-factor PERMANOVA, Pseudo-F = 1.5454 p =0.016). Diptera species *Rheotanytarus sp.* and the dragonfly *Nannophlebia sp.* appeared to distinguish the 2020 sites from the previous baseline year, however 2020 species diversity was still at least 40% similar to baseline sampling.

In 2020 individual species contributing most to the differences between habitats (riffle and edge) were caddisflies (*Chematopsyche wellsae*), black fly larvae (Simuliidae sp.) and dragonfly larvae (*Nannophlebia* sp.). These species are usually more common in riffle habitats and are known to preference higher-flow environments.

5.3.6 Fish - taxonomy and conservation significance

A total of 657 fish representing 25 of the 46 species known from the Keep River catchment (NAFF 2008) were recorded during the current (2020) survey of riverine pools (Appendix 8). Including 2020, a total of 40 of the 46 species known from the Keep River catchment have been recorded over the course of the Keep River surveys of riverine pools (Appendix 9). Of the 25 species caught in 2020, 15 were present in the K1 pool, 10 in K2, 13 in K3, 10 in K4, and 12 across all reference sites. Most common and abundant in the riverine environments were bony bream *Nematalosa erebi* (372 individuals), followed by the blue catfish *Neoarius graeffei* (88 individuals) and the diamond scale mullet *Ellochelon vaigiensis* (54 individuals) (Plate 3). Bony Bream were present at 21 out of 22 sites, only being absent from the reference site KE1 (Milligans Lagoon), while the Blue Catfish were present at 20 out of 22 sites only being absent from K1-2 and K1-4. Other widespread but less abundant species were Diamond Mullet *Planiliza ordensis* (18 sites), Diamondscale Mullet *Ellochelon vaigiensis* (9 sites), Barramundi *Lates calcarifer* (8 sites) and Seven-spot Archerfish *Toxotes chatareus* (6 sites) (Appendix 9). A number of species were only recorded on single occasions from the riverine pools, and represented by single individuals, including the Common Ponyfish *Leiognathus equula* (K1-2), the Spangled Perch *Leiopotherapon unicolor* (K4-1) and the Scaly Croaker *Nibea squamosa* (K3-3).

One species of grunter was caught during the 2020 survey that had only once previously been recorded, in baseline surveys; the Spangled Perch (KE1, 2012) (Appendix 9). The Spangled Perch is the most widespread native freshwater fish in Australia occurring in a range of water quality and habitats and is highly abundant throughout the Kimberley region.

Consistent with baseline sampling, most species recorded are known to be common throughout the north of Australia. The exception to this is the largetooth sawfish *Pristis pristis* (K1-2, K1-2, K3-5, K4-2, KR2). The presence of this species within the current study area has already been discussed in section 4. *P. pristis* is listed as Critically Endangered under the IUCN Redlist (Kyne *et al*. 2013), and within Australia, is protected under Commonwealth and State (NT, WA, Qld) legislation.

Plate 4. Examples of fish species recorded during the 2020 Keep River survey; (A) juvenile bull shark *Carcharhinus leucas*, (B) Barramundi *Lates calcarifer* (C) freshwater longtom *Strongylurua krefftii*, (D) oxeye herring *Megalops cyprinoides* (E) blue salmon catfish *Neoarius graeffei* (F) bony bream *Nematolosa erebi* (All photos by WRM staff).

5.3.7 Fish – univariate analyses

In 2020 amongst pools, mean species richness ranged from 5.33 at K4 to 6.0 at K1. Within pools, total species richness ranged from 3 species at K4-3 to 8 at K3-3. The tendency for greater species richness in the lower system likely reflects proximity to the Estuary and presence of estuarine-marine vagrants. Between pools, mean abundance was greatest in K1 pool (mean 40.8) and lowest at the reference pools (mean 20.75) (Figure 22). Within sites, abundance was greatest at K1-2 (71 fish) and lowest at K4-3 (12 fish). Among pools, total biomass ranged from 13.958 kg (mean 4.6 kg per site) in K4, to 26.965 kg (mean 6.392 kg per site) in K3, with 19.426 kg (mean 4.856 kg per site) at reference sites. There was also a high variability within-pools, e.g. within K4, mean biomass ranged from 1.987 kg at K4-1, to 9.201 kg at K4-2 (Figure 22).

Two-way ANOVA testing between years found no significant difference in abundance between years (P = 0.355) however 2020 was found to have significantly higher species richness than 2013 (P = <0.001) though statistically similar richness to 2011 and 2012 (P = >0.096) (Table 19). The reason for the relatively lower species richness in 2013 is not known, but as postulated for macroinvertebrates (section 5.3.4), may have been associated with extensive algal blooms, as were observed throughout the K1 pool and along the lower half of the K2 pool in 2013. There was no statistically significant difference between sites in regards to richness (two-way ANOVA, P=0.415), though average abundances at the K1 and K2 sites were significantly higher on average than K3 or K4 (two-way ANOVA, P = 0.008) (Table 18A).

There was no significant difference in total biomass among years (two-way ANOVA P = 0.182) however 2020 recorded the lowest average biomass per site (5.562 Kg) of all years. Univariate analyses however, indicated among-pool differences were not statistically significant, though K2 was significantly lower than the reference sites (Table 19A).

Fish data were also adjusted to standardise catch-per-unit effort to a 2.5hr, 60m net set to reduce bias of longer or shorter net times. When catch per unit data was analysed it showed identical trends to the untransformed data (Table 19B).

Table 19. Two-way ANOVA and Tukey's post hoc testing for significant differences in fish abundance, richness and biomass among Keep River pools and Reference sites sampled in 2020 and between years. Average values for untransformed data are provided in brackets. (A) Depicts the unstandardised data and (B) is standardised for CPUE. Sampling events joined by a common line are not significantly different (p < 0.05). Sampling events are arranged in order of ascending average value, left-to right.

A.

Source	ANOVA df	F	*p*	Tukey's *post hoc* tests				
Richness								
Site (2020)	4	1.867	0.415	K4 (5.0)	K2 (5.26)	K2 (5.5)	K3 (5.60)	K1 (6.15)
Year	3	7.172	0.001	2013 (4.30)	2012 (5.43)	2020 (5.64)	2011 (6.83)	

Source	ANOVA df	F	*p*	Tukey's *post hoc* tests				
Abundance								
Site	4	3.765	0.008	K4 (21)	K3 (24)	REF (31.42)	K2 (31.6)	K1 (41.35)
Year	3	1.004	0.396	2013 (27.13)	2012 (29.83)	2020 (29.86)	2011 (35.70)	
Site*Year	12	1.008	0.451					

Source	ANOVA df	F	*p*	Tukey's *post hoc* tests				
Biomass								
Site (2020)	4	3.439	0.013	K2 (4696.1)	K3 (5561.8)	K4 (6364.58)	K1 (9342.75)	REF (11150.74)
Year	3	2.044	0.115	2020 (5562.91)	2013 (7082.57)	2012 (7387.48)	2011 (9872.04)	
Site*Year	12	1.259	0.262					

B.

Source	ANOVA df	F	*p*	Tukey's *post hoc* tests				
Abundance (CPUE)								
Site	4	4.57	0.002	K4 (24.03)	K3 (24.95)	REF (30.68)	K2 (32.72)	K1 (42.62)
Year	3	1.114	0.355	2013 (27.13)	2012 (29.83)	2020 (34.67)	2011 (35.70)	
Site*Year	12	1.03	0.435					

Source	ANOVA df	F	*p*	Tukey's *post hoc* tests				
Biomass (CPUE)								
Site (2020)	4	3.192	0.018	K2 (5150.69)	K3 (5467.4)	K4 (7207.93)	K1 (9565.74)	REF (11124.14)
Year	3	1.434	0.24	2020 (6439.21)	2013 (7082.57)	2012 (7387.48)	2011 (9872.04)	
Site*Year	12	1.358	0.207					

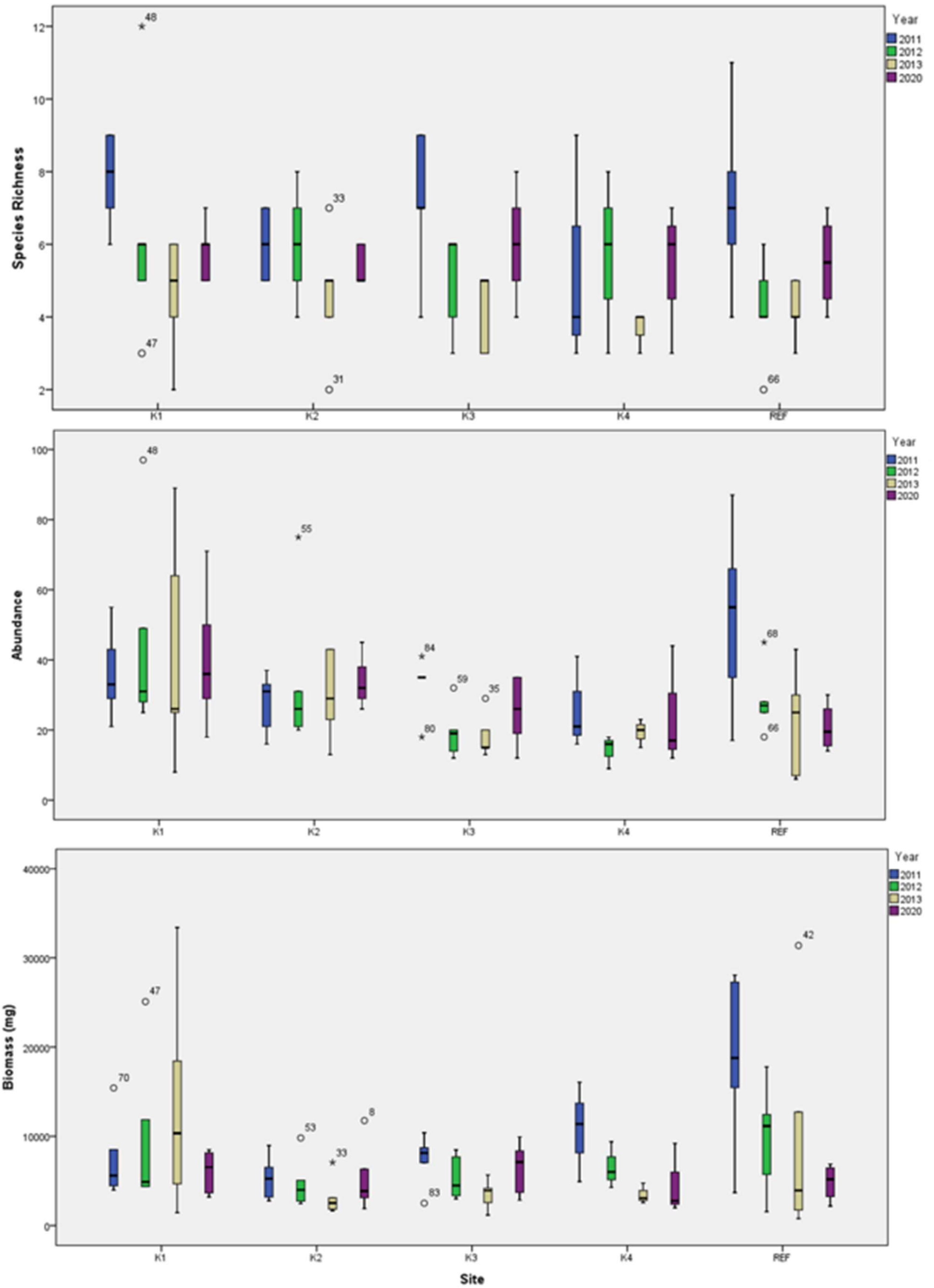


Figure 22. Box plots summarising post development (2020) and baseline data (2011-2013) on total fish species richness, abundance and biomass (total weight in mg) in the Keep River and reference sites. Plots show minimum, 20%ile, median (50%ile), 80%ile and maximum values for each replicate site.

5.3.8 Fish – multivariate patterns in species assemblages

nMDS ordination examining among-site differences in 2020 species assemblages ($\log_{10}$ abundance) showed a general separation of the lower K1 and K2 sites from the upper K3 and K4 sites. Vector overlay showed high abundance of Bony Bream (*Nematalosa erebi*) and lower abundance of Blue salmon Catfish (*Neoarius graeffei*) in K1 and K2 and the reverse in pool K3 and site KE1, and K4-3 which was most responsible for the distinction between these sites (>0.5 correlation) (Figure 23).

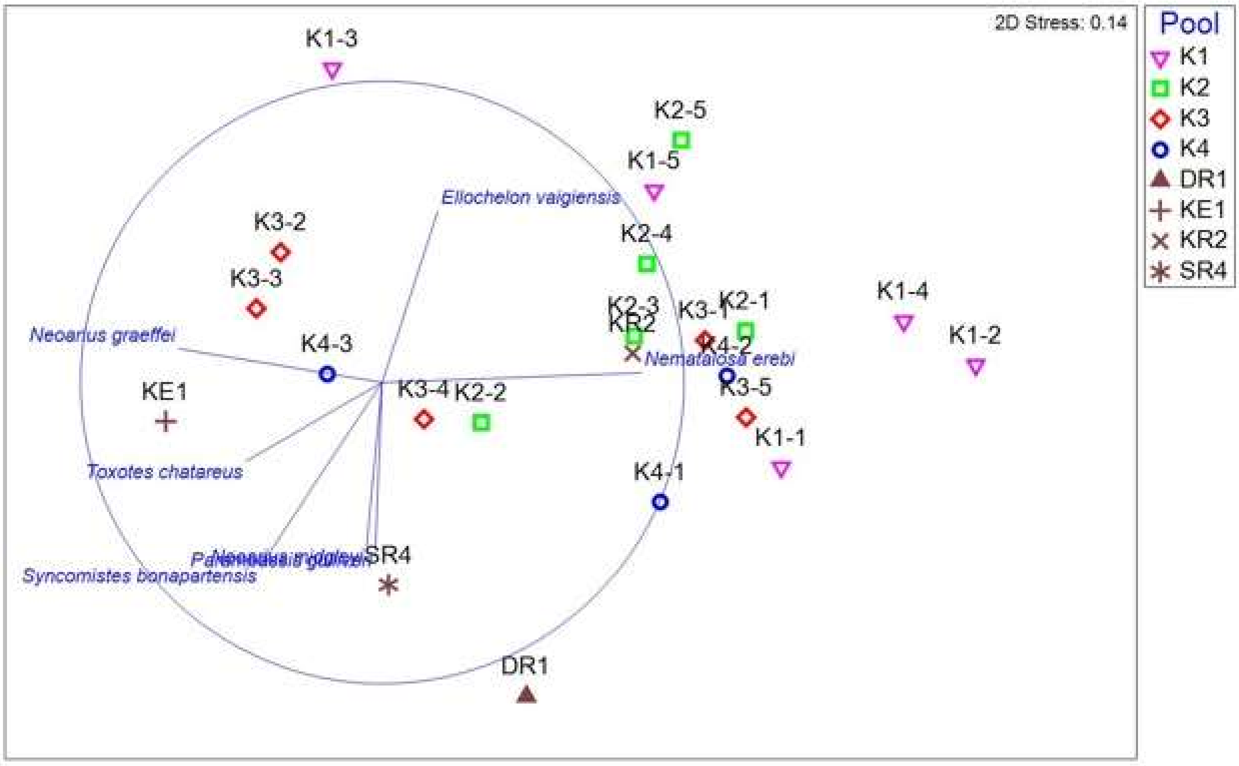


Figure 23. nMDS plot displaying the fish species best distinguishing the distribution of the 2020 Keep river sites. Correlations of water quality variables (untransformed) are shown for variables with correlation > 0.5.

