ORIA STAGE II EXPANSION
KEEP RIVER

BASELINE AQUATIC FAUNA & TARGETED SAWFISH SURVEYS SEPTEMBER/OCTOBER 2012 DRAFTv2 REPORT

Wetland Research & Management

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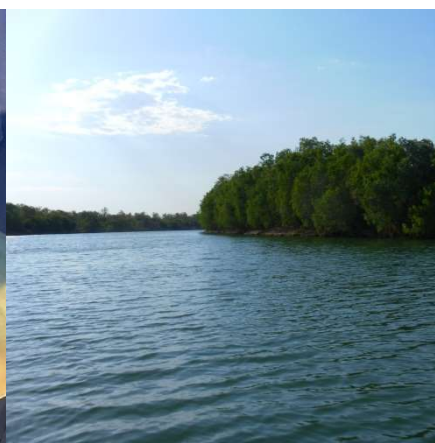

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Disclaimer

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Frontispiece (left to right): measuring *in situ* water quality at Milligan's Lagoon; a juvenile *Pristis clavata* from the Keep River estuary; and the Keep River at pool K2 (all photos by WRM staff ©).

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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 current development of the Weaber and Knox Creek Plains, referred to as the M2 Supply Area, will increase the current area under irrigation from 14,000 ha to potentially 30, 500 ha (being the M2 stage developed in full) (DoW, 2006). Current consumption by Stage 1 is approximately 300 GL/a, with demand for M2 fully developed being approx. 690 GL/a (DoW, 2006). 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, to develop irrigated agriculture on the Weaber Plain. 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 2009. Initially, development is targeting the Weaber Plains area, located approximately 30 km north-east of Kununurra. Approximately 7500 ha will be developed, requiring 80 – 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. The system consists of ditches to collect tail-water, a storage area, and return pumps and pipelines for reuse as irrigation water (GHD 2010). The management of the tail-water system will be seasonal. During the dry season or between intermittent rainfall events, the farms will be irrigated and the system will retain tail-water for reuse. During the wet season, the tail-water system along with other on-farm storage will function to retain the first 25 mm of stormwater runoff. When the surface runoff exceeds this retention capacity, the excess runoff will overflow from the farm at a designated point via a controlled discharge. It is proposed that this excess runoff along the internal buffer area be transported via various internal drains into the upper reaches of Border Creek, which ultimately discharges into the Keep River.

As a result of the irrigation scheme, groundwater accession is expected to occur, although the precise extent and rate of such depends on many factors including wet season rainfall, crop types and the adaptive groundwater management strategy. The groundwater levels will be monitored and, where required, managed using a network of dewatering bores (Strategen 2012a). Where possible, groundwater extracted as part of the groundwater management strategy will be reused for irrigation. When groundwater cannot be reused for irrigation purposes (i.e. if irrigation is in low demand, for example during the wet season, or if long-term groundwater salinity exceeds the limits for shandying with M2 irrigation water) then excess pumped groundwater will be collected in a storage reservoir and/or discharged to the Keep River.

The initial design plan for the greater Ord M2 area, which includes the Weaber, as well as Keep and Knox Creek plains, acknowledged there would be groundwater recharge and increases in groundwater levels, which would require active pumping to manage. The initial design stated that groundwater would be discharged directly into the estuary of the Keep River, where it was anticipated the brackish/saline groundwater would be rapidly mixed given the dynamic nature of the estuary (Kinhill 2000). However, subsequent design planning and costing for the initial Weaber Plains development has highlighted the high cost of conveying pumped groundwater as far as the estuary. Also, through the removal of some land from the development, combined with on-farm management, any recharge and rise in groundwater levels is anticipated to be minimal, with pumping and discharge not required for up to ~10 years post development. The design approved by the Commonwealth is to discharge

groundwater directly to the Keep River in the most downstream pool (pool K1) (Strategen 2012b), but with the option in future years to assess discharge to pool K3, immediately downstream of the Legune Road Crossing. This option previously had not been considered in environmental planning, and so requires re-assessment for ecological impacts.

Under the current plan, brackish/saline groundwater would be discharged into the Keep River at pool K1, however, in the event of exceedance of water quality trigger values as a result off-farm releases down Border Creek, the mitigation option is to discharge M2 water to flush receiving pool K3, K2 and K1 (Strategen 2012b), which are known to support high ecological values (Larson 1999, NCTWR 2005, KBR 2006, WRM 2010a).

Increased groundwater recharge associated with the development is likely to result in increased baseflow in the lower Keep system, with a potential increase in salinity (DAFWA, 2011; Strategen, 2012a). This will affect flows and conductivity in the three pools downstream of the Legune Road Crossing (K3, K2 and K1) to varying extents, but also the pool immediately upstream of the crossing (K4). However, baseflows in these pools have naturally increased since 1999 due to groundwater recharge following a series of wet years, resulting in perennial flows, and a slight increase in conductivity (from ~ 30 to 80+ mS/m; Bennet and George 2012), in a reach that previously had seasonal flows.

Ultimately, the development has the potential to impact water quality and aquatic fauna of the Keep River. The main potential environmental issues relating to aquatic ecosystem health include:

- contaminated stormwater runoff (agricultural fertilisers and agrochemicals) via Border Creek into the Keep River may affect water quality and lead to habitat degradation particularly during low river flow
- discharge of excess abstracted groundwater to the Keep River during high river flows may affect water quality and lead to habitat degradation in the most downstream pool/upper estuary
- discharges to the Border Creek and the Keep River discharge area, may increase erosion especially during periods of surplus stormwater runoff, leading to increased TSS/siltation

Only limited data are currently available on the aquatic ecological values of these Keep River pools. Both surveyed and anecdotal data exist, including:

- incidental records of freshwater sawfish (*Pristis pristis*, previously known as *Pristis microdon*[1]) and dwarf sawfish (*Pristis clavata*) from the system by anglers
- recording of *P. pristis* from pool K4 on one occasion (WRC 2003a)
- assumed social/ecological values based on visitation and comments from anglers
- fish data collected on one occasion by NT Museum by Helen Larson in ~ Nov/Dec 1998 (Larson 1999)
- one sample of fish and invertebrates collected from pool K2 in June/July 2004 by NCTWR (2005), as part of a wider survey of the area
- suspicions that the listed Speartooth sharks (*Glyphis* spp.) may occur in the system as well as the freshwater whiprays.

[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*. As such, this species will be referred to as *Pristis pristis* throughout this document.

In June 2010, the Australian 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 a number of EPBC conditions, issued on 13 September 2011. 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 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*)
- the vulnerable Freshwater Sawfish (*Pristis microdon*; now referred to as *P. pristis*).

The Aquatic Fauna Management Plan addresses each requirement of Condition 10 of the EPBC approval. It outlines specific protective and monitoring measures that are to be implemented for the protection of the listed species and requires approval from the Minister for Sustainability, Environment, Water, Population and Communities prior to the clearance of farm lots. To meet the requirements of the Commonwealth Conditions, Landcorp commissioned WRM to undertake extensive baseline surveys and establish ecological condition, as well as occurrence of listed species. The first round of surveys was completed in September/October 2011 and reported in WRM (2013). This report presents the findings from the second round of sampling undertaken in September 2012. A third and final round of baseline data collection will be conducted in September 2013.

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 (WRM 2013) to develop surface water trigger values for assessing effects of any discharge to the Keep River.

1.2 Scope of work

This report presents the findings from sampling in September 2012 for a number of specific aquatic studies designed to collect sufficient baseline data to allow the detection of future impacts, if any, from the development. These studies include:

1. Analyses of sediment quality in potentially exposed pools
2. Targeted sawfish and shark surveys to ascertain distribution and population size within the potentially affected area
3. Water quality and aquatic fauna studies (macroinvertebrates and fish) in potentially exposed and reference pools, and
4. Sediment, water quality and sawfish surveys in the estuary.

All studies reported below were undertaken under appropriate licences and permits as follows:

- Western Australian Department of Environment and Conservation Regulation 17 Permit – SF008011
- Western Australian Department of Fisheries Exemption for Scientific Purposes – EXEM1819 and EXEM1919
- Northern Territory Department of Parks and Wildlife Permit to Interfere with Protected Wildlife – Permit No. 40868

- Northern Territory Department of Fisheries Special Permit – Licence No. S17/3230.

2 SAMPLING SITES

While a total of 26 sites were sampled (Table 1), not all sites were sampled for all studies (refer to each specific section for a list 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.

CODE	DESCRIPTION	REP. CODE	LATITUDE	LONGITUDE	TYPE
ESTO1	Keep River estuary near end of airstrip	EST01	15º 19.583'	129º 07.087'	PE
ESTO2	Keep River estuary mid-way between EST01 and EST03	EST02	15º 15.483'	129º 07.010'	PE
EST03	Keep River estuary – mid estuary near old NRETAS gauging station	EST03	15º 13.792'	129º 07.314'	PE
K1	Lower reach tidal pool	K1-1	15º 19.540'	129º 05.301'	PE
		K1-2	15º 20.038'	129º 05.764'	PE
		K1-3	15º 20.691'	129º 04.949'	PE
		K1-4	15º 21.129'	129º 05.067'	PE
		K1-5	15º 21.659'	129º 05.025'	PE
K2	Middle reach brackish pool	K2-1	15º 22.122'	129º 05.114'	PE
		K2-2	15º 22.123'	129º 05.175'	PE
		K2-3	15º 22.358'	129º 05.186'	PE
		K2-4	15º 22.531'	129º 05.120'	PE
		K2-5	15º 22.599'	129º 05.034'	PE
K3	Upper reach freshwater pool	K3-1	15º 22.865'	129º 04.782'	PE
		K3-2	15º 23.204'	129º 04.759'	PE
		K3-3	15º 23.503'	129º 04.684'	PE
		K3-4	15º 23.767'	129º 04.669'	PE
		K3-5	15º 23.864'	129º 04.547'	PE
K4	Keep River upstream of Legune Road Crossing	K4-1	15º 24.284'	129º 03.854'	PE
		K4-2	15º 24.505'	129º 03.872'	PE
		K4-3	15º 24.855'	129º 04.187'	PE
KE1	Milligan's Lagoon	KE1	15º 37.069'	129º 00.388'	R
KR1	Alligator Hole	KR1	15º 41.333'	129º 02.217'	R
KR2	Policeman's Waterhole	KR2	15º 44.450'	129º 04.400'	R
SR4	Augustus Hole	SR4	15º 31.517'	129º 19.200'	R
DR1	Dunham River at Sugarloaf Hill	DR1	16º 02.786'	128º 26.605'	R

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 (2013) to establish baseline conditions and 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, including replicate sites within Keep River pools (K1, K2, K3 and K4) and three estuary sites (EST01, EST02, and EST03) to characterise spatial and temporal variability in sediment quality (Figure 1 and Table 1).

3.2.2 Field methods

At sites within potentially exposed Keep River pools and at estuary sites, grab samples of sediment were collected using an Eckman-Birge grab sampler (Plate 1). Separate sediment samples were taken from the left bank, mid-channel and right bank at each site in each pool, and at each estuary site (Table 2). Individual samples were placed in labelled polyethylene bags and transported to the Chem Centre W.A. for analyses of ionic composition, nutrients and metals.

Plate 1. Collecting sediment samples at EST03 with an Eckman-Birge grab sampler.

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	SITE	# OF SITE REPS	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**

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

Concentrations were compared against the ANZECC/ARMCANZ (2000) interim sediment quality guidelines (ISQGs; see Appendix 2). 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 and Simpson 2008). The guidelines include ISQG-Low and ISQG-High values, which represent the 10th percentile (10%ile) and 50th 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

To examine spatial variation in sediment quality, boxplots of selected analytes were produced. In addition, two-way ANOVA was undertaken comparing concentrations of each parameter measured between sites and between years (2011 v 2012). 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. For the purposes of analyses, concentrations below detection limits were reported as half the corresponding detection limit for that parameter. Parameters were log transformed where necessary to conform to ANOVA's assumption of homogeneous variances.

Multivariate

Multivariate analyses were performed using the PRIMER package v 6 (**P**lymouth **R**outines in **M**ultivariate **E**cological **R**esearch; Clarke and Gorley 2006) to investigate differences in sediment quality amongst sites and between years. Analyses applied to the sediment data included some or all of the following:

1. Describing pattern amongst the sediment quality data using ordination techniques based on Euclidean Distance. The clustering technique uses a hierarchical agglomerative method where samples of similar assemblages are grouped and the groups themselves form clusters at lower levels of similarity. Data were first log transformed (where necessary) and normalised in PRIMER.
2. Ordination was undertaken using canonical analysis of principal coordinates (CAP) within the PERMANOVA add-in in PRIMER. This test finds axes through the multivariate cloud of points that either (i) are the best at discriminating among *a priori* groups (discriminant analysis) or (ii) have the strongest correlation with some other set of variables (canonical analysis) (Anderson and Robinson 2003, Anderson *et al.* 2008). The CAP analysis produced an ordination, and vectors corresponding to Spearman Rank Correlations >0.5 (i.e. of sediment quality parameters) were superimposed on this ordination.
3. Two-factor Permutational multivariate analysis of variance (PERMANOVA) was undertaken to determine whether there were any significant differences in sediment quality between sites and years (Anderson 2001a, b, McArdle and Anderson 2001, Anderson and ter Braak 2003, Anderson *et al.* 2008).

3.3 Results and Discussion

3.3.1 Sediment quality

Variability in percent total organic carbon (TOC) was evident at a number of spatial scales, i.e. there was variability between sites as well as between replicates within a site (Figure 2). Variation within replicates (i.e. between left, middle and right-of-bank samples) was also evident (Figure 2). Average TOC ranged from 0.36% (at K1-5) to 1.15% (at K4-3), indicating presence of some organic matter and some microbial activity. There was no significant difference in total organic carbon between sites (Two-way ANOVA; df = 4, p = 0.714) or between years (df = 1, p = 0.329; Table 3).

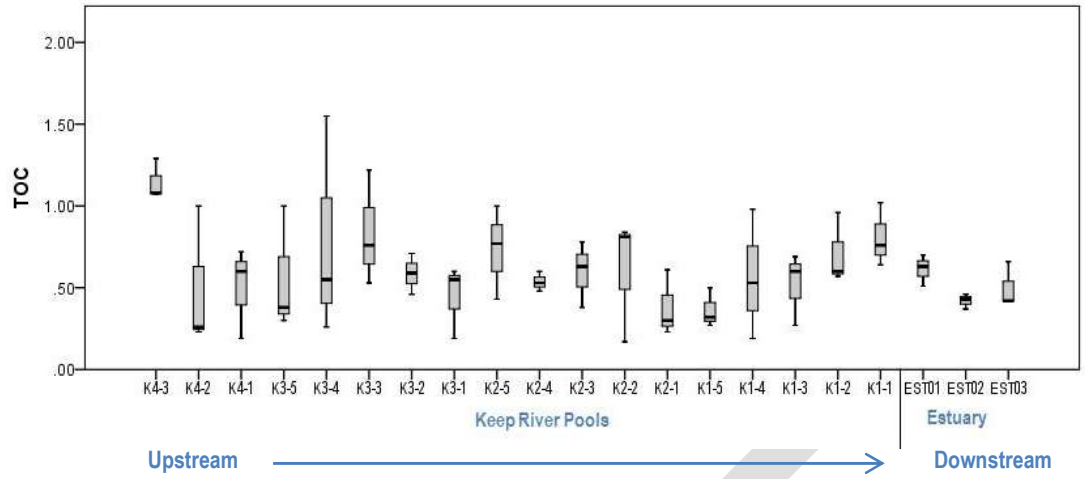

Figure 2. Box plot of total organic carbon content (%) within sediments in Sep-12 from potentially exposed sites. Plots show minimum, 20%ile, median (50%ile), 80%ile and maximum concentrations for each site, using variance between left bank, mid-channel and right bank.

Table 3. Two-way ANOVA results comparing total organic carbon (TOC) content (%) in sediments between site and year (2011 v 2012). Degrees of freedom, f-value and p-value are shown. Between-site differences are summarised using Tukey's HSD multiple range tests, with sites arranged in ascending order of average TOC. A solid line joins those sites not significantly different from one another.

Source	*df*	*F*	*p*	*Tukey's*				
				K2	**Estuary**	**K1**	**K3**	**K4**
Site	4	0.531	0.714					
				2011	**2012**			
Year	1	0.984	0.329					
Site*Year	4	0.637	0.640					
Error	42							
Corrected total	41							

Ionic composition of sediments was generally dominated by calcium cations and chloride anions at both Keep River pools and estuary sites (Figure 3). Ionic composition of sediments reflected salinity of waters, with estuary sites and lower Keep River pools recording higher concentrations of sodium and chloride than upstream pools (Figure 3). Concentrations of all ions measured (calcium, sodium, magnesium, potassium, chloride and sulfate) were significantly different between sites (Appendix 3). Significantly higher concentrations were recorded from the estuary, and in some cases the lower Keep River pool; K1 (Appendix 3). Longitudinal patterns were evident, with lowest ionic concentrations recorded from the most upstream Keep River pool K4 (see Appendix 3). Within-replicate variation of most ions was high, i.e. variation between left, centre and right-of-bank samples within a replicate was high (Figure 3). For the majority of ions, there was no significant change in concentration between years (2011 v 2012). However, significantly higher concentrations of magnesium were recorded from sediments in 2012 when compared with concentrations recorded in 2011 (see Appendix 3).

