ORIA STAGE II EXPANSION
KEEP RIVER

BASELINE AQUATIC FAUNA & TARGETED SAWFISH SURVEYS 2013

8 April 2014

ORIA Stage II Expansion – Keep River

Baseline Aquatic Fauna & Targeted Sawfish Surveys September/October 2013

Prepared for:

LandCorp

Wesfarmers House, 40 The Esplanade, Perth WA 6000
Locked bag 5, Perth Business Centre, Perth WA 6849
Phone: (61 8) 9482 7499, Fax: (61 8) 9481 0861

by:

Wetland Research & Management

16 Claude Street, Burswood, WA 6100
Ph +61 8 9361 4325
e-mail: Andrew.Storey@WetlandsResearch.com.au

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Frontispiece: (top to bottom) juvenile dwarf sawfish (*Pristis clavata*) at EST03; freshwater whipray (*Himantura dalyensis*) at SR4; saltwater crocodile (*Crocodylus porosus*) at K1-2 (photos by WRM ©).

Study Team

WRM
Project Management: Andrew Storey
Fieldwork: Adam Harman & Alex Riemer
Macroinvertebrate identification: Kim Nguyen, Bonita Clark, Simon Ward
Report: Jess Delaney & Sue Davies
Internal review: Andrew Storey

External Experts
Chironomidae taxonomy: Dr Don Edward (The University of Western Australia)

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1 INTRODUCTION

1.1 Background

The Western Australian Government is developing additional land for irrigated agriculture adjacent to the existing Ord River Irrigation Area (Ord Stage 1), in the Kimberley region of Western Australia. The expansion, referred to as greater Ord Stage 2 has identified 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. The first stage of this expansion is of the Weaber and Knox Creek Plains, and this will increase the current area under irrigation from 14,000 ha to potentially 30, 500 ha. Current water consumption by Stage 1 is approximately 300 GL/a, with demand for M2 fully developed being approx. 610 GL/a (DoW 2013). The sustainable diversion limit for future development of the Ord has been determined as 865 GL/a, with a 90% annual reliability (DoW 2006).

The Ord Irrigation Expansion Project was approved by the Western Australian Government in 2008. 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. Initially, development is targeting the Weaber Plains area, located approximately 30 km north-east of Kununurra. Approximately 7,500 ha are under development, 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 requires 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 these pools, 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 specifies that a baseline survey program is 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

[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.

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,
- 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.

LandCorp commissioned WRM to undertake the baseline surveys for the Aquatic Fauna Management Plan. The aim is to survey macroinvertebrate and fish assemblages to establish ecological condition as well as occurrence of listed species, including targeted sampling for sawfish and *Glyphis* sharks. Baseline surveys were completed in September/October 2011 (WRM 2013a) and September/October 2012 (WRM 2013b). The current study forms the third and final round of annual baseline data collection for the Keep River, under the Aquatic Fauna Management Plan.

Data from the baseline macroinvertebrate surveys are also used to satisfy Condition 11F of the Storm Water and Groundwater Discharge Management Plan (SEWPAC 2011), which requires development of AusRivAS (Australian River Assessment System) trigger levels for aquatic macroinvertebrates.

In addition, the Department of Agriculture and Food Western Australia (DAFWA) have been commissioned to undertake regular monitoring of groundwater and surface water flows and quality (*i.e.* DAFWA 2011), which will be used, in conjunction with water and sediment quality data collected by WRM to develop surface water trigger values for assessing effects of any discharge to the Keep River.

1.2 Scope of Work

The scope of work for the 2013 surveys was to repeat the sampling programs conducted for the 2011 and 2012 surveys, in order to provide sufficient baseline data 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 - 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 and 2012 baseline surveys (WRM 2013a,b) but, for completeness, are reproduced in the following sections for each program.

Field sampling was undertaken under appropriate licences and permits as follows:

- Western Australian Department of Environment and Conservation Regulation 17 Permit SF009231.
- Western Australian Department of Fisheries Exemption for Scientific Purposes EXEM1919.
- Northern Territory Department of Parks and Wildlife Permit to Interfere with Protected Wildlife Permit No. 44455.
- Northern Territory Department of Fisheries Special Permit No. S17/3275.

2 SAMPLING SITES

A total of 26 sites were sampled between 27th September and 10th October 2013 (Table 1 & Figures 1 - 2). 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	15º 19.583'	129º 07.087'	PE	Y	Y	
EST02	Keep River estuary mid-way between EST01 and EST03	EST02	15º 15.483'	129º 07.010'	PE	Y	Y	
EST03	Keep River estuary – mid estuary near old NRETAS gauging station	EST03	15º 13.792'	129º 07.314'	PE	Y	Y	
K1	Lower reach tidal pool	K1-1	15º 19.540'	129º 05.301'	PE	Y		Y
		K1-2	15º 20.038'	129º 05.764'	PE	Y		Y
		K1-3	15º 20.691'	129º 04.949'	PE	Y	Y	Y
		K1-4	15º 21.129'	129º 05.067'	PE	Y		Y
		K1-5	15º 21.659'	129º 05.025'	PE	Y		Y
K2	Middle reach brackish pool	K2-1	15º 22.122'	129º 05.114'	PE	Y		Y
		K2-2	15º 22.123'	129º 05.175'	PE	Y		Y
		K2-3	15º 22.358'	129º 05.186'	PE	Y	Y	Y
		K2-4	15º 22.531'	129º 05.120'	PE	Y		Y
		K2-5	15º 22.599'	129º 05.034'	PE	Y		Y
K3	Upper reach freshwater-brackish pool	K3-1	15º 22.865'	129º 04.782'	PE	Y		Y
		K3-2	15º 23.204'	129º 04.759'	PE	Y		Y
		K3-3	15º 23.503'	129º 04.684'	PE	Y	Y	Y
		K3-4	15º 23.767'	129º 04.669'	PE	Y		Y
		K3-5	15º 23.864'	129º 04.547'	PE	Y		Y
K4	Keep River freshwater pool upstream of Legune Road Crossing	K4-1	15º 24.284'	129º 03.854'	PE	Y		Y
		K4-2	15º 24.505'	129º 03.872'	PE	Y	Y	Y
		K4-3	15º 24.855'	129º 04.187'	PE	Y		Y
KE1	Milligan's Lagoon, Keep R.	KE1	15º 37.069'	129º 00.388'	R			Y
KR1	Alligator Hole, Keep R.	KR1	15º 41.333'	129º 02.217'	R			Y
KR2	Policeman's Waterhole, Keep R.	KR2	15º 44.450'	129º 04.400'	R			Y
SR4	Augustus Hole, Sandy Creek	SR4	15º 31.517'	129º 19.200'	R			Y
DR1	Dunham River at Sugarloaf Hill	DR1	16º 02.786'	128º 26.605'	R			Y

Figure 1. Location of sediment sampling and targeted sawfish and shark survey sites in the Keep River (pools and estuary sites).

Figure 2. 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 ANZECC/ARMCANZ (2000) 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 (2013a,b) 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 1 & 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 replicates 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 at each replicate location within river sites (Table 2). Individual samples were placed in separate labelled polyethylene bags and transported to the ChemCentre, Bentley, Western Australia for analyses of ionic composition, nutrients and metals.

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*			*Total # samples*
			LB	*M*	*RB*	
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**

Concentrations were compared against the ANZECC/ARMCANZ (2000) interim sediment quality guidelines (ISQGs; see Appendix 2A). These guidelines were developed from United States effects databases (Long *et al.* 1995) and are termed 'interim' because an understanding of the biological impacts from sediment contamination is still being developed (Batley & Simpson 2008). The guidelines include ISQG-Low and ISQG-High values, which represent the 10^{th} percentile (10%ile) and 50^{th} percentile (50%ile) values for chemical concentrations associated with acute toxicity effects. The ISQG-Low value is the default TV below which '*the frequency of adverse biological effects is expected to be very low*', and if exceeded, should trigger further study. The ISQG-High value corresponds to the median effect concentration as detailed in Long *et al.* (1995), and indicates the concentration above which '*adverse biological effects are expected to occur*'. Reference was also made to the handbook for sediment quality assessment (Simpson *et al.* 2005) in the design of sediment sampling and interpretation of results.

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 v19) 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). For each analyte, the average of the three samples from each replicate within a site (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. 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.

Multivariate

Multivariate analyses were performed using PRIMER v6 (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). 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

3.3.1 Sediment quality – univariate analyses

Summary statistics for baseline sediment data collected from the Keep River and Estuary are provided in Appendix 2B; 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 sediment parameters is given below.

Total organic carbon (TOC)

Spatial variation in total organic carbon (TOC) content of sediments is illustrated in Figure 3. Mean TOC ranged from 0.35% (median 0.4%) at EST02, to 0.7% (median 0.6%) at K4, with values for individual replicates ranging from <0.05% at EST03 in2013, to 1.55% at K3-4 in 2012. There were no significant differences in total organic carbon amongst years (2-way ANOVA df = 2, F = 1.745, p = 0.186). However, there were significant differences amongst sites (2-way ANOVA; df = 4, F = 3.569, p = 0.013), the greatest being between estuary sites (mean 0.4%, median 0.4%) and site K4.

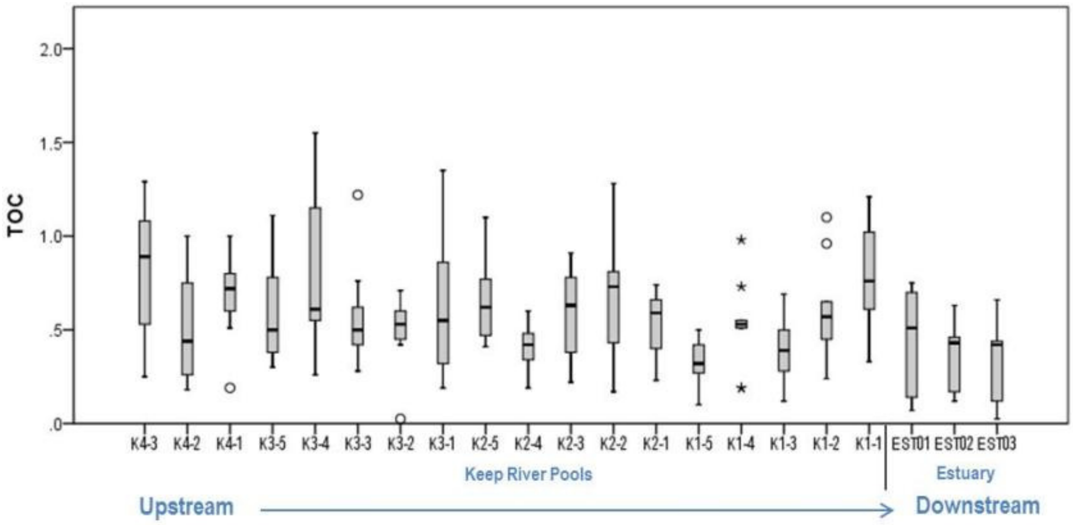


Figure 3. Box plot summarising baseline data (2011-2013) on total organic carbon content (%TOC) within sediments of the Keep River and Keep River Estuary. Plots show minimum, 20%ile, median (50%ile), 80%ile, maximum, outlier (O = greater than 1.5x the upper or lower percentile) and extreme outlier values (★ = greater than 3x the upper or lower percentile) for each replicate site.

Major ions

In both the Keep River and Estuary, calcium (Ca) was the dominant cation, with magnesium (Mg) subdominant, and chloride (Cl) the dominant anion, with sulphate (SO_4) subdominant (Appendix 2B). Concentrations of all major ions differed significantly amongst sites (2-way ANOVA, Appendix 2C Table 2C-1). Ionic composition of sediments reflected the salinity of the overlying water, with relatively higher concentrations of Cl and sodium (Na) at estuary sites and lower Keep River pools (Figure 4) reflecting tidal influence. Longitudinal patterns were evident with lowest ionic concentrations recorded from the most upstream Keep River pool K4 (Figure 4 & Appendix 2B). Within-site variability was high, particularly at the upper Keep River sites. For example Ca at K1-2 in 2012, ranged from 1,500 mg/kg dry weight in left bank sediments to 15,000 mg/kg dry weight in centre channel sediments. There were also significant temporal differences in concentration of Na, Cl, Mg and SO_4 (Appendix 2C Table 2C-1), all of which were higher in 2013 relative to prior years, and K which was relatively higher in 2011, than 2012 or 2013.

Nutrients (N & P)

Spatial variation in nutrient content of sediments is illustrated in Figure 5. Nitrogen nutrients were highest at K4, with a maximum total nitrogen (N-total) concentration of 0.103% (1,030mg/kg dry weight) at K4-3 in 2012, and a maximum ammonium-nitrogen (NH_4-N) concentration of 54 mg/kg dry weight at K4-1 in 2013. There were longitudinal gradients in N-total and NH_4-N, with concentrations broadly decreasing with increasing distance downstream from K4 (Figure 5), and significantly lower concentrations in estuary sediments than in river sediments (Appendix 2C Table 2C-2). Mean N-total concentrations ranged from 524 mg/kg (median 530 mg/kg) at K4 to 0.01 mg/kg (median 0.01 mg/kg) at EST01 (Appendix 2B). Mean NH_4-N concentrations ranged from 16 mg/kg (median 9 mg/kg) at K4 to <1 mg/kg at EST01 and EST02. Between-year differences in N-total and NH_4-N were not statistically significant (Appendix 2C Table 2C-2). Nitrate-nitrogen (NO_3-N) concentrations were typically low (≤1 mg/kg dry weight) at all sites (Figure 5 & Appendix 2B).

In contrast to nitrogen nutrients, total phosphorus (P-total) in sediments was significantly higher in the estuary than any of the river sites (Appendix 2C Table 2C-2). Site means ranged from 115 mg/kg (median 120 mg/kg) at K2 to 233 mg/kg (median 210 mg/kg) at EST03 (Appendix 2B). Again, within-site variation in P-total was high, ranging from 39 mg/kg at K1-4 in 2012, to 320 mg/kg at EST03 in 2012 (Figure 5). There were significant differences in P-total concentrations amongst years, with the greatest difference being between 2011 and 2012 (Appendix 2C Table 2C-2).

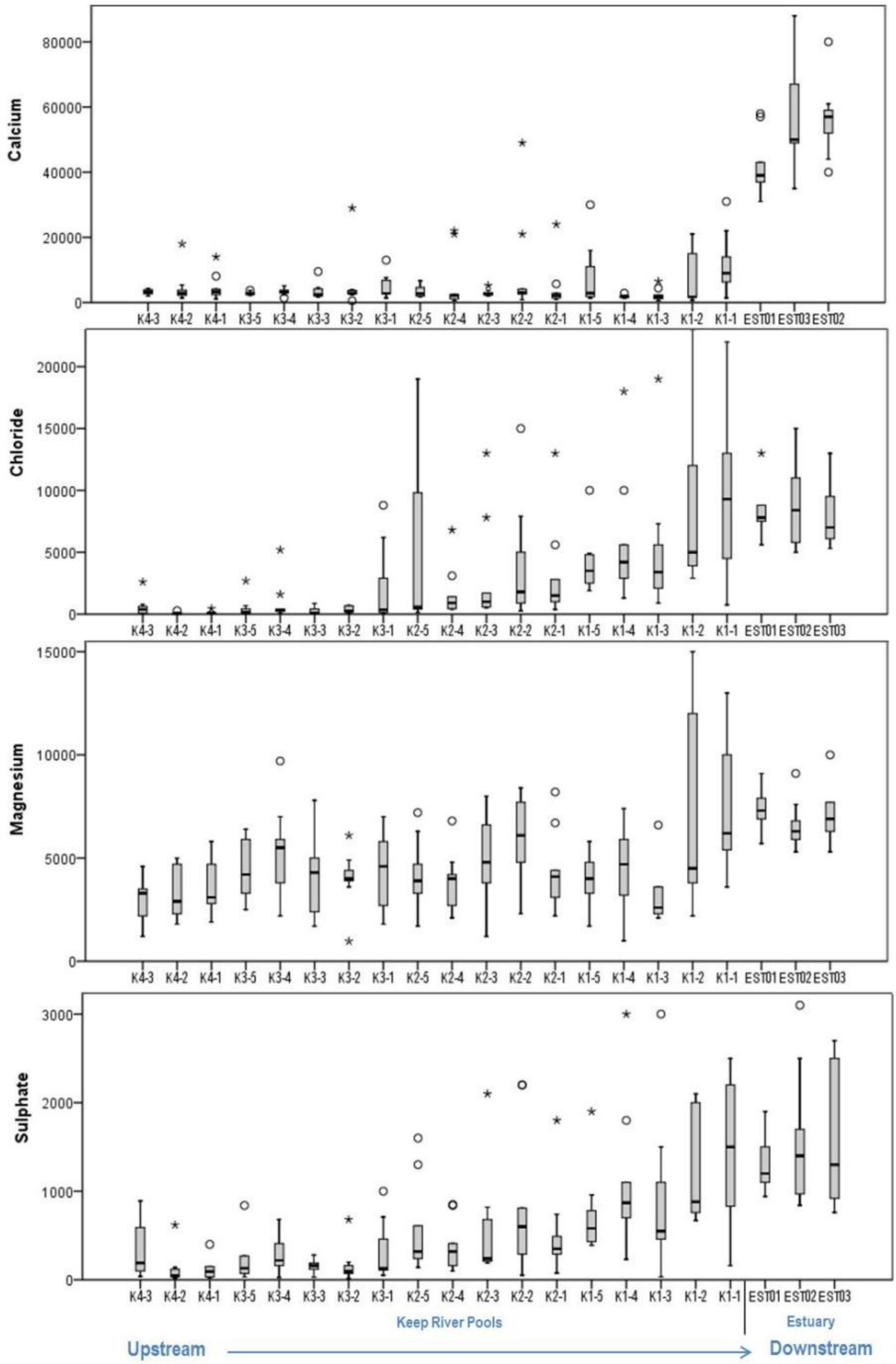


Figure 4. Box plots summarising baseline data (2011-2013) on concentrations of dominant cations and anions (mg/kg dry weight) within sediments of the Keep River and Keep River Estuary. Plots show minimum, 20%ile, median (50%ile), 80%ile, maximum, outlier (○ = greater than 1.5x the upper or lower percentile) and extreme outlier values (★ = greater than 3x the upper or lower percentile) for each replicate site.

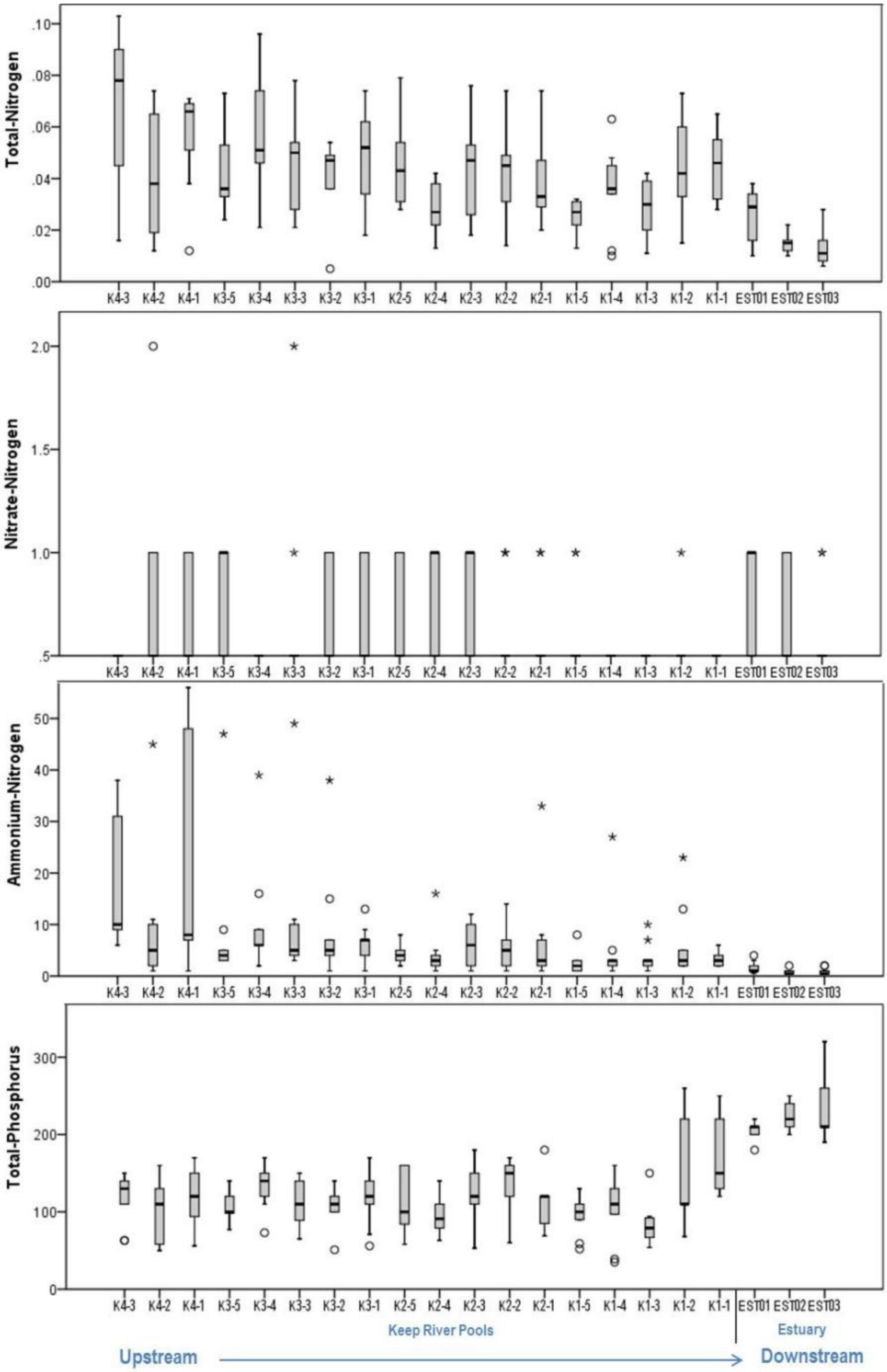


Figure 5. Box plots summarising baseline data (2011-2013) on nutrient concentrations (mg/kg dry weight) within sediments of the Keep River and Keep River Estuary. Plots show minimum, 20%ile, median (50%ile), 80%ile, maximum, outlier (O = greater than 1.5x the upper or lower percentile) and extreme outlier values (★ = greater than 3x the upper or lower percentile) for each replicate site.

Metals

Sediment concentrations of most metals were well below the ISQG values (Appendix 2B). The exceptions were mercury (Hg) and nickel (Ni), which exceeded ISQG values at some sites on some occasions (Figure 6 & Appendix 2B).

Hg exceeded the ISQG-Low value (0.15 mg/kg dry weight) in at least one sample from each site (*i.e.* left, centre or right bank), and exceeded the high ISQG-High value (1.0 mg/kg dry weight) at K1-4 (2011, 2012), K1-5 (2011), K2-1 (2012), K2-3 (2011), K3-1 (2012), K4-1 (2012) and K4-3 (2011) (Figure 6). Most exceedances of the ISQG-High for Hg (1.0 mg/kg dry weight) were from sediment samples collected in the centre of the river. It is not known to what extent Hg in these sediments is bioavailable or potentially bioavailable. The toxicity of Hg to aquatic organisms is well documented in published literature and it is known to readily bioaccumulate in aquatic plants, invertebrates and fish (Phillips & Rainbow 1994, Nice 2009). Lyle (1984) found that numerous species of sharks accumulated relatively high concentrations of Hg in coastal waters of the Northern Territory. Maximum observed concentrations exceeded 1.5 mg/kg in all but six species (Lyle 1984). Concentrations can be biomagnified in higher trophic level organisms (Bowles *et al*. 2001). Exposure pathways can come from the sediments themselves through direct contact or ingestion, and/or from surface or pore water (Phillips & Rainbow 1994, Bowles *et al.* 2001). Hg concentrations in sediments such as those recorded in the current study have been reported to result in toxic effects elsewhere. For example, a sediment concentration of 0.18 mg/kg was reported to result in a 45% reduction in larval oyster survival (PTI 1988) and a concentration of 0.46 mg/kg resulted in behavioural changes including burrowing avoidance in a species of clam (McGreer 1979). During the current study, sediment Hg levels in excess of 0.46 mg/kg were recorded from samples collected from a number of locations, including K4-2, K4-1, K3-4, K3-1, K2-5, K2-4, K2-1, K1-5, K1-4, K1-3, EST02 and EST03 (Figure 6).