There was considerable overlap in species abundances among years though nMDS analysis showed 2011 appeared to weakly separate from other years likely due to the higher average abundance at reference sites and K3 compared to other years (Figure 24). There was also wide variation amongst reference sites. PERMANOVA on the 2020 abundance data found that there was no significant difference between abundance at any of the pools or reference sites (Figure 23, Table 20). Differences in abundance amongst years were statistically significant between 2011 and all other years, but no significant difference was found between 2012, 2013 and 2020 (Figure 24, Table 20).

Ordinations on biomass data yielded similar results to abundance data (Figure 25) indicating there was only slight separation between 2011 and all other years. Two-factor PERMANOVA analyses corroborated the results from nMDS analyses (Table 21). PERMANOVA on biomass data again showed differences amongst years were statistically significant between 2011 and all other years, but no significant difference was found between 2012, 2013 and 2020 (Table 21).

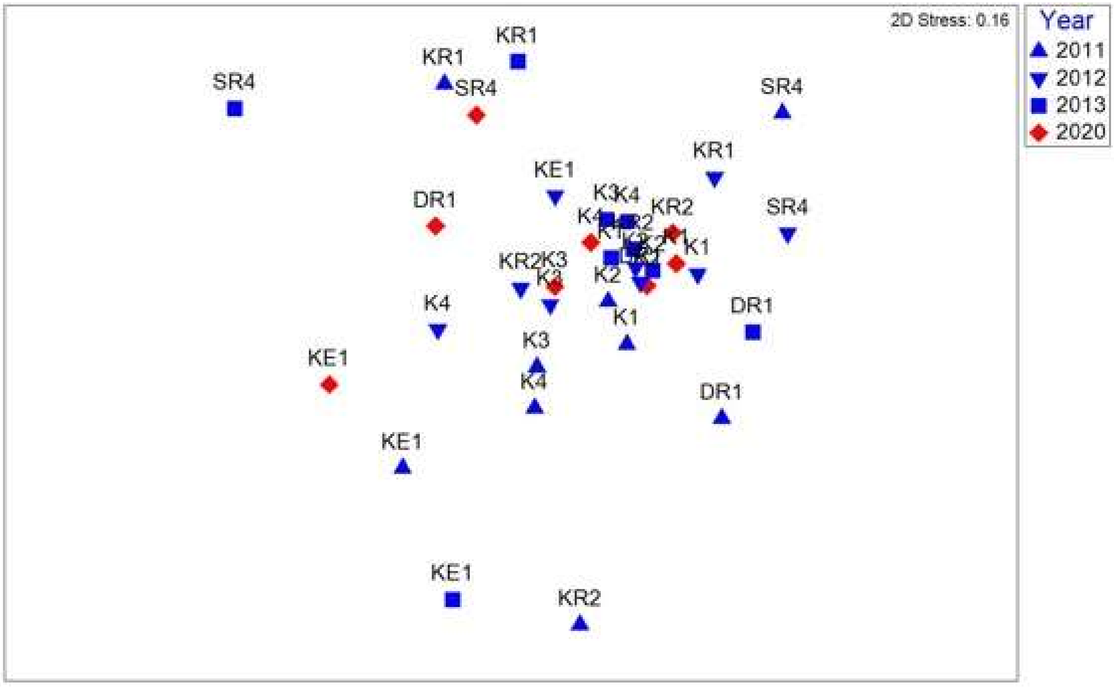


Figure 24. Results of nMDS analyses showing fish species abundance data between pools and years. Analyses based on species log10 transformed abundance data.

Table 20. Summary of two-factor PERMANOVA results comparing fish species assemblages (log10 transformed abundance) between site and year, and PERMANOVA post hoc results showing t-values for all pairwise comparisons between sites, and between years; * = sites significant different (p <0.05).

Two-factor PERMANOVA – fish abundance					
Source	df	SS	MS	Pseudo-F	P(perm)
Site	4	20435	5108.6	2.9687	0.001
Year	3	13637	4545.7	2.6416	0.001
Site x Year	12	22200	1850	1.0751	0.303

PERMANOVA post hoc test for Site (2020)				
	REF	K1	K2	K3
K1	1.3609			
K2	1.4384	0.93119		
K3	0.89524	1.3119	1.2754	
K4	0.66126	0.98052	1.0158	0.7662

PERMANOVA post hoc tests for Years			
	2011	2012	2013
2012	1.942*		
2013	1.5778*	1.1442	
2020	1.9147*	1.0818	1.3124

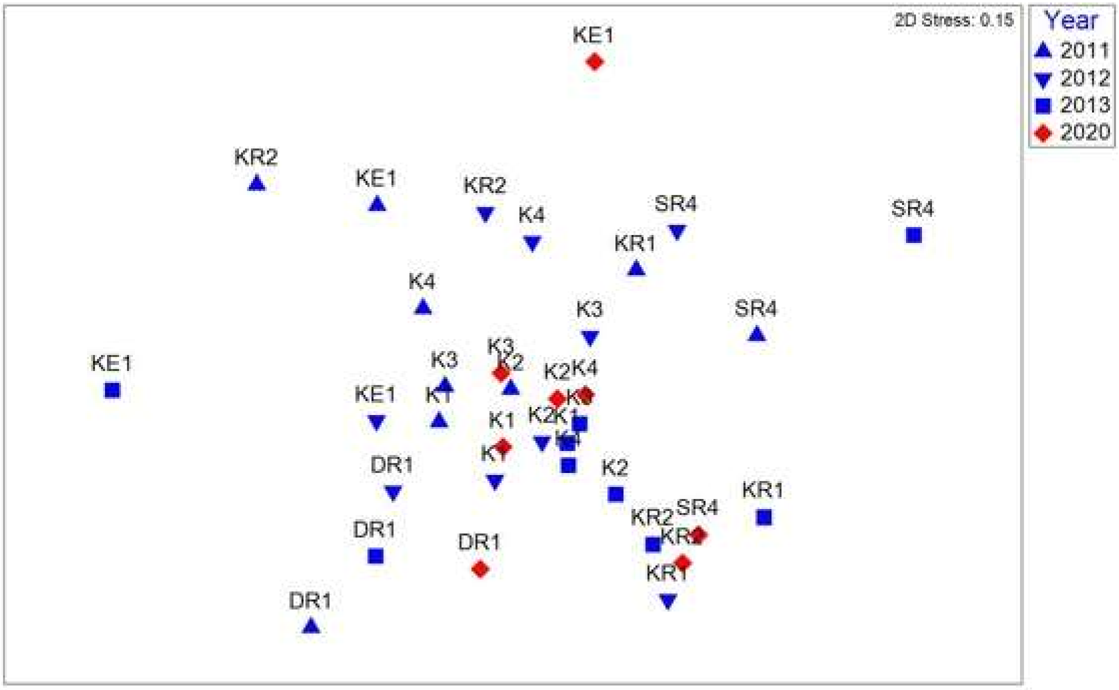


Figure 25. Results of nMDS analyses showing fish species biomass data between pools and years. Analyses based on species log_{10} transformed biomass data.

Table 21. Summary of two-factor PERMANOVA results comparing fish species biomass data between site and year, and PERMANOVA post hoc results showing t-values for all pairwise comparisons between sites, and between years; * = sites significant different (p <0.05).

Two-factor PERMANOVA – fish biomass					
Source	df	SS	MS	Pseudo-F	P(perm)
Site	4	20174	5043.5	2.0004	0.002
Year	3	17460	5820.1	2.3084	0.003
Site x Year	12	34163	2846.9	1.1292	0.206

PERMANOVA post hoc test for Site (2020)				
	REF	K1	K2	K3
K1	1.0887			
K2	1.0617	0.97085		
K3	1.2821	0.8322	0.80455	
K4	0.7152	0.93353	0.50355	0.94482

PERMANOVA post hoc tests for Years			
	2011	2012	2013
2012	1.2872		
2013	1.8475*	1.3904*	
2020	1.7475*	1.3463	0.81778

5.4 Conclusions

In 2020 mean values of Keep River sites indicated the majority of sites were characterised by basic pH (7.29 - 8.07), moderate to high alkalinity (129- 146 mg/L $CaCO_3$) and hardness (95 - 1900 mg/L $CaCO_3$), low turbidity (1.9 – 5.1 NTU), and moderate to high daytime DO (85 – 151.9%). These results were mostly within the baseline range and ANZG (2018) guidelines with the exception of abnormally high DO% at pools K1, K2 and K3. DO (%) exceeded the baseline maximum values at all three estuary sites in 2020 and also exceeded the Bennett and George (2014) interim local trigger values (ILTVs) for Keep River sites K1, K2 and K3.

Consistent with baseline sampling there is significant spatial and temporal (inter-annual) variability in water quality between pools of the main channel of the Keep River. During previous surveys there were pronounced longitudinal gradients in salinity and ionic dominance between the freshwater K4 pool, upstream of Legune Road Crossing, and the tidally-influenced, saline K1 pool, near the head of the Keep Estuary. Interestingly in 2020, however, mean salinity was slightly higher at the K4 upstream site than at the lower pools K3 and K2. Salinity then increased again at the K1 pool and the estuary sites. This was likely due to the influence of irrigation tailwater initially, and then M2 flushing water being released down Border Creek. This is also likely the reason 2020 average conductivity was low compared to baseline years.

Of particular note was the high phosphorus values that exceeded the baseline maximum values at sites K1-5, estuary sites EST01, EST02 and EST03 at reference site KE1. There were also exceedances of the ANZG (2018) guideline values at site K3-5, K3-4 and all sites in the K1 pool. The Bennett and George (2014) ILTV for phosphorus also was exceeded at all K1 sites and there was also a noticeable increasing phosphorus gradient from site K1 to EST03. Total-P was significantly higher in 2020 than all previous baseline years and significantly higher in estuary sites than the Keep river pools or reference sites. The higher total-P in the K1 and estuary pools could be caused by the tidal influence agitating sediment to become suspended in the water column, however, this does not explain the overall increase in total-P between the baseline values and the post-development (2020) Keep River surveys.

Total nitrogen exceeded interim guidelines for Keep River pools proposed by Bennett and George (2014) in pools K1 and K2, however they were within the maximum baseline values recorded by WRM between 2011 and 2013. There appears to be a steady significant trend of total nitrogen in the system increasing since 2011. The increase in nitrogen is most prominent between K3, K2 and K1 where the values are all exceeding or close to the maximum levels recorded during baseline. It is not clear at this time whether this is a result of nitrogen rich irrigation water entering at the upper K3 pool, natural variation or effects from other nearby land-use.

The high dissolved oxygen and the increased nutrient readings compared to baseline values may not be unrelated. It is possible that the increase in nutrients is creating ideal conditions for photosynthetic material (algae) to increase and in turn are contributing to the increase of daytime dissolved oxygen, particularly in the first 1-1.5m of the water column. While this does not appear to be adversely affecting aquatic fauna as of the current survey, during the 2013 baseline it was noted that K1 and K2 were low in species richness of fish and macroinvertebrates likely due to prolific algal blooms at the time of sampling. Potential for a repeat algal bloom event during a particularly extended period of dry conditions is possible with receding pools heightening evapoconcentration effects of nutrients in a system.

In terms of richness and abundance, aquatic macroinvertebrate assemblages recorded during 2020 were found to be statistically similar to most baseline years across all sites. The exception being a significant increase in diversity compared to 2013 at sites K1 and K2 which were notably low in richness due to algal blooms at both sites that year. Species composition continues to be driven by water quality at each site but remains similar in 2020 when compared to baseline years.

Fish species richness was found to be significantly higher overall in 2020 than in the previous survey in 2013 again likely due to the algal blooms, however it was not significantly different from 2011 or 2012. Species richness, abundance and biomass were not significantly different between all pools sampled in 2020. Keep River pools continue to support high diversity of fish species, supporting at least 40 of the 46 species known from the Keep River caught during the current survey. This includes the listed largetooth sawfish *Pristis pristis* which is Critically Endangered and listed under the IUCN Redlist (Kyne *et al*. 2013), and within Australia, is protected under Commonwealth and State (NT, WA, Qld) legislation.

6 CONCLUSIONS AND RECOMMENDATIONS

The data gathered during the course of the current study showed significant increases in some analytes compared to the baseline dataset. Increasing levels of Total-N and in particular nitrate (NO_3) were detected most notably between pool K3 and K1 in both the sediment samples and the water quality readings. Water quality analysis also found total-P was significantly higher in 2020 than all previous baseline years, and significantly higher in estuary sites than the Keep river pools or reference sites. There appears to also be a steady significant trend of increasing total nitrogen in the system since 2011. The increase in nitrogen is most prominent between K3, K2 and K1 where the values are all exceeding or close to the maximum levels recorded during baseline whereas the total-P increases are further downstream. It is not clear at this time whether this is a result of nutrient rich irrigation water entering at the upper K3 pool, natural variation or effects from other nearby land-use.

Many metals in sediment samples taken in 2020 exceeded the maximum values recorded in baseline surveys. These included Al, B, Cr, Cu, Fe, Ga, Li, Ni, Pb, Se, Ti, U, V and Zn. Interestingly these exceedances occurred almost entirely downstream of pool K4, and appear to culminate the most at EST01 and occur all the way to the most downstream estuary site EST03. Dissolved metals analysis was not conducted on the water quality samples due to a combination of the way samples were collected, stored, short holding times required by the laboratory and the remote nature of the sampling.

The distinct increase in nutrient and metal levels between the pools K3 and K1 are of some concern as they are directly below the Border Creek confluence with the Keep River and as such could be attributed to the effects of the discharge down Border Creek. These changes don't appear to be system wide either, as the non-exposed site K4 did not exhibit altered sediment composition between years.