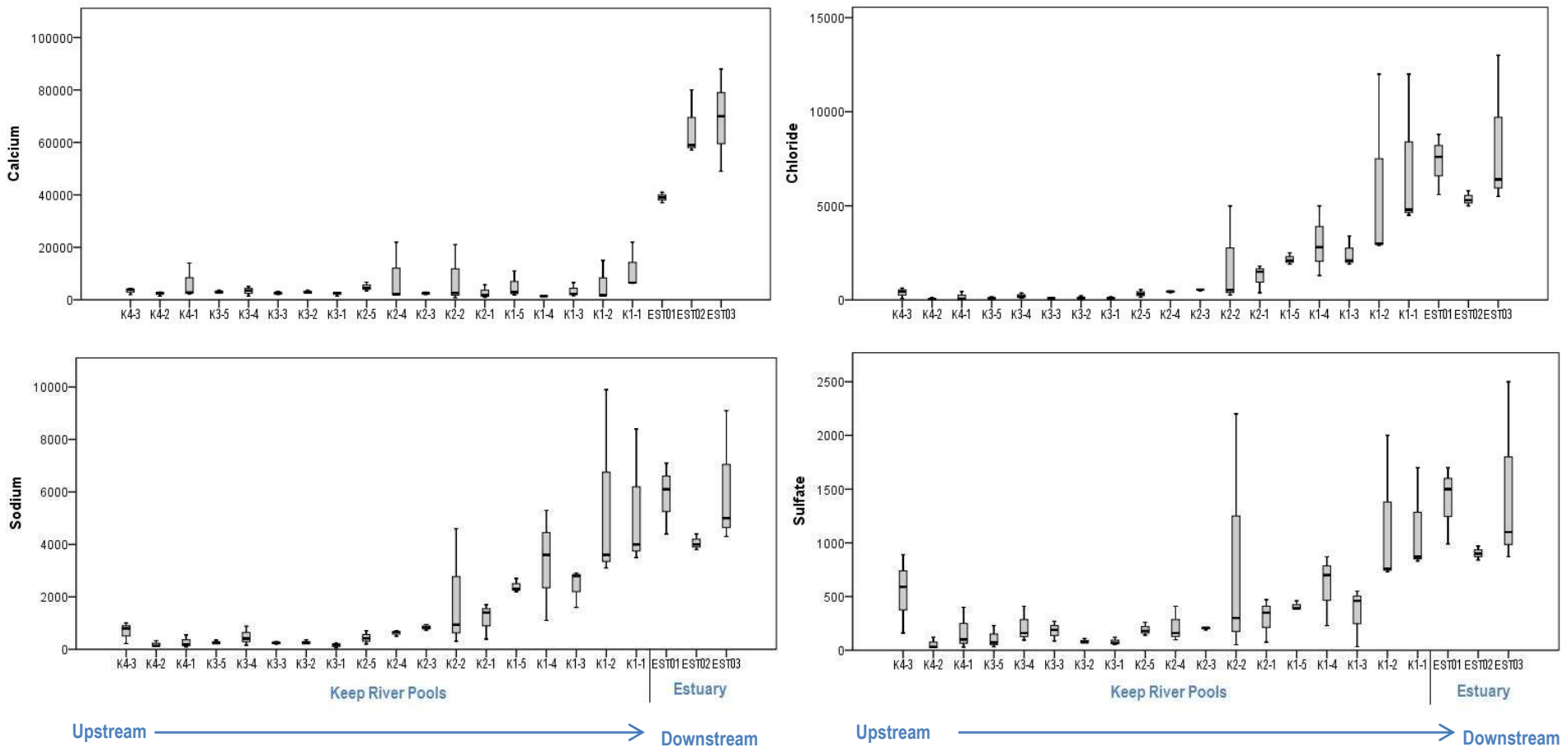

Figure 3. Boxplots of some selected ions within sediments in Sep-12 (mg/kg dry weight). Plots show minimum, 20%ile, median (50%ile), 80%ile and maximum concentrations for each replicate within a site. Boxplots of calcium, chloride, sodium and sulfate are shown. NB – the scale for calcium is different, due to the much higher concentrations recorded.

Nutrient concentrations were also highly variable within- and between-site (Figure 4). The average concentration of ammonia ranged from 0.5 mg/kg dry weight at EST02 to 18 mg/kg dry weight at K4-3 (Figure 4). Ammonia concentrations were significantly highest from K4 and lowest from the estuary sites (Appendix 3). There was no significant difference in ammonia concentrations in sediments between years (Appendix 3). Nitrate was generally low, and below detection limits at a number of sites. The highest average nitrate concentration was recorded from K3-3 (1.17 mg/kg dry weight). Differences in nitrate between sites were significant, with significantly lower concentrations being recorded from K1 in comparison to all other Keep River pools and the estuary (Appendix 3). Nitrate was significantly higher in 2012 than 2011 (Appendix 3). Average phosphorus concentrations were lowest at K1-3 (65 mg/kg dry weight) and highest at EST03 (266.67 mg/kg dry weight; Figure 4). Phosphorus in sediments was significantly higher in the estuary than any of the Keep River pools (Appendix 3). Again, within-replicate variation of nutrient concentrations was high (Figure 4). There was no significant difference in phosphorus concentrations in sediments between years (Appendix 3).

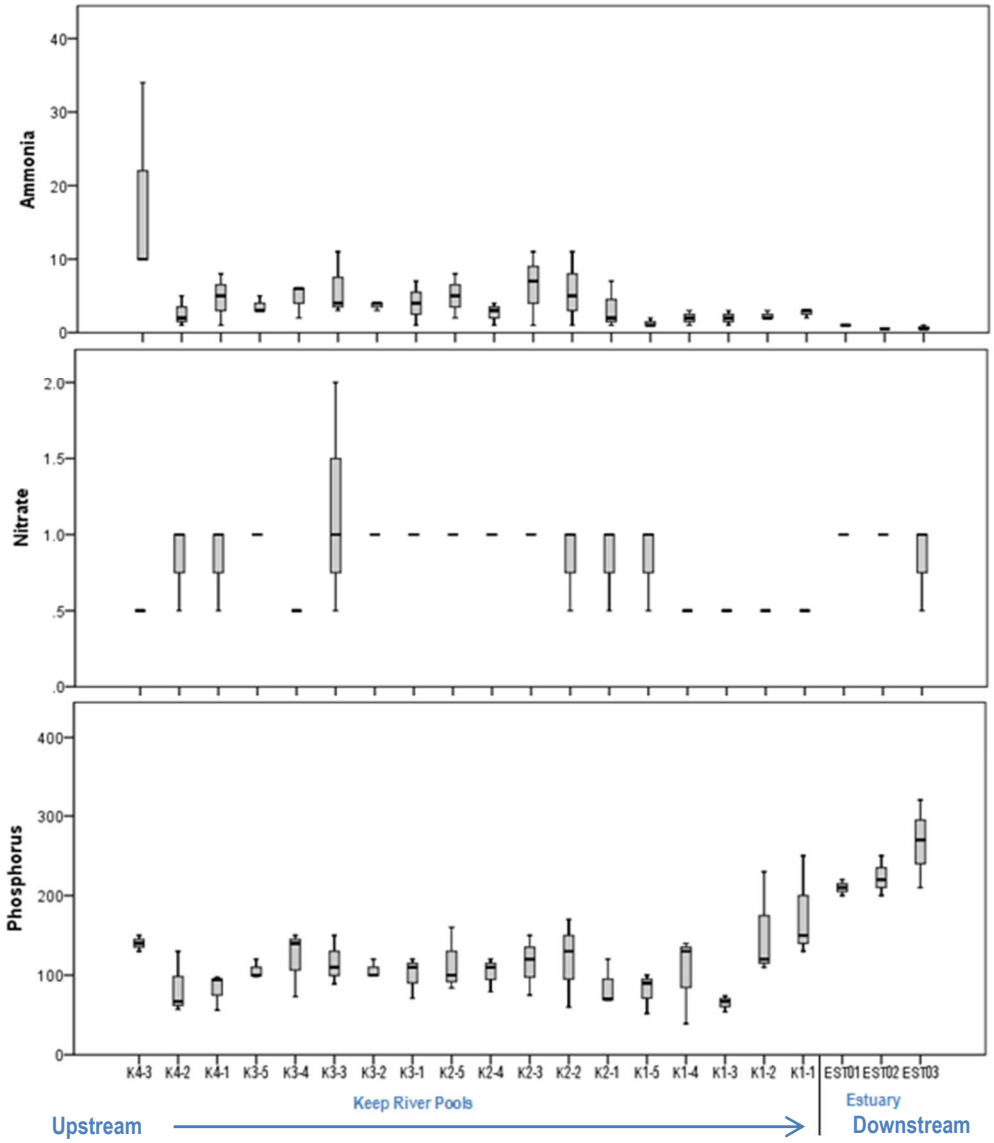

Figure 4. Boxplots of nutrient composition within sediments (mg/kg dry weight) in Sep-12. Plots show minimum, 20%ile, median (50%ile), 80%ile and maximum concentrations for each replicate within a site. Boxplots of ammonia, nitrate and phosphorus are shown. NB – scales are not the same between plots.

Generally, concentrations of heavy metals within sediments were low and well below the Interim Sediment Quality Guidelines (Figure 5). However, concentrations of mercury and nickel exceeded ISQG trigger values. Mercury exceeded the low ISQG TV (0.15 mg/kg dry weight) from at least one sample at all sites (i.e. left, centre or right bank), and exceeded the high ISQG TV (1.00 mg/kg dry weight) at K1-4, K2-1, K3-1 and K4-1 (Figure 5). Interestingly, most exceedances of the high ISQG for mercury were from sediment samples collected in the centre of the river (except K3-1 from the left of bank). Mercury is known to be particularly harmful to aquatic organisms and readily bioaccumulates in aquatic plants, invertebrates and fish (Phillips and Rainbow 1994, Nice 2009). In a study undertaken in coastal waters of the Northern Territory, Lyle (1984) found that sharks of numerous species accumulated relatively high concentrations of mercury. 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 and Rainbow 1994, Bowles *et al.* 2001). Mercury 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). Mercury levels from sediments of the Keep River in excess of 0.46 mg/kg were recorded from samples collected from a number of sites, including K4-2, K4-1, K3-4, K3-1, K2-5, K2-4, K2-1, K1-5, K1-3, EST02 and EST03.

Concentrations of nickel exceeded the ISQG-low trigger value of 21 mg/kg dry weight at K1-3, K2-2 and K3-4 (Figure 5). Although nickel 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 and Fishar 2005). In a study conducted in Port Curtis, Queensland, nickel was found to be enriched in oysters where concentrations were elevated in sediments (Jones *et al.* 2005). Bioconcentration of nickel has been reported for a wide variety of aquatic organisms ranging from bacteria, algae, and invertebrates to fish (Riley and Roth 1971, Wilson 1983, Zaroogian and Johnson 1984, Alikhan *et al*. 1990, Azeez and Banerjee 1991, Wong *et al*. 2000). However, Watras *et al.* (1985) suggested very limited uptake of nickel via the diet, suggesting that elevated nickel is of greater concern in surface waters than sediments. There is the potential for mobilisation of nickel from sediments, should reductions in pH occur.

Although generally low when compared to guidelines, concentrations of most metals varied greatly between site (Figure 5 and Appendix 3). In fact, there was a significant difference in concentration between sites for a number of metals, including:

- Arsenic – significantly higher in the estuary. Also significantly higher in 2012 than 2011.
- Aluminium – significantly different between site. Highest at K1 and lowest in the estuary. Significantly higher in 2012.
- Boron - significantly different between sites. Significantly lowest at pools K3, K4 and K2, with significantly higher B from K1, and highest concentrations from the estuary. Significantly higher in 2012 than 2011.
- Barium – lowest in the estuary and highest at the most upstream pool K4. No significant difference between years.
- Cobalt – significantly lower in the estuary than all Keep River pool sites. No significant difference between years.
- Chromium – lowest concentrations in the estuary and highest at K1. Chromium concentrations were significantly higher in 2012.
- Copper – lowest in the estuary and significantly higher at the Keep River pool sites. No significant difference between years.

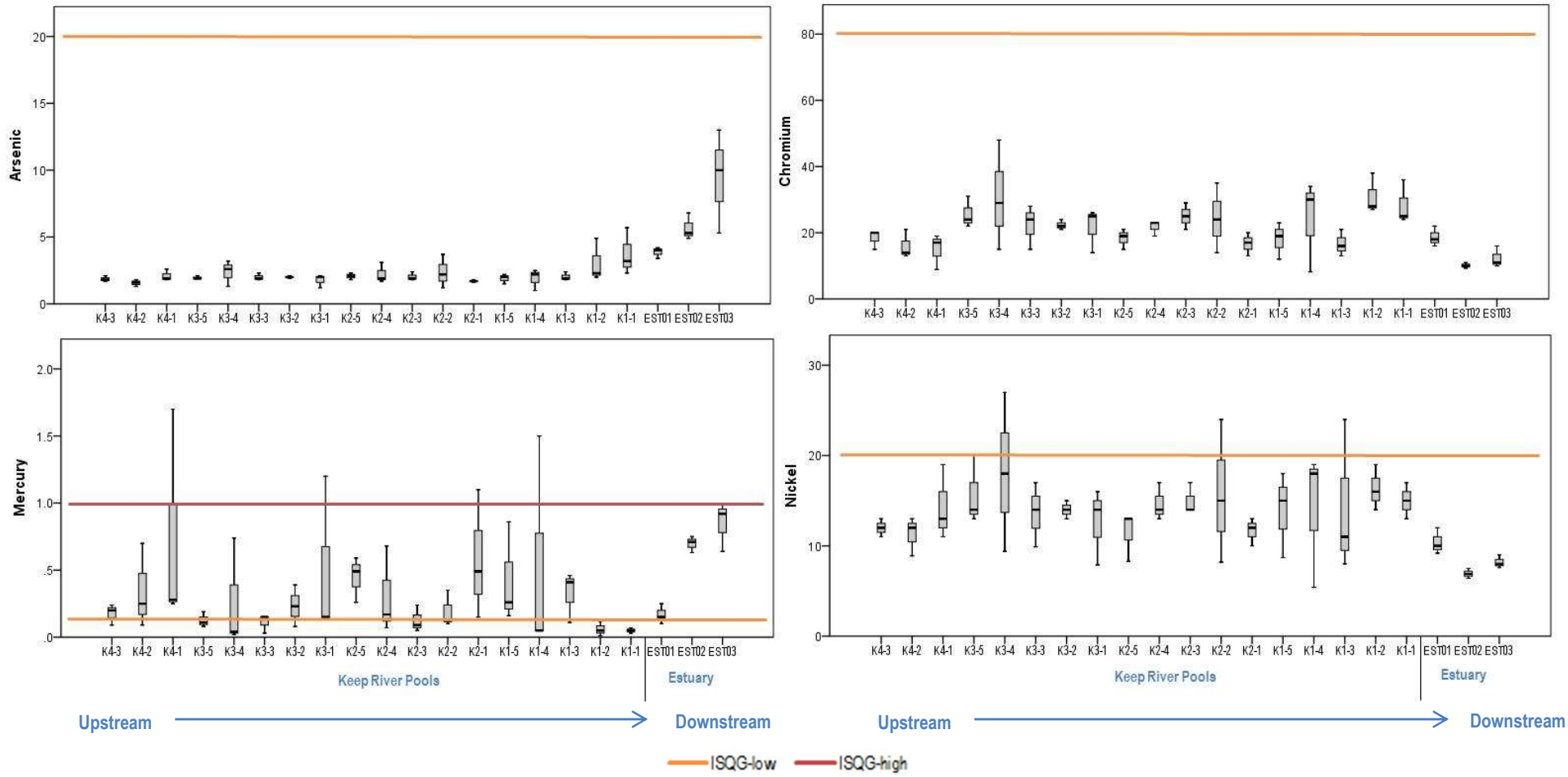

Figure 5. Boxplots of concentrations of some selected metals within sediments (mg/kg dry weight) in Sep-12. Plots show minimum, 20%ile, median (50%ile), 80%ile and maximum concentrations for each replicate within a site. Boxplots of arsenic, chromium, mercury and nickel are shown. The low and high trigger values from the ANZECC/ARMCANZ (2000) Interim Sediment Quality Guidelines are also indicated. NB – scales are not the same between plots.

- Nickel - lowest in the estuary and significantly higher at the Keep River pool sites. Significantly higher in 2012 than 2011.
- Lead – significantly lower in the estuary than all Keep River pools. Lead concentrations were significantly higher in 2012.
- Selenium – lowest in the estuary and highest at the upstream Keep River pool K4. Significantly higher in 2012.
- Titanium – significantly higher in the estuary compared to all Keep River pools. Significantly higher concentrations recorded in 2012.
- Uranium – lowest in the estuary and highest at K2. Significantly higher in 2012.
- Vanadium – significantly lower in the estuary than all Keep River pools. No significant difference in vanadium concentration between years.

As with ions and nutrients, variation across the bed within each replicate was high. This was evident in the considerably large standard error bars, particularly for mercury and nickel (Figure 5).

There was a significant positive correlation for most metals between total organic carbon in sediments and metal concentration (mg/kg dry weight), with the exception of arsenic and mercury (Figure 6). It is generally understood that the higher the percentage TOC and the finer the sediments, the greater the probability of toxicant accumulation in comparison to areas with low TOC and coarse sediments. In the case of arsenic, no correlation was evident ($r = 0.04$, $p = 0.81$), whilst for mercury, there was a significant negative correlation ($r = 0.61$, $p = 0.0001$; Figure 6). That is, as the percentage of TOC increased, the concentration of mercury within sediments decreased (Figure 6).

3.3.2 Patterns in sediment quality – 2011 & 2012 data

Multivariate analyses of Keep River sediment quality samples revealed the following:

- The correlation between the data cloud and the hypothesis of differences amongst sites was high along both canonical axes; 0.98 along CAP1 and 0.91 along CAP2.
- Separations between sites were evident in the CAP ordination (Figure 7). Estuary sites separated from Keep River pools along CAP1. There was considerable overlap in sediment quality between K3 and K4 upstream pools (Figure 7).
- Vector overlay of analytes with Spearman Rank correlations > 0.5 indicated separation of estuary sites from Keep River pools was due to the higher concentrations of calcium, chloride, sodium, sulfate, potassium, boron and titanium, but lower concentrations of barium at the estuary compared with upstream pools (Figure 7). Upstream Keep River pools (K3 and K4) separated from other sites due to their higher concentrations of ammonia (Figure 7).
- Within the Keep River pool sites, there was a longitudinal pattern in overall sediment quality, whereby K3 and K4 were most similar to each other but most different from the downstream site K1 (Figure 7).
- Overall sediment quality was significantly different between sites (Two-factor PERMANVOA; $df = 6$, $p = 0.0001$) and years ($df = 1$, $p = 0.0003$; Table 4). The only sites which were not significantly different from one another (i.e. recorded statistically similar overall sediment quality) were K2 and K3, and EST02 and EST03 (Table 5).