Concentrations of Ni equal to or in excess of the ISQG-Low value (21 mg/kg dry weight) were recorded on eight occasions; K1-3 (2012), K2-2 (2012, 2013), K2-3 (2013), K3-1 (2013), K3-3 (2013) and K3-4 (2012, 2013) (Figure 6). 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.

Concentrations of other metals varied greatly amongst sites and years (Figure 6 & Appendix 2B). Statistically significant spatial and temporal differences in mean concentration were detected for the majority of metals (Appendix 2C Table 2C-3). Of most note were the following:

- Arsenic (As), boron (B) and titanium (Ti) were significantly higher in estuary sediments than river sediments;
- Aluminium (Al), barium (Ba), bismuth (Bi), cobalt (Co), copper (Cu), chromium (Cr), iron (Fe), gallium (Ga), Ni, lead (Pb), selenium (Se), uranium (U) and vanadium (V) were all significantly lower in estuary sediments than in river sediments;
- Boron was significantly elevated at K1 compared to all other river sites;
- There were no strong longitudinal gradients in mean concentrations of metals between K4 and estuary sites, and no consistent patterns in temporal variability.

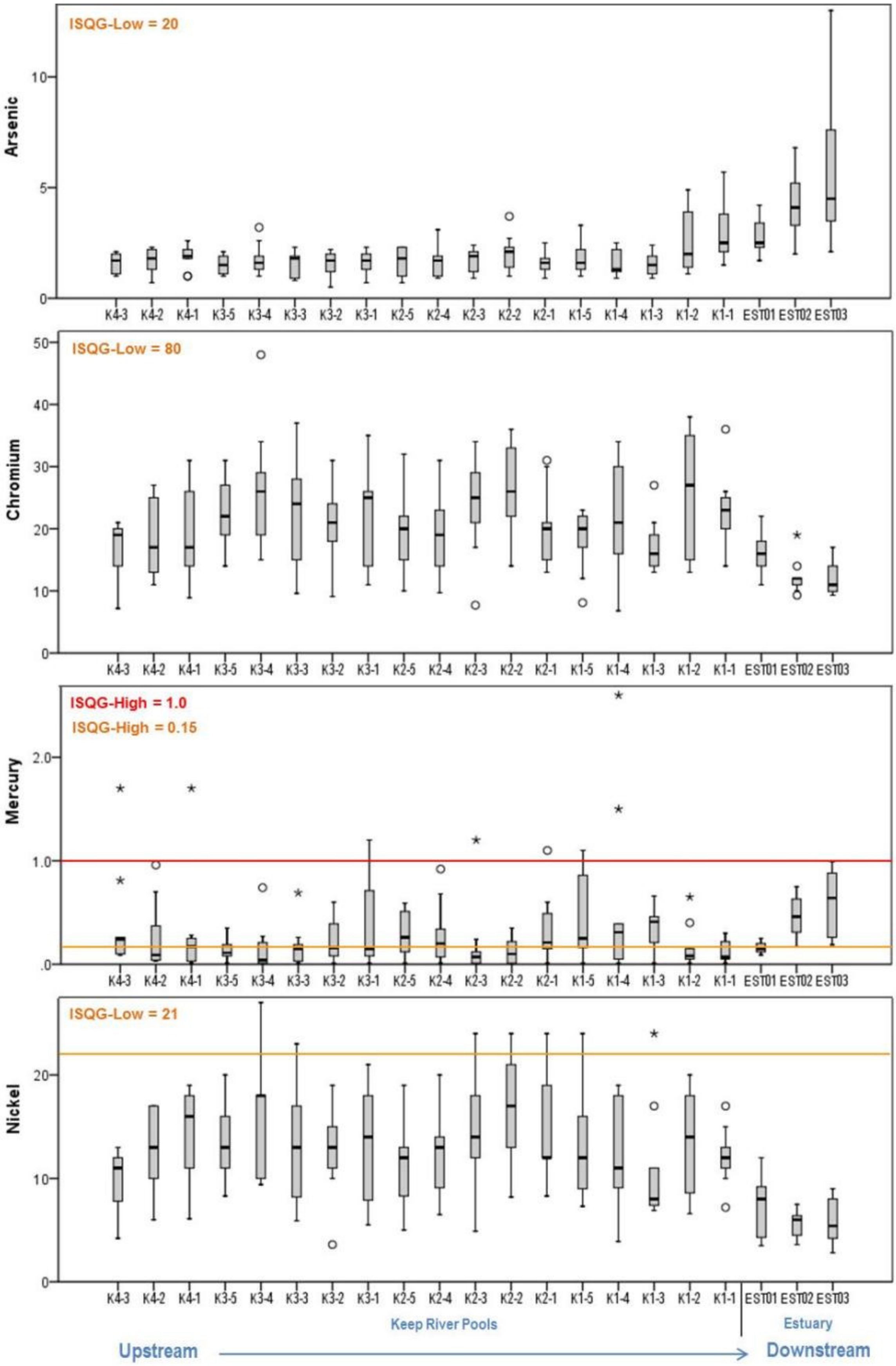


Figure 6. Box plots summarising baseline data (2011-2013) on concentrations of some selected metals (mg/kg dry weight) within sediments of the Keep River and Keep River Estuary. Plots show minimum, 20%ile, median (50%ile), 80%ile, maximum, outlier (**O** = greater than 1.5x the upper or lower percentile) and extreme outlier values (★ = greater than 3x the upper or lower percentile) for each replicate site. ANZECC/ARMCANZ ISQG-Low (—) and ISQG-High values (—) are indicated.

There were significant, though weak, positive linear relationships between TOC and concentrations of Al, Cr, Cu, Ni, Pb and Zn (Figure 7). It is generally accepted that the higher the TOC content and the finer the sediments, the greater the probability of toxicant accumulation, in comparison to areas with low TOC and coarse sediments (Ankley *et al*. 1996, Chapman *et al.* 1998, Strom *et al*. 2011).

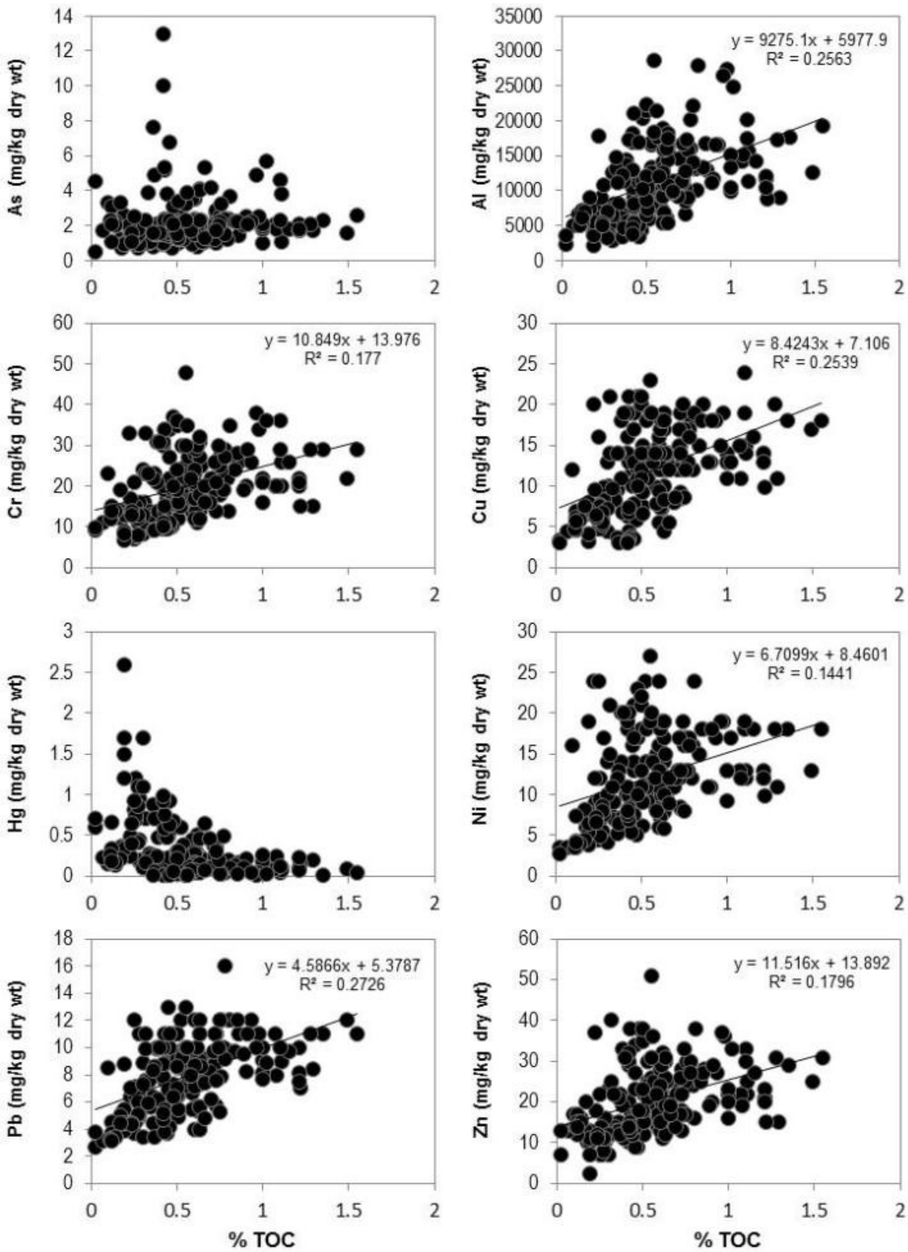


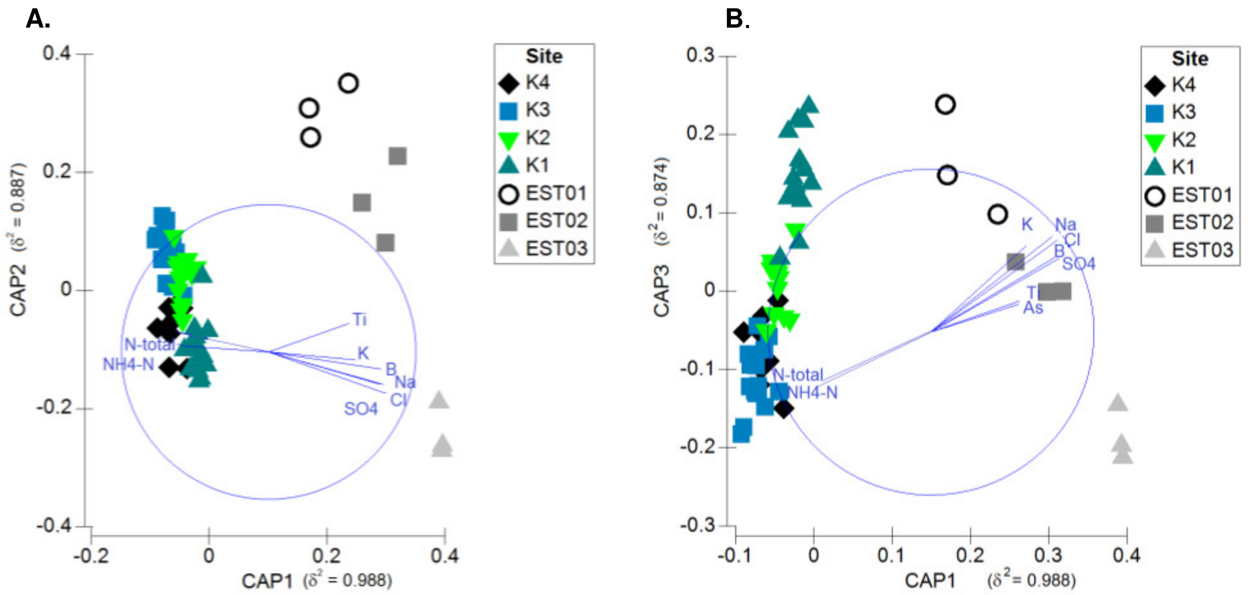
Figure 7. Relationships between concentration of selected metals (mg/kg dry weight) and total organic carbon content (%TOC) of sediments in the Keep River and Estuary. Regression equations and correlation coefficients (R^2)' are provided for significant (p <0.0001) linear relationships. Data are from samples collected during 2011, 2012 and 2013; note, left, centre and right bank replicate samples were not averaged for these analyses.

3.3.2 Multivariate patterns in the sediment data

The CAP ordination plots showed distinct clustering of sediment samples according to both site and year (Figure 8A-C). The first three canonical axes of each ordination had very high canonical correlations (δ^2 >0.85) with the suite of sediment variables, explaining 55.6% of the total variation between sites and 82.5% of the variation between years (Figure8A-C). River sites clustered together and away from estuarine sites along axis 1, while axis 2 separated the estuarine sites from each other (Figure 8A).

Within the river sites, there was a longitudinal pattern in overall sediment quality, whereby upstream sites separated from downstream sites along axis 3 (Figure 8B). Amongst years (Figure 8C), axis 1 separated the 2013 samples from prior years, while axis 2 separated the 2011 samples from the 2012 samples. Together, axes 1 and 2 accounted for 50.8% of inter-annual variation. 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 and Ti, but lower concentrations of N-total and NH_4-N in estuary sediments compared to river sediments (Figure 8A-B). The separation of years was best correlated with relatively higher concentrations of a number of metals in 2013 and 2012, compared to 2011 (Figure 8C).

Two-factor PERMANOVA indicated that the multivariate suite of sediment parameters differed significantly between most K1 to K4 pools, and that each pool differed significantly from the group of reference sites, and from the Estuary (Appendix 2C Table 2C-4). The only sites which were not significantly different from one another were K2 and K3. Differences amongst all years were also statistically significant.



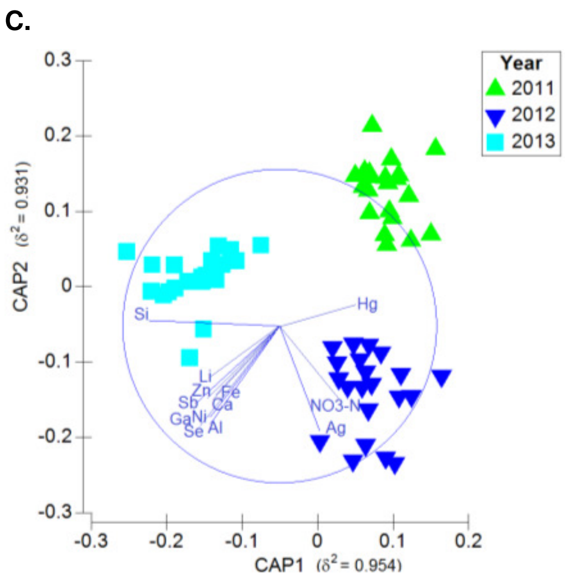


Figure 8. Results of constrained CAP analyses showing (A) axes 1 and 2, and (B) axes 1 and 3, that best discriminated sediment quality amongst sites, and (C) axes 1 and 3 that best discriminated amongst years. The squared canonical correlation values (δ^2) are provided for each axis. Correlations of sediment variables ($\log_{10}(x+1)$ transformed) with the CAP axes are shown for variables with correlation > 0.5.

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. Generally, ionic composition of the sediments reflected geographic location. Estuary and lower Keep River sediments had higher concentrations of 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 were well below ANZECC/ARMCANZ (2000) ISQG values, with the exception of Hg and Ni. Sediment Hg exceeded the ISQG-Low value (0.15 mg/kg dry weight) in at least one sample from each river and estuary site (*i.e.* left, centre or right bank replicate). The ISQG-High value for Hg (1.0 mg/kg dry weight) was also exceeded at river sites K1-4, K1-5, K2-1, K2-3, K3-1, K4-1 and K4-3. Most exceedances of the ISQG-High for Hg were from sediment samples collected in the centre of the river. Concentrations of Ni in river sediments occasionally exceeded the ISQG-Low value (12 mg/kg dry weight); K1-3, K2-2, K2-3, K3-1, K3-3 and K3-4. Elevated Hg and Ni at these sites represents current, pre-Ord Stage II development baseline. The source is unknown and may represent natural background levels associated with surrounding geology. It is important that existing levels are documented so that system specific guidelines may be developed as per ANZECC/ARMCANZ (2000) protocols. Baseline data on sediment quality have been collected for a minimum three years, which will allow future monitoring to better discriminate natural variation from any impacts due to development.

High variability in sediment quality and composition was also recorded between the left, centre and right-of-bank locations within sites. Sediments are known to be highly heterogeneous, both physically and chemically (Simpson *et al.* 2005). The distribution of contaminants is very much dependent on sediment grain size. In general, contaminants that accumulate through adsorption to particles tend to be associated with fine, high surface area particles, such as clay (Simpson *et al.* 2005). Sandy and other coarse grain sediments generally have low contaminant levels and generally pose less threat to benthic organisms.

The data gathered during the course of the current study provide a good baseline dataset against which to assess future changes, such as those that may arise from the ORIA M2 development. The three years' baseline of sediment quality data summarised here characterises spatial and temporal variability for the system, and provides data that maybe used to develop system-specific guidelines.

4 TARGETED SAWFISH AND *GLYPHIS* SHARK SURVEYS

4.1 Rationale

Aquatic fauna surveys (Larson 1999, WRC 2003a, NCTWR 2005, WRM unpub. data) and incidental sightings provide records of *Pristis* sawfish from the Keep River, in areas downstream of potential effects from the ORIA Stage II development. *Pristis* species are listed on national and international conservation lists, and as matters of national environment significance under the EPBC Act (DoE 2014a,b). Another listed species, the sawtooth 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. 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. The baseline surveys were required to document the current occurrence, distribution, population size, and population structure of these listed species in the Keep River and Estuary. Sampling was required to be conducted annually for three years prior to commencement of irrigation to establish baseline conditions.

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 1). Catch records from targeted sampling were also supplemented with incidental captures from the Aquatic Fauna Ecological Health surveys 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), and 8" mesh x 50 m long x 4 m drop (Line 30 - 100 lbs)) deployed specifically to catch listed species. The three nets were set perpendicular to the bank in the mid-reach of each pool/estuary location, and deployed for up to eight hours. Each net was checked regularly (at least every 30 mins) to remove captured listed species, as well as any by-catch. As high catch rates were encountered at EST01, fewer nets were set at this site and at EST02 and EST03 (two nets at each) to ensure no detrimental effects to sawfish associated with being caught in gill nets for any length of time. Sawfish caught in multipanel 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), rostrum length (RL), 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 frozen 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. 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).

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

4.2.3 Data analysis

Population size estimates

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

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 reported by recreational fishers.

4.3 Results and Discussion

4.3.1 Species recorded – *Pristis* sawfish & freshwater whipray *Himantura dalyensis*

Two species of *Pristis* sawfish were recorded during the course of the baseline surveys (Table 3); the largetooth sawfish *Pristis pristis* and dwarf sawfish *Pristis clavata* (Plate 2). All sawfish captured were juveniles, with a size range of 950 - 1,505 mm TL for *P. pristis*, and 840 - 2,740 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 September 2011, but was not recorded during subsequent surveys (Table 3). Eleven individuals of *P. pristis* were recorded, all from Keep River pools, whilst *P. clavata* was found only in the estuary, with a total 30 individuals recorded (Table 3). Estuary site EST01 recorded the greatest number of *Pristis* individuals (19), most of which were caught in 2012. Two *P. pristis* were also caught and tagged at Policeman's Waterhole (KR2) in the Keep River National Park (Table 4), approximately 60 km upstream from the Keep Estuary (refer Figure 1).

Only one tagged individual was recaptured in successive annual surveys during the course of the study. This was a male *P. pristis* initially caught and tagged at K2 in 2011 (tag# 302), and re-caught at the same location in 2012. It was originally recorded as a female (WRM 2013a) in 2011, as sex determination was difficult due to its young age at that time, but in 2012 it was confirmed as male. This *P. pristis* increased in size from 1,100 to 1,490 mm TL; a total of 390 mm in 12 months. Its total rostral length increased from 275 to 370 mm; a growth rate of 95 mm in 12 months.

Plate 2. Juvenile freshwater sawfish *Pristis pristis* (left) and dwarf sawfish *Pristis clavata* (right). Note, dorsal fin is positioned in front of pelvic fins in *P. pristis*, and in-line with/behind the pelvic fins in *P. clavata* (photos WRM staff, 2011 ©).

No *Glyphis* sharks were captured, however, one other species of note, the freshwater whipray *Himantura dalyensis*, was recorded in October 2013. A 300 mm (disc width) individual *H. dalyensis* was captured in a multipanel gill net at EST01, while a larger individual, with an estimated disc width of 1,200 mm, was observed in upstream freshwaters, in a riffle zone at Augustus Hole (SR4). *H. dalyensis* is a recently (2008) described and poorly known species which was previously referred to as *H. chaophraya* (Kyne 2011). It's full distribution is not known[2], and while it is possibly endemic to fresh and estuarine waters of northern tropical Australia, it may also occur in Papua New Guinea. As such, it is currently listed as "Data Deficient" under the IUCN Redlist (Kyne 2011) and the *Territory Parks and Wildlife Conservation Act 2000*. However, it is a noteworthy species of high conservation significance, known from few rivers in northern Australia, and only occurs in low abundance.

[2] The freshwater whipray *Himantura dalyensis* has been recorded in northern Australia from the Ord, Fitzroy and Pentecost Rivers in Western Australia, the Daly, Roper and South Alligator Rivers in the Northern Territory and the Mitchell, Gilbert, Normanby and Wenlock Rivers in Queensland (Thorburn *et al.* 2004, Last &Manjaji-Matsumoto 2008, Last & Stevens 2009). The Daly River (Northern Territory) and Normanby River (Queensland) systems have been identified as sites of significance for the species, given abundances relative to other systems (Thorburn *et al.* 2004).

Table 3. 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 °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	SRL	Left	Right		EC	Temp	DO	pH
Keep River													
K1	05-09-12	*P. pristis*	*	1500	375	355	22	21	M	2532	27.0	87	8.0
K2	18-09-11	*P. pristis*	301	1150	260	240	21	21	M	207	25.7	116	8.0
K2	18-09-11	*P. pristis*	<u>302</u>	1100	275	265	22	21	M	207	25.7	116	8.0
K2	18-09-11	*P. pristis*	303	1040	250	230	19	18	F	207	25.7	116	8.0
K2	18-09-11	*P. pristis*	304	1130	280	265	21	21	F	207	25.7	116	8.0
K2	18-09-11	*P. pristis*	305	1480	350	330	23	23	F	207	25.7	116	8.0
K2	05-09-12	*P. pristis*	<u>302</u>	1490	370	355	22	21	M	2532	27.0	87	8.0
K2	05-09-12	*P. pristis*	*	1500	375	355	22	21	M	2532	27.0	87	8.0
K2	30-09-13	*P. pristis*	*	1900	420	380	21	21	M	2200	32.4	92	8.2
KR2	24-09-11	*P. pristis*	306	950	240	220	20	19	F	45.3	25.8	99	8.3
KR2	15-09-12	*P. pristis*	18	1505	365	350	21	21	F	20.6	25.2	85	7.8
Keep Estuary													
EST01	22-10-11	*P. clavata*	309	1870	368	352	22	21	M	4520	33.2	125	8.2
EST01	22-10-11	*P. clavata*	311	1445	305	290	22	21	M	4520	33.2	125	8.2
EST01	22-10-11	*P. clavata*	312	1925	425	395	21	22	M	4520	33.2	125	8.2
EST01	22-10-11	*P. clavata*	313	~2000	Not measured but tagged & DNA sample taken					4520	33.2	125	8.2
EST01	22-10-11	*P. clavata*	314	1900	418	400	20	20	M	4520	33.2	125	8.2
EST01	22-10-11	*P. clavata*	315	1500	305	290	22	22	M	4520	33.2	125	8.2
EST01	22-10-11	*P. clavata*	316	1650	340	322	21	21	F	4520	33.2	125	8.2
EST01	22-10-11	*P. zijsron*	310	1905	395	372	23	24	F	4520	33.2	125	8.2
EST01	11-09-12	*P. clavata*	1	1820	370	355	22	23	F	4730	22.7	86	8.1
EST01	11-09-12	*P. clavata*	2	1390	290	275	21	21	M	4730	22.7	86	8.1
EST01	11-09-12	*P. clavata*	3	~1900	385	365	21	21	F	4730	22.7	86	8.1
EST01	11-09-12	*P. clavata*	4	1900	368	350	23	23	M	4730	22.7	86	8.1
EST01	11-09-12	*P. clavata*	5	1818	375	360	22	20	F	4730	22.7	86	8.1
EST01	11-09-12	*P. clavata*	6	1330	277	265	23	21	M	4730	22.7	86	8.1
EST01	11-09-12	*P. clavata*	7	890	188	180	23	23	M	4730	22.7	86	8.1
EST01	11-09-12	*P. clavata*	8	1240	265	255	21	20	M	4730	22.7	86	8.1
EST01	14-09-12	*P. clavata*	15	1855	380	360	23	22	M	4730	22.7	86	8.1
EST01	14-09-12	*P. clavata*	16	2420	480	445	19	20	F	4730	22.7	86	8.1
EST01	14-09-12	*P. clavata*	17	2720	515	495	21	23	F	4730	22.7	86	8.1
EST02	04-10-13	*P. clavata*	21	1300	335	300	22	22	F	6100	28.6	95	8.2
EST02	04-10-13	*P. clavata*	19	1500	330	300	23	23	M	6100	28.6	95	8.2
EST03	11-09-12	*P. clavata*	*	830	177	168	--	--	M	5540	24.3	87	8.0
EST03	11-09-12	*P. clavata*	9	1550	227	217	19	19	F	5540	24.3	87	8.0
EST03	11-09-12	*P. clavata*	10	1933	325	310	22	22	M	5540	24.3	87	8.0
EST03	11-09-12	*P. clavata*	11	2260	427	405	22	21	M	5540	24.3	87	8.0
EST03	11-09-12	*P. clavata*	12	1460	310	295	23	22	F	5540	24.3	87	8.0
EST03	11-09-12	*P. clavata*	13	1300	270	255	22	22	F	5540	24.3	87	8.0
EST03	11-09-12	*P. clavata*	14	1540	305	290	21	22	F	5540	24.3	87	8.0
EST03	05-10-13	*P. clavata*	20	1460	310	280	22	20	M	5840	29.0	98	8.2
EST03	05-10-13	*P. clavata*	22	1310	300	275	21	21	M	5840	29.0	98	8.2
EST03	05-10-13	*P. clavata*	*	840	190	200	23	23	M	5840	29.0	98	8.2

*Sawfish released prior to tagging due either to it being too juvenile or evidence of stress in the animal.