Other factors that correlate with the exceedances downstream of pool K4 include:

- major earthworks, upgrade and bituminising of the Legune Road,
- operation of a gravel pit to the west of the Keep River, close to Border Creek, with various points of wet season run-off to the Keep River
- construction of a bridge across the Keep between pools K3 and K4,
- release of irrigation return water down Border Creek,
- release of M2 flushing water down Border Creek into the Keep River upstream of pools K3, and,
- two consecutive years of below-average rainfall prior to the survey.

Further sampling and investigation would be required to identify if any of the above activities were responsible for the observed changes.

In addition to the increased nutrient readings, high dissolved oxygen was recorded at all sites across the system. It is possible that the increase in nutrients is creating ideal conditions for photosynthetic material (algae) to increase and in turn are contributing to the increase of daytime dissolved oxygen, particularly in the first 1-1.5m of the water column. While this does not appear to be adversely affecting aquatic fauna as of the current survey, during the 2013 baseline it was noted that K1 and K2 had low species richness of fish and macroinvertebrates and this was likely due to prolific algal blooms at the time of sampling. Potential for a repeat algal bloom event during a particularly extended period of dry conditions is possible with receding pools heightening evapoconcentration effects of nutrients in a system.

In terms of richness and abundance, aquatic macroinvertebrate assemblages recorded during 2020 were found to be statistically similar to most baseline years across all sites. The exception being a significant increase in diversity compared to 2013 at sites K1 and K2 which were notably low in richness likely due to algal blooms at both sites that year. Species composition continues to be driven by water quality at each site but remains similar in 2020 when compared to baseline years.

The total number of sawfish caught in 2020 (14 individuals) was comparable to baseline years 2012 (22 individuals) and 2011 (14 individuals). Total numbers caught in 2013 (6 individuals) were much lower than all other years and the reason for the low catch is unknown. Listed dwarf sawfish *Pristis clavata* continue to be common in the Keep Estuary, while largetooth sawfish *P. pristis* are widely distributed along the Keep River. All records of *P. clavata* are from the estuary, while all records of *P. pristis* are from the river (Larson 1999, WRC 2003, WRM 2011ab, WRM 2014, current study). To date, formal targeted surveys have not recorded any *Glyphis* sharks within the Keep River or Estuary. Species richness of other fish was found to be significantly higher overall in 2020 than in 2013, again likely due to the algal blooms, however 2020 was not significantly different from 2011 or 2012. Species richness, abundance and biomass was not significantly different between all pools sampled in 2020. Keep River pools continue to support high diversity of fish species, with at least 40 of the 46 species known from the Keep River caught during the current survey.

It is acknowledged the baseline surveys, to which the current data are compared, provide only a snap-shot of the Keep River physio-chemical conditions and faunal assemblages during a single sampling occasion once a year. Similarly, the current survey provides only a snap-shot of parameters which are naturally variable. The river is highly dynamic between wet and dry seasons, and between years, as are many northern Australian river systems, receding from extreme high flows in the wet season, to zero or very low base flows in the late dry season, with large variability in magnitude of wet season rains between years. Many water quality attributes change dramatically (*i.e.* total suspended solids, turbidity, DO, nutrients), and it is likely that many ecological attributes also vary significantly over the year. It is anticipated that standardising to the late dry season has minimised the seasonal effects on aquatic fauna and water quality data, allowing inter-annual comparisons and detection of any response to the ORIA Stage 2 development during the current study.

Analyses presented in this report, comparing data to that collected during the baseline studies 2011, 2012 and 2013, provide a summary of broader spatial and temporal patterns and relationships in water quality and aquatic fauna present in the data. Comparisons in the current report were limited to one year post-development (2020) against three years pre-development (2011, 2012 & 2013). The absence at this stage of temporal replication post-development limits the range and statistical power of the possible analyses. As additional post-development surveys are conducted, with three post-development surveys ultimately to be completed as per Conditions, the strength of analyses to compare pre- and post-development data will improve. Single exceedances/differences post-development reported here should be treated with caution at this stage of the post-development analysis, until survey data for the additional years are available. Analyses to date indicate changes in some sediment (Section 3) and water quality parameters (Section 5.3.1), that have the potential to affect ecosystem health and listed species, but at this stage do not appear to be having any direct adverse effects on the biota. The source of these elevated concentrations is not readily discernible, but may reflect the influence of one or more of a range of pressures, including road construction, bridge construction, gravel pit operation, tailwater discharge or M2 irrigation 'flushing' water discharge.

Given the discharge of tailwater and M2 water down Border Creek, two sites situated on Border Creek that were sampled during baseline years should be added during the next round of post-development surveys. Sampling should include water quality, sediment quality and aquatic fauna (macroinvertebrates and fish) at the two sites. WRM has baseline data for Border Creek and it would be invaluable to discern the source of any adverse effects of releases down Border Creek.

Future sampling should continue to use the standardised current methods, locations and season to collect additional post-development monitoring data to allow direct comparison with existing pre-development data. By repeating the univariate and multivariate analyses presented here, as well as targeted analyses of subsets of the data to assess spatial and temporal changes in individual species and assemblages, it will be possible to detect any future changes in water quality and aquatic fauna, and differentiate natural changes from any effects of the Goomig development.

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8 APPENDICES

Appendix 1 Site Photographs

Photographs illustrating representative habitat at each location.

EST01

EST02

EST03

K1 pool

K2 pool

K3 pool

K4 pool

DR1 (Dunham River)

KR2 (Alligator Hole)

KR1 (Policeman's Waterhole)

KE1 (Milligan's Lagoon)

SR4 (Augustus Hole)

Appendix 2 ANZG (2018) Default Guideline Values for toxicants in sediment

ANZG (2018) interim sediment quality guideline (DGV) values. The DGV value is the trigger value, *i.e.* the threshold concentration below which the frequency of adverse biological effects is expected to be very low. The DGV-high refers to the concentration above which adverse biological effects are expected to occur more frequently.

CONTAMINANT	DGV (guideline value)	GV-High
METALS (mg/kg dry wt)		
Antimony (Sb)	2	25
Cadmium (Cd)	1.5	10
Chromium (Cr)	80	370
Copper (Cu)	65	270
Lead (Pb)	50	220
Mercury (Hg)	0.15	1
Nickel (Ni)	21	52
Silver (Ag)	1	4.0
Zinc (Zn)	200	410
METALLOIDS (mg/kg dry wt)		
Arsenic (As)	20	70
ORGANOMETALLICS (µg/kg dry weight, 1% OC)		
Tributyltin (as tin)	9	70
ORGANICS (µg/kg dry wt) *		
Total PAHs	10000	50000
Total DDT	1.2	5.0
Chlordane	4.5	9
Dieldrin	2.8	7
Endrin	2.7	60
Lindane	0.9	1.4
Total PCBs	34	280
ORGANICS (mg/kg dry weight)		
TPHs	280	550

* normalised to 1% organic carbon

Appendix 3 Baseline Sediment Data

Summary statistics for baseline sediment data collected from the Keep River and Estuary in Sep/Oct 2011, 2012 and 2013. Concentrations in mg/kg dry weight unless specified otherwise. Tables continued overpage.

Analyte	Keep River - K4							Keep River - K3							Keep River - K2							Keep River - K1						
	n	min	20%ile	mean	median	80%ile	max	n	min	20%ile	mean	median	80%ile	max	n	min	20%ile	mean	median	80%ile	max	n	min	20%ile	mean	median	80%ile	max
Ag	45	<0.05	<0.05	<0.05	<0.05	<0.05	0.16	45	<0.05	<0.05	<0.05	<0.05	<0.05	0.12	45	<0.05	<0.05	<0.05	<0.05	<0.05	0.16	45	<0.05	<0.05	<0.05	<0.05	<0.05	0.14
Al	45	2340	6745.6	12169	12100	16620	28600	45	2340	6842	12195	12100	16340	28600	45	3430	7406	12529	12100	17300	27900	45	2190	6582	11687	10500	17000	27400
As	45	0.5	1.1	1.7	1.8	2.1	3.2	45	0.5	1.1	1.6	1.6	2.0	3.2	45	0.7	1.1	1.7	1.8	2.3	3.7	45	0.9	1.2	2.1	1.8	2.5	5.7
B	45	2.5	2.5	2.7	2.5	2.5	6.0	45	2.5	2.5	2.8	2.5	2.5	6.0	45	2.5	2.5	4.2	2.5	6.2	12.0	45	2.5	2.5	9.3	8.0	13.2	35.0
Ba	45	19	91	155	140	170	560	45	19	82	119	110	160	340	45	29	84	150	110	172	820	45	26	49	104	80	114	460
Be	45	0.12	0.32	0.54	0.56	0.73	1.10	45	0.12	0.31	0.52	0.56	0.67	1.10	45	0.16	0.29	0.54	0.52	0.76	1.00	45	0.10	0.31	0.53	0.46	0.75	1.10
Bi	45	<0.05	0.08	0.11	0.12	0.16	0.20	45	<0.05	0.08	0.11	0.12	0.15	0.20	45	<0.05	0.07	0.12	0.11	0.16	0.22	45	<0.05	0.07	0.10	0.10	0.14	0.20
Ca	45	520	2296	4476.4	3200	4140	29000	45	520	2280	3996	2900	4020	29000	45	560	1780	5432	2500	4720	49000	45	620	1500	6394	2200	11200	31000
Cd	45	<0.05	<0.05	<0.05	<0.05	<0.05	0.07	45	<0.05	<0.05	<0.05	<0.05	<0.05	0.07	45	<0.05	<0.05	<0.05	<0.05	<0.05	0.12	45	<0.05	<0.05	<0.05	<0.05	<0.05	0.08
Cl	45	11	62	1041	230	850.4	8800	45	58	86	852	230	694	8800	45	140	486	3355.8	1100	5840	19000	45	750	2740	6758.9	4200	10400	23000
Co	45	9	15	21	19	23	63	45	8.7	14	18	18	22	42	45	11	14	22	19	23	72	45	11	13	19	17	21	47
Cr	45	7	14	21	21	29	48	45	9	15	23	22	29	48	45	8	14	22	21	29	36	45	7	14	21	20	27	38
Cu	45	3	9	13	14	18	23	45	3	10	14	14	18	23	45	5	10	14	13	19	24	45	3	7	12	12	15	19
Fe	45	8100	15800	24575	25000	32000	55000	45	8200	16800	25178	25000	32000	55000	45	8600	17800	25096	24000	33200	51000	45	6300	13800	22153	22000	29400	42000
Ga	45	1.3	3.8	6.2	6.4	8.2	16.0	45	1.7	3.5	5.7	5.7	7.8	12.0	45	1.7	3.6	5.8	5.8	8.3	11.0	45	1.2	3.3	5.4	5.1	7.7	11.0
Hg	45	<0.02	<0.02	0.26	0.1	0.286	1.7	45	<0.02	0.02	0.21	0.14	0.31	1.2	45	<0.02	0.04	0.26	0.15	0.49	1.2	45	<0.02	0.05	0.33	0.21	0.45	2.6
K	45	280	612	1002.4	1000	1300	2200	45	280	740	1107.1	1200	1400	2200	45	460	902	1421.1	1200	2200	2600	45	380	1100	1942.7	1500	2640	5800
La	45	6	12	16	15	20	28	45	6	11	15	15	19	28	45	7	11	17	15	20	41	45	6	10	14	13	18	34
Li	45	1	2	4	4	6	10	45	1	3	4	4	6	10	45	1	3	5	4	7	9	45	1	3	6	4	7	17
Mg	45	970	2300	4137.4	3900	5900	9700	45	970	2700	4503.8	4300	5940	9700	45	1200	2800	4631	4100	6720	8400	45	990	2580	5122	4200	6520	15000
Mn	45	83	348	805	560	748	4200	45	83	320	615	500	740	3200	45	82	324	881	540	1100	5000	45	110	238	592	410	630	3800
Mo	45	0.05	0.15	0.19	0.19	0.22	0.44	45	0.05	0.14	0.18	0.17	0.22	0.41	45	0.08	0.15	0.22	0.18	0.28	0.59	45	0.10	0.17	0.24	0.23	0.32	0.49
N-Total (%)	45	0.01	0.03	0.05	0.05	0.07	0.10	45	0.01	0.03	0.05	0.05	0.06	0.10	45	0.01	0.03	0.04	0.04	0.05	0.08	45	0.01	0.02	0.04	0.03	0.05	0.07
N-Total	45	50	304	524	530	732	1030	45	50	328	472	480	596	960	45	130	250	400	380	522	790	45	100	216	355	340	460	730
NH4-N	45	1	5	16	9	35	56	45	1	3	9	6	9	49	45	1	2	5	4	7.2	33	45	1	2	4.2	3	4.2	27
NO3-N	45	<1	<1	<1	<1	<1	2	45	<1	<1	<1	<1	1	2	45	<1	<1	<1	<1	1	1	45	<1	<1	<1	<1	1	1
Na	45	55	204	920	370	936	5800	45	55	230	853	370	920	5800	45	200	710	2841	1400	5160	11000	45	910	2660	5194	3600	8080	16000
Ni	45	4	9	14	13	18	27	45	4	9	14	13	18	27	45	5	10	14	13	19	24	45	4	7	12	11	17	24
P-Total	45	50	74.2	119	130	150	170	45	51	94	116	120	140	170	45	53	78.2	115	120	160	180	45	35	78	120	110	150	260
Pb	45	3	7	9	9	11	13	45	3	7	9	9	10	13	45	4	7	9	9	11	16	45	4	6	8	8	10	12
SO4	45	14	31	333	120	384	5100	45	14	72.8	232	160	308	1000	45	52	210	571	320	812	2200	45	34	460	1066	830	1820	3000
Sb	45	<0.05	0.05	0.13	0.10	0.13	1.00	45	<0.05	0.05	0.11	0.09	0.12	1.00	45	<0.05	<0.05	0.08	0.09	0.12	0.15	45	<0.05	<0.05	0.07	0.07	0.09	0.18
Se	45	<0.05	0.06	0.09	0.09	0.11	0.17	45	<0.05	<0.05	0.07	0.08	0.10	0.13	45	<0.05	<0.05	0.08	0.08	0.11	0.17	45	<0.05	<0.05	0.07	0.07	0.11	0.14
Si	45	100	130	159	150	190	230	45	100	120	149	140	182	230	45	78	110	138	130	160	220	45	100	110	148	130	190	250
Sn	45	<0.5	<0.5	0.6	0.5	0.8	4.4	45	<0.5	<0.5	0.51	<0.5	0.7	4.4	45	<0.5	<0.5	<0.5	<0.5	0.7	1.9	45	<0.5	<0.5	<0.5	<0.5	0.6	1.1
TOC (%)	45	<0.05	0.4	0.7	0.6	1.0	1.6	45	<0.05	0.4	0.6	0.6	0.8	1.6	45	0.2	0.4	0.6	0.5	0.7	1.3	45	0.1	0.3	0.5	0.5	0.7	1.2
Ti	45	24	34	56	45	73.4	250	45	27	54	79	69	99.2	250	45	30	46	71	63	100	150	45	28	55	86	68	112	280
U	45	0.2	0.6	0.8	0.8	1.0	1.3	45	0.3	0.5	0.7	0.7	0.9	1.3	45	0.3	0.5	0.8	0.7	1.0	1.4	45	0.2	0.4	0.7	0.6	0.8	1.4
V	45	25	45	54	56	66	81	45	31	46	56	56	66	81	45	24	43	54	54	66	82	45	20	34	46	48	56	71
Zn	45	7	12	21	22	29	51	45	7	15	23	23	29.2	51	45	7	14	22	22	31	40	45	3	13	20	20	25	37

Appendix 3 continued.