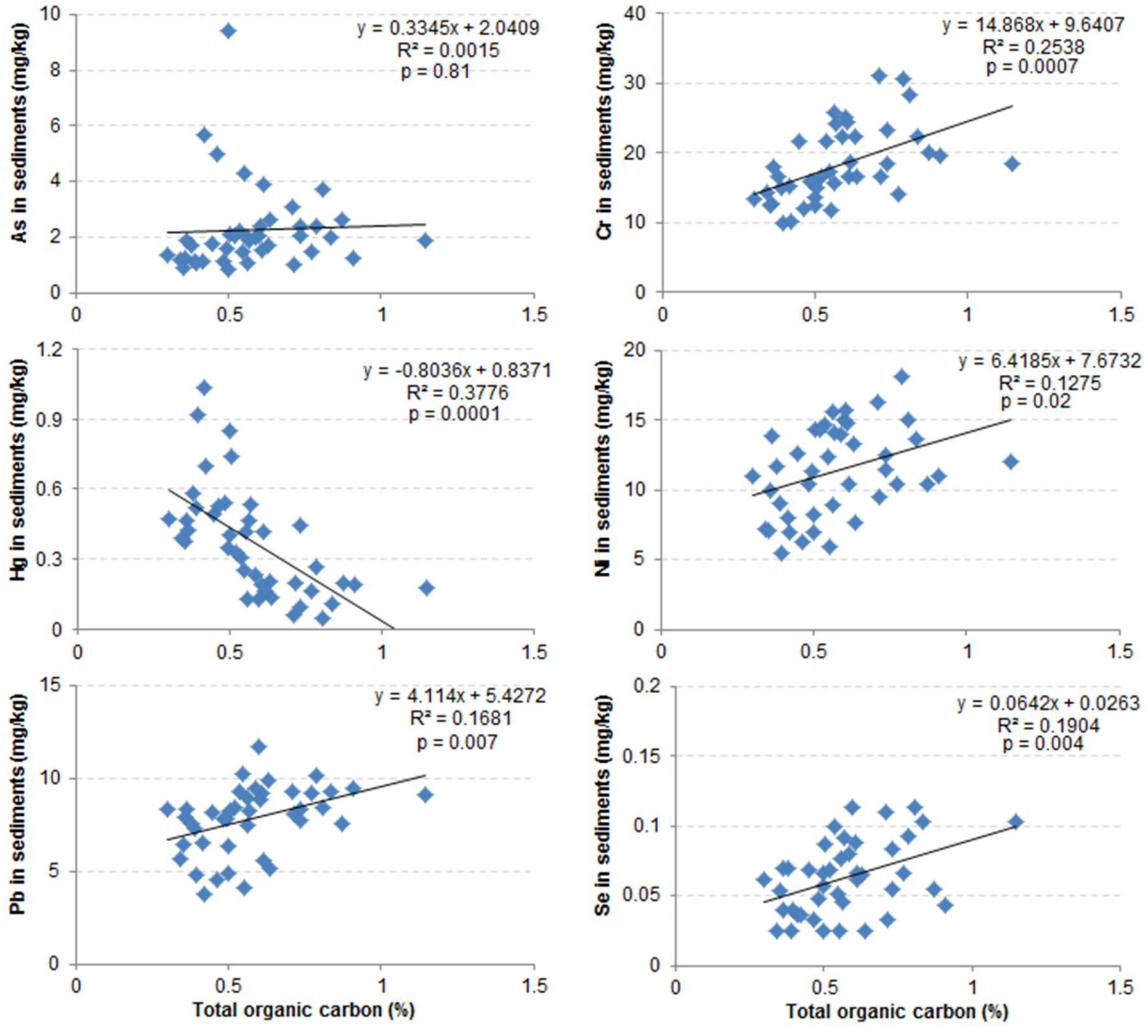

Figure 6. Correlations between metal concentrations in sediments (mg/kg dry weight) and total organic carbon (%), showing R^2 and p-values.

Table 4. Two-factor PERMANOVA results comparing sediment quality between site and year.

Source	df	MS	Pseudo-F	p
Site	6	226.6	8.63	0.0001
Year	1	194.7	7.42	0.0003
Site*Year	6	24.76	0.94	0.5104
Residual	112	26.26		
Total	125			

Table 5. PERMANOVA post-hoc results showing t-values for all pairwise comparisons. * = sites significantly different.

	K1	K2	K3	K4	EST01	EST02
K2	1.84*					
K3	2.76*	**1.45**				
K4	2.84*	1.89*	1.81*			
EST01	2.28*	3.02*	3.93*	3.63*		
EST02	3.18*	3.73*	4.85*	3.96*	4.25*	
EST03	2.86*	3.40*	4.34*	3.57*	1.98*	**1.22**

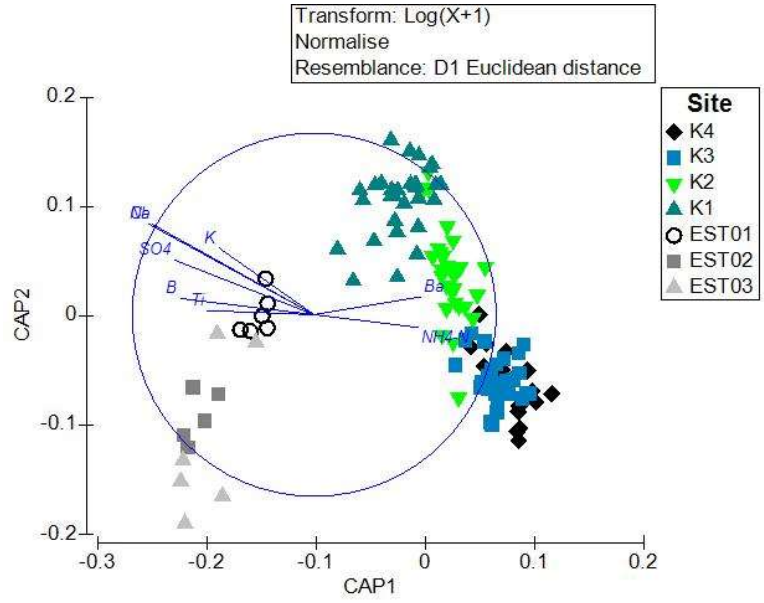

Figure 7. Constrained CAP plot comparing sediment quality data between site (using data collected in 2011 and 2012), with vectors of Spearman rank correlations overlain (correlation >0.5).

3.4 Conclusions

Sediment quality and composition was highly variable between sites. Generally, ionic composition of the sediments reflected the location of each site with respect to the estuary/ocean. That is, estuary and lower Keep River pools recorded higher concentrations of sodium and chloride, reflecting the higher salinity and tidal influence in these areas. Estuary sites also recorded significantly higher concentrations of calcium, magnesium, potassium and sulfate than Keep River pools.

Concentrations of mercury and nickel exceeded the ANZECC/ARMCANZ (2000) Interim Sediment Quality Guidelines. Mercury exceeded the low ISQG from at least one sample at all sites (i.e. left, centre or right bank), and the high ISQG at K1-4, K2-1, K3-1 and K4-1. Concentrations of nickel exceeded the ISQG-low TV at K1-3, K2-2 and K3-4. Elevated concentrations of mercury and nickel at these sites represents current, pre-Ord Stage II development baseline. There is no known reason for any anthropogenic impacts which would have led to elevated metals within sediments, so these data may, in fact, represent natural baseline levels and reflect surrounding geology. It is important to understand natural baseline conditions prior to development, so that system specific TVs may be developed as per ANZECC/ARMCANZ (2000). It is intended that baseline data on sediment quality will be collected for three years from the current locations, which will allow the development of system-specific TVs, which will allow better discrimination of natural variation from any impacts from the development.

High variability in sediment quality and composition was also recorded between the left, centre and right-of-bank locations within a site. 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 little threat to benthic organisms.

These data provide a good baseline dataset with which to assess future impacts from the ORIA M2 development. Sampling of sediment quality will continue for another year to provide a total of three years' baseline data which will characterise spatial and temporal variability, and be used to develop system-specific TVs as per ANZECC/ARMCANZ (2000).

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. These fish are listed on national and international conservation lists, and as matters of national environment significance under the EPBC Act. Therefore, conditions imposed on the development by the Commonwealth government included a requirement for three years of targeted baseline sampling of Pristis species and Glyphis sharks. The baseline surveys were required to document the current occurrence, distribution, population size, and population structure of these listed species (*Pristis* sawfish and *Glyphis* sharks) in the Keep River pools and upper estuary. Sampling was required to be conducted annually for three years (see WRM 2013, this study and 2013) 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 estuary (EST01, EST02 and EST03) (see Table 1 and Figure 1). Catch records were also supplemented by incidental captures as part of baseline aquatic fauna 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 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 fish assemblage 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 2), and
- A tissue sample was taken for DNA analyses.

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

Listed species were processed and returned to the water alive as rapidly as possible. Very juvenile 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).

4.2.3 Data analysis

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.

4.2.4 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

4.3.1 Species recorded

Two species of *Pristis* sawfish were recorded during the September 2012 surveys (Table 6); the freshwater sawfish *Pristis pristis* (Plate 3) and dwarf sawfish *Pristis clavata* (Plate 3). One individual of

the green sawfish *Pristis zijsron* was recorded from the estuary (EST01) in September 2011, but was not recorded during the 2012 surveys. *Pristis microdon* was found in a number of the Keep River pools, whilst *P. clavata* was found only in the estuary (Table 6). The estuary site EST01 recorded the greatest number of *Pristis* individuals (11 individuals; Table 6). Seven individuals recorded from site EST03, but no sawfish were recorded from EST02. One freshwater sawfish was caught and tagged from Policeman's Waterhole in the Keep River National Park (Table 6). This was a different individual to that recorded from this site in 2011 (WRM 2013).

Plate 3. *Pristis pristis* (left) and *Pristis clavata* (right). NB: dorsal fin is positioned in front of pelvic fins in *P. pristis*, and in-line with/behind the pelvic fins in *P. clavata* (photos by WRM staff ©).

Table 6. Details of *Pristis* individuals recorded during the targeted survey (TL = total length, TRL = total rostral length, SRL = standard rostral length).

System	Site	Species	Tag #	Size			Teeth count		Sex
				TL	TRL	SRL	Left	Right	
Keep River	K1	*Pristis pristis*	*	1500	375	355	22	21	M
	K2	*Pristis pristis*	302	1490	370	355	22	21	M
	KR2 (Policemans)	*Pristis pristis*	18	1505	365	350	21	21	F
Keep River Estuary	EST01	*Pristis clavata*	1	1820	370	355	22	23	F
		Pristis clavata	2	1390	290	275	21	21	M
		Pristis clavata	3	~1900	385	365	21	21	F
		Pristis clavata	4	1900	368	350	23	23	M
		Pristis clavata	5	1818	375	360	22	20	F
		Pristis clavata	6	1330	277	265	23	21	M
		Pristis clavata	7	890	188	180	23	23	M juvenile
		Pristis clavata	8	1240	265	255	21	20	M
		Pristis clavata	15	1855	380	360	23	22	M
		Pristis clavata	16	2420	480	445	19	20	F
		Pristis clavata	17	2720	515	495	21	23	F
	EST03	*Pristis clavata*	*	830	177	168			M juvenile
		Pristis clavata	9	1550	227	217	19	19	F
		Pristis clavata	10	1933	325	310	22	22	M
		Pristis clavata	11	2260	427	405	22	21	M
		Pristis clavata	12	1460	310	295	23	22	F
		Pristis clavata	13	1300	270	255	22	22	F
		Pristis clavata	14	1540	305	290	21	22	F

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

One of the individuals recorded from the Keep River Pool K2 was a male sawfish that was previously caught and tagged at this site in 2011 (tag #302). It was originally recorded as a female (WRM 2013), but was still a juvenile in 2011 so sex determination was difficult. This *P. pristis* increased in total length (TL) from 1100 mm to 1490 mm over the 12 months, indicating that it grew 390 mm in length in one year. Its total rostral length increased from 275 mm to 370 mm: a growth of 95 mm in rostral length over a year.

No *Glyphis* sharks were recorded from any of the sites sampled for targeted listed species surveys.

The *Pristis clavata* from EST01 recorded an almost equal sex ratio of 1:1.2, slightly in favour of males (Table 6). At EST03 the sex ratio of *P. clavata* was also almost equal, but was slightly in favour of females (1:1.33). Sawfish of all species ranged in size from 830 cm TL to 2720 cm TL. Juveniles were recorded from the estuary sites EST01 and EST03 (Table 6).

4.3.2 Conservation significance of *Pristis* species recorded

Freshwater sawfish *Pristis pristis* (previously known as *Pristis microdon*)

The freshwater sawfish is an Indo-Pacific species, with a range extending from southern Africa to south-east Asia and the Indo-Australian Archipelago, including Australia and the Philippines (Paxton *et al*. 1989, Last and Stevens 1994). This species is currently listed as:

- **Totally Protected** under Schedule II of the *Fish Resources Management Act (1994)*
- **Vulnerable** under the *Territory Parks and Wildlife Conservation Act (2000)*
- **Vulnerable** under the *Environment Protection and Biodiversity Conservation Act (1999)*
- **Critically Endangered** under the international IUCN Redlist of Threatened Species (IUCN 2012)

It is also listed internationally on Appendix II of the Convention on Trade in Endangered Species of Wild Fauna and Flora (CITES), ensuring that this species is subject to strict trade regulations. Since March 2009, all species of sawfish are listed as 'no take' species under the Queensland Fisheries Regulation 2008.

Populations of *P. pristis* are becoming increasingly rare and fragmented throughout its range (Compagno *et al.* 2006a). All known populations in Australia and overseas are threatened by target and by-catch fisheries (Stobutzki *et al.* 2002, Peverell *et al*. 2004, Compagno *et al.* 2006a, Stevens *et al.* 2008). Virtually all known populations have experienced very serious declines. Their morphology, including their long tooth-studded saw, makes them vulnerable to entanglement in any sort of net gear. They are under particular threat in systems where fishing for barramundi is common practice (Last and Stevens 1994). *Pristis pristis* are also under threat from habitat deterioration, such as siltation from logging or agricultural activities upstream, and pollution from industry and mining operations (Compagno *et al.* 2006a). A combined recovery plan for the listed sawfish and the two species of *Glyphis* freshwater shark is currently under development (SEWPAC 2013). *P. pristis* (as *microdon*) is also included in the DEWHA (2008) North Marine Bioregional Plan: Bioregional Profile.

There are few data available on the biology of the freshwater sawfish, though it is known to be ovoviviparous, *i.e.* gives birth to live young (Rainboth 1996). It is a large growing species of sawfish (> 6 m TL), typically found over sandy or muddy bottoms of shallow coastal waters, estuaries, river mouths and freshwater rivers and lakes (NCTWR 2005). Adults have primarily been collected from estuarine and in-shore marine waters, whereas juveniles are more commonly observed in freshwater habitats of coastal rivers. Preferred river habitat appears to be turbid channels of large rivers over soft mud bottoms (Allen 1991). They usually occur in water greater than 1 m depth but may move into shallow water to feed (Wilson 1999).

In a study of habitat use in the Fitzroy River, Whitty *et al*. (2008) reported a habitat separation between different age classes of *P. pristis*. New recruits (0^+ fish) were found to occur in shallow water (< 0.6 m deep) while larger 1^+ fish were recorded from deeper waters greater than 0.6 m. Whitty *et al*. (2008) provided possible reasons for this habitat partitioning, including predator avoidance and maximisation of growth rate for juveniles in shallow, warmer waters, and more space and manoeuvrability for larger fish in deeper waters. Whitty *et al*. (2008) found sawfish in the Fitzroy River fed predominantly on ariid catfish *Arius graeffei*, mullet and prawns.

Tagging has been undertaken in the Fitzroy River and King Sound in the Kimberley, as part of a collaborative study by Murdoch University, the Kimberley Land Council, the Kimberley Language Resource Centre, and numerous communities of the west Kimberley (Thorburn *et al.* 2004). Juvenile *P. pristis* were found to remain in the Fitzroy River for at least 3 to 5 years before leaving the river to mature in estuarine and/or marine environments. It is a long-lived species with a life span of about 40 years (S. Peverell unpub. data). Sexual maturity is believed to be attained at about 7 years of age (S. Peverell unpub. data). In the Mitchell River (western Cape York Peninsula, QLD), spawning activity has been reported in November and December, *i.e.* the beginning of the wet season (Allen 1991). However, it is still not clear if the adults move into freshwater to give birth, or if they give birth in estuaries, with the young ('pups') moving into freshwater over the wet/late wet season. Pups have been caught in the lower Ord River in April (A.W. Storey, unpub. data).

In the Fitzroy River, Thorburn *et al.* (2004) found upstream migration was hindered by Camballan Barrage. Doupé *et al*. (2003) similarly noted the exclusion of this species above the Lake Kununurra diversion dam on the Ord River. Changes in flow regime which reduce natural flooding during the wet season and increase the flow during the dry season have the potential to affect the seasonal distribution of this species (Thorburn *et al.* 2004).

Dwarf sawfish *Pristis clavata*

The exact distribution of the dwarf sawfish *Pristis clavata* is not known. It is thought to occur only in northern Australia (Larson 1999), but may be more widely distributed through the Indo-Pacific (Cook *et al.* 2006). The species has been recorded from King Sound and the lower Fitzroy and Pentecost rivers in the Kimberley, the Keep and South Alligator rivers and Buffalo Creek in the NT, and around the Gulf of Carpentaria and Cape York Peninsula to Cairns (Last and Stevens 1994, Thorburn *et al*. 2003, Morgan *et al.* 2004, Peverell 2005, Stevens *et al.* 2008). The dwarf sawfish is currently listed as:

- **Vulnerable** under the *Territory Parks and Wildlife Conservation Act 2000*
- **Totally Protected** under the *Western Australian Fish Resources Management Act 1994* (Fish Resources Management Regulations 1995, Part 4 Division 1 - Protected Fish)
- **Vulnerable** under the *Environment Protection and Biodiversity Conservation Act 1999*
- **Critically Endangered** under the IUCN Red List of Threatened Species (Cook *et al.* 2006)

Populations within Australia have been significantly reduced as a result of by-catch, and since fishing pressures from commercial and recreational fisheries continue, these declines are also likely to continue. *P. clavata* is susceptible to capture by estuarine and nearshore gillnet fisheries, such as those targeting barramundi, *Lates calcarifer*, and king salmon, *Eleutheronema tetradactylum* (Thorburn *et al.* 2008). Dwarf sawfish are now considered "virtually extinct in New South Wales and South East Queensland" (Stevens *et al.* 2005). A combined recovery plan for the listed sawfish and the two species of *Glyphis* freshwater shark is currently under development (SEWPAC 2013).