4.3.2 Sawfish sex ratio

Sex ratio data were summed over years and indicated an equal sex ratio for riverine populations of *P. pristis* of 1 male : 1 female, (Table 3). The males ranged in length from 1,100 to 1,900 mm TL , while the females ranged in length from 950 to 1,505 mm TL. For *P. clavata* in the estuary, ratio was 1.6 males : 1 female. Male *P. clavata* ranged in length from 840 to 2,260 mm TL, while females ranged in length from 1,300 to 2,720 mm TL.

4.3.3 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 3. 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.*

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

This clearly underestimates the estuary population size, given that a total of 30 individual *P. clavata* were recorded during the 2011-2013 surveys, 19 of which were caught at EST01, and only one of which (tag# 302) was recaptured.

4.3.4 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 (Table 4 and Figure 9). 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(Table 4 and Figure 9).

A *P. pristis* individual (tag# 302) was recaptured in September 2012 at same location (Keep River pool K2) in which it was originally caught and tagged a year earlier (Table 4 and Figure 9). 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.

4.4 Conclusions

Listed dwarf sawfish *Pristis clavata* are common in the Keep Estuary, and largetooth sawfish *P. pristis* common in 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, current study). A single female green sawfish *P. zijsron*[3] was recorded from the upper Keep Estuary (EST01) during the current 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) and the individual recorded at EST01 is likely to have been a vagrant.

Site EST01 in the upper estuary appears to support the greatest numbers of sawfish (nearly all *P. clavata*). 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

[3] Tissue samples were retained for DNA analysis to confirm taxonomy.

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. Repeated sampling during the dry season would be required to test the hypothesis of a gradual increase in the 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, in the upper estuary is of issue for the Stage 2 development, should there be any adverse effects of the development on water quality of the lower pools and upper estuary.

The total number of sawfish caught in 2013 (6 individuals) was low compared to total numbers caught in 2012 (22 individuals) or 2011 (14 individuals). The reason for the low catch in 2013 is not known. 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.

To date, formal targeted surveys have not recorded any *Glyphis* sharks within the Keep River or Estuary. This includes the current 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.

Table 4. Movement of sawfish using available capture data from anglers and WRM for tagged/previously caught sawfish. GPS locations are provided as WGS84, UTM, Zone 52.

		Originally caught				Re-caught by angler/or WRM during surveys					
Tag#	**Species**	**Date**	**Location**	**Easting**	**Northing**	**Date**	**Location**	**Easting**	**Northing**	**Noted condition**	**Distance travelled**
311	*P. clavata*	22/10/2011	EST01	51202.53	8315494.26	30/06/2012	nr EST03	512021.53	8315494.26	Healthy	13 km downstream
314	*P. clavata*	22/10/2011	EST01	51202.53	8315494.26	27/10/2011	nr EST02	513528.98	8312107.39	Sunburnt, damaged rostrum	7 km downstream
001	*P. clavata*	11/09/2012	EST01	51202.53	8315494.26	26/09/2012	*Recapture location uncertain**			Healthy	Unknown
302	*P. pristis*	18/09/2011	K2	509202.00	8300805.00	06/09/2012	K2	509202.00	8300805.00	Healthy	0 km

* Recapture location of *P. clavata* 001 is uncertain due to the recreational fisherman being unable to adequately identify the location. However, the recapture location is presumed to be in the vicinity of EST01.

Figure 9. Sawfish movement based on recapture locations.

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 those 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 component of aquatic food webs.

Surveys were conducted during the late dry season (Sept.-Oct.), as opposed to earlier in the year, in order 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 during the current surveys (2011-2013), prior to irrigation, will establish benchmark conditions at exposed sites as well as reference sites. Future monitoring at these sites, conducted using the same design and methodology, can then be used to discriminate changes resultant of the development from natural changes, such as climatic variability.

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 2). 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 2). These sites corresponded with those previously designated by KBR (2006) and sampled for water quality by WRM (2010a, 2011). As the K4 pool was much smaller in size, only three replicates were sampled. For reference sites, one sample only was collected from each, and each site treated as a replicate for statistical comparisons of spatio-temporal variability.

In addition, sampling for water quality was also conducted at Estuary sites EST01 to EST03 (Table1 & Figure 1).

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. Concentrations were compared against default ANZECC/ARMCANZ (2000) water quality trigger values (TVs) for the protection of northern tropical systems (see Appendix 3A). Past monitoring has shown that some parameters exceed the default TVs (DAFWA 2011), and so system-specific water quality TVs will be developed from baseline data. These site-specific TVs will be adopted in post development monitoring (refer Strategen 2012a,c).

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). 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

Above average wet seasons 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. 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 3). 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 at Augustus Hole.

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. External specialist taxonomic expertise was sub-contracted to assist with Chironomidae (non-biting midges) (Dr Don Edward, The University of Western Australia).

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 30 m multi-panel gill nets at each site, with each net consisting of 6 x 5 m panels, 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. At each replicate sampling location, two 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 and weight 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.

5.2.5 Data analysis

Univariate and multivariate analyses

Water quality and species abundance data were analysed in the same manner as described for sediment data (section 3.2.3). The exception was that for species data, multivariate analyses were based on Bray-Curtis similarity rather than Euclidean distance, and the SIMPER routine in PRIMER was used to investigate the contribution of individual species to the overall variability between *a priori* groups of sites or years. In addition, the possible influence of water quality on species assemblages was further examined using the BIOENV routine in PRIMER. This routine was used to calculate the minimum suite of water quality parameters that best explained the greatest percent of variation in the species data.

AusRivAS

AusRivAS modelling of baseline (2011 - 2013) macroinvertebrate data and development of biotic TVs for the Keep River has already been reported in December 2013 in WRM (2013c) *ORIA Stage II Expansion Keep River: Developing AusRivAS Trigger Levels for Keep River Ecological Monitoring*. For completeness, a brief summary of the results from WRM (2013c) is included in the current report. Condition 11F of the Storm Water and Groundwater Discharge Management Plan (SEWPAC 2011) requires development of "AusRivAS trigger levels for aquatic macroinvertebrates". The AusRivAs (Australian River Assessment System) model was developed between 1993 and 1997 as a national rapid biological assessment procedure for assessing river condition (Schofield & Davies 1996, Simpson 2000). AusRivAS uses predictive models to compare the occurrence of families of aquatic macroinvertebrates from a particular river, with those expected to occur if the site was in good biological condition, taking into account geographic location and habitat (Coysh *et al.* 2000, Ransom *et al.* 2001, Halse *et al.* 2001). The ratio of observed to expected (O/E) families is used as a measure of river health and the severity of any environmental impairment is assessed using a banding scheme (A to D, and X), based on how much the observed macroinvertebrate assemblage deviates from that expected to occur.

Though the model is not designed for tidally-influenced sites, it is a requirement of licence conditions for all sites on the lower Keep River, and so all sites, including tidally-influenced K1 and K2, were included in analyses (WRM 2013c). Macroinvertebrate species-level data were first reduced to family-level data, then run through the appropriate AusRivAS model. The model chosen was the late dry season edge habitat model for the Northern Territory. Required physico-chemical 'predictor variables' for this model include location (latitude & longitude), total alkalinity (as mg/L $CaCO_3$) and percent cover by macro algae (assessed qualitatively).

Biotic trigger values (TVs) were calculated from the O/E scores, as these provide a continuous quantitative score, as opposed to the categorical model bandings which limit sensitivity and quantitative statistical analysis (WRM 2013c). In accordance with ANZECC/ARMCANZ (2000) protocols, the 20th percentile (20%ile) value of O/E scores was taken as the biotic TV for each site. In this way, if future monitoring detects an O/E score <u>below</u> the appropriate TV for that pool, this would be a trigger for further investigation. The 20%ile values were derived for each individual pool (K1 to K4) on the lower Keep, and for grouped reference sites.

5.3 Results and Discussion

5.3.1 Water quality – univariate analyses

Summary statistics for baseline water quality data collected from the lower Keep River pools (K1 to K4 pools), Estuary and reference sites are provided in Appendix 3B; 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.

<u>**General parameters –DO, pH, alkalinity, DOC, turbidity**</u>

Spatial variation in selected general water quality parameters is illustrated in Figure 10; dissolved oxygen, pH, alkalinity, dissolved organic carbon (DOC) and turbidity. All parameters showed statistically significant variation amongst sites and amongst years (2-way ANOVA, Appendix 3C). Mean values indicated the majority of sites were characterised by basic pH (7.5 - 8.3), moderate to high alkalinity (100 - 182 mg/L $CaCO_3$) and hardness (75 - 6800 mg/L $CaCO_3$), low turbidity (<10 NTU, except Estuary sites[4]), and moderate to high daytime DO (65 - 101%).

Of most note was the particularly low DO 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 years (36.7 - 48.6%). Similarly low daytime levels have been repeatedly recorded these sites during historic sampling (WRC 2003a, NCTWR 2005), and are due to the extensive deposits of organic detritus and associated high microbial activity. Very large, dense zooplankton (ostracods, copepods *etc.*) blooms have also been observed during past sampling (A. Storey, pers. obs.) and these no doubt deplete DO from the water column. Average DO levels of less than 50-60% saturation are known to cause stress to many aquatic fauna (ANZECC/ARMCANZ 2000). Native fish are particularly susceptible as most have high metabolic demand for oxygen. Vertical profiles of DO are shown in Figure 11, and indicate stratification at some Keep River sites on some occasions, and most reference sites on most occasions. In general, 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) and along the entire length of the K2 pool (K2-1 to K2-5), with stratification progressively weakening further upstream, *i.e.* at upper pools K3 and K4. Though salinity profiles were not measured, the stronger DO stratification at K1 and K2 may have been due to halocline formation coupled with high microbial respiration. There was little evidence of strong thermocline development at any of the pools. At reference sites, hypoxia (≤20% DO) prevailed in bottom waters on most occasions, with the exception of Augustus Hole (SR4) which showed little variation in DO with depth.

[4] ANZECC/ARMCANZ (2000) state that "Turbidity is not a very useful indicator in estuarine and marine waters. A move towards the measurement of light attenuation in preference to turbidity is recommended".

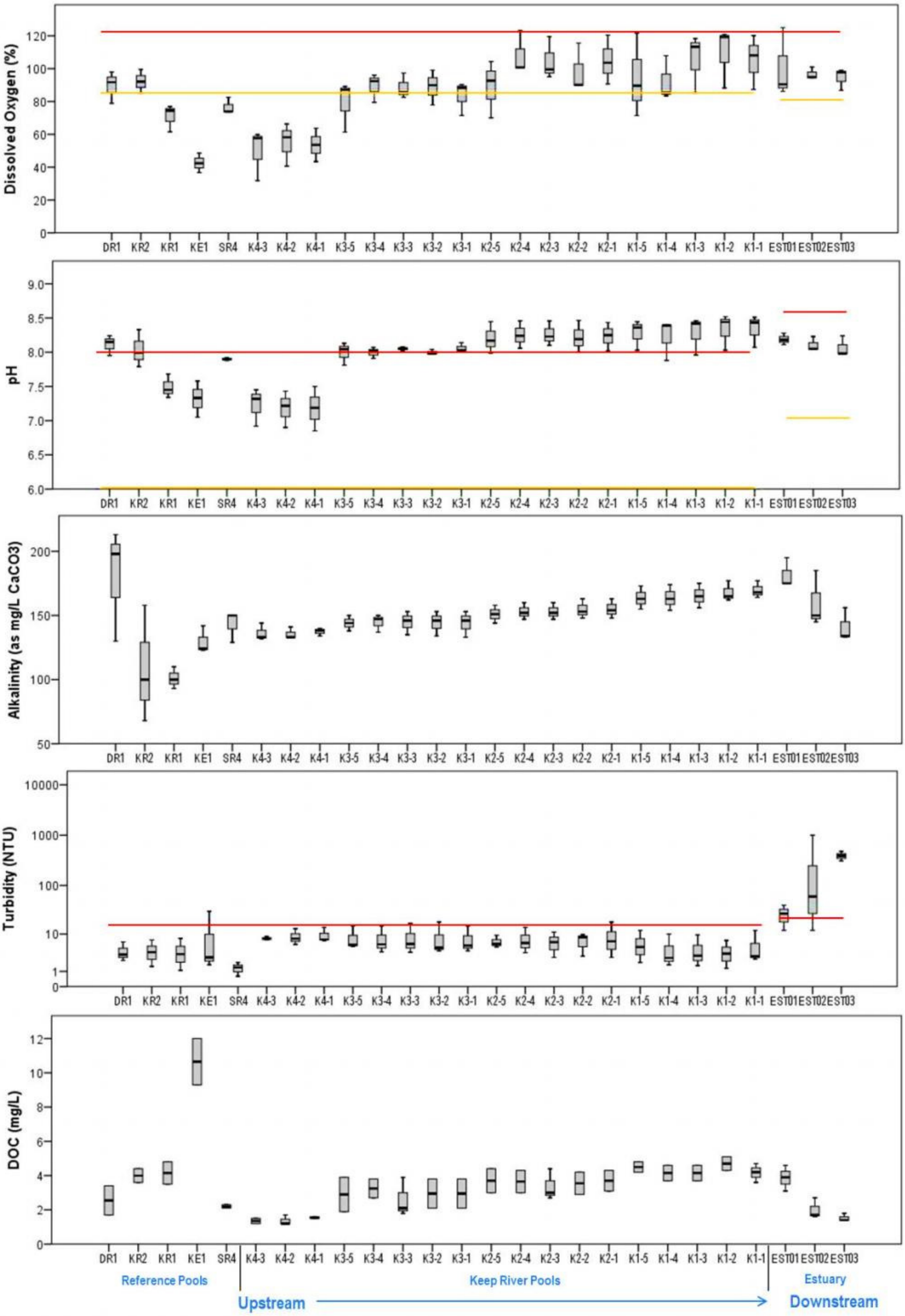


Figure 10. Box plots summarising baseline data (2011-2013) on general water quality parameters within the Keep River, Keep River Estuary and reference sites. Plots show minimum, 20%ile, median (50%ile), 80%ile and maximum values for each replicate site. Note, DOC not measured in 2011. ANZECC/ARMCANZ default upper (—) and lower (—) TVs for fresh or estuarine waters (as appropriate) for protection of 95% of species, are also indicated.

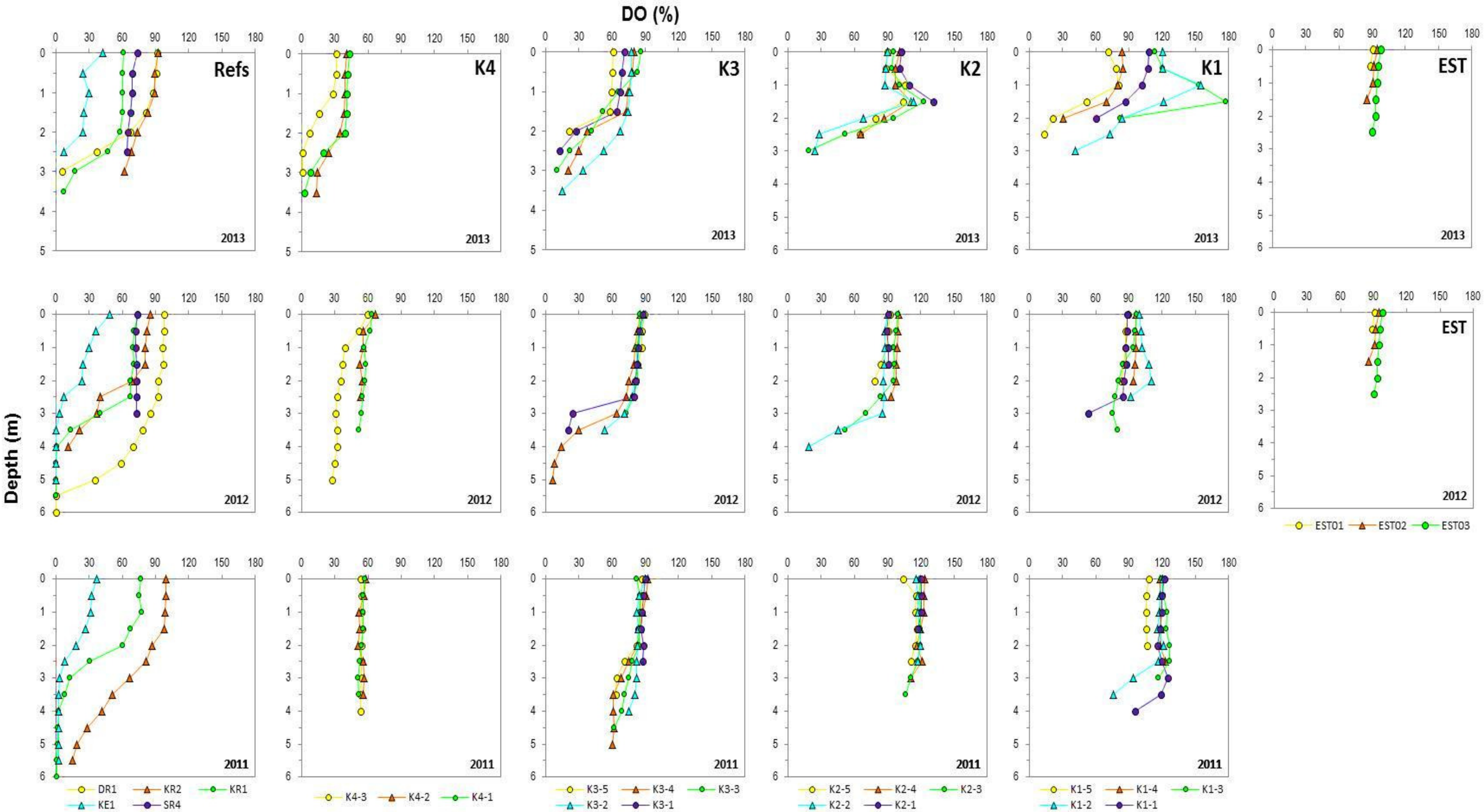


Figure 11. Changes in dissolved oxygen (% saturation) with depth at each Keep River, Estuary and reference site on each sampling occasion. Note, in 2011, depth profiles were not measured at Estuary sites or at reference sites DR1 (Dunham River) or SR4 (Augustus Hole).

In contrast to Keep River (K1 to K4 pools) and reference sites, the relatively shallow Estuary sites appeared to be well mixed and well oxygenated (Figure 11).

Dissolved organic carbon (DOC) varied considerably between sites, with K1 to K4 pools displaying significantly lower concentrations than reference sites, but significantly higher concentrations than Estuary sites (2-way ANOVA, Appendix 3C Table 3C-3). Mean values in the K1 to K4 pools ranged from 2.1 mg/L (K4) to 4.3 mg/L (K1), compared to 1.5 mg/L (EST03) to 3.9 mg/L (EST01) in the Estuary, and 2.6 mg/L (DR1) to 10.7 mg/L (KE1) at reference sites. There was a weak longitudinal gradient in DOC in the Keep River, with DOC increasing with distance downstream, before declining again in the Estuary (Figure 10). 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 (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 between DOC and nitrogen nutrient concentrations (total-N, total organic N & total soluble N) within the Keep River and reference sites (Figure 12). There were however, no significant correlations between DOC and other water quality parameters, or sediment TOC.

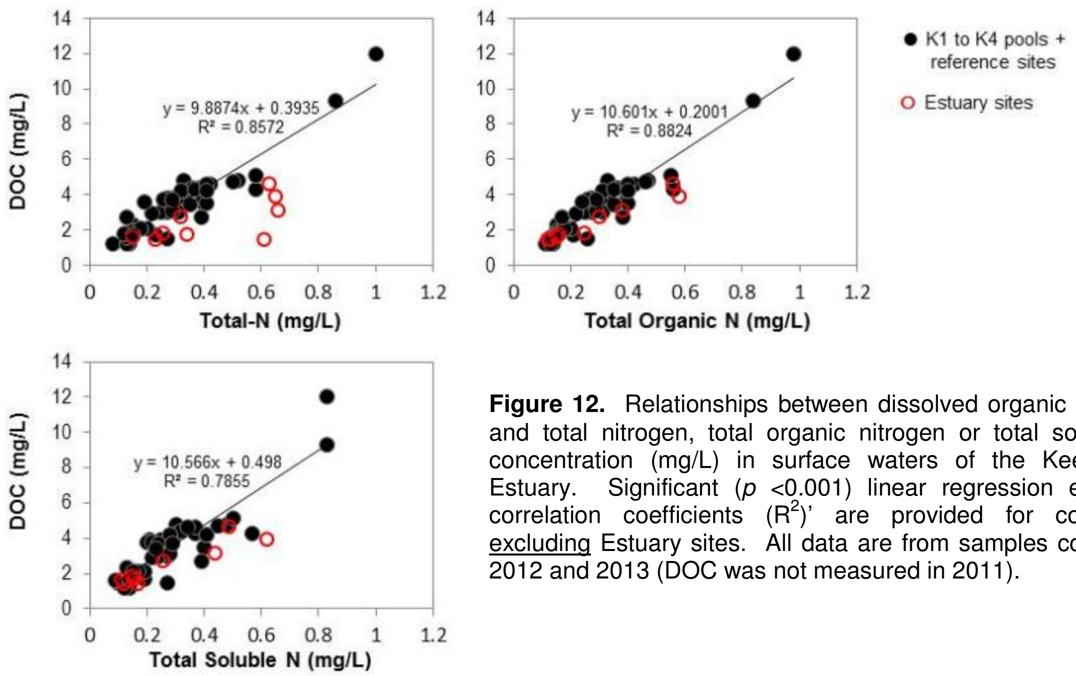


Figure 12. Relationships between dissolved organic carbon (DOC) and total nitrogen, total organic nitrogen or total soluble nitrogen concentration (mg/L) in surface waters of the Keep River and Estuary. Significant (p <0.001) linear regression equations and correlation coefficients (R^2)' are provided for combined data <u>excluding</u> Estuary sites. All data are from samples collected during 2012 and 2013 (DOC was not measured in 2011).

Salinity and major ions

At most river sites, mean and median[5] salinity (as ECond) values exceeded the ANZECC/ARMCANZ (2000) default TV of 25 mS/m (Figure 13). The exception was reference site KR2 (Alligator Hole) with a median of 20.6 mS/m, though the mean (28.7 mS/cm) at this site was in excess of the default TV. In the lower Keep River, salinity ranged from 81.4 mS/cm (450 mg/L TDS) at upstream freshwater pool K4 (K4-2) in 2011, to 4,970 mS/m (34,000 mg/L TDS) at the saline, tidally influenced K1 pool (K1-2) in 2013. Mean salinity at all K1 to K4 pools was significantly higher than the mean for reference sites (31.4 mS/m), but significantly lower than Estuary sites (5,420 mS/m) (2-way ANOVA, Appendix 3C Table 3C-1). There was a pronounced longitudinal gradient in salinity (and major ions) between K1 and K4 pools, with salinity decreasing with increasing distance from the Estuary (Figure 13). Salinity also differed significantly between years, with maxima typically recorded in 2013, and minima in 2011.