Summary statistics for baseline sediment data collected from the Keep River and Estuary in Sep/Oct 2011, 2012 and 2013. Concentrations in mg/kg dry weight unless specified otherwise.

Analyte	Keep Estuary - EST01							Keep Estuary - EST02							Keep Estuary - EST03						
	n	min	20%ile	mean	median	80%ile	max	n	min	20%ile	mean	median	80%ile	max	n	min	20%ile	mean	median	80%ile	max
Ag	9	<0.05	<0.05	<0.05	<0.05	<0.05	0.07	9	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	9	<0.05	<0.05	<0.05	<0.05	<0.05	0.09
Al	9	5020	6878	9032.2	8980	10520	14500	9	4690	5186	5854	5350	6098	9060	9	3340	3668	5504	4690	7370	9620
As	9	1.7	2.3	2.8	2.5	3.6	4.2	9	2.0	3.2	4.2	4.1	5.2	6.8	9	2.1	3.0	5.8	4.5	8.6	13.0
B	9	15	16	20	21	23	30	9	14	16	19	18	22	27	9	11	15	20	18	24	37
Ba	9	12	15	16	16	17	20	9	9	9	11	11	12	19	9	9	9	11	12	12	13
Be	9	0.11	0.14	0.24	0.23	0.34	0.45	9	0.11	0.13	0.18	0.16	0.19	0.36	9	0.06	0.09	0.17	0.14	0.23	0.33
Bi	9	<0.05	<0.05	<0.05	<0.05	<0.05	0.11	9	<0.05	<0.05	<0.05	<0.05	<0.05	0.06	9	<0.05	<0.05	<0.05	<0.05	<0.05	0.09
Ca	9	31000	35400	41778	39000	48600	58000	9	40000	48800	55889	57000	59800	80000	9	35000	46200	55889	50000	68200	88000
Cd	9	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	9	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	9	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Cl	9	5600	7180	8233.3	7800	8800	13000	9	5000	5600	8766.7	8400	11000	15000	9	5300	5860	11244	7000	10900	41000
Co	9	8	9	9	10	10	11	9	9	9	10	10	10	12	9	9	9	10	10	12	12
Cr	9	11	14	16	16	18	22	9	9	11	12	12	13	19	9	9	10	12	11	15	17
Cu	9	4.4	6.1	7.1	6.8	8.5	8.6	9	3.1	3.6	4.7	4.5	5.6	7.6	9	3.0	3.2	4.5	3.9	5.6	7.8
Fe	9	11000	14000	16222	16000	18000	23000	9	12000	13000	14444	14000	15000	20000	9	11000	12600	14889	15000	17000	17000
Ga	9	2.0	2.4	3.3	3.1	4.3	5.5	9	2.0	2.2	2.5	2.3	2.8	3.2	9	1.6	1.9	2.6	2.1	3.3	4.1
Hg	9	0.09	0.11	0.16	0.15	0.21	0.25	9	0.17	0.27	0.45	0.46	0.662	0.75	9	0.19	0.248	0.5878	0.64	0.896	0.99
K	9	1300	1760	2300	2300	2900	3000	9	1100	1360	1588.9	1400	1680	2800	9	870	1060	1563.3	1300	2220	2700
La	9	9	10	11	11	12	12	9	10	10	11	10	12	14	9	9	10	11	11	12	15
Li	9	5	6	7	7	8	10	9	4	5	5	5	6	8	9	4	4	5	5	7	8
Mg	9	5700	6820	7411	7300	7980	9100	9	5300	5860	6611	6300	7120	9100	9	5300	5980	7056	6900	7700	10000
Mn	9	220	240	266	270	290	310	9	240	288	338	320	388	470	9	250	270	416	320	546	780
Mo	9	0.09	0.12	0.18	0.19	0.23	0.30	9	0.12	0.14	0.18	0.19	0.21	0.22	9	0.12	0.14	0.22	0.23	0.30	0.34
N-Total (%)	9	0.01	0.02	0.03	0.03	0.03	0.04	9	0.01	0.01	0.01	0.02	0.02	0.02	9	0.01	0.01	0.01	0.01	0.02	0.03
N-Total	9	100	156	258	290	344	380	9	100	120	147	150	168	220	9	60	72	129	110	176	280
NH4-N	9	<1	<1	2	1	2	4	9	<1	<1	<1	<1	1	2	9	<1	<1	<1	<1	2	2
NO3-N	9	<1	<1	<1	<1	1	1	9	<1	<1	<1	<1	1	1	9	<1	<1	<1	<1	<1	1
Na	9	4400	4920	5856	5600	6560	8000	9	3800	4240	5856	5300	7020	9400	9	3400	4300	7433	5000	7420	25000
Ni	9	4	4	7	8	10	12	9	4	4	6	6	7	8	9	3	4	6	5	8	9
P-Total	9	180	200	204	210	210	220	9	200	206	222	220	240	250	9	190	206	233	210	264	320
Pb	9	3	4	5	5	6	6	9	3	3	4	4	4	4	9	3	4	4	4	5	6
SO4	9	940	1056	1326	1200	1580	1900	9	840	942	1568	1400	2020	3100	9	760	900	2517	1300	2580	11000
Sb	9	<0.05	<0.05	<0.05	<0.05	0.06	0.07	9	<0.05	<0.05	<0.05	<0.05	<0.05	0.06	9	<0.05	<0.05	<0.05	<0.05	0.07	0.08
Se	9	<0.05	<0.05	<0.05	<0.05	0.06	0.07	9	<0.05	<0.05	<0.05	<0.05	<0.05	0.06	9	<0.05	<0.05	<0.05	<0.05	0.05	0.06
Si	9	95	112	135	140	154	180	9	92	106	135	140	160	180	9	92	110	138	120	178	210
Sn	9	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	9	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	9	<0.5	<0.5	5.0	<0.5	0.6	42
TOC (%)	9	0.07	0.13	0.45	0.51	0.71	0.75	9	0.12	0.16	0.37	0.43	0.52	0.63	9	<0.05	0.12	0.35	0.42	0.50	0.66
Ti	9	180	190	209	200	220	270	9	150	196	207	220	224	230	9	150	198	228	240	258	270
U	9	0.4	0.4	0.5	0.5	0.5	0.5	9	0.4	0.4	0.4	0.4	0.4	0.4	9	0.4	0.4	0.4	0.4	0.4	0.5
V	9	19	23	26	25	29	31	9	19	22	23	23	24	30	9	20	21	26	27	30	33
Zn	9	13	16	17	17	18	22	9	12	13	14	13	15	20	9	12	13	14	14	15	17

Appendix 4 Baseline Sawfish Data

Details of *Pristis* individuals recorded during the targeted survey (TL = total length, TRL = total rostral length, SRL = standard rostral length). Underlined tag# indicates recaptured individual. Values for ECond (mS/m EC), temperature oC, DO (%) and pH measured at the time of sampling are also provided.

Site	Date	Species	Tag#	Size			Teeth count		Sex	Water quality			
				TL	TRL	SRL	Left	Right		EC	Temp	DO	pH
Keep River													
K1	5/09/2012	*P. pristis*	*	1500	375	355	22	21	M	2532	27	87	8
K1	24/09/2020	*P. pristis*	24	2010	490	465	21	21	M	8000	32.4	151	8.02
K1	24/09/2020	*P. pristis*	25	1824	425	408	21	21	M	8000	32.4	151	8.02
K2	18/09/2011	*P. pristis*	301	1150	260	240	21	21	M	207	25.7	116	8
K2	18/09/2011	*P. pristis*	302	1100	275	265	22	21	M	207	25.7	116	8
K2	18/09/2011	*P. pristis*	303	1040	250	230	19	18	F	207	25.7	116	8
K2	18/09/2011	*P. pristis*	304	1130	280	265	21	21	F	207	25.7	116	8
K2	18/09/2011	*P. pristis*	305	1480	350	330	23	23	F	207	25.7	116	8
K2	5/09/2012	*P. pristis*	302	1490	370	355	22	21	M	2532	27	87	8
K2	5/09/2012	*P. pristis*	*	1500	375	355	22	21	M	2532	27	87	8
K2	30/09/2013	*P. pristis*	*	1900	420	380	21	21	M	2200	32.4	92	8.2
K3	22/09/2020	*P. pristis*	*	880	221	209	20	20	M	353	30.51	129.5	7.54
K4	23/09/2020	*P. pristis*	*	875	231	214	17	19	F	832	31.47	102.9	7.31
KR2	24/09/2011	*P. pristis*	306	950	240	220	20	19	F	45.3	25.8	99	8.3
KR2	15/09/2012	*P. pristis*	18	1505	365	350	21	21	F	20.6	25.2	85	7.8
KR2	2/10/2020	*P. pristis*	*	923	221	214	19	21	M	164	31.37	121.9	7.84
Keep Estuary													
EST01	22/10/2011	*P. clavata*	309	1870	368	352	22	21	M	4520	33.2	125	8.2
EST01	22/10/2011	*P. clavata*	311	1445	305	290	22	21	M	4520	33.2	125	8.2
EST01	22/10/2011	*P. clavata*	312	1925	425	395	21	22	M	4520	33.2	125	8.2
EST01	22/10/2011	*P. clavata*	313	~2000	Not measured but tagged & DNA					4520	33.2	125	8.2
EST01	22/10/2011	*P. clavata*	314	1900	418	400	20	20	M	4520	33.2	125	8.2
EST01	22/10/2011	*P. clavata*	315	1500	305	290	22	22	M	4520	33.2	125	8.2
EST01	22/10/2011	*P. clavata*	316	1650	340	322	21	21	F	4520	33.2	125	8.2
EST01	22/10/2011	*P. zijsron*	310	1905	395	372	23	24	F	4520	33.2	125	8.2
EST01	11/09/2012	*P. clavata*	1	1820	370	355	22	23	F	4730	22.7	86	8.1
EST01	11/09/2012	*P. clavata*	2	1390	290	275	21	21	M	4730	22.7	86	8.1
EST01	11/09/2012	*P. clavata*	3	~1900	385	365	21	21	F	4730	22.7	86	8.1
EST01	11/09/2012	*P. clavata*	4	1900	368	350	23	23	M	4730	22.7	86	8.1
EST01	11/09/2012	*P. clavata*	5	1818	375	360	22	20	F	4730	22.7	86	8.1
EST01	11/09/2012	*P. clavata*	6	1330	277	265	23	21	M	4730	22.7	86	8.1
EST01	11/09/2012	*P. clavata*	7	890	188	180	23	23	M	4730	22.7	86	8.1
EST01	11/09/2012	*P. clavata*	8	1240	265	255	21	20	M	4730	22.7	86	8.1
EST01	14/09/2012	*P. clavata*	15	1855	380	360	23	22	M	4730	22.7	86	8.1
EST01	14/09/2012	*P. clavata*	16	2420	480	445	19	20	F	4730	22.7	86	8.1
EST01	14/09/2012	*P. clavata*	17	2720	515	495	21	23	F	4730	22.7	86	8.1
ESTO1	27/09/2020	*P. clavata*	26	1920	370	349	21	20	M	8000	30.43	144.7	7.82
ESTO1	27/09/2020	*P. clavata*	27	2020	387	365	20	22	F	8000	30.43	144.7	7.82
ESTO1	27/09/2020	*P. clavata*	28	1720	331	315	22	19	M	8000	30.43	144.7	7.82
ESTO1	27/09/2020	*P. clavata*	*	1090	224	215	21	21	M	8000	30.43	144.7	7.82
EST02	4/10/2013	*P. clavata*	21	1300	335	300	22	22	F	6100	28.6	95	8.2
EST02	4/10/2013	*P. clavata*	19	1500	330	300	23	23	M	6100	28.6	95	8.2
ESTO2	28/09/2020	*P. clavata*	*	1030	209	203	21	21	M	8000	30.06	146.9	7.89
ESTO2	28/09/2020	*P. clavata*	*	980	208	200	22	22	F	8000	30.06	146.9	7.89
ESTO2	28/09/2020	*P. clavata*	*	930	197	191	22	23	F	8000	30.06	146.9	7.89
EST03	11/09/2012	*P. clavata*	*	830	177	168	--	--	M	5540	24.3	87	8
EST03	11/09/2012	*P. clavata*	9	1550	227	217	19	19	F	5540	24.3	87	8
EST03	11/09/2012	*P. clavata*	10	1933	325	310	22	22	M	5540	24.3	87	8
EST03	11/09/2012	*P. clavata*	11	2260	427	405	22	21	M	5540	24.3	87	8
EST03	11/09/2012	*P. clavata*	12	1460	310	295	23	22	F	5540	24.3	87	8
EST03	11/09/2012	*P. clavata*	13	1300	270	255	22	22	F	5540	24.3	87	8
EST03	11/09/2012	*P. clavata*	14	1540	305	290	21	22	F	5540	24.3	87	8
EST03	5/10/2013	*P. clavata*	20	1460	310	280	22	20	M	5840	29	98	8.2
EST03	5/10/2013	*P. clavata*	22	1310	300	275	21	21	M	5840	29	98	8.2
EST03	5/10/2013	*P. clavata*	*	840	190	200	23	23	M	5840	29	98	8.2
ESTO3	30/09/2020	*P. clavata*	29	1290	254	248	22	21	M	8000	30.07	136.8	7.71
ESTO3	30/09/2020	*P. clavata*	30	1535	313	304	21	22	M	8000	30.07	136.8	7.71

Appendix 5 ANZG (2018) Water Quality Guidelines

Table 5A-1. Default trigger values for physical and chemical stressors for tropical Australia for slightly disturbed ecosystems (TP = total phosphorus; FRP = filterable reactive phosphorus; TN = total nitrogen; NOx = total nitrates/nitrites; NH_4^+ = ammonium). Data derived from trigger values supplied by Australian states and territories, for the Northern Territory and regions north of Carnarvon in the west and Rockhampton in the east (ANZECC/ARMCANZ 2000).