Even less is known of the biology of *P. clavata* than *P. pristis*. Preferred habitat appears to be shallow (2 - 3 m) coastal and estuarine waters. Unlike *P. pristis*, *P. clavata* does not move into purely freshwater areas - the species' range is believed to be restricted to brackish and salt water (Thorburn *et al.* 2007, 2008). During the current study, the dwarf sawfish was only recorded from Keep River

estuary sites. In north-western Australia, estuarine habitats are used as nursery areas by dwarf sawfish, with immature juveniles remaining in these areas until they are at least 3 years of age and then moving offshore upon maturation (Thorburn *et al*. 2007, 2008). Adults are known to seasonally migrate back into inshore waters (Peverell 2005), although it is unclear how far offshore the adults travel, as captures in offshore surveys are very uncommon. Although pupping has not been documented, it is likely to occur within estuarine rather than marine environments, probably at a similar time of year as *P. pristis*. Although commonly known as the "dwarf" sawfish, Peverell (2005) recorded a mature male with a total length of 3.06 m, while Thorburn *et al.* (2008) recorded immature individuals in excess of 2.33 m. An individual at 2.72 m was captured, measured and tagged at site EST01 in 2012.

In the Fitzroy River, *P. clavata* feed predominantly on popeye mullet (*Rhinomugil nasutas*) and prawns. Unlike *P. pristis* collected from the Fitzroy River, *P. clavata* does not appear to feed on ariid catfish (Thorburn *et al.* 2008).

4.3.3 Population size estimate for EST01

The estuary site EST01 was the only site where sufficient numbers of individuals were tagged to justify re-sampling the site for re-captures during the September 2012 surveys. Using the Ricker Equation the estimated population size of ***Pristis clavata*** at EST01 is **12** individuals, i.e.

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

4.3.4 Sawfish movement

Recapture records by recreational fishermen and WRM indicate *P. clavata* move around the estuary (Table 7 and Figure 8). 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 (Table 7 and Figure 8).

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 7 and Figure 8). 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 Discussion

During September 2012, listed sawfish species were recorded from the Keep River at pools K1, K2, Policeman's Waterhole (KR2), and the Keep River estuary at EST01 and EST03. *Pristis clavata* were recorded only from the estuary, while *P. pristis* were recorded only from Keep River pools.

No *Glyphis* sharks were recorded from any of the sites sampled.

One juvenile *P. pristis* captured and tagged in 2011 was recaptured at the exact same location in pool K2 in 2012, indicating this individual had not moved location over the interceding twelve months. It had grown 39 cm in a year. The individual appeared healthy when recaptured.

Table 7. Movement of sawfish using 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	None

*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.

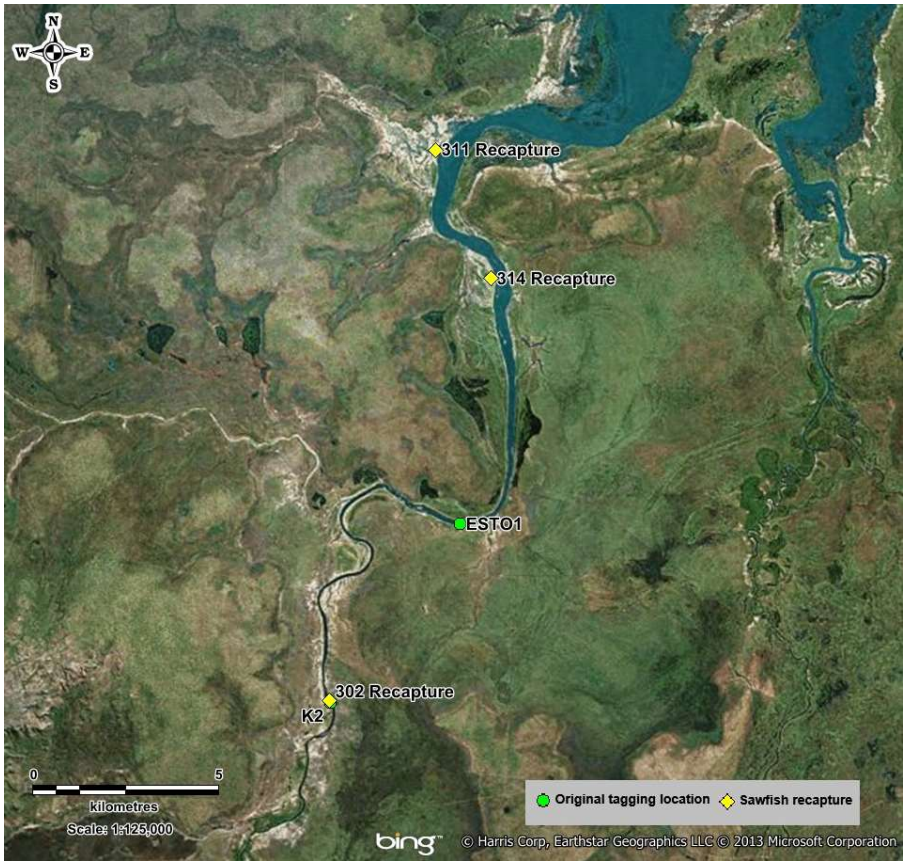

Figure 8. Sawfish movement based on recapture locations.

A single *P pristis* was collected from Policeman's Waterhole, in the Keep River National Park. This site is approximately 45 km from the estuary, indicating freshwater sawfish actively move up the Keep River to seek refuge in inland pools, and the record of one individual from this pool in 2011 was not an anomaly.

As also noted in 2011, site EST01 in the upper estuary supported the highest number of sawfish, all being *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 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 concentration of sawfish in the pool, but the presence of a relatively large number of sawfish in this part of the estuary does pose a risk from the Stage 2 development, should there be any adverse effects of the development on water quality of the lower pools and upper estuary.

5 BASELINE AQUATIC FAUNA SURVEYS

5.1 Rationale

The aim of this aspect of the aquatic fauna monitoring program was to sample aquatic macroinvertebrate and fish assemblages of exposed and reference pools of the Keep River system to establish baseline conditions, against which future changes to species composition may be detected, especially those that may influence listed species (i.e. loss of important prey species). Aquatic 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. Macroinvertebrates are an important food source for many adult and juvenile fish, and many smaller fish (mullet and herrings) are important food sources for piscivores, including listed species of shark and sawfish. Macroinvertebrates are good indicators of the early phases of community change as they are typically less mobile than fish and hence less able to avoid adverse changes in water quality.

Surveys were conducted during the late dry season. This timing, as opposed to earlier in the year, allows the fauna of the downstream pools on the Keep to be exposed to and to integrate effects of any changes in water quality that may result from discharge from the project area towards the end of the wet season/early dry season. Sampling at this time of year also reflects the effectiveness of any mitigation measures that may have been implemented if there have been any exceedances of water quality trigger values (i.e. mitigation such as discharge of water from the M2 channel to flush pools in the late wet/early dry). The long residence time and effects of evapoconcentration of 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. Collection of baseline data will occur annually for three years (WRM 2013, this study, and 2013 survey), prior to irrigation commencing, to establish baseline conditions. Future monitoring, conducted using the same design and methodology, will then be able to test against this baseline for changes as a result of the development, as opposed to natural changes, such as climatic variability, which would also affect the control (reference) sites.

5.2 Methods

5.2.1 Sampling sites

Baseline aquatic fauna sampling was undertaken in potentially exposed sites in the Keep River, as well as reference sites to create a classic BACI design (**B**efore/**A**fter: **C**ontrol/**I**mpact). This will allow differentiation of natural variation (i.e. as a result of climatic variability) from change that may result from development in the future. Sample sites included:

- Potentially exposed = the four main pools on the Keep River (K1, K2, K3 and K4)
- Reference = KE1 (Milligan's Lagoon), KR1 (Alligator Waterhole), KR2 (Policeman's Waterhole), SR4 (Augustus Waterhole) and DR1 (Dunham River at Sugarloaf Hill) (see Table 1 and Figure 9).

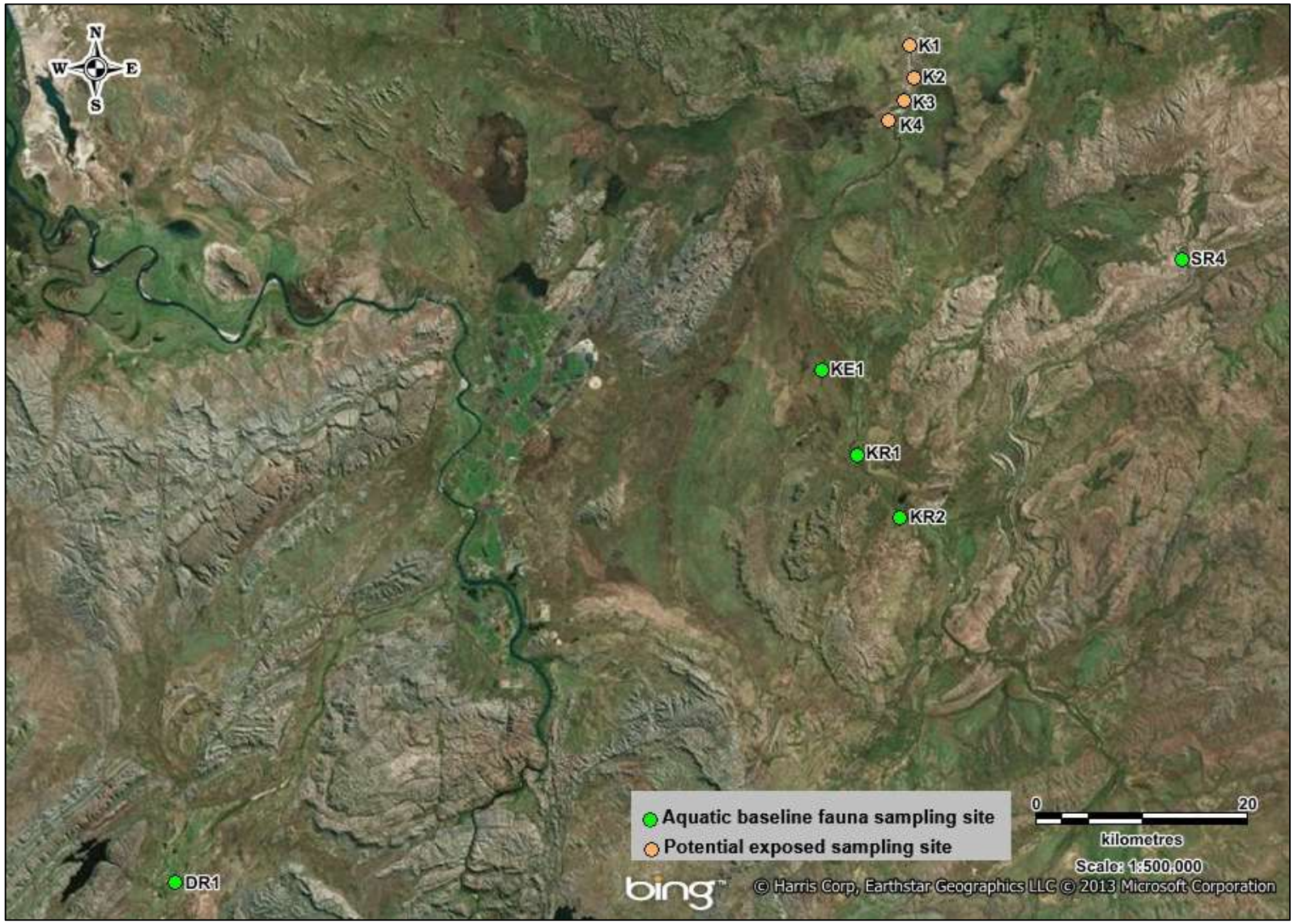

Figure 9. Location of the baseline aquatic survey potentially exposed Keep River pool sites and the five reference sites.

Five replicate sites were sampled within three of the pools on the lower Keep River (K1, K2 and K3). These sites 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 in pool K4. One sample was then collected from each of the reference sites, with each reference site being treated as a replicate in statistical analyses to compare each exposed pool to reference condition. Replication allows for statistical testing of spatial differences between pools, spatial difference between exposed pools and reference sites, and temporal changes in the future (2011 v. 2012 v. 2013, and then pre-development with post development). In addition, as it was part of the conditions for Commonwealth Approval for the project, three sites were also sampled in the estuary for water quality and sediments.

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. In addition, undisturbed water samples were collected for laboratory analysis of ionic composition, dissolved organic carbon (DOC) and nutrient concentrations. Nutrient samples were collected as gulp samples and kept cool on ice whilst in the field. All laboratory analyses were conducted by the Chem Centre WA (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 and c), and allow development of system-specific trigger values for analytes of concern.

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 (sampling conducted to establish baseline conditions for initial AUSRIVAS model development or subsequently as part of national river health audits) or specifically for assessment of impacts associated with Ord Stage 2 development (NCTWR 2005, Storey and 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 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

Following successive above average wet seasons since 1999, and subsequent recharge of the aquifer, permanent flows were established 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, and recharge of the aquifer under the floodplain, the lower Keep developed a small baseflow (5 – 10 L/sec) that persisted throughout the dry season. During the September 2012 surveys, flows were present from pool K4 downstream, providing riffle habitat. Given that riffle zones are known to be biodiversity 'hotspots' (Brown and Brussock 1991, Barbour *et al*. 1999), these riffle habitats were also sampled for macroinvertebrate fauna, with riffles sampled below pool K4 and just upstream of pool K3. 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 Waterhole & Dunham River). Riffle samples were collected by 'kick-

sampling' through the riffle zones with a 250 µm-mesh pond net (see Plate 4). As with the edge habitat samples, riffle samples were washed through a 250 µm sieve to remove debris, preserved in 70% ethanol and transported to the WRM Perth laboratory. As this habitat is not commonly present during the dry season, the design has few sites and low replication, however, this was unavoidable.

Plate 4. Macroinvertebrate sampling in a riffle at Carlton Crossing on the lower Ord River.

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, and so on). 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. All 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 (*Pristis* sawfish or *Glyphis* sharks) were processed as outlined above (see section 4.2.2). Nets sets were deployed either in the morning or afternoon, allowing sufficient time to process the catch before nightfall.

5.2.5 Data analysis

Univariate

Univariate statistics were performed using SPSS software (Version 19.0 for Windows). Independent sites within a pool were used as replicates for the Keep River pools, whilst individual sites were used as replicates for reference sites and the estuary. To examine spatial variation in water quality and species diversity between Keep River pools and reference sites, boxplots were produced.

Two-way analysis of variance (ANOVA) was applied to test for significant differences in water quality parameters and species richness between sites (K1, K2, K3, K4, REFS, and EST) and between years (2011 v 2012). Any water quality data recorded in percentages were arcsin transformed (proportions) prior to analysis. A Levene's test was used in the first instance to test for equality of variances (Levene 1960). Data were log transformed where necessary. Tukey's post-hoc tests were utilised in the case of significant differences to locate site differences.

Multivariate

Multivariate analyses were performed using the PRIMER package v 6 (**P**lymouth **R**outines in **M**ultivariate **E**cological **R**esearch; Clarke and Gorley 2006) to investigate differences in water quality and aquatic fauna amongst sites and between years. Analyses applied to the data included some or all of the following:

1. Describing pattern amongst the water quality data using ordination techniques based on Euclidean Distance. The clustering technique uses a hierarchical agglomerative method where samples of similar assemblages are grouped and the groups themselves form clusters at lower levels of similarity. Data were first log transformed (where necessary) and normalised in PRIMER.
2. Describing pattern amongst the faunal assemblages (macroinvertebrates and fish) using ordination techniques based on the Bray-Curtis Similarity Measure (Bray and Curtis 1957).
3. Ordination was undertaken using canonical analysis of principal coordinates (CAP) within the PERMANOVA add-in in PRIMER. This test finds axes through the multivariate cloud of points that either (i) are the best at discriminating among *a priori* groups (discriminant analysis) or (ii) have the strongest correlation with some other set of variables (canonical analysis) (Anderson and Robinson 2003, Anderson *et al.* 2008). The CAP analysis produced an ordination, and vectors corresponding to Spearman Rank Correlations >0.5 (i.e. of water quality parameters or fauna species) were superimposed on this ordination.
4. The influence of water quality on the faunal assemblages (macroinvertebrates and fish) was further examined using the BVSTEP routine. This routine was used to calculate the minimum suite of parameters that explain the greatest percent of variation (i.e. the parameters which most strongly influence the species ordination).
5. Two-factor permutational multivariate analysis of variance (PERMANOVA) was undertaken to determine whether there were any significant differences in water quality or faunal assemblages between sites or years (Anderson 2001a, b, McArdle and Anderson 2001, Anderson and ter Braak 2003, Anderson *et al.* 2008).

AusRivAS River Health Assessment

The AusRivAs (**Aus**tralian **R**iver **A**ssessment **S**ystem) model was developed between 1993 and 1997 as a national rapid biological assessment procedure for assessing river condition, and was modified from the British River Invertebrate Prediction and Classification System (RIVPACS) (Schofield and Davies 1996). 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, Halse *et al.* 2001). Within the model, the macroinvertebrates predicted ("expected) to occur are compared to those actually present ("observed") at a site, and the ratio of observed/expected (O/E) families is used

as a measure of river health (Ransom *et al.* 2000, Halse *et al*. 2001). The severity of any environmental impairment is assessed using a banding scheme (see Table 8), based on how much the observed macroinvertebrate assemblage deviates from that expected to occur. Simpson and Norris (2000) provide further information on the development of AUSRIVAS and RIVPACS models.

Table 8. Description of the AusRivAS banding scheme. Taken from the user manual (Coysh *et al.* 2000).