[5] ANZECC/ARMCANZ (2000) recommend that, where possible, the median rather than mean of monitoring data be used for comparison against default trigger values. Ideally this median would be calculated from annual or seasonal monthly monitoring data.

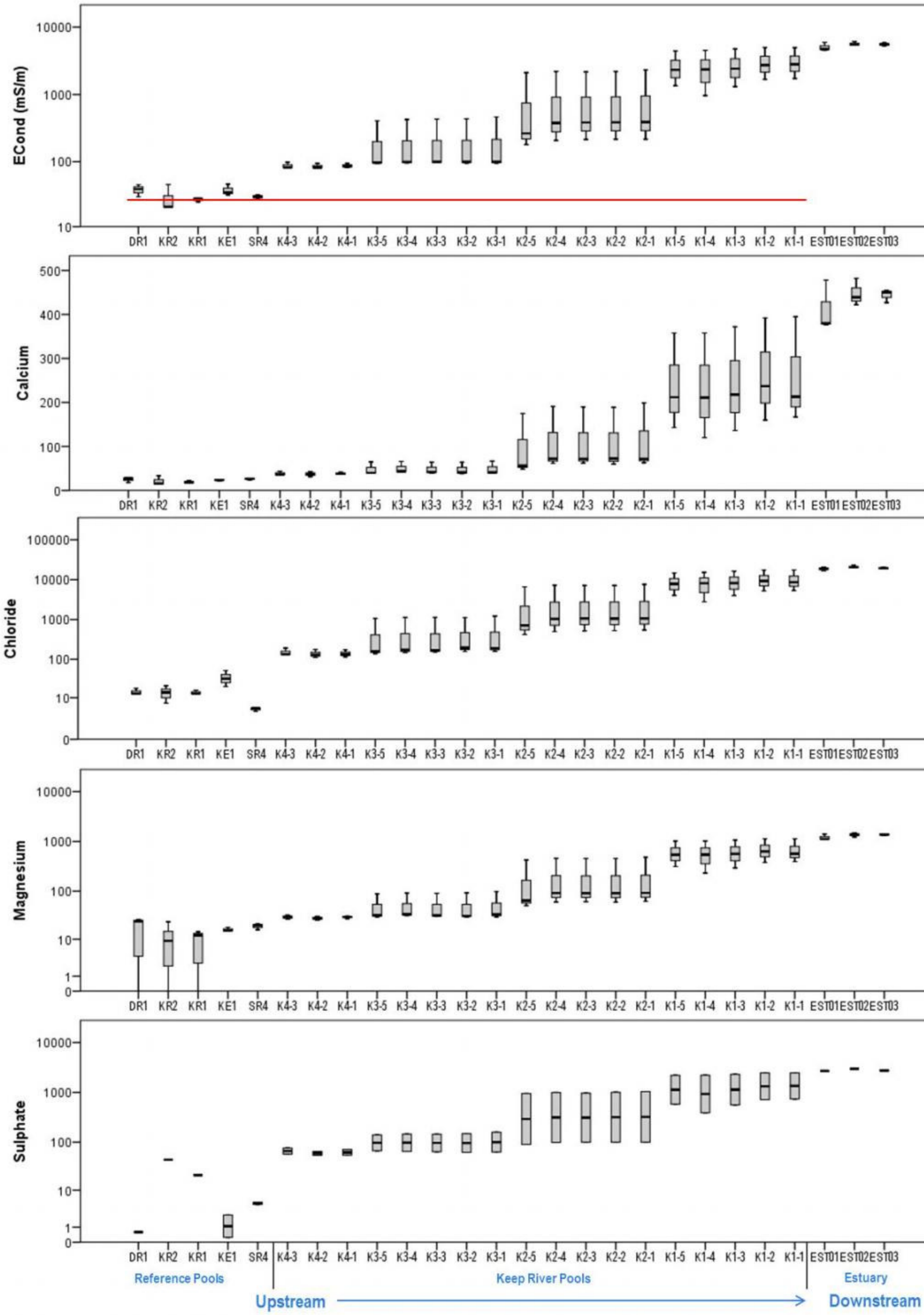


Figure 13. Box plots summarising baseline data (2011-2013) on salinity (as ECond) and selected major ions (Ca, Cl, Mg, SO_4) in surface waters of the Keep River, Keep River Estuary and reference sites. Plots show minimum, 20%ile, median (50%ile), 80%ile and maximum values for each replicate site. Note, SO_4 not measured in 2012. ANZECC/ARMCANZ default TV for ECond (—) for protection of 95% of freshwater species is 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 (Appendix 3B). 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 (Appendix 3B). 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.* Na=Ca>Mg>K : HCO_3>>Cl>SO_4. At Augustus Hole, Mg and SO_4 were the subdominant ions, *i.e.* Ca>Mg>Na=K : HCO_3>>Cl=SO_4. Concentrations of all major ions differed significantly between most sites and years (2-way ANOVA, Appendix 3C Table 3C-2). Longitudinal gradients largely reflected gradients in ECond (Figure 13) and there was a strong linear correlation between ECond and concentration of total dissolved solids (TDS) (Figure 14). There were also significant temporal differences in concentration of Ca, K, Mg, Cl, Mg and SO_4 (Appendix 3C Table 3C-2), all of which were higher in 2013 relative to prior years.

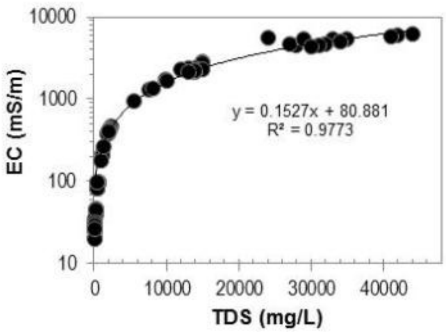


Figure 14. Significant (p <0.001) regression relationship between TDS (mg/L) and ECond (mS/m) in surface waters of the Keep River (K1 to K4 pools), Estuary and reference sites. Regression equation and correlation coefficient (R^2) are also provided. Note axis y is shown as log scale.

Nutrients (N & P)

Phosphorus concentrations were typically less than detection limits at all sites; *i.e*. <0.005 mg/L total-P and total soluble P, and <0.01 mg/L total reactive P (P-TR) and soluble reactive P (P-SR) (Appendix 3C). Total nitrogen (total-N) and ammonia-nitrogen (NH_3-N) however, exceeded ANZECC/ARMCANZ (2000) default TVs for eutrophication at a number of sites (Figure 15). Particularly elevated levels of total-N were recorded from Milligan's Lagoon reference site KE1 (median 0.86 mg/L total-N, 0.02 mg/L NH_3-N), upper Estuary site EST01 (median 0.65 mg/L total-N, 0.07 mg/L NH_3-N) and lowermost Keep River site K1 (median 0.41 mg/L total-N, 0.005 mg/L NH_3-N). Apart from KE1 and EST01, inorganic nitrogen (NH_3-N, NO_2-N, NO_3-N) was generally low (Figure 15). NH_3-N constituted nearly all of the inorganic nitrogen recorded, with levels of NO_2-N and NO_3-N typically less than detection limits (<0.01 mg/L). Total soluble nitrogen typically constituted >70% of total nitrogen at all sites.

Statistically, there were no significant differences in mean concentrations of nitrogen species between the K1 pool and the Estuary, or amongst K1 to K3 pools and reference sites (Appendix 3C Table 3C-3). While total-N and NH_3-N levels in the Estuary were significantly higher than K2 to K4 pools, there were no significant differences in total soluble nitrogen.

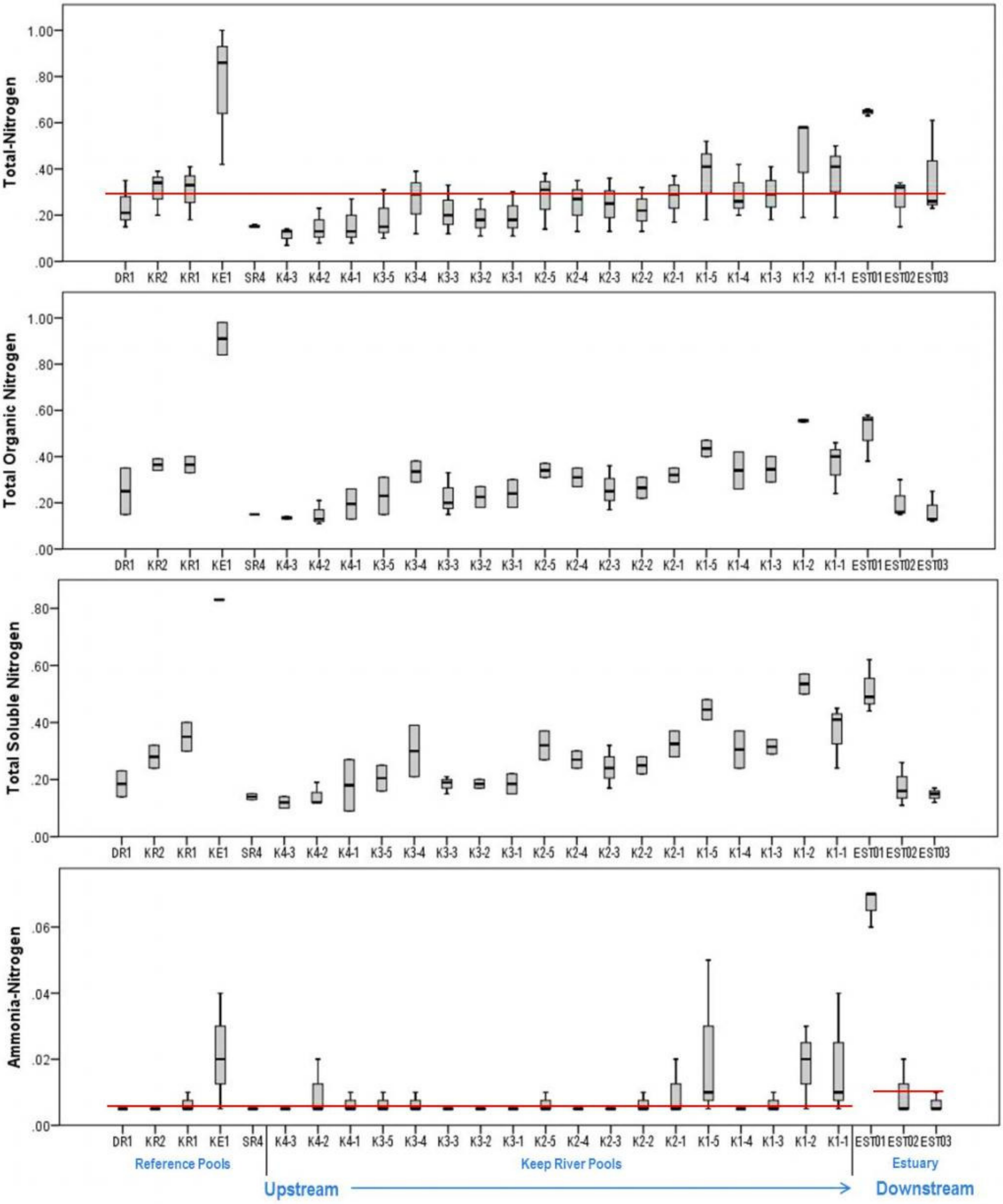
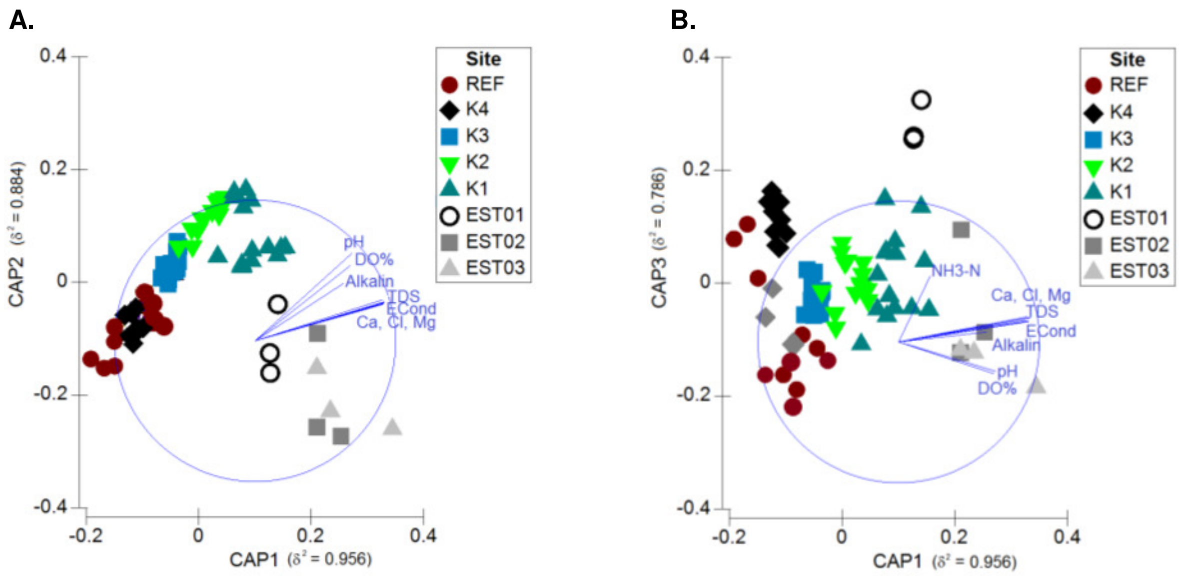


Figure 15. Box plots summarising baseline data (2011-2013) on nitrogen nutrients (mg/L) in surface waters of the Keep River, Keep River Estuary and reference sites. Plots show minimum, 20%ile, median (50%ile), 80%ile and maximum values for each replicate site. Note, total soluble nitrogen not measured in 2011. ANZECC/ARMCANZ default TVs for fresh or estuarine waters (as appropriate) for protection of 95% of species, are also indicated.

5.3.2 Water quality - multivariate patterns

The CAP ordination plots showed distinct clustering of water quality samples according to both site and year (Figure 16A-C). The first two canonical axes of the ordination examining differences amongst sites had very high canonical correlations (δ^2 >0.88) with the suite of water quality variables, explaining 39.7% of the total variation amongst sites (Figure16 A-B). The first canonical axes of the ordination examining differences between years also had high canonical correlation (δ^2 =0.767) with the suite of water quality variables, and together with axis 2 explained 37.1% of the total variation amongst years (Figure 16C). River sites tended to cluster together and away from estuarine sites along axis 1, while axis 2 separated the K1 to K4 pools from each other and from reference (REF) sites (Figure 16A). Similar to sediment quality, there was a longitudinal pattern in overall surface water quality, whereby upstream river sites separated from downstream sites along axis 2 (Figure 16A). Upper Estuary site EST01 separated from EST02 and EST03 along axis 3 (Figure 16B). Amongst years (Figure 16C), axis 1 of the ordination explained nearly all of the temporal variation, with 2013 samples separating from prior years, but little separation between 2011 and 2012.



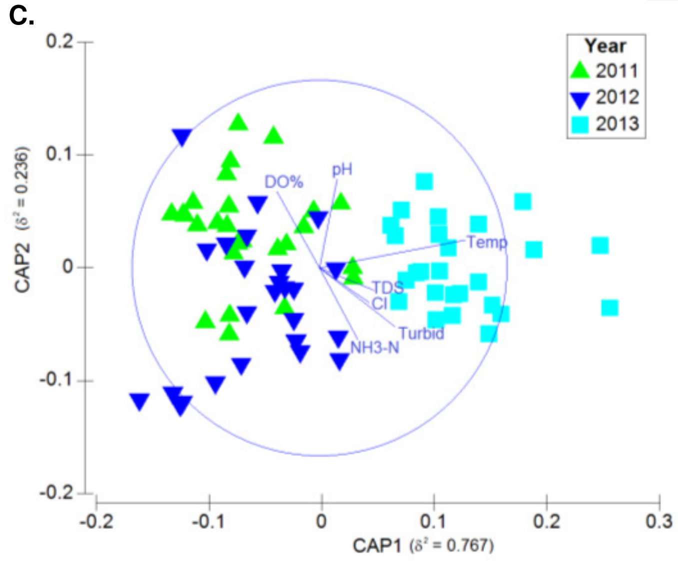


Figure 16. Results of constrained CAP analyses showing (A) axes 1 and 2, and (B) axes 1 and 3, that best discriminated surface water quality amongst sites, and (C) axes 1 and 3 that best discriminated amongst years.
The squared canonical correlation values (δ^2) are provided for each axis. Correlations of water quality variables (untransformed) with the CAP axes are shown for variables with correlation > 0.5.

As expected based on box plots and univariate analyses, vector overlay of analytes with Spearman rank correlation >0.5 indicated the separation of sites in ordination space was associated with higher ECond, TDS, Ca, Cl, Mg, alkalinity, pH, DO and NH_3-N in the Estuary and saline K1 pool, relative to other sites (Figure 16A-B). The separation amongst years was associated with generally higher water temperatures, TDS, Cl and turbidity in 2013, compared to 2012 and 2011 (Figure 16C). Differences in water quality between 2013 and earlier years likely reflected evapoconcentration effects due to very low water levels and high ambient temperatures during the 2013 sampling, especially in the K1 to K3 pools, but also the low rainfall in the preceding dry season.

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 (Appendix 3C Table 3C-4). Differences amongst all years were also statistically significant.

5.3.3 Macroinvertebrates – taxonomy and conservation significance

A total of 235 macroinvertebrate taxa (‘species’) was recorded from all sites and habitats sampled during September 2013 (Appendix 4A). Including taxa recorded during 2011 and 2012, this makes a combined total of 345 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*.).

Insects comprised 87% of taxa collected at all sites, predominantly two-winged flies (Diptera, 28.7%) and aquatic beetles (Coleoptera, 19.0%) (Table 5). Other species-rich faunal groups were true bugs (Hemiptera, 13.2%), mayflies (Ephemeroptera, 9.5%), caddis-flies (Trichoptera, 8.4%) and dragonflies/damselflies (Odonata 6.3%). Approximately 28% of ‘species’ were recorded in only one sample (*i.e.* singletons), and approximately 11% in just two samples (*i.e.* doubletons). Singleton rates in riffle habitat were almost twice those in edge habitats. On average each ‘species’ occurred in only about 10% of samples. Most commonly collected species were the non-biting midges *Cladotanytarsus* sp. (19.3% of samples) and *Larisia* ?*albiceps* (14.7% of samples), true bugs *Paraplea* sp. (17.8%) and *Paracymus pygmaeus* (13.2%), the river prawn *Macrobrachium bullatum* (14.1%), river shrimps *Caridina serratirostris* (13.8%) and *Caridina 'nilotica'* (15.0%), the beetles *Regimbartia attenuata (12.1%), Hydrochus* sp. (14.4%) and *Hydarena* sp. (11.5%), and the leptocerid caddis-fly *Triplectides ciuskus seductus* (12.1%)(Appendix 4A).

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 pygmy water boatmen *Austronecta bartzarum* and *Austronecta micra*, the dragonfly *Nannophlebia mudginberri* (top end archtail) and the mayfly *Manggabora wapitja*. The water boatman *Austronecta bartzarum* is a newly described species, with the description based on a holotype specimen collected from Millstream National Park in the Pilbara region of Western Australia (Tinerella 2013). It has a somewhat restricted distribution in the north of Australia, being known only from the Pilbara, Kimberley and parts of the Northern Territory. In the Kimberley it is known from the Mitchell Plateau, while in the Northern Territory *A. bartzarum* has been recorded from the Daly River, Victoria River, Policeman’s Waterhole, the Keep River and Sandy Creek (Tinerella 2013). It does appear to be locally common within its range. During the current study, *A. bartzarum* was recorded in 2012 from edge habitat sampled at K4 (K4-2, K4-3) and Alligator Hole (KR1). *Austronecta micra* has a similar distribution, but is also known from the extreme north of Queensland (Tinerella 2013). *Austronecta micra* has recently undergone a taxonomic change being transferred from the genus *Micronecta* to *Austronecta* gen. nov. (Tinerella 2013). During the current study, *A. micra* was recorded in 2012 and 2013 from edge habitats at K3 (K3-1), K4 (K4-1, K4-2) and reference sites Alligator Hole (KR1), Policeman's Waterhole (KR2), Augustus Hole (SR4) and the Dunham River (DR1). The top end archtail, *Nannophlebia mudginberri*, is known only from the Northern Territory and Kimberley region of Western Australia (Humphrey *et al.* 2008). It was recorded in 2012 from edge habitat at Milligan's Lagoon and from riffles at K3, Augustus Hole and the Dunham River. 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 collected in 2012 and 2013 from riffle habitat at Augustus Hole.

Table 5. Composition of macroinvertebrate fauna in edge and riffle habitats of the K1 to K4 pools and reference sites. Values are total number of 'species' recorded from all replicate samples (*n*) from 2011, 2012 and 2013 combined. 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 and hence not sampled.

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

5.3.4 Macroinvertebrates – univariate analyses

Spatial variation in species richness is illustrated in Figure 17. Species richness varied between site and habitat, with minimum and maximum values both recorded from edge habitats sampled in 2013; minimum 5 species at K1-1 and K1-5, and maximum 78 species at KR2. 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 17). Average species richness in the downstream, saline K1 pool (15.7 species) was significantly lower than the uppermost freshwater K4 pool (51.3 species) (2-way ANOVA, Appendix 4B, Table 4B-1). The relatively low taxa richness at K1 overall, was considered due to the combination of higher salinity and lower habitat diversity at this site. There was no significant difference in average species richness between the mid-reach K2 (36.3 species) and K3 (41.4 species) pools. Edge habitats in all K1 to K4 pools supported significantly lower average species richness than similar habitats across reference sites, with an average 66.4 species. Despite the lower number of samples collected from edge habitats at reference sites (*n* =15 *cf* 54), the total number of species recorded (246) was greater than the combined total for the K1 - K4 pools (228) (Table 5). This was mostly due to the greater richness of dipteran species at reference sites.

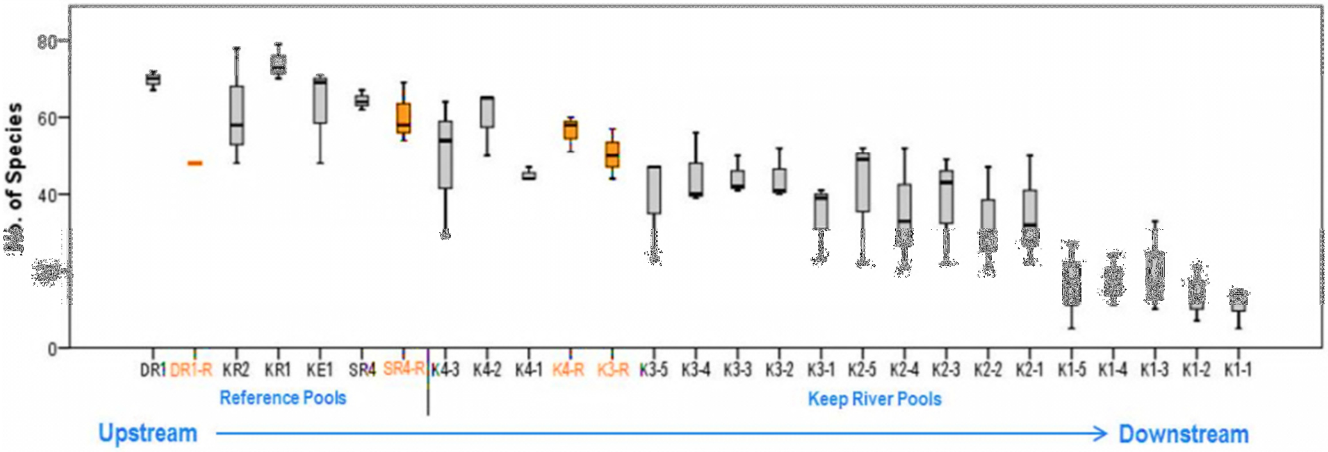


Figure 17. Box plot summarising baseline data (2011-2013) on macroinvertebrate species richness in edge (□) and riffle (■) habitats of the Keep River and reference sites. Plots show minimum, 20%ile, median (50%ile), 80%ile and maximum values for each replicate site.