Ecosystem type	**TP** (mg P/L)	**FRP** (mg P/L)	**TN** (mg/L)	**NOx** (mg N/L)	**NH_4^+** (mg N/L)	**DO** % saturation	**pH**
Upland River^{e}	0.01	0.005	0.15	0.03	0.006^{i}	90-120	6.0-7.5
Lowland River^{e}	0.01	0.004	0.2-0.3^{h}	0.01^{b}	0.01^{i}	85-120	6.0-8.0
Lakes & Reservoirs	0.01	0.005	0.35^{c}	0.01^{b}	0.01^{i}	90-120	6.0-8.0
Wetlands^{e}	0.01-0.05^{g}	0.005-0.025^{g}	0.35-1.2^{g}	0.01	0.01^{i}	90^{b}-120^{b}	6.0-8.0
Estuaries	0.02	0.005	0.25	0.03	0.015^{i}	80-120	7.0-8.5

b = Northern Territory values are 5 µg/L for NO_x, and <80 (lower limit) and >110% saturation (upper limit) for DO;

c = this value represents turbid lakes only. Clear lakes have much lower values;

e = no data available for tropical WA estuaries or rivers. A precautionary approach should be adopted when applying default trigger values to these systems;

f = dissolved oxygen values were derived from daytime measurements. Dissolved oxygen concentrations may vary diurnally and with depth. Monitoring programs should assess this potential variability;

g = higher values are indicative of tropical WA river pools;

h = lower values from rivers draining rainforest catchments.

i = ammonium (NH_4^+) is the principal species typically present in natural waters, however, the proportion of un-ionized ammonia (*i.e.* NH_3), increases at pH >7 and water temperature >25ºC. NH_3 and NH_4^+ species co-exist in equilibrium that is controlled by pH, and to a lesser extent by temperature.

Table 5A-2. Default trigger values for salinity and turbidity for the protection of aquatic ecosystems, applicable to tropical systems in Australia (ANZECC/ARMCANZ 2000).

Aquatic Ecosystem	**Salinity (µs/cm)**	**Comments**
Upland & lowland rivers	20-250	Conductivity in upland streams will vary depending on catchment geology. The first flush may result in temporarily high values
Lakes, reservoirs & wetlands	90-900	Higher conductivities will occur during summer when water levels are reduced due to evaporation
	Turbidity (NTU)	
Upland & lowland rivers	2-15	Can depend on degree of catchment modification and seasonal rainfall runoff
Lakes, reservoirs & wetlands	2-200	Most deep lakes have low turbidity. However, shallow lakes have higher turbidity naturally due to wind-induced re-suspension of sediments. Wetlands vary greatly in turbidity depending on the general condition of the catchment, recent flow events and the water level in the wetland.
Estuarine & marine	1-20	Low values indicative of offshore coral dominated waters. Higher values representative of estuarine waters. Turbidity is not a very useful indicator in estuarine and marine waters.

Appendix 5 continued.

Table 5A-3. ANZG 2018 Default guideline values for toxicants at alternative levels of protection for the protection of aquatic ecosystems, applicable to tropical systems in Australia. Values shaded grey are GVs applicable to slightly-moderately disturbed systems. All values in mg/L.

COMPOUND		Guideline values for freshwater Level of protection (% species)			
		99%	95%	90%	80%
METALS & METALLOIDS					
Aluminium (at pH > 6.5)		0.27	0.55	0.08	0.15
Aluminium (at pH < 6.5)		ID	ID	ID	ID
Arsenic (As III)		0.001	0.024	0.094 [c]	0.36 [c]
Arsenic (As IV)		0.0008	0.013	0.042	0.14 [c]
Boron		0.09	0.37 [c]	0.68 [c]	1.3 [c]
Cadmium	H	0.06	0.2	0.4	0.8 [c]
Chromium (Cr III)	H	ID	ID	ID	ID
Chromium (Cr VI)		0.00001	0.001 [c]	0.006 [A]	0.04 [A]
Cobalt		ID	ID	ID	ID
Copper	H	0.001	0.0014	0.0018 [c]	0.0025 [c]
Fluoride	F	ID	ID	ID	ID
Iron		ID	ID	ID	ID
Lead	H	1	3.4	5.6	9.4 [c]
Manganese		1.2	1.9 [c]	2.5 [c]	3.6 [c]
Mercury (inorganic)	B	0.00006	0.0006	0.0019 [c]	0.0054 [A]
Molybdenum		ID	ID	ID	ID
Nickel	H	8	11	13	17 [c]
Selenium (Se total)	B	5	11	18	34
Selenium (Se IV)	B	ID	ID	ID	ID
Silver		0.00002	0.00005	0.0001	0.0002 [c]
Uranium		ID	ID	ID	ID
Vanadium		ID	ID	ID	ID
Zinc	H	2.4	8 [c]	15 [c]	31 [c]
NON-METALLIC INORGANICS					
Ammonia (total NH_3-N at pH 8)	D	0.32	0.9 [c]	1.43 [c]	2.3 [c]
Chlorine	E	0.0004	0.003	0.006 [A]	0.013 [A]
Nitrate (NO_3)	J	0.017	0.7	3.4 [c]	17 [A]
Hydrogen sulfide	G	0.0005	0.001	0.0015	0.0026

Notes:

A = Figure may not protect key test species from acute toxicity (and chronic).

B = Chemicals for which possible bioaccumulation and secondary poisoning effects should be considered.

C = Figure may not protect key test species from chronic toxicity.

D = Ammonia as TOTAL ammonia as [NH_3-N] at pH 8. For changes in trigger value with pH refer to Section 8.3.7.2 ANZECC/ARMCANZ (2000).

E = Chlorine as total chlorine, as [Cl].

F = No guideline for aquatic ecosystems, but ANZECC/ARMCANZ (2000) recommend a figure of <0.02 mg/L for fluorides for the protection of aquaculture species. Canadian Water Quality Guidelines (CCME 2002) recommend a maximum of 0.4 mg/L total-F (modified for hardness where $CaCO_3$ > 10mg/L) for protection of freshwater species and 1.5 mg/L for protection of estuarine and marine species. CCME guidelines for fluoride are interim pending further research.

G = Sulfide as un-ionised H_2S, measured as [S]; see Section 8.3.7.2.

H = Chemicals for which algorithms have been provided in ANZECC/ARMCANZ (2000) Table 3.4.3 to account for the effects of hardness. The values have been calculated using a hardness of 30 mg/L $CaCO_3$.

J = Figures protect against toxicity and do not relate to eutrophication issues.

ID = Insufficient data to derive a reliable trigger value.

Appendix 6 Baseline Water Quality Data

Summary statistics for baseline water quality data collected from the Keep River, Estuary and Reference sites in Sep/Oct 2011, 2012 and 2013. Concentrations in mg/L unless specified otherwise. Tables continued overpage.

Analyte	Keep River - K4							Keep River - K3							Keep River - K2							Keep River - K1						
	n	min	20%ile	mean	median	80%ile	max	n	min	20%ile	mean	median	80%ile	max	n	min	20%ile	mean	median	80%ile	max	n	min	20%ile	mean	median	80%ile	max
Acidity	12	1.0	1.8	7.8	8.0	11.8	16.0	10	1.0	1.0	6.1	5.0	12.0	14.0	10	1.0	1.0	8.5	5.5	16.4	22.0	10	1.0	1.0	2.4	1.0	1.6	12.0
Alkalinity	15	132	133	139	138	145	153	15	133	137	144	146	151	153	15	144	148	153	152	160	163	15	154	161	166	165	174	177
Ca	15	31	37	43	40	45	67	15	38	40	49	42	65	67	15	48	61	106	72	189	199	15	120	157	246	213	361	395
Cl	15	112	132	307	156	251	1220	15	138	156	488	174	1122	1220	15	422	525	2886	1060	7152	7640	15	2800	4990	9664	8190	15440	17600
CO3	13	<1	<1	<1	<1	<1	<1	11	<1	<1	<1	<1	<1	<1	11	<1	<1	1.273	<1	<1	9	11	<1	<1	5	<1	9	24
DO (%)	15	32	52	65	61	86	99	15	61	79	86	88	93	99	15	70	91	101	101	116	123	15	71	85	101	108	119	122
DOC	13	1.2	1.3	2.1	1.7	2.8	3.9	11	1.8	2.1	2.9	2.7	3.8	3.9	11	2.7	3.0	3.6	3.1	4.3	4.4	11	3.6	3.7	4.3	4.3	4.7	5.1
Econd (mS/m)	15	81	82	145	94	121	465	15	94	96	209	99	427	465	15	180	216	922	384	2176	2320	15	964	1614	2888	2420	4566	4970
F	13	0.14	0.15	0.19	0.16	0.21	0.29	11	0.18	0.18	0.23	0.18	0.28	0.29	11	0.19	0.20	0.33	0.23	0.48	0.51	11	0.48	0.49	0.61	0.53	0.74	0.77
Hardness	13	200	204	284	230	328	570	11	220	220	373	260	540	570	11	410	560	1389	740	2400	2500	11	2800	2900	4036	3200	5300	5700
HCO3	13	161	163	170	170	175	186	11	163	165	173	175	179	186	11	171	179	181	180	185	187	11	146	188	193	197	200	212
K	12	4	4	8	5	12	21	10	5	5	12	12	19	21	10	8	9	63	60	117	125	10	64	87	193	196	296	313
Mg	15	25	28	40	30	36	98	15	30	30	52	33	91	98	15	51	61	200	91	456	482	15	232	367	656	566	1030	1130
N-NH3	15	<0.01	<0.01	0.007	<0.01	0.007	0.02	15	<0.01	<0.01	0.006	<0.01	<0.01	0.01	15	<0.01	<0.01	0.007	0.005	0.006	0.02	15	<0.01	<0.01	0.014	0.005	0.022	0.05
N-NO2	13	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	11	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	11	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	11	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
N-NO3	10	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	6	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	6	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	6	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
N-NOx	15	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	15	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	15	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	15	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
N-org.	13	0.11	0.13	0.20	0.18	0.27	0.38	11	0.15	0.18	0.25	0.27	0.31	0.38	11	0.17	0.25	0.30	0.31	0.35	0.37	11	0.24	0.29	0.40	0.40	0.47	0.56
N-TK	9	0.07	0.08	0.10	0.11	0.12	0.12	5	0.10	0.11	0.11	0.11	0.12	0.12	5	0.13	0.13	0.14	0.13	0.15	0.17	5	0.18	0.18	0.19	0.19	0.19	0.20
N-total	15	0.07	0.10	0.17	0.13	0.24	0.39	15	0.10	0.12	0.21	0.18	0.30	0.39	15	0.13	0.14	0.25	0.27	0.35	0.38	15	0.18	0.19	0.35	0.41	0.50	0.58
N-tot.sol.	13	0.09	0.12	0.18	0.16	0.22	0.39	11	0.15	0.16	0.21	0.20	0.22	0.39	11	0.17	0.24	0.28	0.28	0.32	0.37	11	0.24	0.29	0.39	0.41	0.48	0.57
Na	12	80	84	231	100	366	682	10	103	107	369	354	625	682	10	239	299	1906	1811	3518	3740	10	1770	2350	5603	5670	8816	9230
P-filt.org.	7	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1						<0.01	1						<0.01	1						<0.01
P-org.	13	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	11	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	11	<0.01	<0.01	<0.01	<0.01	0.01	0.01	11	<0.01	<0.01	<0.01	<0.01	<0.01	0.01
P-SR	15	<0.01	<0.01	<0.01	<0.01	0.01	0.01	15	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	15	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	15	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
P-total	15	<0.005	<0.005	<0.005	<0.005	0.01	0.02	15	<0.005	<0.005	<0.005	<0.005	<0.005	0.01	15	<0.005	<0.005	0.006	<0.005	<0.01	0.01	15	<0.005	<0.005	0.006	<0.005	<0.01	0.01
P-tot.sol	13	<0.005	<0.005	<0.005	<0.005	<0.005	0.01	11	<0.005	<0.005	<0.005	<0.005	<0.005	0.01	11	<0.005	<0.005	<0.005	<0.005	<0.005	0.01	11	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
P-TR	13	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	11	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	11	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	11	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
pH [H$^+$]	15	6.9	7.1	7.5	7.5	8.0	8.1	15	7.8	8.0	8.0	8.0	8.1	8.1	15	8.0	8.1	8.2	8.2	8.4	8.5	15	7.9	8.0	8.3	8.4	8.4	8.5
Redox	15	-90	-64	-34	-27	-18	64	15	-90	-85	-63	-69	-60	64	15	-94	-93	-85	-87	-74	-70	15	-93	-91	-87	-89	-83	-79
SiO2	9	30	31	35	33	39	42	5	30	30	32	31	33	34	5	28	29	29	29	29	29	5	19	19	20	19	21	23
SO4-S	12	54	58	85	68	105	159	10	62	64	106	104	146	159	10	90	100	546	526	1002	1040	10	390	576	1465	1475	2340	2460
TDS-180C	15	420	448	753	508	671	2300	15	490	508	1074	540	2120	2300	15	980	1180	5632	1900	14000	15000	15	5500	9540	18073	14000	31200	34000
TDS-calc	9	520	532	1764	2280	2416	2600	5	2200	2280	2380	2400	2440	2600	5	12000	12000	12200	12000	12200	13000	5	24000	24800	25800	26000	27000	27000
Temp (°C)	15	23.2	24.2	26.3	25.7	28.0	31.5	15	24.3	24.8	27.1	27.3	29.4	31.5	15	25.1	25.7	28.5	27.4	32.5	33.7	15	24.2	27.0	28.4	27.7	30.4	32.7
TSS	13	1	1.5	1.5	1.5	1.5	2	11	1.5	1.5	1.5	1.5	1.5	2	11	1.5	1.5	1.6	1.5	1.5	3	11	1.5	1.5	2.6	1.5	1.5	14
Turbid (NTU)	15	3.8	5.9	9.0	7.9	13.2	18.0	15	3.8	4.1	8.6	5.7	15.0	18.0	15	2.8	3.6	7.6	6.6	10.0	18.0	15	1.3	1.9	5.2	3.1	9.7	12.0

Appendix 6 continued.

Summary statistics for baseline water quality data collected from the Keep River, Estuary and Reference sites in Sep/Oct 2011, 2012 and 2013. Concentrations in mg/L unless specified otherwise. Tables continued overpage.