Band	Description	O/E taxa	O/E interpretations
X	MORE BIOLOGICALLY DIVERSE THAN REFERENCE	O/E greater than 90th percentile of reference sites used to create the model	More families found than expected. • Potential biodiversity "hot-spot" or mild organic enrichment. • Continuous irrigation flow in a normally intermittent stream.
A	SIMILAR TO REFERENCE	O/E within range of central 80% of reference sites used to create the model.	Expected number of families within the range found at 80% of the reference sites.
B	SIGNIFICANTLY IMPAIRED	O/E below the 10th percentile of reference sites used to create the model. Same width as band A.	Fewer families than expected. • Potential impact either on water and/or habitat quality resulting in a loss of families.
C	SEVERELY IMPAIRED	O/E below band B. Same width as band A.	Many fewer families than expected. • Loss of families from substantial impairment of expected biota caused by water and/or habitat quality.
D	EXTREMELY IMPAIRED	O/E below band C down to zero.	Few of the expected families present and only the hardy, pollution tolerant families remain. • Severe impairment.

Condition 11F of the Storm Water and Groundwater Discharge Management Plan (SEWPAC 2011) requires development of "AusRivAS trigger levels for aquatic macroinvertebrates". Therefore, the macroinvertebrate data from Keep River pools and reference sites was first reduced from species-level data to family-level data, and then run through the appropriate AusRivAS program. The model chosen for this analysis was the late dry season edge habitat model for the Northern Territory. Required 'predictor variables' for this model included location (latitude and longitude), alkalinity (mg/L) and cover by macro algae (percent cover). Data calculated by the model for each site included the O/E taxa ratio and an assessment of biological impairment (banding scheme). Values of O/E can range from 0 (indicating that none of the families expected at a site were found) to a theoretical maximum of 1.0 (indicating a perfect match between the families expected to occur and those that were recorded. However, the maximum can actually exceed 1.0 in the case where more families were recorded than would be expected to occur. While this can indicate an unusually diverse site, it may also indicate mild enrichment by organic pollution, where additional nutrients have allowed families not normally found at a site to establish, but enrichment is not sufficient to adversely affect the resident fauna (ANZECC/ARMCANZ 2000).

Model bands from running the 2011 and 2012 data though the AusRivAS model were presented visually on a map of the Keep River. Biotic trigger values (TVs) were developed based on AusRivAS results and were calculated from the OE50 scores, as these provide a continuous quantitative score,

as opposed to the categorical Model Bandings (A – D), which limit sensitivity and quantitative statistical analysis. In a similar way to the development of water quality trigger values as outlined in ANZECC/ARMCANZ (2000) guidelines, where a lower limit is required (i.e. pH & dissolved oxygen), the 20th percentile was taken as the biotic TV for each site. In this way, a future O/E score as part of any monitoring program that falls below the appropriate TV for that pool would be a trigger for further investigation (see section 5.3.3 for information relating to how the biotic TVs can be applied to monitoring data in the future). To determine 20th percentiles, individual sites within a pool were used as replicates for each Keep River pool and individual reference sites as replicates for the reference category. TVs developed here are preliminary, utilising data collected in 2011 and 2012, and will be updated once the 2013 data are available and O/E scores have been determined for that year.

5.3 Results

5.3.1 Water quality

Keep River pools were characterised by circum-neutral to slightly basic pH, high alkalinity (well buffered against rapid changes in pH) and generally low nutrient levels (Figures 10 to 13; Appendix 5). In other aspects of water quality, there was considerable variation between Keep River pools. Electrical conductivity and ionic concentrations were much higher from the downstream K1 site in comparison to the more upstream sites (Figures 10 & 12). This is a result of regular tidal influence on water quality in the lower pools. Dissolved oxygen was also considerably lower from the upstream pool (K4). Turbidity increased slightly with distance upstream (Figure 11).

Generally, water quality parameters from Keep River pools were within ANZECC/ARMCANZ (2000) guidelines for the protection of northern tropical systems (see Appendix 4 for trigger values). Past monitoring has shown that some parameters exceed the default water quality trigger values (DAFWA 2011), and so system-specific water quality trigger values are being developed using baseline data, which will be adopted in post development monitoring (see Strategen, 2012a and c). A number of sites recorded dissolved oxygen levels outside the default ANZECC/ARMCANZ (2000) guidelines, with values lower than the low trigger value (60%) being recorded from the upstream pool K4 (Figure 10). Dissolved oxygen at this site was not considered low enough to cause ecological stress to resident aquatic fauna (i.e. critical level considered to be ~20%). Interestingly, low DO values have been repeatedly recorded from this site during previous sampling (WRC 2003a, NCTWR 2005, WRM 2013). Milligan's Lagoon also demonstrated low DO levels in the open and deeper portions of the lagoon, but levels were elevated in the shallows, where there was dense macrophyte growth. No DO values in excess of ANZECC/ARMCANZ (2000) trigger values were recorded from Keep River pools (Figure 10).

While electrical conductivity (EC) exceeded ANZECC guidelines at all Keep River pools (Figure 10), it is likely that the aquatic fauna at each site is adapted to the salinity levels characteristic of that site. Observed salinity levels are due to the influence of tides in the lower reaches, where saline waters from the estuary are mixed with fresher water from the river. Waters in the upper Keep River pools (K4 and K3) were fresh as defined by the DoE (2003)[2]. Monitoring by DAFWA using *in situ* loggers show tidal effects, especially on spring tides and king tides, on salinity levels as far upstream as pool K3. This reflects spring tides pushing water from the downstream pool into the adjacent upstream pool (i.e. estuary into K1, K1 into K2, and K2 into K3), resulting in salinity being variable, and higher following these intrusions. At the time of sampling in September 2012, EC at all K3 sites (range 942-962 µS/cm) was lower than the interim water quality TV[3] developed for this pool by WRM (2010b). In

[2] Fresh defined as < 1500 µS/cm, Brackish = 1500 – 4500 µS/cm, Saline = 4500 – 50,000 µS/cm, Hypersaline > 50,000 µS/cm (DoE 2003). Classifications were presented as TDS (mg/L) in DoE (2003) so a conversion factor of 0.68 was used to convert to conductivity µS/cm as recommended by ANZECC/ARMCANZ (2000).

[3] The interim TV for EC at K3 is 1824 µS/cm (WRM 2010b).

freshwater systems there is a general acceptance that when conductivity is less than 1500 µS/cm, freshwater ecosystems experience little ecological stress (Hart *et al.* 1991, Horrigan *et al.* 2005), despite EC readings being higher than the ANZECC default guideline. In the mid-reaches (K2), waters were brackish and ranged from 2640 µS/cm to 3900 µS/cm (Figure 10). As noted above, this pool, as well as K3, receives occasional inputs from high spring tides (DAFWA 2011), but a low baseflow of fresher water from pool K4. In contrast, the lower tidally-influenced pool (K1) was highly saline, with EC ranging from 23,300 µS/cm to 28,100 µS/cm (Figure 10).

While total nitrogen concentrations at Keep River pools were generally low, values in excess of the default ANZECC guidelines were recorded from K3-4 (0.39 mg/L), K2-5 (0.31 mg/L), K1-5 (0.41 mg/L), K1-2 (0.58 mg/L) and K1-1 (0.41 mg/L) (Figure 13). The interim site-specific TV for pool K3 also deferred to the default ANZECC value, so total nitrogen at this pool exceeded the interim water quality TVs developed by WRM (2010b) at one replicate within the pool (K3-4). A large number of total phosphorus concentrations from Keep River pools were below detection limits (<0.01 mg/L). No total phosphorus values exceeded either the ANZECC/ARMCANZ (2000) TVs or the interim water quality TV for pool K3 (WRM 2010b) (Figure 13).

Reference sites also recorded circum-neutral pH and high alkalinity (well buffered), but they were also characterised by low electrical conductivity, low turbidity and low ionic concentrations (Figures 10 to 13).

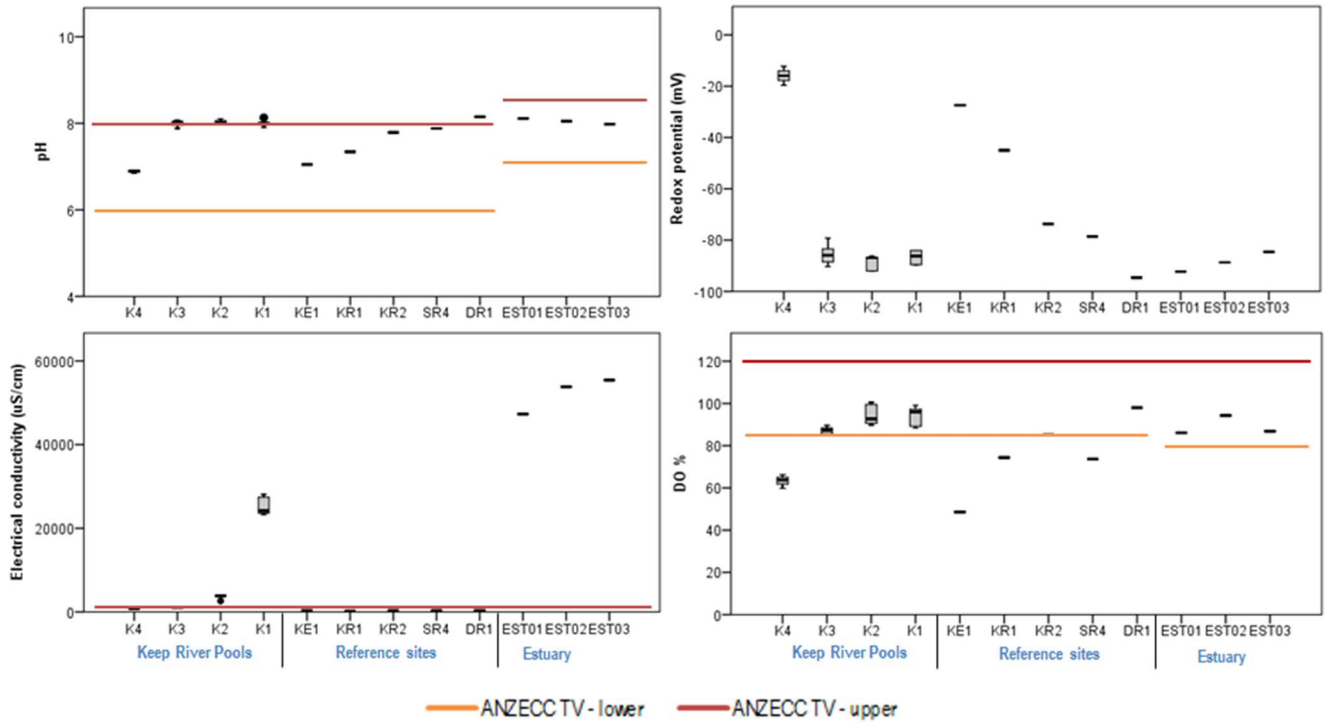

Figure 10. Boxplots of some water quality parameters, including pH, redox potential (mV), electrical conductivity (µS/cm) and dissolved oxygen (%). Plots show minimum, 20%ile, median (50%ile), 80%ile and maximum concentrations for each site. The corresponding ANZECC/ARMCANZ (2000) water quality trigger values are also indicated.

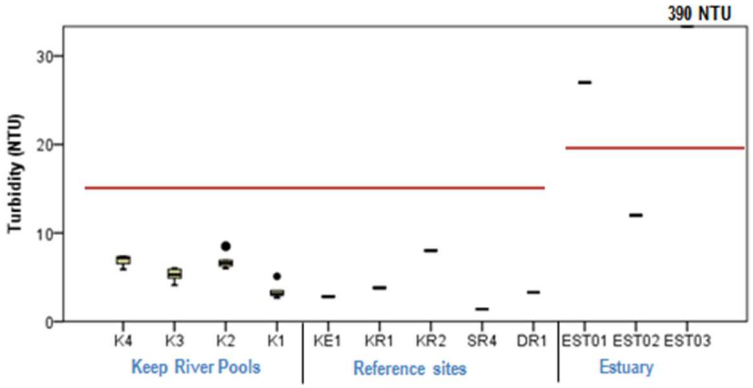

Figure 11. Boxplot of turbidity levels (NTU) recorded from Keep River pools, reference sites and the estuary. The minimum, 20%ile, median (50%ile), 80%ile and maximum concentrations are shown for each site.

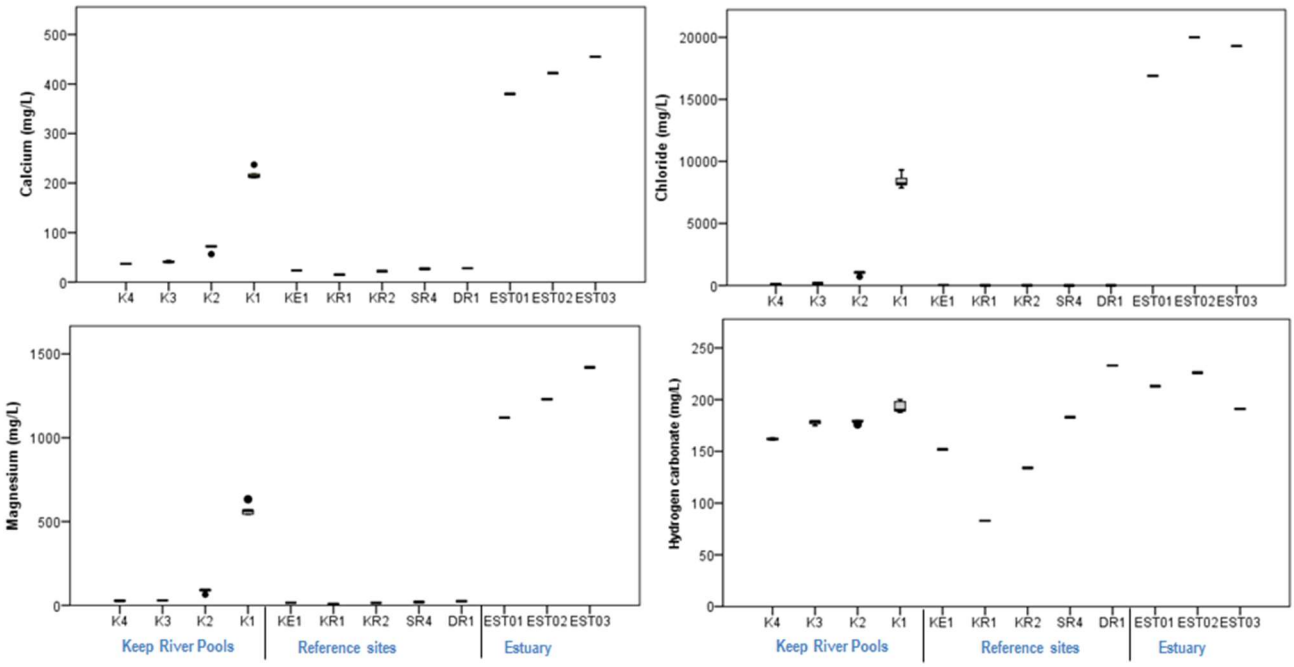

Figure 12. Boxplots of concentrations of selected ions (mg/L). Plots show minimum, 20%ile, median (50%ile), 80%ile and maximum concentrations for each site. NB – scales are not the same between plots.

Similar to the Keep River pools, water quality at reference sites was generally within the ANZECC/ARMCANZ (2000) guidelines. Parameters which recorded values outside the guidelines included dissolved oxygen, electrical conductivity and total nitrogen (Figures 10 and 13). Dissolved oxygen levels lower than the guidelines were recorded from Milligan's Lagoon (KE1), Alligator Waterhole (KR1) and Augustus Waterhole (SR4), however, no levels were considered low enough to cause severe ecological impact to biota. As with the upper Keep River pools, most reference sites exceeded guidelines for electrical conductivity but waters at all sites were fresh as defined by the DoE (2003). EC at Alligator Waterhole was within guidelines (<250 µS/cm). EC at reference sites ranged from 206 µS/cm at Alligator Waterhole to 386 µS/cm at the Dunham River (DR1). Lastly, total nitrogen was elevated in comparison to the default ANZECC TVs at Milligan's Lagoon (KE1), Alligator Waterhole and Policemen's Waterhole (KR2). The concentrations of total nitrogen at Milligan's Lagoon was almost three times the default TV (0.86 mg/L) and was higher than all other sites sampled during Sep-12 (Figure 13). Heavy cattle stocking in mustering yards adjacent to Milligan's Lagoon may be responsible for the elevated nitrogen levels.

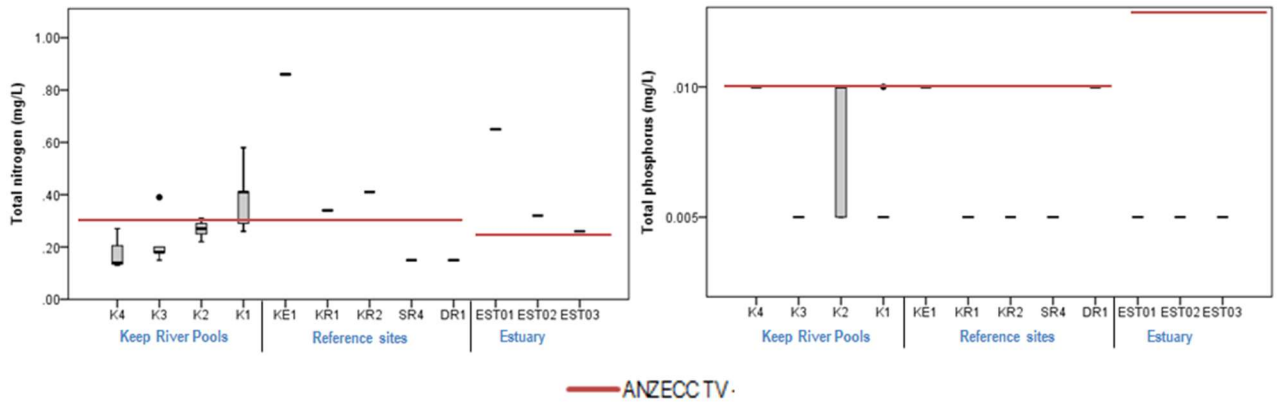

Figure 13. Boxplots of total nitrogen and total phosphorus concentrations (mg/L). Plots show minimum, 20%ile, median (50%ile), 80%ile and maximum concentrations for each site. The corresponding ANZECC/ARMCANZ (2000) water quality trigger values are also indicated.

As would be expected, water quality at the Keep River estuary sites was considerably different to the upstream pools and reference sites (see Figures 10 to 13). The estuary sites were characterised by circum-neutral pH, reasonably high dissolved oxygen, high EC (saline waters) and high concentrations of ions.