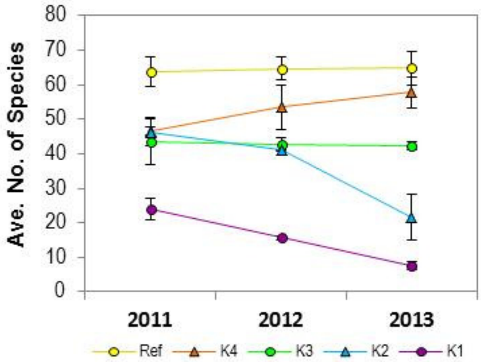


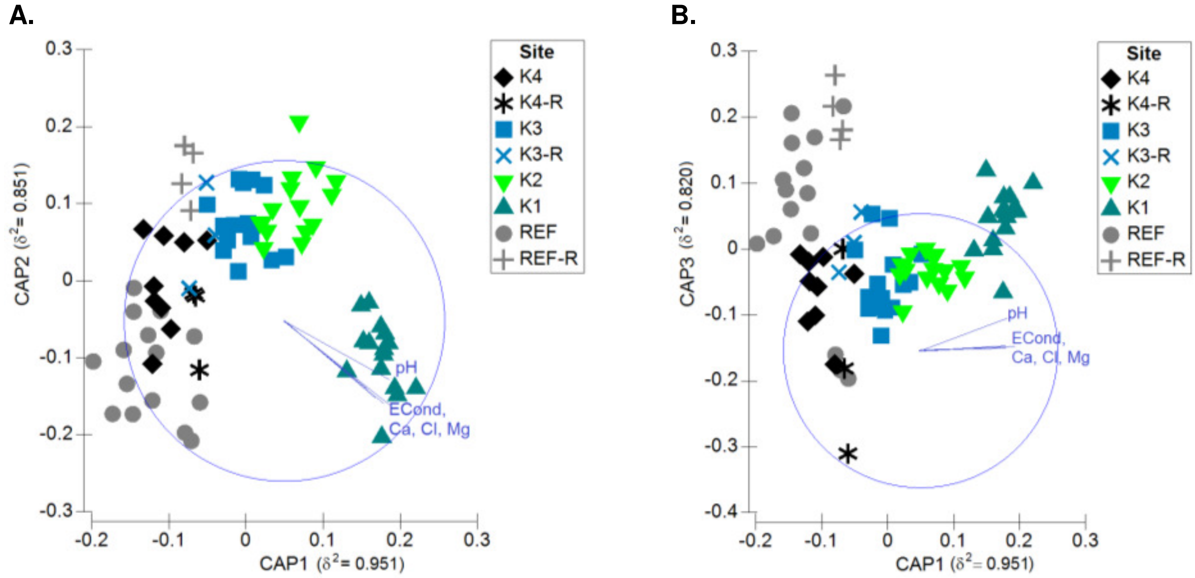
Figure 18. Temporal variability in average (±SE) species richness of macroinvertebrates at each of the Keep River and reference sites.

There were also significant amongst-year differences, with significantly lower richness recorded from edge habitats sampled in 2013 than those sampled in either 2012 or 2011 (Appendix 4B Tables 4B-1 & 4B-2). This was due to significantly lower species richness in both K1 and K2 pools in 2013, compared to 2012 or 2011 (Figure 18). At K1, average species richness in 2013 was 7.6, compared to 15.6 in 2012 and 23.8 in 2011. At K2, average species richness in 2013 was 21.6, compared to 41.0 in 2012 and 46.4 in 2011. There were no significant differences in species richness between years at K3, K4 or reference sites (Appendix 4B Table 4B-2). One possible explanation for the observed declines 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).

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 (n = 6), and one-way ANOVA used to compare K3/K4 against the combined dataset for reference riffles at SR4 and DR1 (n = 4). Despite the greater number of species recorded from K3/K4 overall (*i.e.* 139 *cf* 116, Table 5), ANOVA indicated no significant difference in average species richness between K3/K4 and reference riffles (df = 1, F = 0.640, p = 0.447); acknowledging low statistical power for small sample sizes. Riffle data were insufficient for statistical comparison of temporal variability, but this reflected the limited number of riffles present in the system in late dry season. 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 = 6) for analysis against K3 and K4 riffle data (n = 6). One-way ANOVA indicated no significant difference in average species richness between riffle and edge habitats (df = 1, F = 3.109, p = 0.108). Both riffle and edge habitat at reference sites tended to support a greater number of mayfly species, but fewer beetles and true bugs than similar habitats at K3/K4 sites.

5.3.5 Macroinvertebrates - multivariate patterns in species assemblages

The first three canonical axes of the CAP ordination examining differences amongst sites had very high canonical correlations (δ^2 ≥0.82) with macroinvertebrate species assemblages ($\log_{10}$ abundance class), explaining 40.5% of the total variation amongst sites (Figure19 A-B). The first canonical axes of the ordination examining differences amongst years also had high canonical correlation (δ^2 =0.80) with species assemblages, and together with axis 2, explained 43.0% of the total variation amongst years (Figure 19C). Samples from the more saline K1 pool clustered together and away from all other sites along axis 1, while axis 2 separated the reference samples and a number of K4 samples from all others (Figure 19A). Similar to sediment and water quality, there was a longitudinal pattern in species assemblages from K2 to K4 pools, whereby upper sites separated from those further downstream along axis 2 (Figure 19A). Samples from reference sites separated from all others along axis 3 (Figure 19B). Differences amongst years (Figure 19C) were best explained by axis 1 of the ordination, though there was a degree of overlap between samples from 2013 and 2012, and between 2012 and 2011.



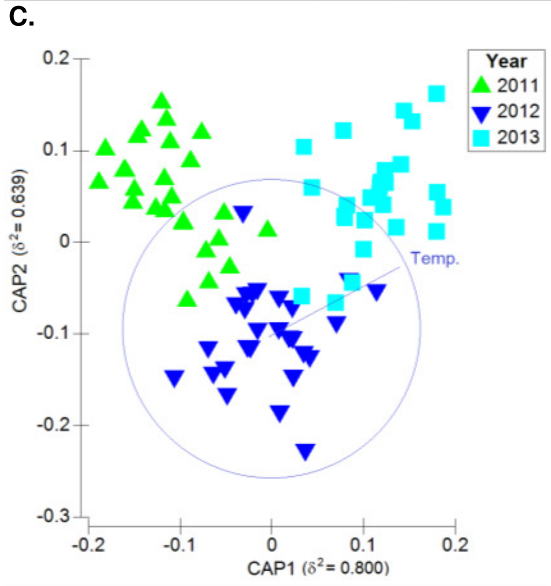


Figure 19. Results of constrained CAP analyses showing (A) axes 1 and 2, and (B) axes 1 and 3, that best discriminated macroinvertebrate species assemblages amongst sites, and (C) axes 1 and 3 that best discriminated amongst years. Analyses based on species $\log_{10}$ abundance class.
The squared canonical correlation values (δ^2) are provided for each axis. Correlations of water quality variables with the CAP axes are shown for variables with correlation ≥ 0.65.

Vector overlay of water quality analytes indicated pH, ECond, Ca, Cl and Mg were best correlated (correlation >0.65) with the groupings of species assemblages produced by the CAP ordination (Figure 19A-B). All these water quality parameters were relatively higher in the saline K1 pool. The BIOENV routine similarly indicated that ECond, Ca and Mg were most strongly correlated (ρ >0.65, p =0.01) with the underlying Bray-Curtis dissimilarity matrix of species abundance. Vector overlay of individual species on the CAP ordination (not shown) indicated groupings were most strongly associated (correlation >0.65) with the higher abundance of estuarine species such as polychaetes and juvenile mussels and snails 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., the notonectid *Nychia Sappho*, and chironomids *Clinotanypus crux*, *Nanocladius* sp., *Polypedilum* sp.1 and Tanypodinae sp. ORT20.

Temporal differences in species assemblages were best correlated with average water temperature, which was relatively high in 2013, compared to prior years (Figure 19C). Temporal variability was attributable to a large number of individual species, each contributing only a small amount (< 3%) to the total variation (SIMPER). Individual species most strongly correlated (vector correlation = 0.5) with temporal patterns were aquatic beetles *Hydroglyphus basalis* and *Hydraena* sp. and juvenile *Macrobrachium* prawns, abundances of which tended to be higher in 2011 and 2012. However, this does not imply a causal link between water temperature and abundance of these species.

Two-factor PERMANOVA indicated species assemblages in edge habitats differed significantly between each of the K1 to K4 pools, and that each pool differed significantly from the reference sites (Appendix 4B Table 4B-3). Differences amongst years were also statistically significant.

Comparison amongst riffle habitats showed species assemblages in the K3 and K4 riffles (combined) differed significantly from reference riffles (DR1 & SR4) (one-factor PERMANOVA, Pseudo-F = 1.682, p =0.009). For statistical comparison of species assemblages between riffle and edge habitats, species presence-absence data (rather than $\log_{10}$ class abundance data) were used in order to combine replicate samples for each of K3 (K3-1 to 5) and K4 (K4-1 to 3) for each year. These data (n = 6) were then analysed against K3 and K4 riffle data (n = 6). One-way PERMANOVA indicated a significant difference in species assemblages between riffle and edge habitats at K3 and K4 (df = 1, Pseudo-F = 6.877, p = 0.002). While differences between habitats may partly reflect greater sampling effort in the edge habitats, this wasn't echoed in total species richness (refer section 5.3.4). Individual species contributing most to the differences between habitats were juvenile mayflies (*Cloeon* sp.), water boatmen (notonectids) and backswimmers (*Micronecta*/*Austronecta* spp., *Paraplea* sp.), and *Hydrovatus* and *Laccophilus* beetles, all which were absent or in low abundance in riffle habitat. Species more common in riffle habitats included taxa with a known preference for higher-flow environments, such as riffle beetles (*Austrolimnius* sp.), black fly larvae (simulids), the small aquatic clam *Corbicula* sp., moth larva (*Margosticha* sp.)., and non-biting midges *Parakiefferiella* sp. 2 and *Nilotanypus* sp. nov.

5.3.6 AusRivAS trigger values

Table 6 lists the O/E[6] scores and corresponding model bands determined from the AusRivAS late dry season channel model for the Northern Territory (WRM 2013c). O/E scores varied both within and between sites and between years. Scores ranged from low at K1-1 (0.13) and K1-5 (0.12) in 2013, to high at reference KR1 (1.11) in 2011, KR2 (1.11) in 2013 and DR1 (1.12) in 2011 and 2012. Corresponding model bands ranged from 'D' extremely impaired, to 'A' similar diversity to AusRivAS reference condition. Sites closest to the estuary, which are tidally influenced and receive salt-water intrusion (*i.e.* K1 and K2, and to a lesser extent K3), typically recorded the lowest O/E scores, while upper freshwater K4 pool recorded relatively high O/E scores. O/E scores for reference sites were mostly high with grades in the 'A' band. The exception was Milligan's Lagoon (KE1) in 2013 (Table 6). Water levels in this pool had receded dramatically in 2013, with the pool much reduced in area compared with 2011 and 2012 (WRM 2013c). Relatively low DO (42.4%) was also recorded at KE1 in 2013 and, combined with the reduced habitat, likely resulted in lower diversity in 2013 (WRM 2013c).

[6] O/E score = ratio of observed to expected number of families based on the reference condition for the AusRivAS predictive model.

Table 6. AusRivAS O/E scores (OE50) and corresponding bands for each site, based on macroinvertebrate family-level data from 2011, 2012 and 2013. Bands: A = similar diversity to AusRivAS reference condition; B = significantly impaired; C = severely impaired; D = extremely impaired.

		2011		2012		2013	
	Site	**OE50 score**	**Band**	**OE50 score**	**Band**	**OE50 score**	**Band**
Reference	**DR1**	1.12	A	1.12	A	1.05	A
	KR2	1.05	A	0.99	A	1.11	A
	KR1	1.11	A	1.05	A	0.99	A
	KE1	0.92	A	0.98	A	0.62	B
	SR4	1.05	A	1.05	A	0.87	A
Keep River pools	**K4-3**	0.62	B	1.05	A	0.87	A
	K4-2	0.99	A	0.99	A	0.99	A
	K4-1	0.68	B	0.80	B	0.86	A
	K3-5	0.71	B	0.71	B	0.84	B
	K3-4	0.74	B	0.80	B	0.68	B
	K3-3	0.86	A	0.86	A	0.86	A
	K3-2	0.86	A	0.80	B	0.86	A
	K3-1	0.68	B	0.74	B	0.62	B
	K2-5	0.75	B	0.75	B	0.50	C
	K2-4	0.93	A	0.68	B	0.49	C
	K2-3	0.86	A	0.74	B	0.56	B
	K2-2	0.95	A	0.50	C	0.57	B
	K2-1	0.76	B	0.76	B	0.50	C
	K1-5	0.50	C	0.31	C	0.12	D
	K1-4	0.56	B	0.37	C	0.31	C
	K1-3	0.69	B	0.31	C	0.19	C
	K1-2	0.50	C	0.25	C	0.25	C
	K1-1	0.50	C	0.37	C	0.13	D

Summary statistics for baseline O/E scores for potentially exposed Keep River pools and reference sites are provided in Table 7. The AusRivAS trigger values for each of the Keep River K1 to K4 pools are equivalent to the 20%ile of the baseline data (Table 7). In order to test for changes in macroinvertebrate community structure over time, future monitoring data for each pool will need to be statistically compared against each TV; *e.g.* testing the median O/E score from monitoring data against the TV using the equivalent of a one-sample T-test. Details of this approach are provided in WRM (2013c).

Table 7. Summary statistics for O/E scores, showing TVs for each pool based on the 20th percentile (20%ile) of 2011, 2012 & 2013 data (using reference sites as replicates for the reference category).

	O/E scores (20101, 2012, 2013)			
	20%ile (= TV)	**mean**	**median**	**80%ile**
Reference	0.97	1.01	1.05	1.11
K4	0.75	0.87	0.87	0.99
K3	0.70	0.77	0.80	0.86
K2	0.50	069	0.74	0.78
K1	0.24	0.36	0.31	0.50

When applying TVs to monitoring data, a significant decrease (or increase) in O/E score should not necessarily be viewed as indicative of a response to the ORIA Stage 2 development. Any changes in a potentially exposed pool need to be considered in light of any concurrent changes at the upstream reference sites (WRM 2013c). If such a change is accompanied by a similar change in O/E score at the upstream reference sites relative to their corresponding TV, then the change in macroinvertebrate community structure could be due to other factors such as climatic change.

All macroinvertebrate data from 2011, 2012 and 2013 were run through the appropriate AusRivAS model to assess ecological health and to develop trigger values for future monitoring, as required under Commonwealth Condition 11F. During application of AusRivAS to these data, and development of the trigger values, a series of concerns were identified over the validity of applying AusRivAS in this situation. These concerns are reported in detail in WRM (2013c), and relate to application of the model to tidally-influenced sites, limitations of AusRivAS for impact assessment, limited baseline for characterising temporal variability, and limitations of family level data, as used in AusRivAS, to detect subtle changes that will be first reflected at species level. As a result of these concerns, the IRG has approached the Commonwealth to amend Condition 11F so that it is based on analysis of species data using an appropriate sampling design and use of univariate and multivariate statistical analyses, rather than AusRivAS models and derived trigger values.

5.3.7 Fishes - taxonomy and conservation significance

A total 2,249 fish representing 40 of the 46 species known from the Keep River catchment (NAFF 2008) were recorded during the 2011 - 2013 baseline surveys of riverine pools (Appendix 5A & Plate 4). Of the 40 species, 25 were present in the K1 pool, 22 in K2, 19 in K3, 13 in K4, and 18 across all reference sites. Most common and abundant in the riverine environments were bony bream *Nematalosa erebi* (1,057 individuals), followed by diamond mullet *Liza alata* (305 individuals) and blue catfish *Neoarius graeffei* (268 individuals). Bony bream and blue catfish were present at all 23 sites surveyed, while diamond mullet were present at 22 sites, the exception being Alligator Hole (KR1). Other widespread but less abundant species were seven-spot archerfish *Toxotes chatareus* (20 sites), barramundi *Lates calcarifer* (18 sites) and common ponyfish *Leiognathus equulus* (14 sites) (Appendix 5A). A number of species were only recorded on isolated occasions from the riverine pools, and represented by single individuals, including three species from the saline K1 pool (long-snouted catfish *Plicofollis argyropleuron*, giant queenfish *Scomberoides commersonianus* & mangrove jack *Lutjanus argentimaculatus*), two species from the freshwater-brackish K3 pool (empire gudgeon *Hypseleotris compressa* & soldier croaker *Nibea soldado*), two species from the freshwater K4 pool (giant glass fish *Parambassi gulliveri* & northern trout gudgeon *Mogurnda mogurnda*), and two species from Augustus Hole (SR4) (threadfin silver-biddy *Geres filamentosus* & freshwater whipray *Himantura dalyensis*) (Appendix 5A).

Most species recorded are known to be common throughout the north of Australia. The exceptions were two listed species; the freshwater whipray *H. dalyensis* (SR4) and the largetooth sawfish *Pristis pristis* (K1-2, K2-3, K2-4, K2-5, KR2). The presence of these species within the current study area has already been discussed in section 4.3.1. *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. *H. dalyensis* is a poorly known species (Kyne 2011) and its full distribution has not been adequately documented (Kyne 2011). As such, it is currently listed as Data Deficient under the IUCN Redlist (Kyne 2011) and the *Territory Parks and Wildlife Conservation Act 2000*.

Plate 4. Examples of fish species recorded during the course of the baseline surveys; (A) barred javelinfish *Pomadasys kaakan*, (B) barramundi *Lates calcarifer*, (C) western sooty grunter *Hephaestus jenkinsi*, (D) oxeye herring *Megalops cyprinoides*, (E) blue catfish *Neoarius graeffei*, (F) long-snouted catfish *Plicofollis argyropleuron*, (G) western rainbowfish *Melanotaenia australis* (photo G. Allen ©), and (H) whipray *Himantura dalyensis*. Photos continued overpage.

Plate 4 continued. Examples of fish species recorded during the course of the baseline surveys; (I) juvenile bull shark *Carcharhinus leucas*, (J) female nurseryfish *Kurtus gulliveri* , (K) freshwater longtom *Strongylurua kreftii*, (L) giant threadfin *Polydactylus macrochir*. (All photos by WRM staff ©, unless otherwise indicated).

5.3.8 Fishes – univariate analyses

Two-way ANOVA testing for year and pool effects on fish species metrics, indicated significant among-pool differences in total species abundance, but not richness, and significant among-year differences in total species richness, but not total abundance (Appendix 5B Table 5B-1). Amongst pools, mean species richness ranged from 5.0 (median 4.0) at K4 to 6.8 (median 6.0) at K1. Within pools, total species richness ranged from 5 at the reference Dunham River site (DR1), to 19 at K1-1. The tendency for greater species richness in the lower system likely reflects proximity to the Estuary and presence of estuarine-marine vagrants. Amongst years, mean species richness was slightly but significantly greater in 2011 (6.8), than in either 2012 (5.8) or 2013 (4.9). 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. Another possible explanation was variable sampling effort, however, as this was comparable between years, it was considered unlikely to have a major influence catch data.

In contrast to total species richness, total species abundance was slightly higher in 2013 (mean 35.7) than either 2012 (mean 32.1) or 2011 (mean 33.6). Amongst pools, mean abundance was greatest in K1 pool (mean 45.6, median 33.0) and lowest in K3 pool (mean 23.6, median 20.0) (Figure 20). Within pools, species abundance was greatest at K1-1 (286) and lowest at K2-3 (39).

Total biomass among years, varied from a maximum to a maximum 133.8 kg (mean 8.6 kg) in 2011, to 120.3 kg (mean 7.4 kg) in 2012, and a minimum 105.7 kg (mean 7.2 kg) in 2013. Among pools, total biomass ranged from 62.1 kg (mean 4.6 kg) in K2, to 157.5 kg (mean 10.5 kg) in K1, with 149.6 kg (mean 11.5 kg) at reference sites. Univariate analyses however, indicated among-year and among-pool differences were not statistically significant (Appendix 5B Table 5B-1). This was primarily due to high variability within-pools, *e.g.* within K1, mean biomass (all years combined) ranged from 24.8 kg at K1-1, to 4.8 kg at K1-1 (Figure 20).

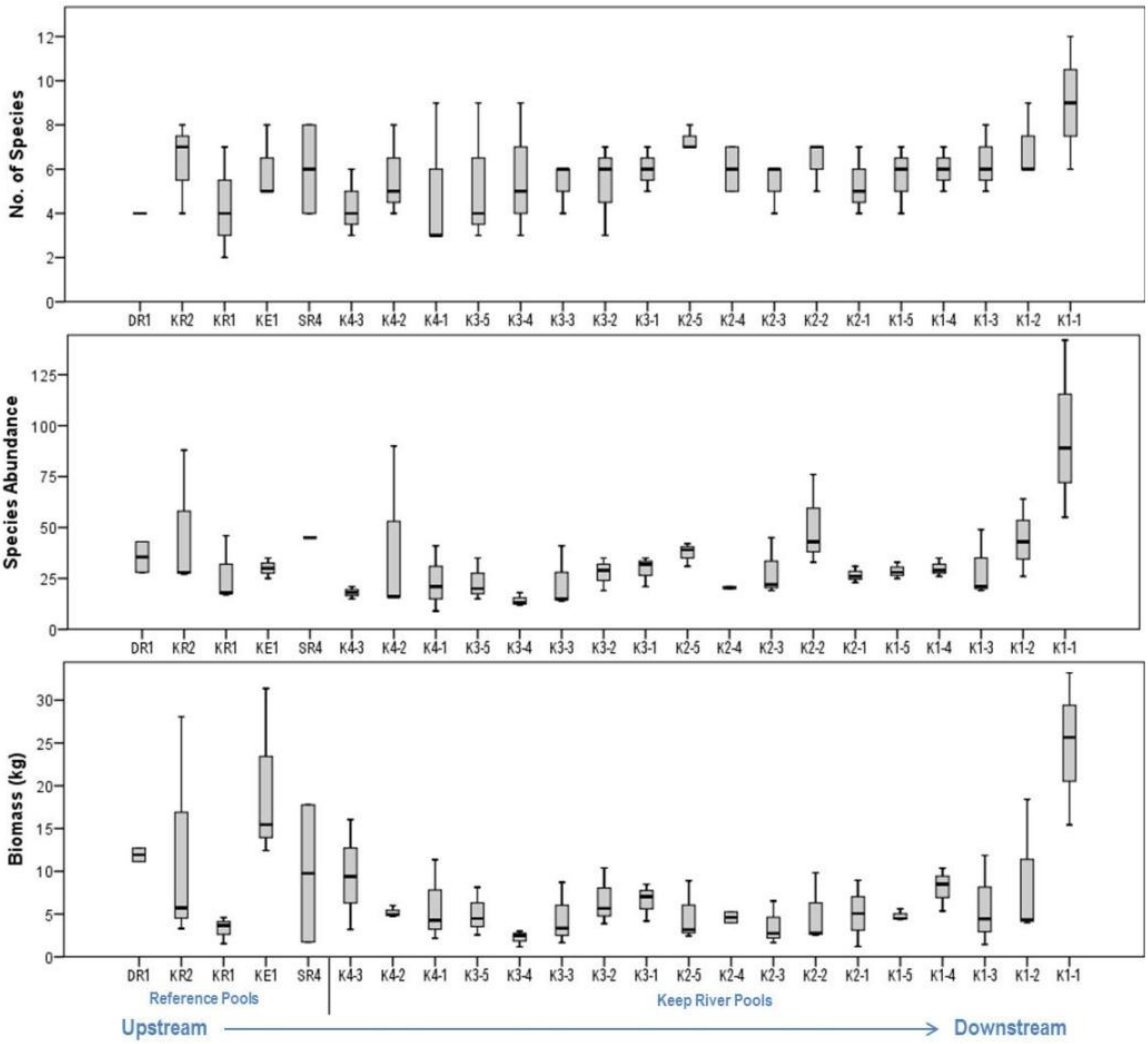


Figure 20. Box plots summarising baseline data (2011-2013) on total fish species richness, abundance and biomass (total weight in kg) in the Keep River and reference sites. Plots show minimum, 20%ile, median (50%ile), 80%ile and maximum values for each replicate site.