Analyte	Keep Estuary EST01							Keep Estuary EST02							Keep Estuary EST03						
	n	min	20%ile	mean	median	80%ile	max	n	min	20%ile	mean	median	80%ile	max	n	min	20%ile	mean	median	80%ile	max
Acidity	2	5.0	7.6	11.5	11.5	15.4	18	2	5.0	7.2	10.5	10.5	13.8	16	2	10.0	11.0	12.5	12.5	14.0	15.0
Alkalinity	3	175	175	182	175	187	195	3	145	147	160	150	171	185	3	133	133	141	134	147	156
Ca	3	376	378	411	380	439	478	3	422	429	448	439	465	482	3	427	436	444	450	453	455
Cl	3	16900	17740	18833	19000	19960	20600	3	20000	20120	21067	20300	21860	22900	3	19200	19240	19767	19300	20200	20800
CO3	3	<1	<1	6	<1	11	18	3	<1	<1	5	<1	9	15	3	<1	<1	5	<1	9	15
DO%	3	86	88	101	91	111	125	3	94	95	97	95	99	101	3	87	91	95	98	98	99
DOC	3	3.1	3.4	3.9	3.9	4.3	4.6	3	1.6	1.6	2.0	1.7	2.3	2.7	3	1.4	1.4	1.5	1.4	1.6	1.8
Econd (mS/m)	3	4520	4604	5057	4730	5444	5920	3	5380	5416	5650	5470	5848	6100	3	5290	5390	5557	5540	5720	5840
F	3	0.68	0.71	0.76	0.75	0.80	0.84	3	0.79	0.80	0.86	0.81	0.92	0.99	3	0.83	0.83	0.89	0.83	0.93	1
Hardness	3	5500	5500	6000	5500	6400	7000	3	6100	6380	6733	6800	7100	7300	3	6600	6680	6800	6800	6920	7000
HCO3	3	177	191	209	213	228	238	3	153	163	185	177	206	226	3	131	144	162	163	180	191
K	1						374	1						419	1						397
Mg	3	1110	1114	1213	1120	1294	1410	3	1230	1298	1370	1400	1448	1480	3	1340	1356	1380	1380	1404	1420
N-NH3	3	0.06	0.06	0.07	0.07	0.07	0.07	3	<0.01	<0.01	0.01	<0.01	0.014	0.02	3	<0.01	<0.01	<0.01	<0.01	<0.01	0.01
N-NO2	3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
N-NO3	2	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
N-NOx	2	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2	<0.01	<0.01	0.013	0.013	0.017	0.02
N-org.	3	0.38	0.45	0.51	0.56	0.57	0.58	3	0.15	0.15	0.20	0.16	0.24	0.30	3	0.12	0.12	0.17	0.13	0.20	0.25
N-TK	0							0							0						
N-total	3	0.63	0.64	0.65	0.65	0.66	0.66	3	0.15	0.22	0.27	0.32	0.33	0.34	3	0.23	0.24	0.37	0.26	0.47	0.61
N-tot.sol.	3	0.44	0.46	0.52	0.49	0.57	0.62	3	0.11	0.13	0.18	0.16	0.22	0.26	3	0.12	0.13	0.15	0.15	0.16	0.17
Na	1						11500	1						12200	1						11400
P-filt.org.	1						0.005	1						<0.01	1						<0.01
P-org.	3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
P-SR	3	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	3	<0.01	<0.01	<0.01	<0.01	<0.01	0.01
P-total	3	<0.005	<0.005	0.02	<0.005	0.03	0.05	3	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	3	<0.005	<0.005	0.019	<0.005	0.032	0.05
P-tot.sol	3	<0.005	<0.005	<0.005	<0.005	<0.005	0.01	3	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	3	<0.005	<0.005	<0.005	<0.005	<0.005	0.01
P-TR	3	<0.01	<0.01	0.013	0.01	0.019	0.025	3	<0.01	<0.01	0.012	<0.01	0.017	0.025	3	<0.01	<0.01	<0.01	<0.01	<0.01	0.01
pH [H$^+$]	3	8.1	8.1	8.2	8.2	8.2	8.3	3	8.0	8.0	8.1	8.1	8.2	8.2	3	8.0	8.0	8.1	8.0	8.1	8.2
Redox	3	-96	-95	-88	-92	-83	-76	3	-89	-88	-82	-86	-78	-72	3	-85	-84	-80	-83	-77	-73
SiO2	0							0							0						
SO4-S	1						2690	1						2970	1						2740
TDS-180C	3	27000	27400	32333	28000	36400	42000	3	29000	31400	36000	35000	40400	44000	3	24000	27600	32667	33000	37800	41000
TDS-calc	2	26000	27400	29500	29500	31600	33000	2	30000	30800	32000	32000	33200	34000	2	30000	30400	31000	31000	31600	32000
Temp (°C)	3	22.7	25.1	28.2	28.7	31.4	33.2	3	23.2	25.4	27.3	28.6	29.6	30.2	3	24.3	26.2	27.7	29.0	29.4	29.7
TSS	3	43	49.4	58	59	66.8	72	3	5	47	405	110	704	1100	3	430	462	523.3	510	582	630
Turbid (NTU)	3	12	18	26.33	27	34.8	40	3	12	31.2	357.3	60	624	1000	3	310	342	393.3	390	444	480

Appendix 6 continued.

Summary statistics for baseline water quality data collected from the Keep River, Estuary and Reference sites in Sep/Oct 2011, 2012 and 2013. Concentrations in mg/L unless specified otherwise. Tables continued overpage.

Analyte	Reference - Dunham River DR1							Reference - Alligator Hole KR2							Reference - Policeman's Waterhole KR1							Reference - Milligan's Lagoon KE1						
	n	min	20%ile	mean	median	80%ile	max	n	min	20%ile	mean	median	80%ile	max	n	min	20%ile	mean	median	80%ile	max	n	min	20%ile	mean	median	80%ile	max
Acidity	2	4.0	4.2	4.5	4.5	4.8	5.0	2	3.0	3.2	3.5	3.5	3.8	4.0	2	3.0	3.2	3.5	3.5	3.8	4.0	2	6.0	6.8	8.0	8.0	9.2	10.0
Alkalinity	3	130	157	180	198	207	213	3	68	81	109	100	135	158	3	93	96	101	100	106	110	3	123	123	130	124	135	142
Ca	3	18	22	24	28	28	28	3	15	15	21	16	26	33	3	17	17	19	18	21	22	3	22	23	24	24	24	25
Cl	3	13	13	15	13	16	18	3	7	10	14	14	18	21	3	13	13	14	13	15	16	3	20	25	35	32	44	52
CO3	2	<1	1	2	2	3	4	2	<1	<1	<1	<1	<1	<1	2	<1	<1	<1	<1	<1	<1	2	<1	<1	<1	<1	<1	<1
DO (%)	3	79	84	90	92	95	98	3	85	88	92	92	97	100	3	62	67	71	74	76	77	3	37	39	43	42	46	49
DOC	2	1.7	2.0	2.6	2.6	3.1	3.4	2	3.6	3.8	4	4	4.2	4.4	2	3.5	3.8	4.2	4.2	4.5	4.8	2	9.3	9.8	10.7	10.7	11.5	12
Econd (mS/m)	3	29.6	33.2	37.77	38.6	42.5	45.1	3	20.3	20.4	28.7	20.6	35.4	45.3	3	24.5	25.7	26.6	27.5	27.6	27.7	3	31.4	32.7	37.3	34.7	41.4	45.9
F	2	0.23	0.24	0.27	0.27	0.29	0.30	2	0.06	0.06	0.07	0.07	0.07	0.07	2	0.09	0.09	0.10	0.10	0.10	0.10	2	0.10	0.12	0.14	0.14	0.16	0.18
Hardness	2	100	114	135	135	156	170	2	75	75	75	75	75	75	2	79	85	95	95	104	110	2	120	124	130	130	136	140
HCO3	2	159	174	196	196	218	233	2	83	91	103	103	114	122	2	122	124	128	128	132	134	2	152	156	163	163	169	173
K	2	2	4	8	8	12	14	2	3	4	6	6	8	9	2	3	4	6	6	8	9	2	3	4	6	6	8	9
Mg	3	<0.01	10	17	24	26	27	3	<0.01	4	11	9	18	24	3	<0.01	5	9	12	14	15	3	15	15	16	15	17	18
N-NH3	3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	3	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	3	<0.01	0.011	0.022	0.02	0.032	0.04
N-NO2	3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
N-NO3	2	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1						<0.01	1						<0.01	1						<0.01
N-NOx	3	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	3	<0.01	<0.01	0.01	<0.01	0.014	0.02	3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
N-org.	2	0.15	0.19	0.25	0.25	0.31	0.35	2	0.34	0.35	0.37	0.37	0.38	0.39	2	0.33	0.34	0.37	0.37	0.39	0.40	2	0.84	0.87	0.91	0.91	0.95	0.98
N-TK	1						0.18	1						0.18	1						0.18	1						0.42
N-total	3	0.15	0.17	0.24	0.21	0.29	0.35	3	0.20	0.26	0.31	0.34	0.37	0.39	3	0.18	0.24	0.31	0.33	0.38	0.41	3	0.42	0.60	0.76	0.86	0.94	1.00
N-tot.sol.	2	0.14	0.16	0.19	0.19	0.21	0.23	2	0.24	0.26	0.28	0.28	0.30	0.32	2	0.30	0.32	0.35	0.35	0.38	0.40	2	0.83	0.83	0.83	0.83	0.83	0.83
Na	1						29	1						22	1						17	2	17	20	23	23	27	30
P-filt.org.	0							0							0							0						
P-org.	2	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2	0.01	0.014	0.02	0.02	0.026	0.03
P-SR	3	<0.01	<0.01	<0.01	0.01	0.01	0.01	3	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
P-total	3	<0.005	<0.005	0.011	0.01	0.016	0.02	3	<0.005	<0.005	<0.005	<0.005	<0.005	0.01	3	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	3	<0.005	<0.005	0.015	0.01	0.022	0.03
P-tot.sol	2	<0.005	<0.005	<0.005	<0.005	<0.005	0.01	2	<0.005	<0.005	<0.005	<0.005	<0.005	<0.01	2	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	2	0.01	0.01	0.01	0.01	0.01	0.01
P-TR	2	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
pH [H^+]	3	8.0	8.0	8.1	8.2	8.2	8.2	3	7.8	7.9	8.0	8.0	8.2	8.3	3	7.3	7.4	7.5	7.5	7.6	7.7	3	7.1	7.2	7.3	7.3	7.5	7.6
Redox	3	-95	-89	-83	-81	-77	-74	3	-86	-81	-71	-74	-61	-53	3	-47	-46	-40	-45	-34	-27	3	-33	-31	-29	-27	-27	-26
SiO2	1						33	1						17	1						17	1						4.4
SO4-S	1						0.6	1						44	1						21	2	0.3	0.7	1.4	1.4	2.1	2.5
TDS-180C	2	150	162	180	180	198	210	2	110	140	185	185	230	260	2	120	126	135	135	144	150	3	160	164	186.7	170	206	230
TDS-calc	2	160	170	185	185	200	210	2	110	110	110	110	110	110	2	130	134	140	140	146	150	1						250
Temp (°C)	3	27.1	28.2	29.7	29.8	31.2	32.1	3	25.2	25.4	27.4	25.8	29.1	31.3	3	28.5	28.6	28.8	28.7	29.1	29.3	3	24.9	25.4	26.8	26.2	28.1	29.3
TSS	2	0.5	0.6	0.75	0.75	0.9	1	2	1	2.4	4.5	4.5	6.6	8	2	5	5.4	6	6	6.6	7	2	1.5	1.5	1.5	1.5	1.5	1.5
Turbid (NTU)	3	2.3	2.7	4.1	3.3	5.3	6.7	3	1.5	2.4	4.2	3.8	6.0	7.4	3	1.1	2.0	4.2	3.4	6.2	8.0	3	1.7	2.1	11.5	2.8	19.1	30.0

Appendix 6 continued.

Summary statistics for baseline water quality data collected from the Keep River, Estuary and Reference sites in Sep/Oct 2011, 2012 and 2013. Concentrations in mg/L unless specified otherwise.

Analyte	Reference - Augustus Hole SR4						
	n	min	20%ile	mean	median	80%ile	max
Acidity	2	1.0	2.0	3.5	3.5	5.0	6.0
Alkalinity	3	129	137	143	150	150	150
Ca	3	24	25	26	27	27	27
Cl	3	4	4	5	5	5	5
CO3	2	<1	<1	<1	<1	<1	<1
DO (%)	3	74	74	77	74	79	83
DOC	2	2.1	2.1	2.2	2.2	2.3	2.3
Econd (mS/m)	3	26.9	28.0	29.4	29.7	30.9	31.7
F	2	0.11	0.11	0.12	0.12	0.13	0.13
Hardness	2	120	126	135	135	144	150
HCO3	2	157	162	170	170	178	183
K	2	3	3	3	3	3	3
Mg	3	16	18	19	20	21	21
N-NH3	3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
N-NO2	3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
N-NO3	2	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
N-NOx	3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
N-org.	2	0.15	0.15	0.15	0.15	0.15	0.15
N-TK	1						0.16
N-total	3	0.15	0.15	0.15	0.15	0.16	0.16
N-tot.sol.	2	0.13	0.13	0.14	0.14	0.15	0.15
Na	2	3	3	4	4	4	4
P-filt.org.	0						
P-org.	2	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
P-SR	3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
P-total	3	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
P-tot.sol	2	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
P-TR	2	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
pH [H^+]	3	7.9	7.9	7.9	7.9	7.9	7.9
Redox	3	-79	-79	-70	-78	-64	-54
SiO2	1						18
SO4-S	2	4.7	4.8	5.0	5.0	5.2	5.3
TDS-180C	3	150	150	153.3	150	156	160
TDS-calc	1						150
Temp (°C)	3	25.2	27.2	28.7	30.3	30.4	30.5
TSS	2	1.5	1.5	1.5	1.5	1.5	1.5
Turbid (NTU)	3	0.6	0.9	1.3	1.4	1.8	2.0

Appendix 7 Macroinvertebrate data 2020

Macroinvertebrate species abundance data for Sep/Oct 2020, edge and riffle habitats combined. Data are log_{10} abundance classes; 1 = 1 - 10 individuals, 2 = 11 - 100 individuals, 3 = 101-1000 individuals, 4 = >1000. Taxonomic codes: F = female, L = larva, P = pupa, juv. = juvenile.-*