Generally, water quality parameters from estuary sites were within ANZECC/ARMCANZ (2000) guidelines for the protection of estuaries in tropical northern Australia. However, some water quality variables did exceed guidelines at some sites; turbidity (Figure 11) and total nitrogen (Figure 13). Turbidity was above ANZECC/ARMCANZ (2000) guidelines for estuaries (20 NTU) at EST01 and EST03 (Figure 11). Turbidity recorded from EST03 was almost twenty times the ANZECC TV (390 NTU) and much higher than that recorded from the other estuary sites, reflecting the dynamic nature of this area, with high tidal energy. Total nitrogen was elevated in comparison to the estuarine ANZECC TV (0.25 mg/L) at all sites, with the concentration from EST01 being more than twice the trigger value. Total nitrogen recorded from EST03 was only marginally elevated above ANZECC guidelines (0.26 mg/L).

Dissolved oxygen (%) depth profiles for Keep River pools, reference sites and the estuary are provided in Figure 14. Reference sites generally showed greater change in DO with depth, particularly Milligan's Pool (KE1), Alligator Waterhole (KR1) and the Dunham River (DR1). At these pools, anoxic conditions (0% DO) were recorded at 3.5 m, 4.5 m and 6.5 m, respectively (Figure 13). The greatest variation in DO between the surface and bottom of a pool was recorded from the Dunham River reference site (DR1; 98% change in DO) and the least from K2 (0.3% DO change), followed by EST01 (0.9% DO change). There was little variation in DO with depth at the estuary sites (Figure 14), but these sites were shallow and likely easily mixed. There was little change in DO with depth at Keep River pools K1, K2 and K4 (Figure 14). This suggests mixing, either due to groundwater inflow, possible by tidal inflows, or more likely by wind fetch. The pools are orientated primarily in a north-south alignment, and afternoon sea breezes tend to generate significant wave action along the pools (except K4), which may be sufficient to disrupt any stratification. Ambient winds were shown to be sufficient to cause mixing and prevent anoxia in the lower Ord during a shut-down of flows to trial drought flows (WRC, 2003b; DoW, 2006). However, pool K3 did show considerable change in DO with depth and varied between 87.3% at the surface to 20.8 at the bottom of the pool (3.5 m depth).

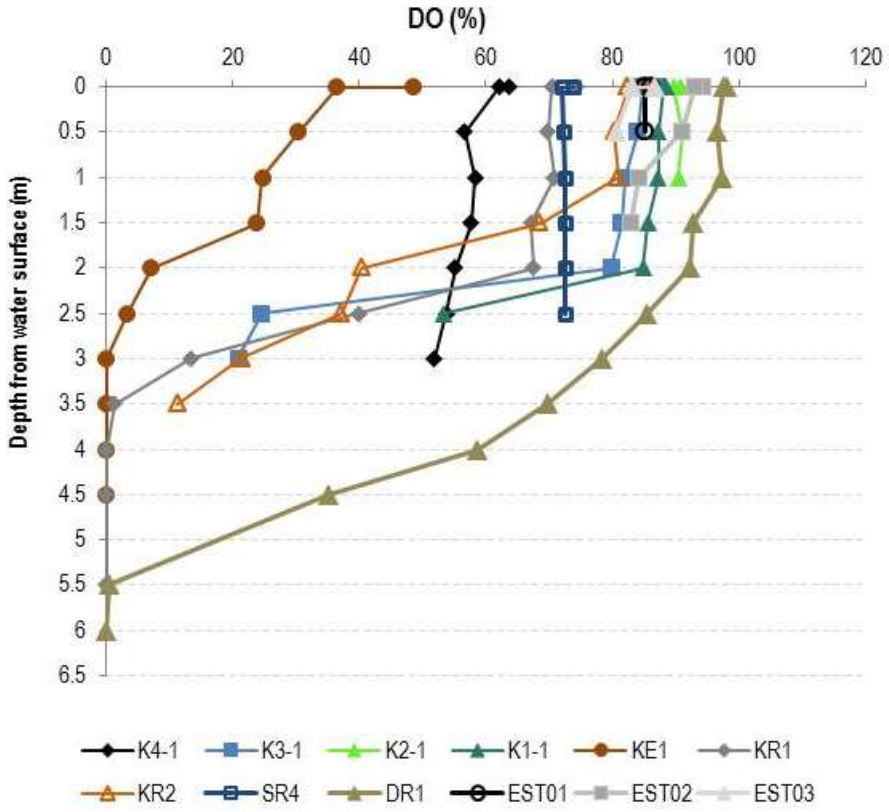

Figure 14. Sep-12 dissolved oxygen (%) depth profiles.

Contributions of dissolved organic carbon (DOC) varied considerably between sites (Figure 15). DOC ranged from 1.2 mg/L at K4-3 and K4-2 to 9.3 mg/L at KE1 (Milligans Lagoon). There was a longitudinal pattern in DOC along Keep River pools, with increasing DOC with distance downstream (Figure 15). While there is no guideline for DOC in surface waters, UNESCO *et al.* (1996) suggest that concentrations greater than 10 mg/L should be further investigated. No values this high were recorded during the current study.

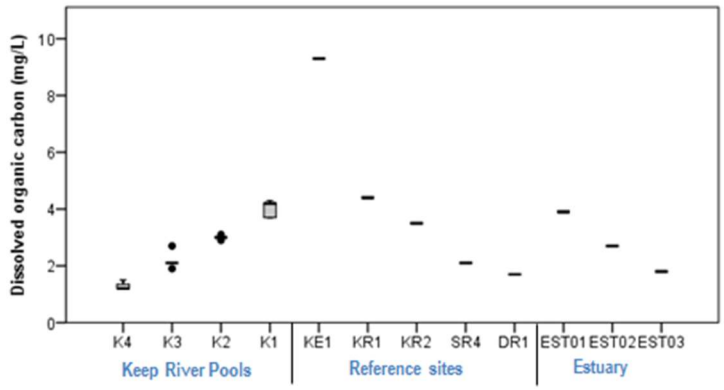

Figure 15. Boxplot of dissolved organic carbon concentrations (mg/L). The minimum, 20%ile, median (50%ile), 80%ile and maximum concentrations are shown for each site.

A number of water quality parameters were significantly different between sites and/or between years (Appendix 5). ANOVA results for significantly different water quality parameters are summarised below:

- pH was significantly different between site, with the lower Keep River pools and estuary (K3, K2, & K1) having statistically similar pH that was significantly higher than that from K4 or the reference sites. pH was significantly different between K4 and reference sites and was lowest at K4. pH was significantly higher in 2011.
- DO (%) was significantly different between sites, and was lowest at K4 and highest at K1. Significantly higher DO was recorded in 2011.
- EC was significantly lower at reference sites and Keep River pools upstream of K1 (i.e. K2, K3 & K4). K1 and the estuary recorded significantly different EC from one another, with highest EC being recorded from the estuary. EC was significantly higher in 2012 than 2011.
- Turbidity was significantly higher from the estuary than all other sites. There was no significant difference in turbidity between years.
- Calcium was significantly different between sites. Reference sites and two of the Keep River pools upstream (K4 & K3) were not significantly different from one another and recorded the lowest Ca concentrations. The remaining sites all recorded significantly different Ca from one another, with the order of concentration being K2<K1<estuary. Ca was significantly higher in 2012 than the previous year.
- Similar results were found for chloride concentration, but the concentration at K2 was statistically similar to the reference sites, K4 and K3. Cl was also significantly higher in 2012.
- Magnesium results were the same as for chloride.
- There was a significant difference in ammonia concentration between site with significantly higher concentrations recorded from the estuary than all other sites. Concentrations of ammonia were significantly higher in 2012.
- Total N was also significantly different between sites. Lowest total N concentrations were recorded from K4 and highest from the estuary. Significantly higher total N was recorded in 2012 compared with 2011.
- There was no significant difference in total P between site, but there was between year. Significantly higher total P was recorded in 2011.

Multivariate analyses of Keep River pools, estuary sites and reference pool water quality revealed the following:

- The correlation between the data cloud and the hypothesis of differences amongst sites was notably high along both canonical axes; 1.00 along CAP1 and 0.99 along CAP2.
- Separations between sites were evident in the CAP ordination (Figure 16). All Keep River pools separated from each other along CAP1 in a longitudinal pattern with respect to location along the river, i.e. the greatest separation was of the upstream pool K4 from the lower tidally-influenced pool K1, with K2 and K3 sitting in between. Reference sites also appeared to separate from Keep River pool sites (Figure 16). Site K4 was most similar to reference sites Milligans Lagoon (KE1) and KR1 (Alligator Waterhole). Estuary sites separated from all other sites along CAP1 (from reference sites) and CAP2 (Keep River pools).
- Vector overlay of water quality parameters with Spearman Rank correlations > 0.5 indicated separation of K1 and estuary sites along CAP1 from the upper Keep River pools and reference sites was primarily due to the higher EC, DO, pH and concentrations of Mg, Ca and Cl. The separation of the estuary from K1 was influenced by greater alkalinity and total nitrogen concentrations in the estuary (Figure 16).
- Differences in overall water quality were significantly different between site[4] (Two-factor PERMANOVA; df = 5, Pseudo F = 17.09, p = 0.0001) and year (df = 1, p = 0.0001; Table 9).

[4] individual reference sites used as replicates for this analysis

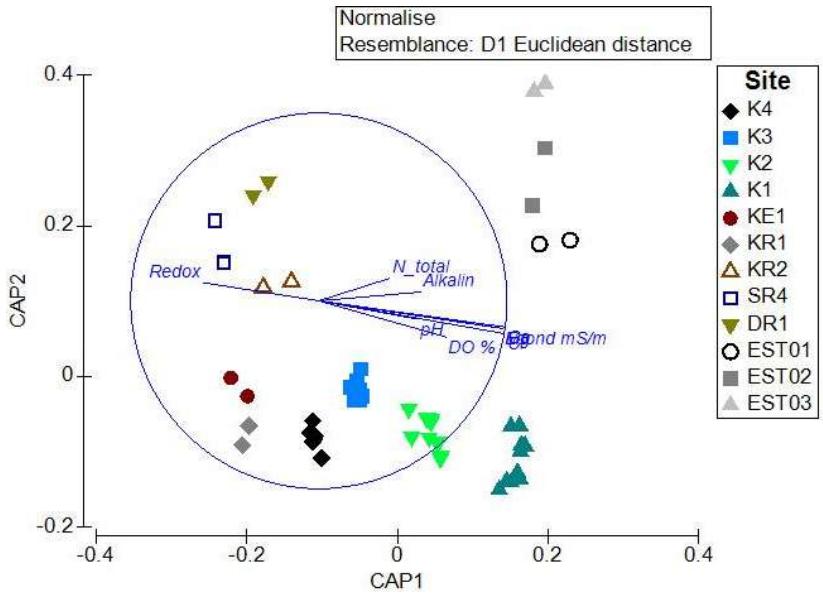

Figure 16. Constrained CAP plot comparing water quality (2011 & 2012 data) between site. Vectors of Spearman rank correlations > 0.5 are overlain.

Table 9. Two-Factor PERMANOVA results comparing water quality data between site[3] and year.

Source	df	MS	Pseudo-F	p-stat
Site	5	79.78	17.09	0.0001
Year	1	40.10	8.59	0.0001
Site*Year	5	7.35	1.57	0.0325
Residual	40	4.67		
Total	51			

5.3.2 Macroinvertebrates

A total of 246 macroinvertebrate taxa was recorded from all sites and habitats sampled during September 2012 (Appendix 6). Including taxa recorded from 2011, this makes a total of 310 macroinvertebrate taxa known from Keep River pools and reference sites. This list also includes groups which could not be identified to species level due to lack of suitable taxonomic keys (i.e. some Diptera families, some families of Coleoptera, etc). Therefore, the total species richness is likely greater than 310. Of the edge habitat samples, reference sites recorded a greater number of Odonata and Diptera taxa than Keep River pools, despite a much lower number of sites being sampled (Table 10). A greater number of Ephemeroptera, Odonata, Diptera and Trichoptera were recorded from reference site riffle habitats (Table 10).

The majority of macroinvertebrate taxa recorded during the current study were common, ubiquitous species, with distributions extending throughout Australia, northern Australia or Australasia. A number of taxa, however, have somewhat restricted distributions, including the water boatmen *Austronecta bartzarum* (Plate 5) and *Austronecta micra*, dragonfly *Nannophlebia mudginberri*, and 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.*

Plate 5. The northern restricted water boatman *Austronecta bartzarum* recorded from the edge habitat of K4-2 (photo by Anton Mittra/WRM ©).

bartzarum has been recorded from the Daly River, Victoria River, Policemans 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 from edge habitat samples at K4 (K4-2 and K4-3) and Alligator Waterhole (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 from edge sample from K3, K4 and the reference sites Alligator Waterhole (KR1), Policemans Waterhole (KR2), Augustus Waterhole (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 from edge habitat at Milligans Lagoon and from riffles at K3, Augustus Waterhole and the Dunham River during September 2012. The mayfly *Manggabora wapitja* is also restricted to the extreme northern Kimberley region and the Northern Territory (Dean and 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 from the riffle at Augustus Waterhole.

Table 10. Composition of macroinvertebrates in different habitat types from Keep River Pools and Reference sites. The number of sites sampled from each category is provided in parentheses.

Macroinvertebrate Group	*No. of taxa*			
	Edge Habitat		*Riffle Habitat*	
	Keep Pools (18)	Ref (5)	Keep Pools (2)	Ref (2)
Nemertea	0	0	0	0
Turbellaria (flat worms)	1	0	1	1
Nematoda (round worms)	0	0	0	0
Oligochaeta (aquatic segmented worms)	4	4	3	2
Polychaeta (aquatic bristle worms)	3	0	1	1
Cnidaria (freshwater hydra)	1	1	1	1
Mollusca (snails & bivalves)	8	6	3	1
Crustacea (prawns, crabs, shrimp etc)	10	7	1	0
Acarina (water mites)	2	2	1	2
Collembolla (spring tails)	1	0	1	0
Ephemeroptera (mayflies)	10	9	6	9
Odonata (dragonflies & damselflies)	11	20	3	5
Hemiptera (true bugs)	26	20	2	3
Coleoptera (aquatic beetles)	29	29	15	12
Diptera (two-winged flies)	26	39	31	34
Trichoptera (caddis-flies)	14	13	8	12
Thysanoptera (thrips)	1	0	0	0
Neuroptera (spongeflies)	0	0	0	1
Lepidoptera (moths)	0	0	3	4
Total number of taxa	**147**	**150**	**80**	**88**

The number of taxa recorded varied between site and habitat, and ranged from 14 taxa at K1-2 (edge habitat) to 75 at KE1 (Milligans Lagoon; edge habitat; Figure 17). Taxa richness from edge habitats generally decreased along the Keep River, with the greatest richness being recorded from K4 (Figure 17). The lowest macroinvertebrate taxa richness from riffle habitats was 48 (at K4 and DR1) and the greatest was 66 (at SR4; Figure 17).

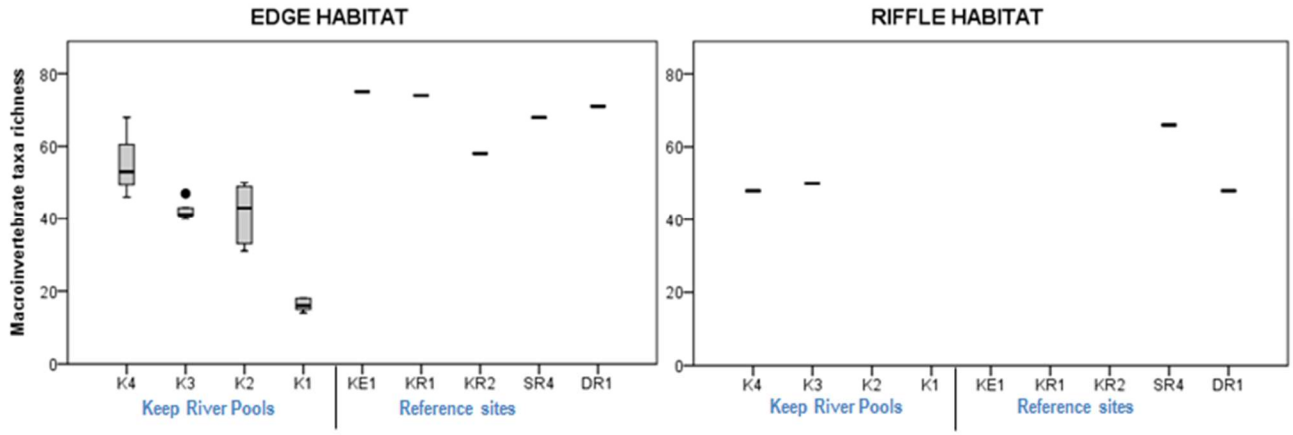

Figure 17. Boxplots of macroinvertebrate taxa richness from edge and riffle habitats in 2012. Plots show minimum, 20%ile, median (50%ile), 80%ile and maximum values, where applicable, for each site.

Average macroinvertebrate taxa richness from edge habitat samples was significantly different between sites (Two-way ANOVA; df = 4, p = 0.000) but not years (df = 1, p = 0.757; Table 11). The downstream, saline pool K1, on the Keep River, recorded the lowest mean macroinvertebrate taxa richness of all edge habitats sampled, with the highest mean richness at the reference sites (Table 11). Keep River pools from the mid- and upper-reaches (K2, K3 and K4) recorded intermediate average taxa richness (to K1 and reference sites) which was statistically similar to each other (Table 11). The low taxa richness at K1 likely reflects the effects of higher conductivity due to salt water intrusion, combined with the lower habitat diversity.

Table 11. Two-way ANOVA results comparing macroinvertebrate taxa richness in edge habitat between sites (Keep River pools and reference sites) and years. Degrees of freedom, f-value and p-value are shown. Between-site differences are summarised using Tukey's HSD multiple range tests, with sites arranged in ascending order, and mean species richness values for each site show. A solid line joins those sites not significantly different from each other.