5.3.9 Fishes – multivariate patterns in species assemblages

CAP ordination examining among-site differences in species assemblages (log_{10} abundance) showed a clear separation of the freshwater K4 pool from all other Keep River pools (K1 to K3) along axis 1 (Figure 21A-B). There was considerable overlap in species assemblages among the K1, K2 and K3 pools, though along axis 3 of the ordination there was some evidence of an upstream-downstream gradient in assemblages between these pools (Figure 21B). There was also wide variation amongst reference sites. In all, the first three axes of the CAP ordination only explained 21.2% of the total among-site variation in fish assemblages. No individual species were strongly correlated with the CAP axes. At best, vector overlay suggested that the separation of the K4 pool from other Keep River pools was mostly due to relatively higher abundance of narrow-fronted tandans, but lower abundance of bony bream, diamond mullet, ponyfish, and absence of snub-nosed garfish and bull sharks (Figure 21A-B). Western rainbowfish were also restricted to reference sites and the K4 pool.

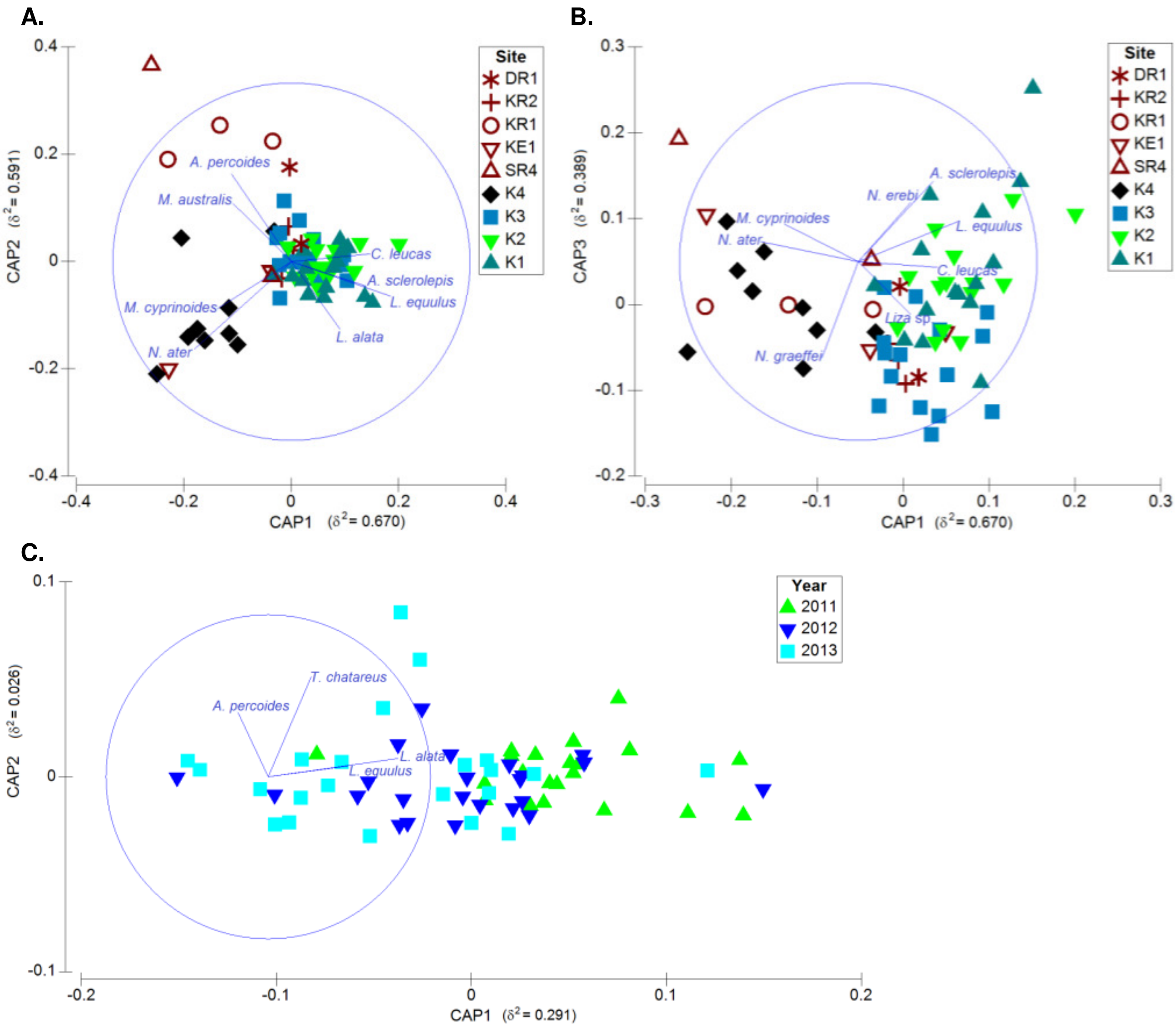


Figure 21. Results of constrained CAP analyses showing (A) axes 1 and 2, and (B) axes 1 and 3, that best discriminated fish species assemblages amongst sites, and (C) axes 1 and 3 that best discriminated amongst years. Analyses based on species log_{10} transformed abundance data. The squared canonical correlation values (δ^2) are provided for each axis. Correlations of individual fish species with the CAP axes are shown for species with correlations of 0.4 to 0.5 (no species showed correlations >0.5).

For the CAP ordination examining temporal differences (Figure 21C), axis 1 best discriminated amongst years, and indicated a temporal gradient predominantly influenced by the decrease in abundance of diamond mullet and, to a lesser extent, common ponyfish between 2011 and 2013. However, there was also considerable overlap between years, in particular 2012 and 2013. Axes 1 and 2 of this ordination, together explained 51.5% of the total temporal variation.

Ordinations on biomass data yielded similar results to abundance data (Figure 22A-C) in that there was a distinct separation of K4 sites from all other sites. K1 to K3 sites however clustered with reference sites.

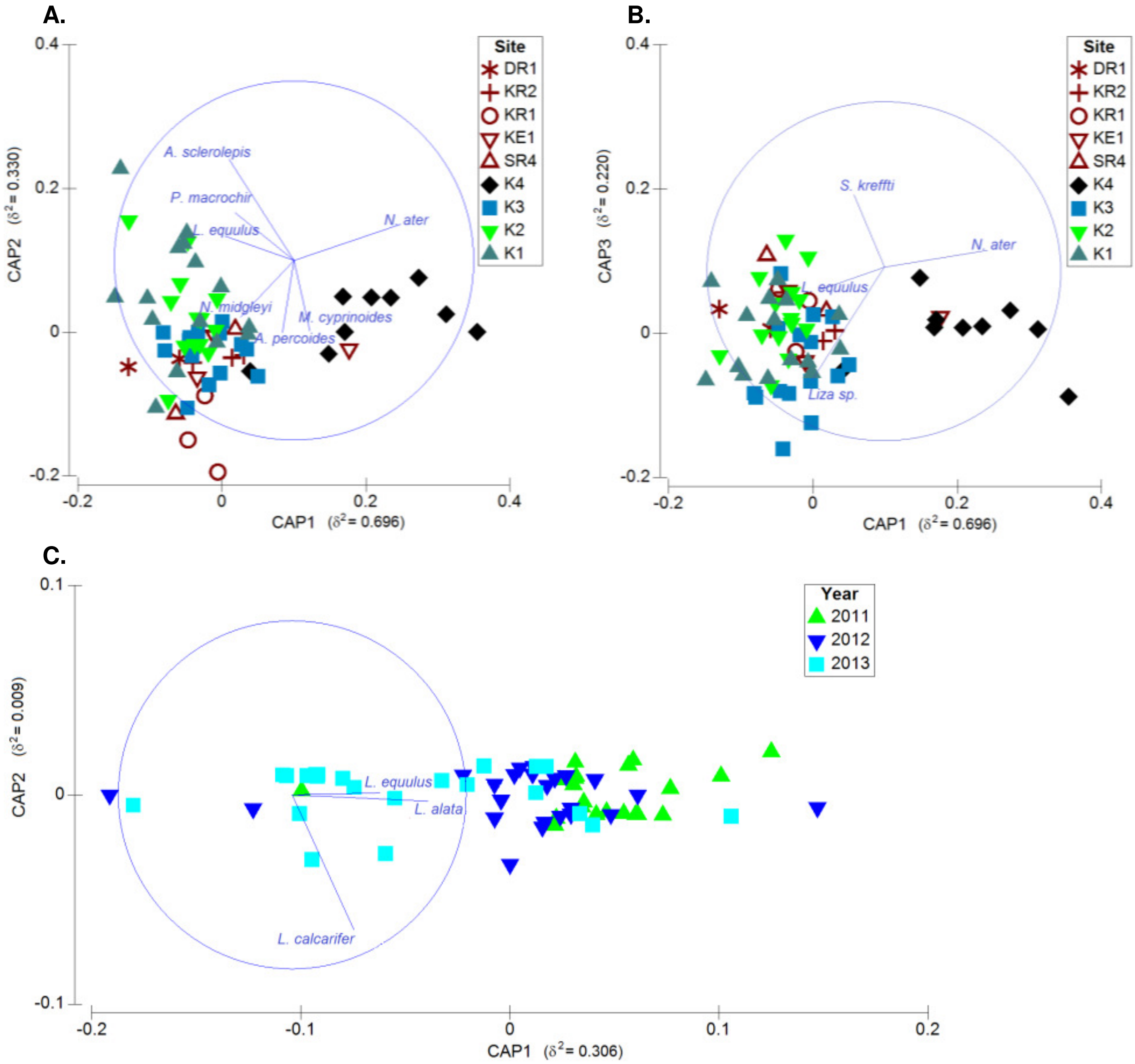


Figure 22. Results of constrained CAP analyses showing (A) axes 1 and 2, and (B) axes 1 and 3, that best discriminated total fish biomass (kg) amongst sites, and (C) axes 1 and 3 that best discriminated amongst years. Analyses based on species log_{10} transformed biomass data. The squared canonical correlation values (δ^2) are provided for each axis. Correlations of individual fish species with the CAP axes are shown for species with correlations >0.5.

Two-factor PERMANOVA analyses corroborated the results from CAP analyses (Appendix 5 Tables 5B-1 to 5B-3). PERMANOVA on abundance data, indicated fish species assemblages differed significantly between each of the K1 to K4 pools, and that each pool differed significantly from the group reference sites (Appendix 5B Table 5B-2). Differences in abundance amongst years were statistically significant for

2011 and later years, but not between 2012 and 2013 (Appendix 5B Table 5B-2). Analyses on biomass however indicated a significant difference between 2013 and earlier years, but not between 2011 and 2012 (Appendix 5B Table 5B-3).

5.4 Conclusions

Combined baseline data from the 2011, 2012 and 2013 dry season surveys provide a benchmark, against which future changes in water quality or aquatic fauna assemblages (macroinvertebrates and fish) may be assessed. These data incorporate a measure of existing spatial and inter-annual variability in the aquatic ecosystem of the Keep River. Additional water quality (monthly samples) and flow data (continuous measurement) are being collected by DAFWA (2011), using the same suite of analytes as described for the current report. The combined datasets will be used to address the various Conditions relating to water quality, and to develop system-specific water (and sediment) quality trigger values (TVs).

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. But as noted in section 5.3.6 above, 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.

There is significant spatial and temporal (inter-annual) variability in water quality between pools of the main channel of the Keep River. Not unexpectedly, there are 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. Compared to other main channel pools (K1, K2, K3), water quality at K4 is more strongly influenced by groundwater, and ionic dominance more similar to reference sites (Augustus Hole, Alligator Hole, Milligan's Lagoon, Policeman's Waterhole, Dunham River). There are also longitudinal gradients in pH and dissolved oxygen (DO) along the Keep River, with values decreasing with increasing distance from the Estuary. At K4, particularly low day-time DO levels occur throughout the water column in some years (*e.g.* 31.8 - 42.4% in 2013) and vertical DO stratification occurs at all pools in most years, often resulting in hypoxic (<20% DO saturation) bottom waters. Stronger DO stratification at K1 and K2 in 2013 was possibly due to active algal blooms at the time of sampling, combined with halocline formation, though salinity profiles were not measured as part of the current program. In contrast to the Keep River pools and reference sites, the relatively shallow Estuary sites are well mixed and well oxygenated.

Total nitrogen (total-N) and ammonia-nitrogen (NH_3-N) exceeded ANZECC/ARMCANZ (2000) default TVs[7] for eutrophication in the K1 pool (median total-N 0.65 mg/L, NH_3-N 0.07 mg/L), and total-N exceeded the default TV in the upper Estuary (EST01) (median total-N 0.41 mg/L, NH_3-N 0.005 mg/L). NH_3-N constituted nearly all of the dissolved inorganic nitrogen recorded, with levels of NO_2-N and NO_3-N typically less than detection limits (<0.01 mg/L). Total soluble nitrogen typically constituted >70% of total nitrogen at all sites.

Immediately prior to the current baseline sampling round (conducted between 28 Sept. - 10 Oct. 2013), and prior to completion of the M2 channel, there were 3 discharge events from the Stage 1 area, *via* the M2 infrastructure, into Border Creek and into the Keep River at the upper end of the K3 pool. During the first event, a total of approximately 92.5 ML were discharged over a period of 6 days (9 - 15 September). The following events were of shorter duration (2-3 days) and smaller magnitude, *i.e.* ~8.8 ML (23 - 26 Sept.) and ~0.3 ML (28 - 30 Sept.). Although it is possible that nutrients in irrigation waters discharged to upper K3 may have contributed to algal blooms and hypoxia in K2 and K1 downstream, the evidence suggests the releases were not the cause. The algal blooms were present in K1 before the releases, and neither K3, nor the upper end of K2, were affected by algal blooms, as would have been expected if the discharge events were the major contributing factor. In addition, water levels in K3 were very low compared to previous years, reflecting low wet season rains, and would have been higher if the discharge events had filled K3 and then moved through this pool into K2 and K1.

In general, aquatic macroinvertebrate and fish assemblages were found to be influenced by the above differences in water quality. River condition, as determined by the AusRivAS models for macroinvertebrate communities, was considered to be A grade (similar to reference condition) at the reference sites, and was most 'impaired' at the downstream Keep River pool, K1 (WRM 2013b,c). As noted in WRM (2013b), it is not surprising that the lowland river pools on the Keep, K3, K2 and K1 appear as significantly (B grade) to severely (C grade) degraded according to the AusRivAS model output. The proximity of these pools to the estuary, and the effect of regular salt water incursions into these pools sets them beyond the bounds of habitats to which the AusRivAS model should be applied. The current condition of these pools likely reflects the effects of salinity on freshwater macroinvertebrate fauna, but also simplification of habitat in these lowland pools, as well as the effects of run-off from upstream and adjacent pastoral land.

The K1 to K4 pools continue to support high diversity of fish species, supporting at least 37 of the 46 species known (NAFF 2008) to occur across the Keep River catchment. This includes the listed largetooth sawfish *Pristis pristis* and the freshwater whipray *Himatura dalyensis*. Though *H. dalyensis* has not yet been recorded from the K1 to K4 pools, its presence in the Keep Estuary (this study), as well as Augustus Hole (this study) on Sandy Creek tributary, and in the Ord River (Storey 2003), suggests it likely occurs in the main Keep River channel.

It is acknowledged that the baseline surveys presented here provide only a snap-shot of the Keep River each year. 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 not possible to access the Keep system during the wet season due to flooding and road conditions. Even if

[7] ANZECC/ARMCANZ (2000) default TVs for eutrophication: **lowland river** – total-N 0.3 mg/L, NO_X-N 0.01 mg/L, NH_4-N 0.01 mg/L, total-P 0.01 mg/L, P-SR 0.004 mg/L; **estuary** – total-N 0.25 mg/L, NO_X-N 0.03 mg/L, NH_4-N 0.015 mg/L, total-P 0.02 mg/L, P-SR 0.005 mg/L.

access was possible, it would be extremely difficult to sample the pools under high flows. Therefore, the decision was made to standardise sampling to the late dry season for this sampling program. It is anticipated that standardising to the late dry season will minimise seasonal effects on aquatic fauna and water quality data, allowing inter-annual comparisons and detection of any response to the ORIA Stage 2 development.

Analyses presented in this report, using data collected over 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. This dataset provides a comprehensive baseline against which future changes in water quality and aquatic fauna may be assessed. Future sampling should be standardised to the current methods, locations and season to allow direct comparison with existing 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, guilds and assemblages, it will be possible to detect future changes in water quality and aquatic fauna, and differentiate natural changes from any effects of the M2 development.

6 REFERENCES

Anderson MJ (2001a) A new method for non-parametric multivariate analysis of variance. *Austral Ecology* **26**:32-46.

Anderson MJ (2001b) Permutation tests for univariate or multivariate analysis of variance and regression. *Canadian Journal of Fisheries and Aquatic Sciences* **58**: 626-639.

Anderson MJ, Robinson J (2003) Generalised discriminant analysis based on distances. *Australian and New Zealand Journal of Statistics* **45**: 301-318.

Anderson MJ, ter Braak CJF (2003) Permutation tests for multi-factorial analysis of variance. *Journal of Statistical Computation and Simulation* **73**: 85-113.

Anderson MJ, Gorley RN, Clarke KR (2008) Permanova + for PRIMER: guide to software and statistical methods. PRIMER-E Ltd, Plymouth, UK.

Ankley GT, Di Toro DM, Hansen DJ, Berry WJ (1996) Technical basis and proposal for deriving sediment quality criteria for metals. *Environmental Toxicology and Chemistry* 15: 2056-2066.

ANZECC/ARMCANZ (2000) Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australia and New Zealand Environment and Conservation Council and the Agriculture and Resource Management Council of Australia and New Zealand. Paper No. 4. Canberra.

Baken S, Degryse F, Verheyen L, Merckx R, Smolders E (2011) Metal complexation properties of freshwater dissolved organic matter are explained by its aromaticity and by anthropogenic ligands. *Environmental Science and Technology* **45(7)**: 2584-90

Barbour MT, Gerritsen J, Snyder B.D, Stribling JB (1999) Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates and fish, second edition. EPA 841-B-99-002. Environmental Protection Agency; Office of Water; Washington, D.C.

Batley G, Simpson S (2008) Advancing Australia's sediment quality guidelines. *Australasian Journal of Ecotoxicology* **14**: 11-20.

Brown AV, Brussock PP (1999) Comparisons of benthic invertebrates between riffles and pools. *Hydrobiologia* **220**: 99-108.

CCME (2002) Canadian water quality guidelines for the protection of aquatic life: Inorganic fluorides. *In*: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.

Clarke KR, Gorley RN (2006) PRIMER v6: User manual/Tutorial, Primer E: Plymouth. Plymouth Marine Laboratory, Plymouth, UK.

Chapman PM, Wang F, Janssen C, Persoone G, Allen HE (1998) Ecotoxicology of metals in aquatic sediments: binding and release, bioavailability, risk assessment, and remediation. *Canadian Journal of Fisheries and Aquatic Sciences* **55**:2221-2243.

Coysh J, Nichols S, Ransom G, Simpson J, Norris R, Barmuta L, Chessman B (2000) AUSRIVAS Macroinvertebrate Bioassessment: Predictive Modelling Manual. CRC for Freshwater Ecology, Canberra, ACT; University of Tasmania, Hobart, Tasmania; NSW Department of Land and Water Conservation, Parramatta, NSW.

DAFWA (2011) Surface Water Characteristics of the Weaber Plain and Lower Keep River Catchments: Data Review and Preliminary Results, Department of Agriculture and Food Resource Management Technical Report No. 370, Perth.

DoE (2014a) *Pristis pristis* in Species Profile and Threats Database, Department of the Environment, Canberra. Available from: http://www.environment.gov.au/sprat. [Accessed 29-Jan-2014].

DoE (2014b) *Pristis clavata* in Species Profile and Threats Database, Department of the Environment, Canberra. Available from: http://www.environment.gov.au/sprat. [Accessed 29-Jan-2014].

DoE (2014c) *Pristis zjsron* in Species Profile and Threats Database, Department of the Environment, Canberra. Available from: http://www.environment.gov.au/sprat. [Accessed 29-Jan-2014].

DoW (2006) Ord River Water Management Plan. Department of Water, Government of Western Australia, Water Resource Allocation Planning Series Report No WRAP 15.

DoW 2013 Ord Surface Water Allocation Plan. Water Resource Allocation and Planning Series. WRAP48. Water and Rivers Commission, Perth, Western Australia. September 2013.

Faria VV, McDavitt MT, Charvet P, Wiley TR, Simpfendorfer CA, Naylor GJP (2013) Species delineation and global population structure of critically endangered sawfishes (Pristidae). *Zoological Journal of the Linnean Society* **167**: 136–164.

Field IC, Charters R, Buckworth RC, Meekan MG, Bradshaw CJA (2008) Distribution and abundance of *Glyphis* and sawfishes in northen Australia and their potential interactions with commercial fisheries: final report May 2008. Canberra, ACT: Department of the Environment, Water, Heritage and the Arts. Available from: http://www.environment.gov.au/coasts/publications/glyphis-sawfish-distribution.html. [Accessed 29-Jan-2014].

GHD (2010) Report for Phase 2 Ord River Irrigation Area Expansion of the Weaber Plain Keep River Catchment, Hydraulic and Hydrodynamic Modelling. Report to Landcorp, October 2010.

Halse SA, Scanlon MD, Hocking JS (2001) First National Assessment of River Health: Western Australian Program. Milestone Report 5 and Final Report. July 1994-June2001. Science Division, Department of Conservation and Land Management, W.A.

Kyne PM (2011) *Himantura dalyensis*. *In*: IUCN 2013. IUCN Red List of Threatened Species. Version 2013.2. Available from www.iucnredlist.org. [Accessed 29-Jan 2014].

Kyne PM, Carlson J, Smith K (2013) *Pristis pristis*. *In*: IUCN 2013. IUCN Red List of Threatened Species. Version 2013.2. Available from: http://www.iucnredlist.org. [Accessed 29-Jan-2014].

Larson HK (1999) Keep River Aquatic Fauna Survey. Museum and Art Gallery of the Northern Territory Research Report Number 4. Unpublished report to Kinhill Pty. Ltd., February 1999.

Last PR, Manjaji-Matsumoto BM (2008) *Himantura dalyensis* sp. nov., a new estuarine whipray (Myliobatoidei: Dasyatidae) from northern Australia. *In*: PR Last PR, WT White & JJ Pogonoski (eds) Descriptions of new Australian Chondrichthyans. CSIRO Marine and Atmospheric Research. pp. 283-291.

Last PR, Stevens JD (2009) Sharks and Rays of Australia (2nd ed.). Harvard University Press. pp. 442-443.

Long ER, MacDonald DD, Smith SL, Calder FD (1995) Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. *Environmental Management* **19**: 81-97.

McArdle BH, Anderson MJ 2001 SEWPAC (2011) Conditions of Approval for the Weaber Plain Development Project (EPBC 2010/5491). Department of Sustainability, Environmental, Water, Population and Communities. September 2011.

NAFF 2008 Fish Atlas of North Australia. National Centre for Tropical Wetland Research (NCTWR) and the Centre for Riverine Landscapes (Griffith University). Available from: http://www.jcu.edu.au/archive/actfr_old_ Projects/FishAtlas/Index.htm [Accessed 29-Jan-2014].

NCTWR (2005) Aquatic Fauna of the Ord Stage II M2 Area: Final Report, September 2005. Unpublished report to the Department of Industry & Resources (WA) by the National Centre for Tropical Wetland Research.

Ransom G, Coysh J, Nichols S (2000) AUSRIVAS Macroinvertebrate Predictive Modelling: User Manual. CRC for Freshwater Ecology, Canberra, ACT.

Schofield NJ, Davies PE (1996) Measuring the health of our rivers. Water (Australia) 23: 39-43.

SEWPAC (2011) Conditions of Approval for the Weaber Plain Development Project (EPBC 2010/5491). Department of Sustainability, Environmental, Water, Population and Communities. September 2011.

Simpson SL, Batley GE, Chariton AA, Stauber JL, King CK, Chapman JC, Hyne RV, Gale SA, Roach AC, Maher WA (2005) Handbook for Sediment Quality Assessment. CSIRO Bangor, NSW.

Simpson JC, Norris RH (2000) Biological assessment of river quality: development of AusRivAS models and outputs. [In] Wright, DW Sutcliffe and MT Furse (eds) *Assessing the Biological Quality of Fresh Waters: RIVPACS and Other Techniques*. Freshwater Biological Association, Ambleside, UK.

Stevens JD, Pillans RD, Salini J (2005) Conservation Assessment of *Glyphis* sp. A (Speartooth Shark), *Glyphis* sp. C (Northern River Shark), *Pristis microdon* (Freshwater Sawfish) and *Pristis zijsron* (Green Sawfish). Hobart, Tasmania: CSIRO Marine Research. Available from: http://www.environment.gov.au/coasts/publications/ pubs/assessment-glyphis.pdf. [Accessed 29-Jan-2014].