Phylum/Class/Order	Family	Lowest taxon	Riffle Sites			Reference Sites					Keep River Pools																	
			SR4 - Riffle	K3 Riffle	K4 Riffle	KR1	SR4	DR1	KE1	KR2	K1-1	K1-2	K1-3	K1-4	K1-5	K2-1	K2-2	K2-3	K2-4	K2-5	K3-1	K3-2	K3-3	K3-4	K3-5	K4-1	K4-2	K4-3
CNIDARIA																												
Hydrozoa																												
Anthoathecata	Hydridae	*Hydra* spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
NEMATODA		Nematoda spp.	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0
MOLLUSCA																												
Bivalvia																												
Cardiida	Cyrenidae	*Corbicula* spp.	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2
Unionoida	Hyriidae	Lortiella sp.	0	0	0	0	0	0	0	0	3	3	3	3	4	0	1	0	0	0	0	0	0	0	0	0	0	0
		Velesunio wilsonii	1	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gastropoda																												
Architaenioglossa	Viviparidae	Notopala sp.	0	0	0	0	0	2	0	0	3	2	3	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0
Cerithimorpha	Thiaridae	Melanoides sp.	0	0	0	0	2	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hygrophila	Lymnaeidae	*Bullastra vinosa*	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Planorbidae	Amerianna sp.	0	0	0	1	1	0	3	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0
		Ferrissia petterdi	0	0	2	0	0	1	0	0	0	0	0	0	0	0	2	0	1	0	0	2	0	0	0	2	0	0
		Gyraulus sp.	0	2	3	3	3	2	3	2	2	3	0	0	2	0	1	1	0	0	2	2	2	0	1	3	0	3
Hypsogastropoda	Bithuniidae	Bithyniidae spp.	0	0	0	1	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ANNELIDA																												
Polychaeta		Polychaeta sp.	0	0	0	0	0	0	0	0	2	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oligochaeta		Oligochaeta spp.	3	4	2	2	3	3	0	3	0	0	0	0	0	1	2	0	1	0	2	2	3	2	3	2	1	2
ARTHROPODA																												
CRUSTACEA																												
Branchiopoda																												
Diplostraca	Cyclestheriidae	*Cyclestheria hislopi*	0	0	0	0	0	0	3	0	0	0	0	0	0	0	2	0	0	0	0	1	2	0	0	0	0	0
Malacostraca																												
Amphipoda	?Corophiidae	?Corophiidae sp.	0	0	0	0	0	0	0	0	3	3	3	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0
Decapoda	Atyidae	Atyidae sp.	0	0	0	2	2	0	0	2	0	1	0	0	0	2	1	0	0	1	0	1	0	2	0	2	0	3
		Caridina 'nilotica' *complex*	0	2	0	3	3	0	0	3	2	2	0	0	2	2	0	0	2	1	0	2	2	2	2	2	2	0
		Caridina serratirostris	0	0	1	2	0	1	0	2	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	3	3	3
	Palaemonidae	*Macrobrachium bullatum*	0	0	0	1	1	0	2	2	0	3	2	3	2	2	0	1	0	0	0	2	0	0	0	2	2	2
		Macrobrachium rosenbergii	0	0	0	0	0	0	0	0	3	3	3	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0
		Palaemonidae sp.	1	0	0	0	0	0	2	0	0	0	2	2	2	2	0	0	0	0	0	0	0	0	1	2	1	1
ARACHNIDA		Acarina spp.	3	3	2	2	3	3	3	3	0	0	0	0	0	0	0	0	0	0	0	1	0	0	3	2	0	2
COLLEMBOLA																												
ENTOGNATHA																												
Entomobryomorpha		Entomobryoidea sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 7 continued.

Phylum/Class/Order	Family	Lowest taxon	Riffle Sites			Reference Sites					Keep River Pools																	
			SR4 - Riffle	K3 Riffle	K4 Riffle	KR1	SR4	DR1	KE1	KR2	K1-1	K1-2	K1-3	K1-4	K1-5	K2-1	K2-2	K2-3	K2-4	K2-5	K3-1	K3-2	K3-3	K3-4	K3-5	K4-1	K4-2	K4-3
INSECTA																												
Diptera	**Ceratopogonidae**	Ceratopogonidae spp. (P)	0	0	0	2	2	2	0	2	0	0	0	0	0	2	2	2	2	2	1	2	3	2	2	2	0	2
		Ceratopogoninae spp.	2	0	3	2	3	3	0	3	0	0	2	0	2	0	2	2	2	2	2	2	0	2	2	3	2	2
		Dasyheleinae spp.	0	0	1	0	0	0	0	0	0	0	0	0	0	2	2	1	2	2	2	2	2	0	0	0	0	0
		Forcipomyiinae sp.	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
	Chironomidae	Chironomidae spp. (P)	2	2	3	2	1	2	2	2	2	3	2	0	2	0	0	2	2	0	2	2	2	2	2	2	2	2
	Chironominae	Chironominae sp.	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Chironomini	*Chironomini* sp. 1 (ORC9)	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Chironomus sp.	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Cryptochironomus ?griseidorsum (ORC10)	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	2	0	0	0	2
		Dicrotendipes sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
		Dicrotendipes sp. 1 (ORC3)	0	0	2	0	0	2	1	2	0	0	0	0	0	0	0	0	0	0	0	2	0	3	2	3	3	0
		Dicrotendipes sp. 2 (ORC22)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
		Harnischia sp. (ORC7)	0	0	0	0	0	0	0	2	0	0	0	0	3	0	0	0	0	0	0	0	1	0	0	0	0	2
		Kiefferulus sp.	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Parachironomus sp. (ORC11)	0	0	0	0	0	2	2	2	0	0	0	0	0	2	0	0	2	0	0	2	0	0	0	0	3	0
		Paratendipes sp. K1 (ORC24)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	3
		Polypedilum (Pentapedilum) *leei* (ORC4)	0	0	2	3	2	0	2	2	0	0	0	2	2	0	3	3	4	3	2	3	3	3	2	0	3	3
		Polypedilum nubifer (ORC6)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	0	0
		Polypedilum watsoni (ORC8)	0	0	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	2	0	0	0	2	2	0	0	3
		Skusella ?subvittata (ORC5)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
		Stempellina sp. (ORC31)	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Stenochironomus watsoni (ORC17)	0	0	2	0	1	2	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	2
		Xenochironomus sp. (ORC18)	0	0	0	0	0	2	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tanytarsini	*Cladotanytarsus* sp. (ORC2)	2	0	0	0	3	0	2	2	3	0	4	4	4	2	2	2	0	2	0	3	2	3	2	3	4	3
		Rheotanytarsus sp. (ORC15)	4	0	3	0	0	2	2	2	0	0	0	0	0	2	2	0	3	1	0	2	0	2	2	0	0	2
		Tanytarsus sp. (ORC1)	3	0	2	3	2	2	1	2	1	3	0	0	3	2	0	0	2	0	0	3	2	3	2	4	3	3
	Orthocladiinae	*Corynoneura* sp. (ORO4)	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0
		Cricotopus sp. (ORO1)	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Nanocladius sp. 1 (ORO2)	1	0	1	0	0	2	0	3	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	2	0
		Parakiefferiella sp. 2 (ORO6)	0	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Parametriocnemis ornaticornis (ORO7)	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Rheocricotopus sp.	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Thienemanniella sp. (ORO5)	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tanypodinae	*Ablabesmyia* sp. (ORT6)	0	0	0	0	0	2	0	3	0	0	0	1	3	0	0	0	0	1	1	0	1	0	0	0	0	0
		Clinotanypus crux (ORT9)	3	0	0	1	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
		Djalmabatista sp. (ORT7)	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Larsia ?albiceps (ORT1)	3	2	2	1	3	3	2	3	0	0	0	0	0	3	2	2	3	2	3	3	3	3	3	3	3	2
		Nilotanypus sp. nov. (ORT4)	3	3	0	0	0	0	0	0	0	0	0	0	0	3	0	0	1	0	0	0	0	0	0	0	0	0
		Paramerina sp. (ORT5)	3	0	3	2	3	2	1	3	0	0	0	0	0	2	1	0	0	0	2	3	2	1	3	3	3	4
		Procladius sp. (ORT2)	0	0	0	1	2	2	0	2	0	0	0	0	3	0	0	0	0	0	2	0	0	0	0	3	2	2
		Tanypodinae sp. (ORT15)	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	1	0	2	2	0
		Zavreliella ?marmorata	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Culicidae	Culicidae spp. (P)	0	0	3	0	0	2	0	1	0	0	0	0	0	0	0	0	1	0	2	0	0	0	0	2	0	0
		Aedes spp.	0	0	0	0	0	0	2	0	0	0	0	0	0	0	3	0	0	1	0	0	0	0	0	0	0	0
		Anopheles spp.	0	0	0	2	0	0	0	0	0	0	0	0	0	1	0	0	2	1	2	3	3	3	2	1	0	0
		Culex spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	2	0	0	0	0	0	1	0
	Dolichopodidae	Dolichopodidae sp.	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Muscidae	Muscidae spp.	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Sciomyzidae	Sciomyzidae sp.	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
	Simuliidae	Simuliidae sp.	3	3	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Simuliidae sp. (P)	2	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Stratiomyidae	Stratiomyidae spp.	0	0	1	0	2	3	0	0	0	0	0	0	0	0	1	0	0	0	0	2	0	0	2	0	2	2
	Tabanidae	Tabanidae sp.	3	3	3	1	2	2	1	1	0	0	0	0	0	1	2	2	0	0	0	1	2	2	2	0	2	1

Appendix 7 continued.

Phylum/Class/Order	Family	Lowest taxon	Riffle Sites			Reference Sites					Keep River Pools																	
			SR4 - Riffle	K3 Riffle	K4 Riffle	KR1	SR4	DR1	KE1	KR2	K1-1	K1-2	K1-3	K1-4	K1-5	K2-1	K2-2	K2-3	K2-4	K2-5	K3-1	K3-2	K3-3	K3-4	K3-5	K4-1	K4-2	K4-3
Odonata																												
Anisoptera		Anisoptera spp. (imm/dam.)	3	0	2	0	2	2	3	2	0	0	0	0	3	1	0	1	1	0	2	0	1	0	2	2	2	2
	Gomphidae	*Antipodogomphus neophytus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
		Austrogomphus gordoni	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Austrogomphus pusillus	2	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Libellulidae	*Diplacodes bipunctata*	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
		Diplacodes haematodes	0	2	2	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	1	0	0	0	0	0	2	0
		Hydrobasileus brevistylus	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Nannophlebia sp.	2	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Orthetrum caledonicum	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Tramea sp.	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zygoptera		Zygoptera spp. (imm/dam.)	0	0	0	1	2	2	3	0	2	3	3	2	3	1	3	2	3	2	2	2	3	2	2	2	2	2
	Coenagrionidae	*Ischnura aurora*	0	0	0	0	0	0	3	0	1	1	0	0	0	1	0	0	0	0	0	1	1	0	0	0	0	0
		Ischnura sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
		Pseudagrion aureofrons	0	0	0	0	0	0	0	1	2	2	2	3	3	1	1	2	0	0	0	0	0	0	0	0	1	0
		Pseudagrion microcephalum	0	0	0	0	0	0	0	0	0	2	3	3	3	1	0	0	0	0	2	2	1	1	1	0	0	0
	Platycnemididae	Nososticta sp.	0	0		0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
Trichoptera	**Calamoceratidae**	Anisocentropus sp.	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	Ecnomidae	Ecnomina sp.	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Ecnomus sp.	2	1	0	2	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	2	1	0
	Helicopsychidae	Helicopsyche sp.	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Hydropsychidae	*Cheumatopsyche* sp. AV8	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Cheumatopsyche wellsae	3	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
		Hydropsychidae sp.	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Hydroptilidae	*Hellyethira* sp.	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Orthotrichia sp.	2	3	0	0	2	2	1	2	0	0	0	0	1	0	0	0	0	0	0	2	0	0	0	0	0	0
	Leptoceridae	Leptoceridae sp.	0	2	1	2	0	2	0	2	0	0	0	0	0	0	2	0	1	0	2	2	1	2	3	2	0	0
		Leptocerus atsou	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Oecetis sp.	2	2	0	0	3	3	2	3	0	0	0	0	2	0	2	0	2	0	0	2	1	2	2	2	2	2
		Triaenodes sp.	0	3	2	0	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	2	0	0	2	1	0	0
		Triplectides australicus	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Leptoceridae	*Triplectides ciuskus seductus*	0	2	1	2	3	2	1	2	0	1	0	0	0	2	1	1	0	1	2	2	2	2	2	2	3	2
		Triplectides sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
	Philopotamidae	*Chimarra uranka*	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Philopotamidae sp.	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Polycentropodidae	*Paranyctiophylax* sp. AV5	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ephemeroptera	**Baetidae**	Baetidae spp. (imm/dam.)	3	3	2	3	2	3	3	3	0	0	0	0	2	0	3	2	2	0	1	3	3	3	2	3	2	0
		Cloeon fluviatile	0	0	0	0	2	0	0	3	0	0	0	1	0	0	2	2	0	0	0	0	2	2	0	2	0	0
		Cloeon sp. Red Stripe	0	0	0	2	0	0	2	0	0	0	0	0	2	0	0	0	0	0	0	0	2	0	0	0	2	0
		Pseudocloeon hypodelum	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Pseudocloeon plectile	3	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
	Caenidae	Caenidae spp. (imm/dam.)	3	4	3	2	3	2	2	4	0	0	0	0	2	1	2	2	2	0	1	3	2	3	3	3	2	2
		Tasmanocoenis sp. M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	2	0	0	0
		Tasmanocoenis sp. P/arcuata	2	1	2	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	1
		Wundacaenis dostini	0	0	0	2	3	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Leptophlebiidae	Leptophlebiidae sp.	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Manggabora wapitja	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Thraulus sp.	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 7 continued.