Source	*df*	*F*	*p*	*Tukey's*				
				K1	**K3**	**K2**	**K4**	**REF**
Site	4	32.64	0.000	20.00	41.80	44.00	49.17	67.50
				2012	**2011**			
Year	1	1.00	0.757	44.00	44.17			
Site*Year	4	1.44	0.239					
Corrected total	45							

Multivariate analyses of macroinvertebrate assemblages from Keep River pools and reference sites revealed the following:

- The correlation between the data cloud and the hypothesis of differences amongst sites was high along both canonical axes; 0.97 along CAP1 and 0.94 along CAP2.

- Separations between sites were evident in the CAP ordination. The downstream, saline Keep River pool (K1) separated from all other sites along CAP1 (Figure 18). CAP2 separated the remaining Keep River pools and reference sites (Figure 18). The upstream Keep pool (K4) was most similar to the reference sites, with considerable overlap of samples in ordination space (Figure 18). K2 and K3 clustered together and appeared to separate slightly from K4 and reference sites (Figure 18).
- Vector overlay of water quality parameters with Spearman Rank correlations > 0.6 indicated that the macroinvertebrate assemblages of K1 were influenced by the higher alkalinity, EC (viz. salinity), calcium, pH and dissolved oxygen at this site (Figure 18).
- The BVSTEP routine indicated that water quality variables which had a significant influence on the macroinvertebrate assemblages were alkalinity, calcium and EC (BVSTEP; Rho = 0.77, p = 0.0001).
- A number of species influenced the separation of K1, most of which were species known to tolerate estuarine/saline waters. Such taxa included Polychaeta spp., estuarine mussels Bivalvia spp. (?estuarine) and shrimp *Caridina nilotica* (Figure 18). The latter species of shrimp is widespread and has been reported to be reasonably tolerant of salinity (Slaughter *et al.* 2008).
- The separation of reference sites from Keep River pools was influenced by higher abundances of a large number of taxa, including the chironomids *Clinotanypus crux*, Tanypodinae sp. ORT20, and *Polypedilum* sp.1, watermites Hydracarina spp., notonectid *Nychia sappho*, and caddisfly *Trianodes* sp. and *Ecnomus* sp.
- PERMANOVA concurred with these patterns, and found that macroinvertebrate assemblages were significantly different between site and year (Two-factor PERMANOVA; Table 12). Post-hoc results revealed that all sites had significantly different macroinvertebrate assemblages.

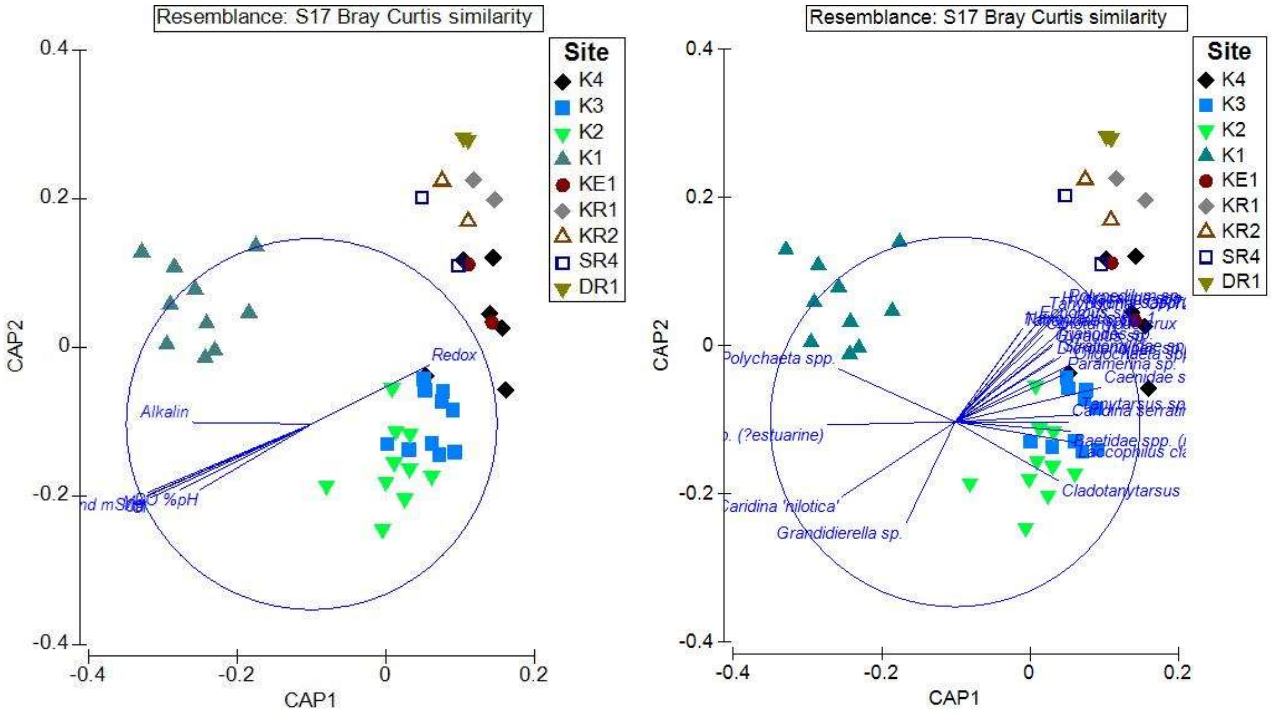

Figure 18. Constrained CAP plot of macroinvertebrate abundance data between site. Vectors of water quality Spearman Rank Correlations (correlation >0.6) (left) and species correlations (right) are overlain on the ordination.

Table 12. Two-Factor PERMANOVA results comparing macroinvertebrate log_{10} abundance data between site and year.

Source	df	MS	Pseudo-F	p-stat
Site	4	8855.90	7.91	0.0001
Year	1	6151.70	5.49	0.0001
Site*Year	4	1959.60	1.75	0.0001
Residual	36	1120.10		
Total	45			

5.3.3 AusRivAS

Current results

OE50 scores from Keep River pools determined from the AusRivAS model ranged from 0.50 (at K1-1, K1-2 and K1-5) to 0.99 (at K4-2) in 2011, and 0.25 (at K1-2) to 1.05 (at K4-3) in 2012 (Table 13). Corresponding bands ranged from C 'severely impaired' to A 'similar to reference' (Table 13 and Figure 19). As would be expected, the grades from sites closer to the estuary which undergo tidal influence and salt-water intrusion (i.e. K1) recorded the lowest O/E scores, while the fresher sites furthest upstream (i.e. K4) recorded the highest O/E scores. All O/E scores from reference sites were high and resulted in grades within the A 'similar to reference' band (Table 13 and Figure 19).

Table 13. Results from running the AusRivAS model, detailing OE50 scores and bands for each site using macroinvertebrate family-level data from 2011 and 2012.

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

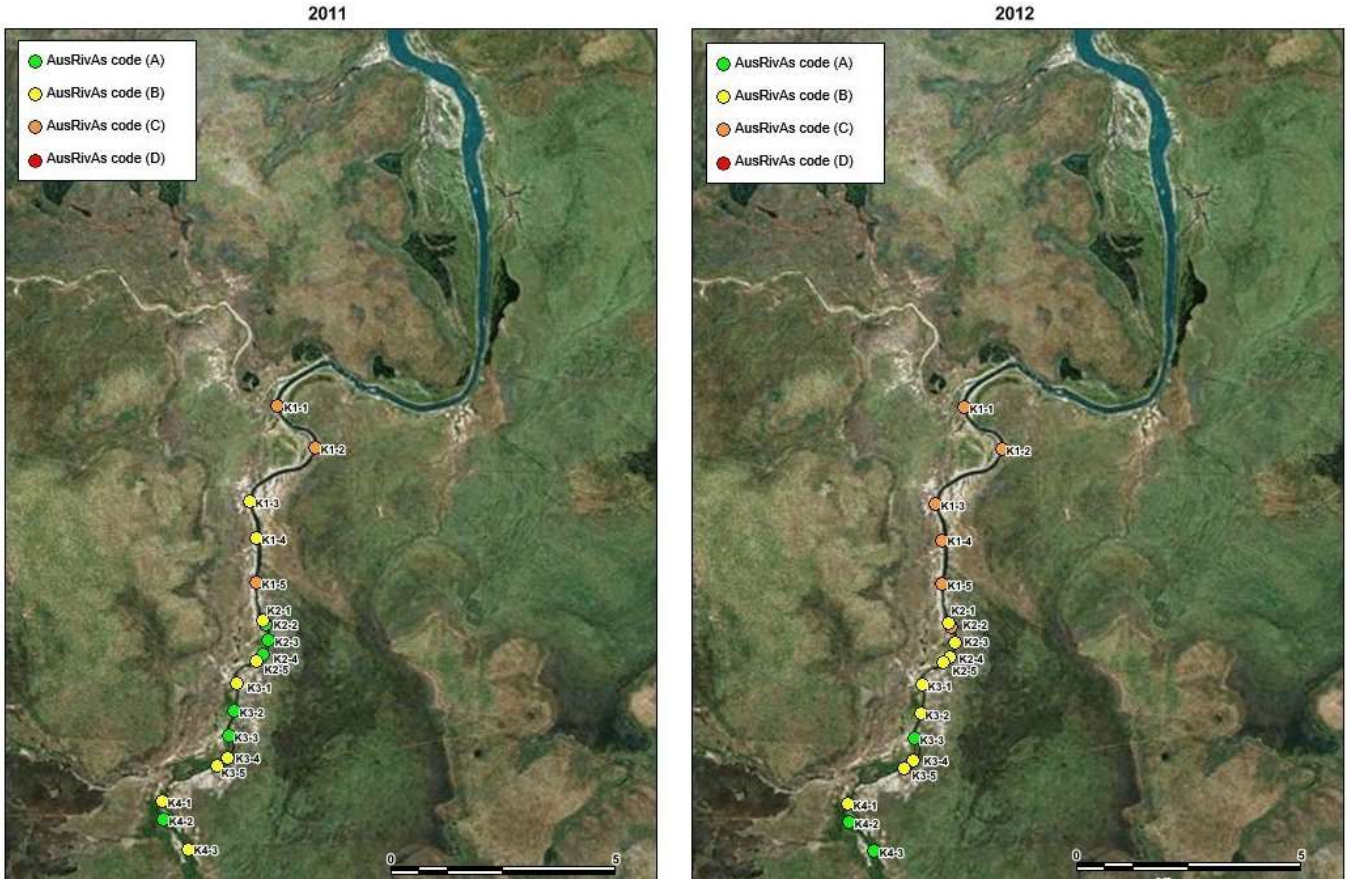

Figure 19. Results of AusRivAS band grades for each potentially exposed site in 2011 (left) and 2012 (right).

Development of trigger values

Trigger values (TVs), whether biotic or chemical (i.e. water quality TVs), are usually set in terms of some quantum of change from 'reference' condition, with the extent of allowable change sufficiently small as to minimise risk of 'significant' disturbance to the ecosystem. ANZECC/ARMCANZ (2000) has set the national standard for developing such targets, whereby the guideline values for indicators are set at the 80%ile and/or 20%ile of the reference (or baseline) condition. This approach has been adopted widely in Australia for monitoring wetlands and rivers, and assessing ecological health (see Fukuda and Townsend 2006, Storey *et al.* 2007, FBA 2009, Batley *et al*. 2003). The 20%ile and 80%ile are deemed to be approximately equivalent to ± one standard deviation around the median, and it is argued that this level of change is unlikely to result in a high risk of disturbance to the ecosystem (ANZECC/ARMCANZ 2000). In the case of biotic indices such as that based on AusRivas data, the 20%ile is the relevant calculation, i.e. the minimum expected value that monitoring data should not fall below as this would suggest a reduction in 'ecological health'. The 20th percentile will then act as the 'trigger', below which, further investigation and/or management actions may be required. It is important to note that the use of trigger values is not intended as a 'pass-fail' approach to ecosystem management. Their main purpose is to inform managers and regulators that changes in biological condition are occurring and may need to be investigated (ANZECC/ARMCANZ 2000). In this way, trigger values are precisely that, a 'trigger' for further examination and assessment.

In order to develop meaningful AusRivAS TVs for the Keep River that are in-line with national best practice, the 20%ile of O/E scores of baseline data (2011 & 2012 for preliminary TVs presented here) were calculated for each pool. This approach was adopted not only because it concurs with current best practice in the development of environmental trigger values, but also because the O/E scores are

continuous numerical values which provide a means for robust statistical analyses to test for change in the future. The categorical band grades (i.e. A through to D) do not provide such a means, and may be less conservative (viz. protective) in certain cases where, for example, a large shift in O/E score occurs within a pool over time that doesn't actually result in a change in band. In this case, concern that the macroinvertebrate community has changed may not be raised and addressed. In the alternative scenario, if an O/E score sits in the lower end of a band, and a small change in the future monitoring data results in a shift of band into a lower one (i.e. a shift from a B grade to a C grade), concerns may be raised, even if the change in the macroinvertebrate community is minor.

The ANZECC/ARMCANZ (2000) guidelines recommend using monthly data for at least two years to determine trigger values for water quality parameters. However, biological parameters likely require longer datasets to account for trends and natural variability. The Western Australian Department of Water recommend a minimum of three years data for trend analysis to ensure seasonal cycles are accounted for within the data (Hall *et al.* 2006). AusRivas TVs for Keep River pools will be based on three years' data once the 2013 surveys have been completed. Results presented here are preliminary.

Summary statistics of baseline O/E scores determined from running the AusRivAS Northern Territory late-dry season edge model are provided in Table 14. Preliminary AusRivAS trigger values (TVs) for Keep River pools K1, K2, K3 and K4, are O/E scores of 0.31, 0.73, 0.71 and 0.68, respectively (Table 14).

Table 14. Summary statistics of O/E scores, showing TVs for each pool based on the 20th percentile of 2011 & 2012 data (using reference sites as replicates for the reference category).

	O/E scores (2011 & 2012)			
Pool	Average	20th percentile ~ TV	Median	80th percentile
K1	0.44	0.31	0.44	0.51
K2	0.77	0.73	0.76	0.87
K3	0.78	0.71	0.77	0.86
K4	0.86	0.68	0.90	0.99
Reference	1.04	0.99	1.05	1.11

Application of trigger values to future monitoring data

In order to test whether the macroinvertebrate community at Keep River pools has changed relative to the AusRivAS TVs, the monitoring data should be statistically compared against each TV using a Wilcoxons One-Sample test. This is a non-parametric one-tailed test which compares the median value of monitoring data (i.e. data collected from each pool post-development) to the TV (i.e. the one sample). If a significant p-value is recorded, the median needs to be compared against the TV to ascertain whether the monitoring data is in fact LOWER than the TV[5], thus inferring a reduction in O/E score and adverse change in ecological health. If $p > 0.05$, then the median of the monitoring data is not significantly different from the TV (i.e. no reduction in O/E score and therefore no negative impact to the macroinvertebrate community).

In order to test this approach, O/E data from Keep River pools, as sampled in 2011 and 2012, were analysed (separately) against the corresponding TVs using the Wilcoxons Test (see Table 15). As would be expected, there was no significant difference in O/E scores between the TV and survey data for any pool or either year (Table 15).

[5] This is because the monitoring data may be significantly different to the TV, but the median value may be HIGHER than the TV, indicating improvement in the macroinvertebrate community/ecological health.

Table 15. Example of applying the TVs to monitoring data using data from the 2011 & 2012 surveys of Keep River pools, showing results from Wilcoxons Test.

		Comparison against TVs – Wilcoxons results				
Pool	AusRivas TV	Year	z	p-value	Median O/E	Comments
K1	0.31	2011	-1.5	0.138	0.50	Not significantly different to TV
		2012	0.5	0.59	0.31	Not significantly different to TV
K2	0.73	2011	-1.5	0.138	0.86	Not significantly different to TV
		2012	1.2	0.225	0.74	Not significantly different to TV
K3	0.71	2011	-1.3	0.178	0.74	Not significantly different to TV
		2012	-1.3	0.178	0.80	Not significantly different to TV
K4	0.68	2011	-0.3	0.789	0.68	Not significantly different to TV
		2012	-1.1	0.285	0.99	Not significantly different to TV

When applying TVs to monitoring data, a significant reduction in O/E score from a Keep River pool does not necessarily indicate a negative impact from the ORIA Stage II development. If such a decline is accompanied by a significant reduction in O/E score at the upstream reference sites compared to the corresponding TV (i.e. O/E score of 0.99; see Table 14), then the change in macroinvertebrate community could be considered due to natural variability and may be a reflection of climatic changes across the catchment, such as reductions (or increases) in rainfall and streamflow.

If a significant reduction in O/E score at Keep River pools is not accompanied by a similar reduction at reference sites and/or reductions cannot be explained by parameters such as rainfall or streamflow data, further investigation would be required. Investigations and actions may include:

1. Examining water quality data to ascertain whether the reduction in O/E score can be related to a change in water quality associated with the ORIA Stage II development
2. Undertaking multivariate analyses on macroinvertebrate abundance data (species-level data) using control charts to assess whether there has been a significant change in overall community structure at Keep River pools
3. Investigate the risk to the environment in consultation with external experts and assess whether there is a need to flush the system with M2 water to manage negative impacts from the development
4. Re-survey the aquatic macroinvertebrate fauna to assess whether the reduction in O/E score is part of an ongoing trend and/or to assess recovery of macroinvertebrates following management actions, such as discharge of M2 water.

An example decision support tree is provided in Figure 20 to guide management decisions and/or response to a failure to meet AusRivAS TVs.