Strategen (2012a) Ord River Irrigation Area – Weaber Plain Development Project: Stormwater and Groundwater Discharge Management Plan, report prepared for LandCorp.

Strategen (2012b) Ord River Irrigation Area – Weaber Plain Development Project: Groundwater Management Plan, report prepared for LandCorp.

Strategen (2012c) Ord River Irrigation Area – Weaber Plain Development Project: Aquatic Fauna Management Plan, report prepared for LandCorp.

Strom D, Simpson SL, Batley GE, Jolley DF (2011) The influence of sediment particle size and organic carbon on toxicity of copper to benthic invertebrates in oxic/suboxic surface sediments. *Environmental Toxicology and Chemistry* **30**(7): 1599-1610.

Storey AW, Lynas J (2000) The application of the functional habitat concept to the regulated Lower Ord River, Western Australia, Part 1, macroinvertebrate assemblages. *Hydrobiologia* **592**: 499-512.

Thorburn DC, Peverell S, Stevens S, Last JD, Rowland AJ (2004) Status of Freshwater and Estuarine Elasmobranches in Northern Australia. Report to Natural Heritage Trust. Canberra, ACT: Natural Heritage Trust. Available from: http://www.environment.gov.au/coasts/publications/elasmo-north.html. [Accessed: 29-Jan-2014].

Wetzel RG (1992) Gradient-dominated ecosystems: sources and regulatory functions of dissolved organic matter in freshwater ecosystems. *Hydrobiologia* **229**: 181-198.

Winch S, Ridal J, Lean D (2002) Increased metal bioavailability following alteration of freshwater dissolved organic carbon by ultraviolet B radiation exposure. *Environmental Toxicology* **17(3)**: 267-274.

WRC (2003) Productivity and Water Flow Regulation in the Ord River of North West Australia. Environmental Flows Initiative Project. Final Report on Sampling, May 2003. Water and Rivers Commission, Western Australia.

WRM (2010a) ORIA Stage II Expansion Aquatic Fauna Surveys: Late Wet Season Sampling 2009. Unpublished report to Strategen Pty. Ltd. by Wetland Research & Management, August 2010.

WRM (2010b) Lower Keep River Interim Water Quality Trigger Values. Report by Wetland Research & Management to Benchmark Projects Australasia, Western Australia. October 2010.

WRM (2011) ORIA Stage II: Weaber Plain / Keep River Water Quality and Aquatic Fauna Sampling, 2009-2010. Unpublished report to Strategen Pty. Ltd. by Wetland Research & Management. February 2011.

WRM (2012) ORIA Stage II Expansion Aquatic Fauna Management Plan; Keep River Aquatic Fauna Survey Design. Unpublished report by Wetland Research & Management to LandCorp. May 2012.

WRM (2013a) Keep River Baseline Aquatic Fauna and Targeted Sawfish Surveys: September/October 2011. Unpublished report by Wetland Research & Management to Landcorp. February 2013.

WRM (2013b) Keep River Baseline Aquatic Fauna and Targeted Sawfish Surveys: September/October 2012. Unpublished DRAFTv2 report by Wetland Research & Management to Landcorp. August 2013.

WRM (2013c) ORIA Stage II Expansion Keep River: Developing AusRivAS Trigger Levels for Keep River Ecological Monitoring. Unpublished DRAFTv1 report by Wetland Research & Management to Landcorp. December 2013.

7 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 2A ANZECC/ARMCANZ ISQGs

ANZECC/ARMCANZ (2000) interim sediment quality guideline (ISQG) values. The ISQG-low 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 ISQG-high refers to the concentration above which adverse biological effects are expected to occur more frequently.

CONTAMINANT	ISQG-Low (trigger value)	ISQG-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	3.7
Zinc (Zn)	200	410
METALLOIDS (mg/kg dry wt)		
Arsenic (As)	20	70
ORGANOMETALLICS		
Tributyltin (µg Sn/kg dry wt)	5	70
ORGANICS (µg/kg dry wt) *		
Low Molecular Weight PAHs	552	3160
High Molecular Weight PAHs	1700	9600
Total PAHs	4000	45000
Total DDT	1.6	46
Total PCBs	23	-

* normalised to 1% organic carbon

Appendix 2B 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 2B 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 2C Sediment ANOVA & PERMANOVA Results

Table 2C-1. Results from two-way ANOVA and Tukey's *post hoc* testing for significant year or site effects on ionic composition of sediments ($\log_{10}(x+1)$ transformed means). Only significant results are shown (significance level p <0.05). Sites are arranged in order of increasing mean value of the variable tested; sites joined by a common line are not significantly different.

Major Ion	Source	df	F	p	Tukey's post-hoc				
Ca	Site	4	32.394	0.000	K4	K3	K1	K2	EST
	Year	2	0.656	0.524	2013	2012	2011		
	Site*Year	8	1.022	0.433					
	Corrected total	62							
Cl	Site	4	74.254	0.000	K4	K3	K2	K1	EST
	Year	2	22.432	0.000	2012	2011	2013		
	Site*Year	8	2.450	0.026					
	Corrected total	62							
K	Site	4	17.316	0.000	K4	K3	K2	EST	K1
	Year	2	8.049	0.001	2011	2012	2013		
	Site*Year	8	1.319	0.257					
	Corrected total	62							
Mg	Site	4	10.378	0.000	K4	K3	K2	K1	EST
	Year	2	13.220	0.000	2011	2012	2013		
	Site*Year	8	0.988	0.457					
	Corrected total	62							
Na	Site	4	101.76	0.000	K4	K3	K2	K1	EST
	Year	2	24.225	0.000	2012	2011	2013		
	Site*Year	8	0.4238	0.001					
	Corrected total	62							
SO_4	Site	4	25.881	0.000	K4	K3	K2	K1	EST
	Year	2	6.573	0.003	2012	2011	2013		
	Site*Year	8	0.826	0.584					
	Corrected total	62							

Table 2C-2. Results from two-way ANOVA and Tukey's *post hoc* testing for significant year or site effects on nutrient composition of sediments ($\log_{10}(x+1)$ transformed means). Only significant results are shown (significance level p <0.05). Sites are arranged in order of increasing mean value of the variable tested; sites joined by a common line are not significantly different.

Nutrient	Source	df	F	p	Tukey's post-hoc				
NH_4-N	Site	4	26.394	0.000	EST	K1	K2	K3	K4
	Year	2	14.403	0.095	2012	2011	2013		
	Site*Year	8	2.665	0.017					
	Corrected total	62							
NO_3-N	Site	4	3.490	0.014	K1	K4	K3	EST	K2
	Year	2	26.330	0.000	2013	2011	2012		
	Site*Year	8	2.455	0.026					
	Corrected total	62							
N-total	Site	4	11.910	0.000	EST	K1	K2	K3	K4
	Year	2	2.436	0.098	2011	2012	2013		
	Site*Year	8	1.280	0.276					
	Corrected total	62							
P-total	Site	4	17.887	0.000	K4	K2	K3	K1	EST
	Year	2	6.179	0.004	2011	2013	2012		
	Site*Year	8	0.822	0.587					
	Corrected total	62							

Table 2C-3. Results from two-way ANOVA and Tukey's *post hoc* testing for significant year or site effects on metals composition of sediments ($\log_{10}(x+1)$ transformed means). Only significant results are shown (significance level p <0.05). Sites are arranged in order of increasing mean value of the variable tested; sites joined by a common line are not significantly different.

Metal	*Source*	*df*	*F*	*p*	*Tukey's post-hoc*				
Ag	Site	4	0.259	0.903	EST	K2	K3	K4	K1
	Year	2	19.761	0.000	2011	2013	2012		
	Site*Year	8	0.265	0.974					
	Corrected total	62							
Al	Site	4	9.952	0.000	EST	K4	K1	K3	K2
	Year	2	16.986	0.000	2011	2012	2013		
	Site*Year	8	2.054	0.060					
	Corrected total	62							
As	Site	4	24.947	0.000	K3	K4	K2	K1	EST
	Year	2	16.038	0.000	2011	2013	2012		
	Site*Year	8	2.518	0.023					
	Corrected total	62							
B	Site	4	72.618	0.000	K4	K3	K2	K1	EST
	Year	2	10.801	0.001	2011	2012	2013		
	Site*Year	8	2.624	0.018					
	Corrected total	62							
Ba	Site	4	67.822	0.000	EST	K1	K3	K2	K4
	Year	2	0.206	0.815	2011	2012	2013		
	Site*Year	8	0.764	0.636					
	Corrected total	62							
Bi	Site	4	62.210	0.000	EST	K1	K3	K2	K4
	Year	2	9.127	0.000	2011	2012	2013		
	Site*Year	8	3.905	0.001					
	Corrected total	62							
Co	Site	4	19.629	0.000	EST	K3	K1	K2	K4
	Year	2	0.462	0.633	2011	2013	2012		
	Site*Year	8	0.310	0.958					
	Corrected total	62							
Cr	Site	4	13.059	0.000	EST	K4	K1	K2	K3
	Year	2	23.298	0.000	2011	2012	2013		
	Site*Year	8	2.495	0.024					
	Corrected total	62							
Cu	Site	4	34.783	0.000	EST	K4	K1	K2	K3
	Year	2	10.683	0.000	2011	2012	2013		
	Site*Year	8	1.953	0.073					
	Corrected total	62							
Fe	Site	4	11.183	0.000	EST	K4	K1	K2	K3
	Year	2	15.017	0.000	2011	2012	2013		
	Site*Year	8	1.652	0.135					
	Corrected total	62							
Ga	Site	4	21.947	0.000	EST	K1	K4	K3	K2
	Year	2	60.983	0.000	2011	2012	2013		
	Site*Year	8	5.525	0.000					
	Corrected total	62							
Hg	Site	4	1.493	0.219	K3	K2	K4	K1	EST
	Year	2	10.167	0.000	2013	2012	2011		
	Site*Year	8	0.903	0.522					
	Corrected total	62							
La	Site	4	6.246	0.000	EST	K1	K3	K4	K2
	Year	2	5.763	0.006	2011	2012	2013		
	Site*Year	8	0.740	0.656					
	Corrected total	62							
Li	Site	4	5.525	0.001	K4	K3	K2	K1	EST
	Year	2	12.510	0.000	2011	2012	2013		
	Site*Year	8	1.579	0.156					
	Corrected total	62							

Metal	*Source*	*df*	*F*	*p*	*Tukey's post-hoc*				
Mn	Site	4	4.934	0.002	EST	K1	K3	K2	K4
	Year	2	1.238	0.299	2013	2012	2011		
	Site*Year	8	0.309	0.959					
	Corrected total	62							
Ni	Site	4	27.323	0.000	EST	K4	K1	K3	K2
	Year	2	16.538	0.000	2011	2013	2012		
	Site*Year	8	4.999	0.000					
	Corrected total	62							
Pb	Site	4	37.800	0.000	EST	K1	K4	K3	K2
	Year	2	3.071	0.056	2011	2013	2012		
	Site*Year	8	2.301	0.036					
	Corrected total	62							
Sb	Site	4	5.039	0.002	EST	K1	K2	K4	K3
	Year	2	16.650	0.000	2011	2012	2013		
	Site*Year	8	1.727	0.116					
	Corrected total	62							
Se	Site	4	10.826	0.000	EST	K1	K3	K2	K4
	Year	2	16.650	0.000	2011	2012	2013		
	Site*Year	8	1.562	0.161					
	Corrected total	62							
Si	Site	4	3.006	0.027	EST	K2	K1	K3	K4
	Year	2	121.888	0.000	2012	2011	2013		
	Site*Year	8	8.379	0.000					
	Corrected total	62							
Ti	Site	4	77.180	0.000	K4	K2	K3	K1	EST
	Year	2	19.328	0.000	2011	2013	2012		
	Site*Year	8	2.507	0.023					
	Corrected total	62							
U	Site	4	14.185	0.000	EST	K1	K4	K3	K2
	Year	2	11.596	0.000	2011	2012	2013		
	Site*Year	8	1.977	0.070					
	Corrected total	62							
V	Site	4	52.789	0.000	EST	K1	K4	K2	K3
	Year	2	3.987	0.025	2011	2012	2013		
	Site*Year	8	1.318	0.258					
	Corrected total	62							
Zn	Site	4	9.283	0.000	EST	K4	K1	K2	K3
	Year	2	23.607	0.000	2011	2012	2013		
	Site*Year	8	2.444	0.026					
	Corrected total	62							

Table 2C-4. 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 sites, and (C) between years; ∗ = sites significant different (p <0.05).

A.

Two-factor PERMANOVA				
Source	*df*	*MS*	*Pseudo-F*	*p*
Site	4	214.71	11.783	0.001
Year	2	191.24	10.495	0.001
Site*Year	8	31.563	1.732	0.012
Residual	48	18.221		
Total	62			

B.

PERMANOVA post hoc tests for Site				
	K1	*K2*	*K3*	*K4*
K2	1.87*			
K3	2.48*	1.48		
K4	2.37*	1.77*	1.58*	
EST	3.89*	5.45*	5.98*	4.94*

C.

PERMANOVA post hoc tests for Year		
	2011	*2012*
2012	2.82*	
3.89	2.52*	2.90*

Appendix 3A ANZECC/ARMCANZ (2000) Water Quality Guidelines

Table 3A-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 >25°C. NH_3 and NH_4^+ species co-exist in equilibrium that is controlled by pH, and to a lesser extent by temperature.

Table 3A-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 3A continued.

Table 3A-3. ANZECC/ARMCANZ (2000) Default trigger values for toxicants at alternative levels of protection for the protection of aquatic ecosystems, applicable to tropical systems in Australia. Values shaded grey are TVs applicable to slightly-moderately disturbed systems. All values in mg/L.

COMPOUND		Trigger 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 3B 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 (^oC)	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 3B 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 3B 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 3B 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 3C Water Quality ANOVA & PERMANOVA Results

Table 3C-1. Results from two-way ANOVA and Tukey's *post hoc* testing for significant year or site effects on general water quality parameters ($\log_{10}(x+1)$ transformed means). Sites are arranged in order of increasing mean value of the variable tested; sites joined by a common line are not significantly different (p >0.05).

Parameter	*Source*	*df*	*F*	*p*	*Tukey's post-hoc*					
Acidity (mg/L)*	Site	5	11.284	0.000	K1	K3	REF	K2	K4	EST
	Year	1	41.405	0.000	2012	2013				
	Site*Year	5	14.203	0.000						
	Corrected total	51								
DO%	Site	5	24.160	0.000	K4	REF	K3	EST	K1	K2
	Year	2	7.456	0.001	2013	2012	2011			
	Site*Year	10	2.001	0.049						
	Corrected total	77								
EC (mS/m)	Site	5	2391	0.000	REF	K4	K3	K2	K1	EST
	Year	2	252.87	0.000	2011	2012	2013			
	Site*Year	2	64.2	0.000						
	Corrected total	77								
pH	Site	5	55.040	0.000	K4	REF	K3	EST	K2	K1
	Year	2	16.765	0.000	2012	2013	2011			
	Site*Year	10	2.267	0.025						
	Corrected total	77								
Temp. (°C)	Site	5	8.136	0.000	K4	K3	EST	REF	K1	K2
	Year	2	67.887	0.000	2012	2011	2013			
	Site*Year	10	8.531	0.000						
	Corrected total	77								
Turbid (NTU)	Site	5	30.536	0.000	REF	K1	K2	K3	K4	EST
	Year	2	15.622	0.000	2011	2012	2013			
	Site*Year	10	0.658	0.758						
	Corrected total	77								

*Acidity not measured in 2011.

Table 3C-2. Results from two-way ANOVA and Tukey's *post hoc* testing for significant year or site effects on concentration (mg/L) of major ions, alkalinity and hardness ($\log_{10}(x+1)$ transformed means) in surface waters. Sites are arranged in order of increasing mean value of the variable tested; sites joined by a common line are not significantly different (p >0.05).

Major Ions	*Source*	*df*	*F*	*p*	*Tukey's post-hoc*					
Alkalinity	Site	5	6.394	0.000	REF	K4	K3	K2	EST	K1
	Year	2	0.470	0.627	2012	2013	2011			
	Site*Year	10	0.788	0.640						
	Corrected total	77								
Ca	Site	5	1061.6	0.000	REF	K4	K3	K2	K1	EST
	Year	2	96.142	0.000	2011	2012	2013			
	Site*Year	10	27.028	0.000						
	Corrected total	77								
Cl	Site	5	759.58	0.000	REF	K4	K3	K2	K1	EST
	Year	2	62.120	0.000	2011	2012	2013			
	Site*Year	10	13.206	0.000						
	Corrected total	77								
F*	Site	5	257.74	0.000	REF	K4	K3	K2	K1	EST
	Year	1	83.215	0.000	2012	2013				
	Site*Year	5	13.622	0.000						
	Corrected total	51								
K**	Site	3	1543.0	0.000	K4	K3	K2	K1		
	Year	1	946.89	0.000	2011	2013				
	Site*Year	3	165.82	0.000						
	Corrected total	35								
Hardness*	Site		1060.1	0.000	REF	K4	K3	K2	K1	EST
	Year		156.56	0.000	2012	2013				

	Site*Year		43.151	0.000						
	Corrected total									
HCO_3*	Site	5	5.796	0.000	REF	K4	K3	K2	K1	EST
	Year	1	0.043	0.836	2013	2012				
	Site*Year	5	0.407	0.841						
	Corrected total	51								
Mg	Site	5	220.35	0.000	REF	K4	K3	K2	K1	EST
	Year	2	6.863	0.002	2011	2012	2013			
	Site*Year	10	13.918	0.000						
	Corrected total	77								
SO_4**	Site	3	1314.5	0.000	K4	K3	K2	K1		
	Year	1	873.37	0.000	2011	2013				
	Site*Year	3	196.91	0.000						
	Corrected total	35								
TDS@180°C	Site	5	2414.3	0.000	REF	K4	K3	K2	K1	EST
	Year	2	294.35	0.000	2011	2012	2013			
	Site*Year	10	64.681	0.000						
	Corrected total	77								
TSS*	Site	5	36.502	0.000	K1	K2	K3	K4	REF	EST
	Year	1	3.702	0.061	2012	2013				
	Site*Year	5	2.085	0.087						
	Corrected total	51								

* F, hardness (as $CaCO_3$), HCO_3 and TSS not measured in 2011;

** K and SO_4 only measured at K1 to K4 sites and not measured in 2012.

Table 3C-3. Results from two-way ANOVA and Tukey's *post hoc* testing for significant year or site effects on concentration (mg/L) of nutrients and dissolved organic carbon ($\log_{10}(x+1)$ transformed means) in surface waters. Sites are arranged in order of increasing mean value of the variable tested; sites joined by a common line are not significantly different (p >0.05).

Nutrient	*Source*	*df*	*F*	*p*	*Tukey's post-hoc*					
DOC*	Site	5	8.517	0.000	K4	EST	K3	K2	REF	K1
	Year	1	4.972	0.031	2012	2013				
	Site*Year	5	0.895	0.494						
	Corrected total	51								
NH_3-N	Site	5	4.272	0.002	K3	K2	K4	REF	K1	EST
	Year	2	1.771	0.179	2011	2012	2013			
	Site*Year	10	0.630	0.782						
	Corrected total	77								
N-organic*	Site	5	3.198	0.016	K4	K3	K2	EST	REF	K1
	Year	1	0.513	0.478	2012	2013				
	Site*Year	5	0.485	0.785						
	Corrected total	51								
N-total soluble*	Site		3.255	0.015	K4	K3	EST	K2	REF	K1
	Year		0.013	0.911	2012	2013				
	Site*Year		0.350	0.879						
	Corrected total									
N-total	Site		7.071	0.000	K4	K3	K2	REF	K1	EST
	Year		7.425	0.001	2011	2012	2013			
	Site*Year		1.610	0.126						
	Corrected total									

* DOC, N-organic and N-total soluble not measured in 2011.

Table 3C-4. Summary of (A) two-factor PERMANOVA results comparing surface water quality between site and year, and (B) PERMANOVA *post hoc* results showing t-values for all pairwise comparisons between sites, and (C) between years; ∗ = sites significant different (p <0.05).

A.

Two-factor PERMANOVA				
Source	*df*	*MS*	*Pseudo-F*	*p*
Site	5	100.28	33.908	0.001
Year	2	36.291	12.271	0.001
Site*Year	10	8.667	2.931	0.001
Residual	60	0.647		
Total	77			

B.

PERMANOVA post hoc tests for Year		
	2011	**2012**
2012	1.99*	
2013	3.94*	3.92*

C.

PERMANOVA post hoc tests for Site					
	REF	**K1**	**K2**	**K3**	**K4**
REF					
K1	5.78*				
K2	3.37*	6.75*			
K3	1.73*	10.15*	5.79*		
K4	2.40*	12.22*	14.27*	11.29*	
EST	5.67	3.84*	6.27*	7.20*	6.03*

Appendix 4A Macroinvertebrates 2013

Macroinvertebrate species abundance data for Sep/Oct 2013, 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.-*

TAXA	REFERENCE SITES					KEEP RIVER POOLS K4 TO K1																	
	DR1	KR2	KR1	KE-1	SR4	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
PLATYHELMINTHES																							
Turbellaria sp.	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NEMATODA	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NEMERTEA	1	0	0	3	0	2	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ANNELIDA																							
OLIGOCHAETA																							
Oligochaeta sp.	0	2	0	0	1	0	2	2	2	0	0	2	1	0	0	0	0	0	0	0	0	0	0
Tubificida																							
Naididae																							
Allonais inaequalis	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Allonais paraguayensis	2	2	0	0	2	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Allonais pectinata	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Allonais ranauana	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bratislavia unidentata	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dero furcata	2	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dero sp.	0	0	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naidinae spp.	4	3	0	3	3	2	0	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Pristina spp.	0	1	0	2	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
POLYCHAETA																							
Phyllodocida																							
Nereididae	0	0	0	0	0	0	0	0	0	0	0	0	1	3	3	3	3	3	3	3	3	3	3
CNIDARIA																							
HYDROZOA																							
Hydridae																							
Hydra sp.	0	0	0	4	0	1	0	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MOLLUSCA																							
BIVALVIA																							
Bivalvia sp. A (estuarine)	0	0	0	0	0	0	0	0	2	3	3	3	3	3	0	4	3	3	0	0	0	0	0
Corbiculidae																							
Corbicula sp.	1	0	0	0	0	0	2	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GASTROPODA																							
Gastropoda sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
Ancylidae																							
Ferrissia petterdi	2	2	0	1	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lymnaeidae																							
Bullastra vinosa	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Planorbidae																							
Amerianna sp.	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gyraulus sp.	2	3	3	3	2	2	2	2	3	3	0	2	3	0	0	0	0	0	0	0	0	0	0
Tateidae																							
Tateidae sp. KEEP01	0	0	0	0	0	0	0	0	0	0	2	3	3	2	0	3	2	3	0	0	0	0	0
Tateidae sp. KEEP02	0	0	0	2	0	0	0	0	0	0	0	0	0	1	0	4	2	4	0	0	0	0	0
Thiaridae																							
Thiara sp.	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AMPHIPODA																							
Corophiidae?	0	0	0	0	0	0	0	0	3	0	3	3	3	3	3	3	3	3	3	3	3	2	2

Appendix 4A continued.