Phylum/Class/Order	Family	Lowest taxon	Riffle Sites			Reference Sites					Keep River Pools																	
			SR4 - Riffle	K3 Riffle	K4 Riffle	KR1	SR4	DR1	KE1	KR2	K1-1	K1-2	K1-3	K1-4	K1-5	K2-1	K2-2	K2-3	K2-4	K2-5	K3-1	K3-2	K3-3	K3-4	K3-5	K4-1	K4-2	K4-3
Hemiptera	**Belostomatidae**	Belostomatidae spp. (imm/dam.)	0	0	2	2	0	0	2	0	0	0	0	0	0	0	1	0	0	1	2	2	1	0	0	1	0	1
		Diplonychus spp.	0	0	2	2	0	0	2	1	0	2	0	0	0	0	0	0	0	2	0	2	0	0	1	0	2	0
Corixoidea		Corixoidea spp. (imm/dam.)	0	0	0	3	1	1	0	0	0	0	0	0	3	1	0	0	1	0	0	2	0	0	2	2	0	2
	Micronectidae	*Austronecta bartzarum*	0	0	0	1	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	3	0	0
		Austronecta micra	0	1	0	0	0	2	0	3	0	0	0	0	0	0	1	2	2	0	2	3	3	3	3	3	0	2
		Micronecta adelaidae	0	0	0	2	0	1	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
		Micronecta annae	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Micronecta gracilis	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Micronecta ludibunda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
		Micronecta paragoga	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
		Micronecta sp.	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Micronecta sp. (F)	0	0	0	0	0	0	1	0	0	2	0	0	3	0	0	0	1	0	0	0	0	0	0	0	2	0
	Naucoridae	*Naucoris subopacus*	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Nepidae	Nepidae sp.	0	0	0	0	0	2	2	0	0	0	0	0	0	0	2	2	0	2	1	0	0	0	0	0	0	0
	Hebridae	*Laccotrephes tristis*	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2
		Ranatra diminuta	0	0	0	1	0	0	0	2	0	2	0	0	2	0	2	1	0	1	1	0	0	0	2	0	2	1
	Notonectidae	*Enithares atra*	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Enithares loria	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
		Notonectidae sp.	0	0	0	2	3	0	2	3	0	0	0	0	0	2	2	2	2	0	2	2	2	2	3	2	0	0
		Nychia sappho	0	0	0	3	3	0	0	3	0	0	0	0	0	0	2	1	0	0	2	2	0	2	2	2	1	0
		Nychia sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
	Pleidae	*Paraplea* spp.	0	1	2	3	2	3	3	3	1	2	0	0	3	2	3	3	3	3	4	3	3	3	3	4	3	3
	Veliidae	*Nesidovelia herberti*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
		Nesidovelia peramoena	0	0	0	0	0	0	2	0	0	0	0	0	0	1	2	0	0	0	0	0	0	1	0	0	0	0
		Petrovelia katherinae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
		Veliidae sp.	0	0	1	0	2	0	2	0	0	0	0	0	0	1	0	0	0	1	0	2	2	2	0	0	1	2
		Veliidae sp. (F)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Neuroptera	**Sisyridae**	Sisyridae spp. (L)	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coleoptera	**Dytiscidae**	*Clypeodytes feryi*	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2
		Copelatus nigrolineatus	0	3	2	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
		Cybister tripunctatus	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Hydaticus vittatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
		Hydroglyphus basalis	0	2	3	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	2	0	2	0	2	2	2	0
		Hydroglyphus grammopterus	0	3	3	3	3	2	2	0	0	0	0	0	0	2	0	0	0	0	2	0	1	0	0	0	0	0
		Hydroglyphus orthogrammus	0	3	2	3	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
		Hydrovatus ovalis	0	0	0	0	0	2	0	2	0	0	0	1	0	0	0	0	0	0	2	0	1	0	0	2	0	3
		Hyphydrus decemmaculatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
		Hyphydrus lyratus	1	0	2	2	3	0	3	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0	0
		Laccophilus cingulatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
		Laccophilus clarki	0	0	0	3	3	2	3	3	0	0	0	0	0	2	2	2	2	2	2	2	2	0	1	3	3	3
		Laccophilus seminiger	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2
		Laccophilus sharpi	0	0	0	2	0	1	0	0	0	0	1	1	1	2	0	0	0	1	0	0	0	0	0	2	4	3
		Laccophilus sp. (L)	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Laccophilus walkeri	0	0	0	0	0	2	0	3	0	0	0	0	0	0	1	0	1	0	2	0	0	1	0	0	0	0
		Limbodessus compactus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
		Megaporus ruficeps	0	0	0	0	2	0	2	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	0	2	3	2
		Rhantaticus congestus	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
		Tiporus undecimmaculatus	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Elmidae	*Austrolimnius* sp. (L)	3	3	2	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Austrolimnius sp.	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Georissidae	Georissus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
	Gyrinidae	*Dineutus australis*	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Macrogyrus paradoxus	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 7 continued.

Phylum/Class/Order	Family	Lowest taxon	Riffle Sites			Reference Sites					Keep River Pools																	
			SR4 - Riffle	K3 Riffle	K4 Riffle	KR1	SR4	DR1	KE1	KR2	K1-1	K1-2	K1-3	K1-4	K1-5	K2-1	K2-2	K2-3	K2-4	K2-5	K3-1	K3-2	K3-3	K3-4	K3-5	K4-1	K4-2	K4-3
	Hydraenidae	*Hydraena* sp.	0	3	3	2	2	3	1	2	0	0	0	0	0	1	2	2	2	0	2	3	3	3	3	2	2	3
		Ochthebius sp.	0	2	1	0	0	0	0	2	0	0	0	0	0	1	2	1	0	0	0	0	2	2	1	0	0	0
	Hydrochidae	*Hydrochus* sp.	1	2	3	3	3	3	0	3	0	0	1	0	0	3	3	3	3	3	3	3	3	3	3	2	3	3
		Hydrochus sp. (L)	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Hydrophilidae	*Amphiops australicus*	0	0	0	0	0	0	2	2	0	0	0	0	0	2	0	0	1	0	0	1	0	0	0	0	0	0
		Amphiops sp. (imm/dam)	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Anacaena sp. WRM01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
		Berosus pulchellus	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
		Chaetarthria nigerrima (L)	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Enochrus deserticola	0	3	3	1	0	0	2	0	2	0	1	1	1	2	1	0	0	0	0	0	2	0	0	2	3	2
		Helochares clypeatus	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Helochares sp. (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0
		Helochares tatei	0	0	2	0	0	0	0	0	0	2	0	0	0	1	1	0	2	1	2	0	1	0	1	0	0	0
		Helochares tristis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
		Laccobius billi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
		Paracymus pygmaeus	1	3	3	2	3	2	0	2	0	0	0	0	0	3	3	2	3	2	3	1	3	3	2	0	2	2
		Paracymus sp. (imm/dam)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
		Paracymus sp. (L)	0	0	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Regimbartia attenuata	0	0	2	2	0	1	3	1	0	1	2	0	2	2	2	2	3	2	2	0	2	2	2	1	3	2
	Limnichidae	Limnichidae sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	1	0	0	2	2	2	0	0	0	2
		Limnichidae sp. (L)	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Noteridae	*Hydrocanthus micans*	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2	0	0
		Neohydrocoptus subfasciatus	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		Notomicrus tenellus	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
	Scirtidae	Scirtidae spp. (L)	1	0	0	2	2	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Spercheidae	Spercheus sp. (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
	Staphylinidae	Staphylinidae sp.	0	2	0	0	0	0	0	2	0	0	0	0	0	3	1	3	2	2	2	0	0	0	0	0	0	1
Lepidoptera	**Crambidae**	Acentropinae spp. (imm/dam.)	3	3	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Eoophyla repetitalis	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Eoophyla sp.	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Margarosticha sp. 3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Tetrernia sp. 1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Taxa richness	54	52	58	63	58	59	55	60	16	24	18	14	37	43	52	33	46	32	45	51	50	42	50	59	56	56

Appendix 8 Fish Species 2020

	Keep River Pools																		Reference				
Row Labels	K1-1	K1-2	K1-3	K1-4	K1-5	K2-1	K2-2	K2-3	K2-4	K2-5	K3-1	K3-2	K3-3	K3-4	K3-5	K4-1	K4-2	K4-3	DR1	KE1	KR2	SR4	Grand Total
Amniataba percoides					1	1							1			1						2	6
Anodontiglanis dahli																						2	2
Ariidae sp.	2																						2
Arrhamphus sclerolepis		1		1	3																		5
Carcharhinus leucas					1																		1
Eleutheronema tetradactylum	2																						2
Ellochelon vaigiensis			3	2	8	3		3	15	17	2	1											54
Lates calcarifer	2						3			1	2	1	2		2		1						14
Leiognathus equula		1																					1
Leiopotherapon unicolor																1							1
Marilyna meraukensis				1					1			1											3
Megalops cyprinoides							2	2									2			2			8
Mugil cephalus	7	1																					8
Nematalosa erebi	18	63	10	45	13	22	8	24	19	11	22	2	10	6	19	12	32	4	6		21	5	372
Neoarius graeffei	1		3		3	1	6	7	7	1	3	7	7	7	1	1	6	7	1	9	7	3	88
Neoarius midgleyi																			3				3
Neosilurus ater							1									1						1	3
Nibea squamosa													1										1
Pristis pristis		2													1		1				1		5
Parambassis gulliveri															1				6				7
Planiliza ordensis	4	3	1	1		2	6	2	3	1	5		2	3	10	1	1		3	2	1		51
Strongylura krefftii			1								1		2										4
Syncomistes bonapartensis																			1	1		1	3
Thryssa sp.														3	1								4
Toxotes chatareus										1			1				1	1	2	3			9
Grand Total	36	71	18	50	29	29	26	38	45	32	35	12	26	19	35	17	44	12	22	17	30	14	657

Appendix 9 Fish baseline species 2011-2013

Fish species abundance recorded from each site, all baseline years (2011, 2012, 2013). Note, data include visual records.

2011	Keep River Pools																		Reference					
Scientific Name	K1-1	K1-2	K1-3	K1-4	K1-5	K2-1	K2-2	K2-3	K2-4	K2-5	K3-1	K3-2	K3-3	K3-4	K3-5	K4-1	K4-2	K4-3	DR1	KE1	KR1	KR2	SR4	Grand Total
Ambassis interruptus							1								1									2
Amniataba percoides																			1		8	1	27	37
Anodontiglanis dahli																				2			2	4
Arrhamphus sclerolepis		5					1																	6
Carcharhinus leucas	1	9	3											2										15
Elops australia	1		1		1		1							1										5
Glossamia aprion				1																1				2
Hephaestus jenkinsi																							4	4
Hypseleotris compressa														1										1
Kurtus gulliveri		1																						1
Lates calcarifer		1		2	1	2					2	1		1	3	1				3		18		35
Leiognathus equulus	5	3	3		3	5	1			2	2				1									25
Planiliza ordensis	15	11	8	10	2	4	5	6	4	3	8	7	8	2	9	11	9	4	6	7		14		153
Ellochelon vaigiensis	6		1								3	1			2									13
Lutjanus argentimaculatus				1																				1
Megalops cyprinoides																2			2	1	2			7
Mogurnda mogurnda																1								1
Nematalosa erebi	24	11	2	13	22	14	17	4	9	24	13	10	20	4	14	18	1		15	10	4	1	22	272
Neoarius graeffei	1	1	2	2	3	2		2	5	4	4	14	12	5	1	2	3	16	1	10	3	51	10	154
Neoarius midgleyi																			16					16
Neosilurus ater																4	3	1	2					10
Parambassis gulliveri																1			7					8
Polydactylus macrochir	1							1																2
Strongylura kreffti						2								1					1			1		5
Syncomistes bonapartensis									1										3				1	5
Syncomistes trigonicus																			1					1
Thryssa Kammalensis							7	3	2	2		1			3									18
Toxotes chatareus	1	1	1		1	2				2	3	1	1	1	1	1				1		1		18
Grand Total	55	43	21	29	33	31	33	16	21	37	35	35	41	18	35	41	16	21	55	35	17	87	66	821

2012	Keep River Pools																		Reference					
	K1-1	K1-2	K1-3	K1-4	K1-5	K2-1	K2-2	K2-3	K2-4	K2-5	K3-1	K3-2	K3-3	K3-4	K3-5	K4-1	K4-2	K4-3	DR1	KE1	KR1	KR2	SR4	Grand Total
Amniataba percoides																					1	1		2
Ambassis sp.											1													1
Thryssa sp.	11							1																12
Carcharhinus leucas												1												1
Ellochelon vaigiensis	3	2			1							2			1									9
Arrhamphus sclerolepis	8	1	1																					10
Hephaestus jenkinsi									1															1
Kurtus gulliveri							1			1														2
Leiopotherapon unicolor																				1				1
Lates Calcarifer	3										5	1	1			1	4	7		3		2		27
Megalops cyprinoides									1				1				1							3
Mugil cephalus	3				3																			6
Nematolosa vlaminghi		4																						4
Nematolosa erebi	55	15	34	26	16	17	56	16	9	18	10		6	9	15		5	3	17	9	17	9	42	404
Neoarius graeffei		3	3	1		4	6	2	2	4	14	5	1		3	5	1	2	5	2		9	1	73
Neoarius midgleyi																			2					2
Neosilurus ater																3	2	1						6
Nibea squamosa										2	1													3
Planiliza ordensis	10		9	4	4	4	9	1	3	2	1	9	4	2	1		1	4	4	10		2	1	85
Polydactylus macrochir	1																							1
Leiognathus equulus					2		2	1	3	1		1	1											11
Scomberoides commersonnianus	1																							1
Acanthopagrus palmaris			1																					1
Strongylura krefftii						1				1				1			1							4
Marilyna meraukensis									1															1
Toxotes chatareus	1		1		2		1			2							1	1				4	1	14
Unknown catfish	1																							1
Grand Total	97	25	49	31	28	26	75	21	20	31	32	19	14	12	20	9	16	18	28	25	18	27	45	686

2013	Keep River Pools																		Reference					
Species	K1-1	K1-2	K1-3	K1-4	K1-5	K2-1	K2-2	K2-3	K2-4	K2-5	K3-1	K3-2	K3-3	K3-4	K3-5	K4-1	K4-2	K4-3	DR1	KE1	KR1	KR2	SR4	Grand Total
Amniataba percoides																			2					2
Anodontiglanis dahli																							2	2
Arrhamphus sclerolepis								7		3														10
Carcharhinus leucas				2							1		1											4
Eleutheronema tetradactylum	6				8										1									15
Ellochelon vaigiensis		3				1			1	4														9
Gerres filamentosus																							1	1
Lates calcarifer	7	2			2				1	3										1				16
Leiognathus equulus											1													1
Marilyna meraukensis												1		1										2
Megalops cyprinoides	2																			3				5
Nematalosa erebi	70	47	6	19	13	15	38	36	9	10	14	24	4	7	13	18	16	8	26		5	16	1	415
Neoarius graeffei	3	3		2						4	2	4	8	3		2	3	2		1	1	4	1	43
Neoarius midglei	1												1						2					4
Neosilurus ater																	1	1		1				3
Parambassis gulliveri							1									1								2
Planiliza ordensis		8	2	2	2	4	1		2	4	2			1				4	13	24		2		71
Pristis clavata						1																		1
Strongylura krefftii		1																					1	2
Syncomistes bonapartensis																					1			1
Thryssa kammalensis							1						1	1										3
Toxotes chatareus				1		2	2			1					1	2						3		12
Grand Total	89	64	8	26	25	23	43	43	13	29	20	29	15	13	15	23	20	15	43	30	7	25	6	624