TAXA	REFERENCE SITES					KEEP RIVER POOLS K4 TO K1																	
	DR1	KR2	KR1	KE-1	SR4	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
DECAPODA																							
Atyidae																							
Caridina 'nilotica' sp.	0	3	2	0	0	2	0	2	3	2	3	0	0	0	0	2	2	0	0	1	0	0	0
Caridina serratirostris	2	2	3	0	2	2	3	2	3	3	2	2	0	2	0	2	3	2	0	0	0	0	0
Caridina sp. (juv.)	0	0	0	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Hymenosomatidae																							
Amarinus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0
Palaemonidae																							
Macrobrachium bullatum	0	2	0	0	2	0	2	0	2	0	1	0	0	1	0	0	0	2	1	2	2	0	0
Macrobrachium rosenbergii	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Macrobrachium sp. (juv.)	2	0	0	0	0	1	0	2	2	0	0	0	0	0	0	0	2	0	0	2	0	1	2
ARACHNIDA																							
Trombidiformes																							
Hydracarina spp.	3	3	3	2	3	0	0	2	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0
COLLEMBOLA																							
ENTOGNATHA																							
Entomobryomorpha																							
Entomobryoidea sp.	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
INSECTA																							
NEUROPTERA																							
Sisyridae	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EPHEMEROPTERA																							
Baetidae																							
Baetidae spp. (juv.)	3	3	3	2	3	3	3	3	3	3	3	2	0	2	2	2	0	0	0	0	0	0	0
Cloeon fluviatile	3	3	3	2	2	0	3	2	2	3	1	0	0	0	2	0	0	0	0	0	0	0	0
Cloeon sp.	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
Cloeon sp. ('red stripe')	0	0	2	0	0	3	2	0	0	0	1	0	0	0	2	0	0	0	0	0	0	0	0
Pseudocloeon sp.	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Caenidae																							
Caenidae sp. (juv.)	3	3	3	2	3	0	2	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tasmanocoenis sp. M	2	2	2	0	2	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tasmanocoenis sp. P/*arcuata*	2	2	2	0	2	1	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wundacaenis dostini	3	3	0	2	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Leptophlebiidae																							
Leptophlebiidae sp. (juv.)	2	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Manggabora wapitja	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ODONATA																							
ANISOPTERA																							
Anisoptera spp.	2	2	1	0	2	3	1	1	2	2	2	2	0	0	0	2	0	1	0	0	0	0	0
Austrocorduliidae																							
Austrocordulia territoria	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coenagrionidae																							
Coenagrionidae spp. (juv.)	0	0	0	0	0	3	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
Ischnura heterosticta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Ischnura sp. (juv.)	0	0	2	2	2	2	0	0	1	2	0	0	0	2	3	3	3	3	0	0	0	0	0
Pseudagrion microcephalum	2	2	0	1	0	2	2	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Pseudagrion sp. (juv.)	0	0	0	0	0	0	0	1	0	3	2	2	2	3	2	2	2	3	0	0	0	0	0
Corduliidae																							
Hemicordulia intermedia	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hemicordulia sp. (juv.)	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gomphidae																							
Austrogomphus arbustorum	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 4A continued.

TAXA	REFERENCE SITES					KEEP RIVER POOLS K4 TO K1																	
	DR1	KR2	KR1	KE-1	SR4	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
Libellulidae																							
Crocothemis nigrifrons	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Diplacodes haematodes	0	1	2	0	0	0	2	2	2	3	3	1	0	0	0	0	0	0	0	0	0	0	0
Diplacodes sp. (juv.)	0	0	0	0	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrobasileus brevistylus	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Libellulidae sp. (juv.)	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Macrodiplax cora	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	2	0	0	0	0	0	0
Nannophlebia spp.	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Orthetrum caledonicum	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ZYGOPTERA																							
Zygoptera spp. (juv.)	2	2	2	2	2	2	2	1	0	1	2	2	2	1	3	2	2	3	0	0	0	0	0
Isostictidae																							
Eurysticta kununurra	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Platycnemididae	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nososticta sp. (juv.)	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HEMIPTERA	0																						
Belostomatidae	0																						
Belostomatidae sp. (juv.)	0	0	1	2	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diplonychus sp.	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Corixidae/Micronectidae (juv.)	1	0	1	2	0	0	0	3	0	0	2	2	0	0	0	0	0	0	0	0	1	0	0
Gerridae																							
Gerridae sp. (juv.)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Limnogonus fossarum gilguy	0	0	0	0	0	2	0	2	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Limnogonus luctuosus	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rhagadotarsus anomalus	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hebridae																							
Hebridae sp.	0	1	0	2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Merragata hackeri	1	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mesoveliidae																							
Mesovelia horvathi	1	1	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Mesovelia sp. (juv.)	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Mesovelia vittigera	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Mesoveliidae sp. (juv.)	1	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0
Micronectidae																							
Austronecta micra	1	2	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Micronecta adelaidae	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Micronecta annae	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Micronecta paragoga	0	0	1	3	0	0	2	0	2	0	3	2	0	0	0	0	0	0	0	0	0	0	0
Micronecta spp. (juv.)	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Micronectidae sp. (juv.)	0	0	0	0	0	0	0	0	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0
Nepidae																							
Austronepa angusta	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nepidae sp. (juv.)	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Ranatra diminuta	0	0	0	0	0	0	1	0	2	1	0	0	0	0	0	0	0	0	0	0	1	0	0
Ranatra occidentalis	0	0	2	0	0	0	0	1	0	0	1	0	0	0	1	2	2	1	0	0	0	0	0
Ranatra spp.	0	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Notonectidae																							
Enithares loria	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Notonectidae sp. (juv.)	2	3	2	2	0	2	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Nychia sappho	0	3	2	0	2	2	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pleidae																							
Paraplea sp.	3	3	3	3	2	2	3	2	3	2	1	2	2	0	2	2	2	2	0	0	0	0	0

Appendix 4A continued.

TAXA	REFERENCE SITES					KEEP RIVER POOLS K4 TO K1																	
	DR1	KR2	KR1	KE-1	SR4	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
Veliidae																							
Microvelia herberti	0	1	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Microvelia katherinae	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Microvelia malipatili	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Microvelia odontogaster	0	1	1	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Microvelia peramoena	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Microvelia sp. (juv.)	0	2	2	0	2	2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Veliidae sp. (juv.)	2	2	0	0	2	2	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
COLEOPTERA																							
Carabidae	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dytiscidae																							
Batrachomatus sp. (L)	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bidessini sp. (L)	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0
Clypeodytes feryi	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Copelatus nigrolineatus	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cybister godeffroyi	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroglyphus basalis	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroglyphus fuscolineatus	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroglyphus leai	0	0	0	2	3	3	2	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Hydrovatus parallelus	0	0	1	0	0	0	1	1	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Hyphydrus lyratus	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Laccophilus cingulatus	2	0	2	0	0	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Laccophilus clarki	0	3	2	0	2	2	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Laccophilus sharpi	0	0	2	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Laccophilus sp. (L)	0	2	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Laccophilus unifasciatus	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Laccophilus walkeri	1	0	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Limbodessus compactus	0	1	1	1	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Megaporus ruficeps	0	0	0	0	0	0	0	0	1	1	2	1	0	0	0	2	1	1	0	0	0	0	0
Neobidessodes sp.	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sternopriscus aquilonaris	1	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.	0	0	0	0	3	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Austrolimnius sp. (L)	3	0	0	0	4	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Georissidae																							
Georissus sp.	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gyrinidae																							
Macrogyrus darlingtoni	0	0	0	0	3	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydraenidae																							
Hydraena sp.	2	3	3	0	0	2	2	2	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0
Hydraena sp. (L)	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Limnebius sp.	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ochthebius sp.	2	2	0	0	1	3	1	0	0	0	0	1	1	0	1	2	0	2	0	0	0	0	0
Hydrochidae																							
Hydrochus sp.	3	3	3	3	2	3	2	1	1	3	2	2	3	2	0	0	0	0	0	0	0	0	0
Hydrophilidae																							
Amphiops australicus	0	0	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	1	0	0	0	0	0
Amphiops duplopunctulatus	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphiops sp.	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphiops sp. (L)	0	1	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Berosus pulchellus	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enochrus deserticola	0	2	1	0	0	2	2	0	1	0	2	0	0	0	0	0	0	1	0	0	0	0	0

Appendix 4A continued.

TAXA	REFERENCE SITES					KEEP RIVER POOLS K4 TO K1																	
	DR1	KR2	KR1	KE-1	SR4	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
Helochares marreensis	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
Helochares sp. (L)	0	2	0	2	1	0	1	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Helochares tatei	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Paracymus pygmaeus	0	2	1	0	2	2	2	2	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Paracymus spenceri	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Regimbartia attenuata	0	1	2	2	2	1	1	0	0	0	0	1	0	2	1	2	2	0	0	1	2	1	0
Regimbartia sp. (L)	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Limnichidae	0	2	0	0	2	2	2	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Noteridae	2	0	0	0	0	0	0	1	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0
Hydrocanthus micans	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Neohydrocoptus subfasciatus	1	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Notomicrus tenellus	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scirtidae																							
Scirtidae sp. (L)	2	1	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Staphylinidae	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DIPTERA																							
Cecidomyiidae	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Ceratopogonidae																							
Ceratopogonidae spp. (P)	0	2	2	0	2	0	0	0	2	1	1	1	2	0	1	0	0	0	0	0	0	3	0
Ceratopogoninae spp.	3	2	0	3	2	2	3	3	2	2	2	3	0	2	2	2	2	0	0	0	0	0	0
Dasyheleinae spp.	2	2	0	2	3	3	1	2	0	0	0	1	1	1	0	0	0	0	0	0	1	4	0
Forcipomyiinae spp.	0	0	2	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chironomidae																							
Ablabesmyia sp. (ORT6)	2	1	2	0	1	0	0	0	2	2	2	0	1	0	0	0	0	0	0	0	0	0	0
Chironomidae spp. (P)	3	3	2	0	3	2	2	3	3	1	2	2	2	3	3	3	2	1	0	0	0	0	0
Chironomini sp. (ORC35)	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chironomini sp. (ORC36)	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chironomini sp. (ORC38)	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chironomini sp. (ORC39)	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chironomini sp. (ORC41)	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chironomini sp. (ORC43)	0	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chironomini sp. (ORC46)	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chironomini sp. (ORC47)	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chironomini sp. (ORC48)	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chironomus aff. *alternans*	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cladotanytarsus sp. (ORC2)	3	3	0	2	3	3	2	3	2	3	3	3	3	3	4	3	2	3	0	0	0	0	0
Clinotanypus crux	2	2	1	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Corynoneura sp. (ORO4)	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cricotopus sp. (ORO1)	2	0	1	0	3	0	0	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cryptochironomus ?griseidorsum	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dicrotendipes sp. 1	2	1	1	2	2	2	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dicrotendipes sp. 2	2	2	0	1	0	1	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Harnischia sp. (ORC7)	0	2	0	0	0	0	2	3	2	2	0	2	0	0	0	0	0	0	0	0	0	0	0
Harrisius sp. (ORC34)	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kiefferulus ?intertinctus	3	1	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Larsia ?albiceps	3	3	3	2	3	2	3	3	3	2	3	0	3	0	0	0	0	0	0	0	0	0	0
Nanocladius sp. 1	2	2	1	1	3	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nilotanypus sp. nov. (ORT4)	0	0	0	0	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Orthocladiinae sp. (ORO9)	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Parachironomus sp. (ORC11)	2	0	0	2	2	2	1	1	3	2	3	2	3	0	0	0	0	0	0	0	0	0	0
Paracladopelma nr. sp. M1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Parakiefferiella sp. 2	0	0	0	0	3	0	0	2	3	0	0	0	0	0	0	0	0	0	0	1	0	0	0

Appendix 4A continued.

TAXA	REFERENCE SITES					KEEP RIVER POOLS K4 TO K1																	
	DR1	KR2	KR1	KE-1	SR4	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
Paramerina sp. (ORT5)	0	0	3	0	3	1	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Parametriocnemis ornaticornis	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polypedilum (*Pentapedilum*) *leei*	3	2	2	2	3	3	2	3	3	2	2	2	2	2	2	0	0	0	0	0	0	0	0
Polypedilum nubifer	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polypedilum sp. 1	0	3	3	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polypedilum watsoni	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
Procladius sp. (ORT2)	4	2	0	0	2	0	3	3	2	0	1	1	0	0	0	0	0	0	0	0	1	0	0
Rheotanytarsus sp. (ORC15)	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rheotanytarsus sp. 2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rheotanytarsus sp. 3	3	3	2	0	4	0	1	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Skusella ?subvittata	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tanypodinae sp. (ORT15)	0	0	1	0	1	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tanypodinae sp. (ORT20)	3	3	0	0	2	2	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tanytarsus sp. (ORC1)	2	3	3	2	3	3	3	3	2	0	0	0	1	0	2	2	2	2	0	0	0	0	0
Thienemanniella sp. (ORO5)	0	0	0	0	3	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Culicidae																							
Aedes sp.	0	0	0	0	0	0	0	0	0	3	2	0	0	0	0	0	0	0	0	0	0	0	0
Anopheles spp.	2	0	1	0	0	2	0	1	3	2	2	2	3	2	1	1	0	0	0	0	0	0	0
Culex sp.	1	0	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Culicidae spp. (P)	0	0	0	0	0	0	0	0	0	1	2	1	1	2	0	0	0	0	0	0	0	0	0
Ephydridae	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Muscidae	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Psychodidae	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Simuliidae																							
Simuliidae spp.	0	0	0	0	4	0	0	2	3	0	0	0	2	0	0	0	0	0	0	1	0	0	1
Simuliidae spp. (P)	0	0	2	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stratiomyidae	1	2	2	1	2	3	2	2	1	0	2	2	2	0	0	0	0	0	0	0	0	0	0
Tabanidae	0	2	2	0	3	0	0	2	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0
Tanyderidae	2	0	2	1	2	2	0	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
TRICHOPTERA																							
Calamoceratidae																							
Anisocentropus sp.	0	0	2	0	2	0	1	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Ecnomidae																							
Ecnomus sp.	2	2	2	0	2	2	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Helicopsychidae	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydropsychidae																							
Cheumatopsyche wellsae	0	0	0	0	3	0	0	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroptilidae																							
Hellyethira sp.	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Orthotrichia sp.	0	2	2	1	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Leptoceridae																							
Leptoceridae sp. (juv.)	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Oecetis sp.	3	3	0	0	2	2	2	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Triaenodes sp.	2	2	2	0	2	0	3	0	1	0	0	1	0	0	0	0	0	0	0	1	0	0	0
Triplectides ciuskus seductus	2	2	2	0	2	1	2	2	2	1	1	2	2	0	0	0	0	0	0	0	0	0	0
Triplectides helvolus	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Philopotamidae	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chimarra sp. AV14	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 4A continued.

TAXA	REFERENCE SITES					KEEP RIVER POOLS K4 TO K1																	
	DR1	KR2	KR1	KE-1	SR4	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
LEPIDOPTERA																							
Lepidoptera spp.	0	0	0	0	3	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Crambidae																							
Eoophyla repetitalis	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Margarosticha sp. 3	0	0	0	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Parapoynx spp.	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrernia spp.	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 4B Macroinvertebrate ANOVA & PERMANOVA results

Table 4B-1. Results from two-way ANOVA and Tukey's *post hoc* testing for significant year or site effects on macroinvertebrate 'species' richness (log_{10} transformed means) in edge habitats. Sites are arranged in order of increasing mean value of the variable tested; sites joined by a common line are not significantly different.

Metric	*Source*	*df*	*F*	*p*	*Tukey's post-hoc*				
Richness	Site	4	95.024	0.000	K1	K2	K3	K4	Ref
	Year	2	10.487	0.000	2013	2012	2011		
	Site*Year	8	8.549	0.000					
	Corrected total	68							

Table 4B-2. Results from one-way ANOVA and Tukey's *post hoc* testing for significant year effects on macroinvertebrate 'species' richness (log_{10} transformed means) in edge habitats at individual Keep River pools (K1 to K4) or reference sites. Sites are arranged in order of increasing mean value of the variable tested; sites joined by a common line are not significantly different.

Site	*Source*	*df*	*F*	*p*	*Tukey's post-hoc*		
K1	Year	2	20.487	0.000	2013	2012	2011
	Total	14					
K2	Year	2	25.051	0.000	2013	2012	2011
	Total	17					
K3	Year	2	0.068	0.935	2011	2013	2012
	Total	17					
K4	Year	2	1.153	0.358	2011	2012	2013
	Total	11					
Ref	Year	2	0.017	0.983	2011	2013	2012
	Total	18					

Table 4B-3. Summary of (A) two-factor PERMANOVA results comparing macroinvertebrate 'species' assemblages (untransformed log_{10} abundance class) between site and year, and (B) PERMANOVA *post hoc* results showing t-values for all pairwise comparisons between sites, and (C) between years; ∗ = sites significant different (*p* <0.05).

A.

Two-factor PERMANOVA				
Source	**df**	**MS**	**Pseudo-F**	**p**
Site	4	13287	13.792	0.001
Year	2	8870	9.208	0.001
Site*Year	8	3435	3.566	0.001
Residual	54	963		
Total	68			

B.

PERMANOVA post hoc tests for Year		
	2011	**2012**
2012	2.21*	
2013	3.68*	3.04*

C.

PERMANOVA post hoc tests for Site				
	REF	**K1**	**K2**	**K3**
K1	5.45*			
K2	3.68*	4.16*		
K3	2.78*	4.65*	1.99*	
K4	1.97*	4.60*	2.90*	1.98*

Appendix 5A Fish species 2011-2013

Table 5A-1. Fish species abundance recorded from each site, all years combined (2011, 2012, 2013). Note, data include visual records. IUCN conservation codes: CR = critically endangered; DD = data deficient.

Family & Species	Common name	IUCN	Reference					K4			K3					K2					K1					Total
			DR1	KR2	KR1	KE1	SR4	-3	-2	-1	-5	-4	-3	-2	-1	-5	-4	-3	-2	-1	-5	-4	-3	-2	-1	
Ambassidae																										
Ambassis sp.	Glassfish									1	1				1				1							**4**
Parambassis gulliveri	Giant glassfish									1																**1**
Apogonidae																										
Glossamia aprion	Mouth almighty					1																1				**2**
Ariidae																										
Neoarius graeffei	Blue catfish		5	64	17	13	2	20	7	9	4	8	17	23	20	12	7	4	6	6	3	5	5	7	4	**268**
Neoarius midgleyi	Shovel-nosed catfish		4										1										4		1	**10**
Plicofollis argyropleuron	Long-snouted catfish																								1	**1**
Belonida																										
Strongylura krefftii	Freshwater longtom			1	1		1		1			2				1	1		1	3				1		**13**
Carangidae																										
Scomberoides commersonianus	Giant queenfish																								1	**1**
Carcharhinidae																										
Carcharhinus leucas	Bull shark											2	1	1	1			1				2	4	9	1	**22**
Centropomidae																										
Lates calcarifer	Barramundi			20		7		7	4	2	3	1	5	2	7	4		1		2	3	2	6	3	10	**89**
Clupeidae																										
Nematalosa erebi	Bony bream		43	26	28	19	43	11	22	36	42	20	30	34	37	61	18	56	111	46	51	58	42	73	150	**1057**
Nematalosa vlaminghi	Perth herring																							4	44	**48**
Dasyatidae																										
Himantura dalyensis	Freshwater whipray	**DD**					1																			**1**
Eleotridae																										
Hypseleotris compressa	Empire gudgeon											1														**1**
Mogurnda mogurnda	Northern trout gudgeon									1																**1**
Elopidae																										
Elops australis	Herring											1							1		1		1		1	**5**
Engraulidae																										
Thryssa kammalensis	Anchovy									7	3	2	2		1		3									**18**
Thryssa sp.	Anchovy											1	1					1	1						11	**15**
Gerreidae																										
Geres filamentosus	Threadfin silver-biddy						1																			**1**
Haemulidae																										
Pomadasys kaakan	Barred javelinfish																					1	1			**2**

Family & Species	Common name	IUCN	Reference					K4			K3					K2					K1					Total
			DR1	KR2	KR1	KE1	SR4	-3	-2	-1	-5	-4	-3	-2	-1	-5	-4	-3	-2	-1	-5	-4	-3	-2	-1	
Hemiramphidae																										
Arrhamphus sclerolepis	Snub-nosed garfish															3		7	1			1	1	6	8	**27**
Kurtidae																										
Kurtus gulliveri	Nurseryfish															1			2					1		**4**
Leiognathidae																										
Leiognathus equulus	Common ponyfish					1					1		1	1	4	3	3	1	3	5	5		3	3	5	**39**
Lutjanidae																										
Lutjanus argentimaculatus	Mangrove jack																					1				**1**
Megalopidae																										
Megalops cyprinoides	Oxeye herring				2	4			1	2			1				1								2	**13**
Melanotaeniidae																										
Melanotaenia australis	Western rainbowfish				15		31		68																	**114**
Mugilidae																										
Liza alata	Diamond mullet		17	19		41	1	12	10	11	10	5	12	16	11	11	7	7	15	12	8	16	19	19	26	**305**
Liza sp.	Mullet										4			3	3	5				1	1		1	3	6	**27**
Mugil cephalus	Sea mullet																				3				3	**6**
Plotosidae																										
Anodontiglanis dahli	Toothless catfish					2	2																			**4**
Neosilurus ater	Narrow-fronted tandan					1		3	6	7																**17**
Polynemidae																										
Eleutheronema tetradactylum	Blue threadfin																				8	1		2	8	**19**
Polydactylus macrochir	Giant threadfin																	1							2	**3**
Pristidae																										
Pristis pristis	Freshwater sawfish	**CR**		2												2		4		1				1		**10**
Sciaenidae																										**3**
Nibea soldado	Soldier croaker														1											**1**
Nibea squamosa	Scaly croaker															2										**2**
Terapontidae																										
Amniataba percoides	Barred grunter		2	2	14		7																			**25**
Hephaestus jenkinsi	Western sooty grunter				2												1									**3**
Tetraodontidae																										
Marilyna meraukensis	Merauke toadfish											1		1			1									**3**
Toxotidae																										
Toxotes chatareus	Seven-spot archerfish			9	2	1	1	1	3	1	2	1	1	1	3	5			3	4	3	2	2	1	2	**48**
	Total		**71**	**143**	**81**	**90**	**90**	**54**	**122**	**71**	**70**	**44**	**71**	**83**	**89**	**114**	**41**	**87**	**153**	**80**	**86**	**90**	**89**	**133**	**297**	**2249**

Appendix 5B Fish ANOVA & PERMANOVA results

Table 5B-1. Results from two-way ANOVA and Tukey's *post hoc* testing for significant year or site effects on fish species richness, abundance or biomass (log_{10} transformed means). Sites are arranged in order of increasing mean value of the variable tested; sites joined by a common line are not significantly different ($p > 0.05$). Note difference in results for ANOVA and Tukey's analyses on biomass; ANOVA indicated significant year and site effects for biomass, but Tukey's did not.

Metric	*Source*	*df*	*F*	*p*	*Tukey's post-hoc*				
Richness	Site	4	2.178	0.085	K4	Ref	K3	K2	K1
	Year	2	4.297	0.019	2013	2012	2011		
	Site*Year	8	0.982	0.461					
	Corrected total	65							
Abundance	Site	4	3.794	0.009	K4	K3	K2	Ref	K1
	Year	2	1.358	0.266	2012	2013	2011		
	Site*Year	8	1.213	0.310					
	Corrected total	65							
Biomass	Site	4	2.839	0.034	K2	K3	K4	K1	Ref
	Year	2	3.484	0.038	2013	2012	2011		
	Site*Year	8	0.587	0.784					
	Corrected total	65							

Table 5B-2. Summary of (A) two-factor PERMANOVA results comparing fish species assemblages (log_{10} transformed abundance) between site and year, and (B) PERMANOVA *post hoc* results showing t-values for all pairwise comparisons between sites, and (C) between years; * = sites significant different ($p < 0.05$).

A.

Two-factor PERMANOVA – fish abundance				
Source	*df*	*MS*	*Pseudo-F*	*p*
Site	4	4086	3.624	0.001
Year	2	3342	2.964	0.001
Site*Year	8	1878	1.666	0.005
Residual	51	1127		
Total	65			

B.

PERMANOVA post hoc tests for Year		
	2011	**2012**
2012	1.54*	
2013	2.29*	1.18

C.

PERMANOVA post hoc tests for Site				
	REF	**K1**	**K2**	**K3**
K1	1.89*			
K2	1.90*	1.44*		
K3	1.60*	1.67*	1.57*	
K4	1.61*	2.59*	2.72*	2.09*

Tables continued overpage.

Appendix 5B continued.

Table 5B-3. Summary of (A) two-factor PERMANOVA results comparing fish species assemblages (log_{10} transformed biomass) between site and year, and (B) PERMANOVA *post hoc* results showing t-values for all pairwise comparisons between sites, and (C) between years; * = sites significant different (p <0.05).

A.

Two-factor PERMANOVA – fish biomass				
Source	*df*	*MS*	*Pseudo-F*	*p*
Site	4	3560	3.407	0.001
Year	2	3892	3.724	0.001
Site*Year	8	1515	1.450	0.039
Residual	51	1045		
Total	65			

B.

PERMANOVA post hoc tests for Year		
	2011	**2012**
2012	1.10	
2013	2.50*	1.58*

C.

PERMANOVA post hoc tests for Site				
	REF	**K1**	**K2**	**K3**
K1	1.67*			
K2	1.74*	1.29		
K3	1.37	1.34	1.47	
K4	1.98*	2.85*	3.23*	2.66*