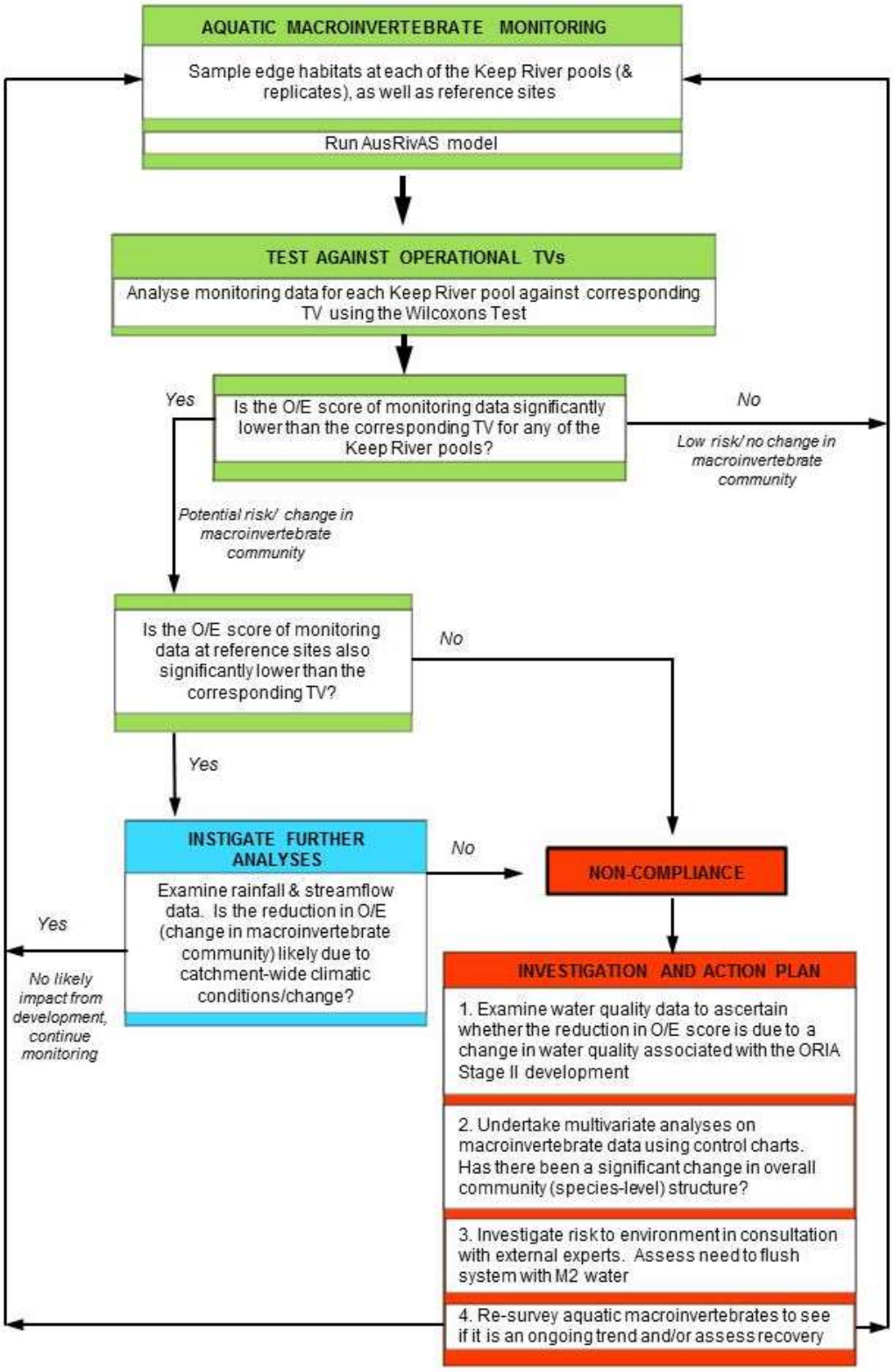

Figure 20. Example showing generalised decision support tree for assessing and responding to failure to meet the AusRivAS TVs at Keep River pools.

5.3.4 Fish

A total of 31 species of fish were recorded during the current study, including 14 freshwater species and 17 estuarine/marine species (Table 16). Freshwater species included bony bream *Nematalosa*

erebi, blue catfish (or lesser salmon catfish) *Neoarius graeffei*, shovel-nosed catfish *Neoarius midgleyi*, narrow-fronted tandan *Neosiluris ater*, freshwater longtom *Strongylura kreffti*, glassfish *Ambassis* sp., barramundi *Lates calcarifer* (Plate 6), spangled perch *Leiopotherapon unicolor*, barred grunter *Amniataba percoides*, Jenkins' grunter *Hephaestus jenkinsi* (Plate 6), seven-spot archerfish *Toxotes chatareus*, two species of mullet *Liza alata* and *Liza* sp., and the freshwater sawfish *Pristis pristis* which was recorded during the targeted surveys detailed in section 4 of this report (see Table 16 for the complete list of fish species and records). Estuarine/marine species included the long-snouted catfish *Plicofollis argyropleuron* (Plate 6), bull shark *Carcharhinus leucas* (Plate 6), Perth herring *Nematalosa vlaminghi*, anchovies *Thryssa kammalensis* and *Thryssa* sp., queenfish *Scomberoides commersonianus,* oxeye herring *Megalops cyprinoides*, common ponyfish *Leiognathus equulus*, nurseryfish *Kurtus gulliveri* (Plate 6), snub-nosed garfish *Arrhamphus sclerolepis*, blue threadfin *Eleutheronema tetradactylum*, king threadfin *Polydactylus macrochir*, scaly croaker *Nibea squamosa*, soldier croaker *Nibea soldado*, Merauke toadfish *Marilyna meraukensis*, sea mullet *Mugil cephalus* and barred javelinfish *Pomadasys kaakan* (Plate 6; Table 16). Including fish reported in WRM (2013) from the 2011 surveys, a total of 40 species have been recorded from the Keep River pools and reference sites.

In September 2012, bony bream, diamond mullet and lesser salmon catfish were the most commonly encountered species, being recorded from 21, 20 and 19 of the 23 sites, respectively (Table 16). This was followed by barramundi and seven-spot archerfish (both recorded from 9 sites in 2012). A number of species were only recorded from one site, including the shovel-nosed catfish, long-snouted catfish, glassfish, spangled perch, Jenkin's grunter, bull shark, giant queenfish, anchovy, giant threadfin, scaly croaker, soldier croaker and Merauke toadfish (Table 16). All species recorded are known to be common throughout the north of Australia, with the exception of the freshwater sawfish. The freshwater sawfish was the only species of conservation significance recorded (see section 4.3.2 for information pertaining to the conservation significance of the freshwater sawfish).

The greatest number of fish recorded from any given site during September 2012 was 14 species, which was recorded from a lower Keep River pool site (K1-1) which is tidally influenced (Figure 21). This was followed by eight species, recorded from the Keep River pool sites K4-2 and K2-5. Taking into account fish records from 2011 and combining species richness with that recorded in 2012, the total number of fish species recorded from Keep River pools ranged from six at K2-3 to 18 at K1-1 (Figure 21). Total species richness at reference sites ranged from four at KR1 (Alligator Waterhole) to 11 at DR1 (the Dunham River at KR).

Multivariate analyses of Keep River and reference pool fish assemblages revealed the following:

- The correlation between the data cloud and the hypothesis of differences amongst sites was reasonably high along both canonical axes; 0.86 along CAP1 and 0.79 along CAP2.
- Patterns were evident in the CAP ordination. Keep River pools generally separated from the reference sites, with the exception of SR4 and DR1 in 2012 which had similar fish assemblages to K2 and K3 (Figure 22). The fresh upstream Keep River pool (K4) also separated from the lower Keep River pools. There was considerable overlap in fish assemblage samples from the lower Keep River pool sites (K3, K2 and K1; Figure 22).
- Variation amongst reference sites was high. Fish assemblages of KE1 (Milligan's Lagoon) and KR2 (Policemen's Waterhole) were most similar to K4 (Figure 22). KR1 (Alligator Waterhole) was most different to all other reference sites. Temporal (between-year) variation was high at KR1, SR4 (Augustus) and DR1 (Dunham River).
- Vector overlay of fish species with Spearman Rank correlations > 0.5 indicated the lower Keep River pools separated from other sites based on their greater occurrence of *Leiognathus equulus*, *Toxotes chatereus*, *Liza* sp. and *Arrhamphus sclerolepis* (Figure 22).

Table 16. Fish species recorded from each site (* indicates species was recorded during the 2011 surveys; WRM 2013).

	Family	Species	Common name	K1-1	K1-2	K1-3	K1-4	K1-5	K2-1	K2-2	K2-3	K2-4	K2-5	K3-1	K3-2	K3-3	K3-4	K3-5	K4-1	K4-2	K4-3	KE1	KR1	KR2	SR4	DR1	No. occur. 2012
Freshwater	Clupeidae	*Nematalosa erebi*	Bony bream	✓*	✓*	✓*	✓*	✓*	✓*	✓*	✓*	✓*	✓*	✓*	*	✓*	✓*	✓*	*	✓*	✓	✓*	✓*	✓*	✓*	✓*	21
		Neoarius graeffei	Blue catfish	*	✓*	✓*	✓*	*	✓*	✓	✓*	✓*	✓*	✓*	✓*	✓*	*	✓*	✓*	✓*	✓*	✓*	*	✓*	✓*	✓*	19
	Ariidae	*Neoarius midgleyi*	Shovel-nosed catfish																						✓*	1
		Anodontiglanis dahli	Toothless catfish																		*			*		0
	Plotosidae	*Neosilurus ater*	Narrow-fronted tandan																✓*	✓*	✓*					*	3
	Belonidae	*Strongylura kreffti*	Freshwater longtom						✓*	✓			✓				✓*			✓				*		*	5
		Parambassis gulliveri	Giant glassfish																*							*	0
	Ambassidae	*Ambassis* sp.	Glassfish											✓													1
	Centropomidae	*Lates calcarifer*	Barramundi	✓			*	*	*					✓*	✓*	✓	*	*	✓*	✓	✓	✓*		✓*			9
		Leiopotherapon unicolor	Spangled perch																			✓					1
		Amniataba percoides	Barred grunter																				✓*	✓*	*	*	2
		Hephaestus jenkinsi	Jenkins' grunter									✓													*		1
		Syncomistes butleri	Butler's grunter									*													*	*	0
	Terapontidae	*Syncomistes trigonicus*	Long-nose grunter																							*	0
	Apogonidae	*Glossamia aprion*	Mouth almighty				*															*					0
	Toxotidae	*Toxotes chatareus*	Seven-spot archerfish	✓*	*	✓*	✓	✓*	*				✓*	*	*	*	*	*	*	✓	✓	*		✓*	✓		9
		Liza alata	Mullet	✓*	*	✓*	✓*	✓*	✓*	✓*	✓*	✓*	✓*	✓*	✓*	✓*	✓*	✓*	*	✓*	✓*	✓*		✓*	✓	✓*	20
	Mugilidae	*Liza* sp.	Mullet	✓*		*		✓						*	✓*			✓*									4
		Hypseleotris compressa	Empire gudgeon														*										0
	Eleotridae	*Mogurnda mogurnda*	Northern trout gudgeon																*								0
	Pristidae	*Pristis pristis*	Freshwater sawfish	✓						✓*														✓*			3
Estuarine/Marine	Ariidae	*Plicofollis argyropleuron*	Longsnouted catfish	✓																							1
	Carcharhinidae	*Carcharhinus leucas*	Bull shark	*	*	*									✓		*										1
	Carangidae	*Scomberoides commersonianus*	Giant queenfish	✓																							1
	Clupeidae	*Nematalosa vlaminghi*	Perth herring	✓	✓																						2
		Thryssa kammalensis	Anchovy	✓						*		*	*		*			*									1
	Engraulidae	*Thyrssa* sp.	Anchovy								✓*																1
	Elopidae	*Elops australis*	Herring	*		*		*		*							*										0
	Megalopidae	*Megalops cyprinoides*	Oxeye herring									✓				✓			*	✓		*	*			*	3
	Mugilidae	*Mugil cephalus*	Sea mullet	✓				✓																			2
	Leiognathidae	*Leiognathus equulus*	Common ponyfish	*	*	*		✓*	*	✓*	✓	✓	✓*	*	✓	✓		*									7
	Lutjanidae	*Lutjanus argentimaculatus*	Mangrove jack				*																				0
	Kurtidae	*Kurtus gulliveri*	Nurseryfish							✓			✓														2
	Hemiramphidae	*Arrhamphus sclerolepis*	Snub-nosed garfish	✓	✓*	✓	✓			*																	4
	Ambassidae	*Ambassis interruptus*	Long-spined glassfish							*								*									0
	Polynemidae	*Eleutheronema tetradactylum*	Blue threadfin	✓	✓		✓																				3
		Polydactylus macrochir	Giant threadfin	✓*							*																1
	Sciaenidae	*Nibea squamosa*	Scaly croaker										✓														1
		Scomberoides commersonianus	Soldier croaker											✓													1
	Tetraodontidae	*Marilyna meraukensis*	Merauke toadfish									✓															1
	Haemulidae	*Pomadasys kaakan*	Barred Javelinfish			✓	✓																				2
			Number of species 2012	**14**	**5**	**6**	**7**	**6**	**4**	**7**	**5**	**7**	**8**	**6**	**6**	**6**	**3**	**4**	**3**	**8**	**6**	**5**	**2**	**7**	**4**	**4**	
			Total number of species 2011 & 2012	**18**	**9**	**10**	**10**	**9**	**7**	**11**	**6**	**9**	**9**	**9**	**9**	**7**	**9**	**9**	**9**	**8**	**6**	**9**	**4**	**8**	**8**	**11**	

Plate 6. Some of the fish recorded during the current study, including the barred javelinfish *Pomadasys kaakan* (top left), barramundi *Lates calcarifer* (top right), Jenkins' grunter *Hephaestus jenkinsi* (middle left), long-snouted catfish *Plicofollis argyropleuron* (middle right), Bull shark *Carcharhinus leucas* (bottom left), and nurseryfish *Kurtus gulliveri* (bottom right). All photos by WRM staff ©.

- The upstream site (K4) separated from other sites based on the greater occurrence of *Neosilurus ater* and *Lates calcarifer* (Figure 22).
- Environmental variables which influenced the fish assemblage structures included pH, alkalinity, and electrical conductivity. However, the correlation was low (BVSTEP; Rho = 0.41, p = 0.002).
- Differences in fish assemblages between site[6] were significant (Two-factor PERMANOVA; df = 4, Pseudo F = 5.31, p = 0.0001; Table 17). Post-hoc results revealed that all sites were significantly different from one another. Fish assemblages were not significantly different

[6] individual reference sites used as replicates for this analysis

between year, and there was no significant interaction between site and year (Two-factor PERMANOVA; Table 17).

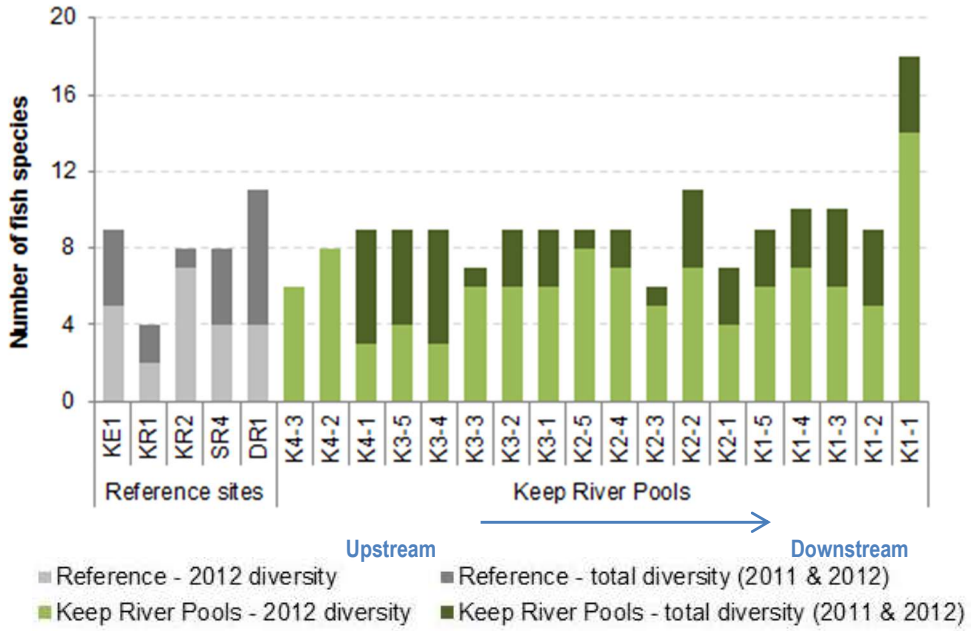

Figure 21. Number of fish species recorded from each site in 2012, and the total number of fish recorded from each site including both sampling events combined (2011 & 2012 data).

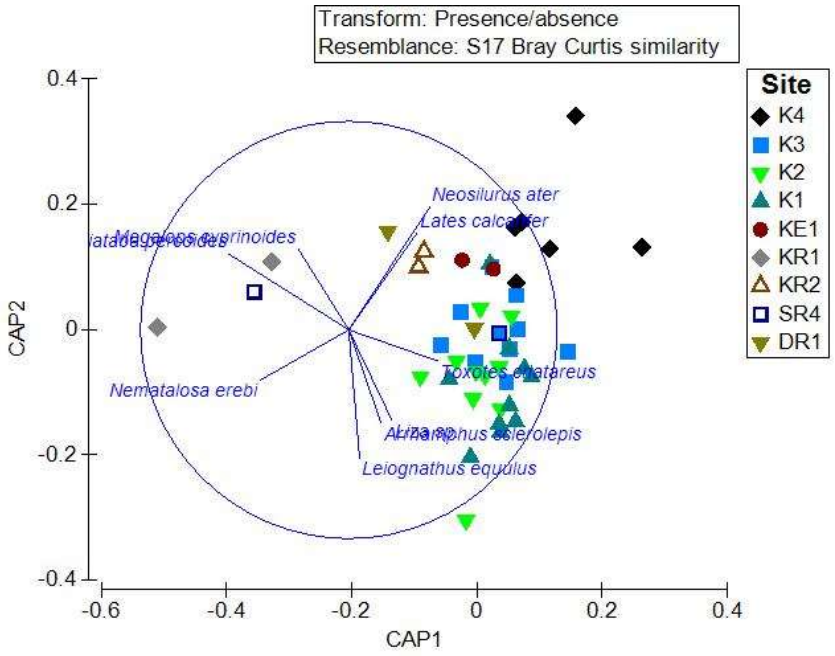

Figure 22. Constrained CAP plot of fish presence/absence data between site, with vectors of Spearman rank correlations overlain (correlation >0.5).

Table 17. Two-Factor PERMANOVA results comparing fish presence/absence data between site and year.

Source	df	MS	Pseudo-F	p-stat
Site	4	4767.9	5.31	0.0001
Year	1	841.45	0.94	0.4909
Site*Year	4	1180.3	1.43	0.0733
Residual	36	897.09		
Total	45			

There was considerable variation in the size and weight of fish, including blue catfish, diamond mullet and bony bream, both within- and between-sites (Figure 23).

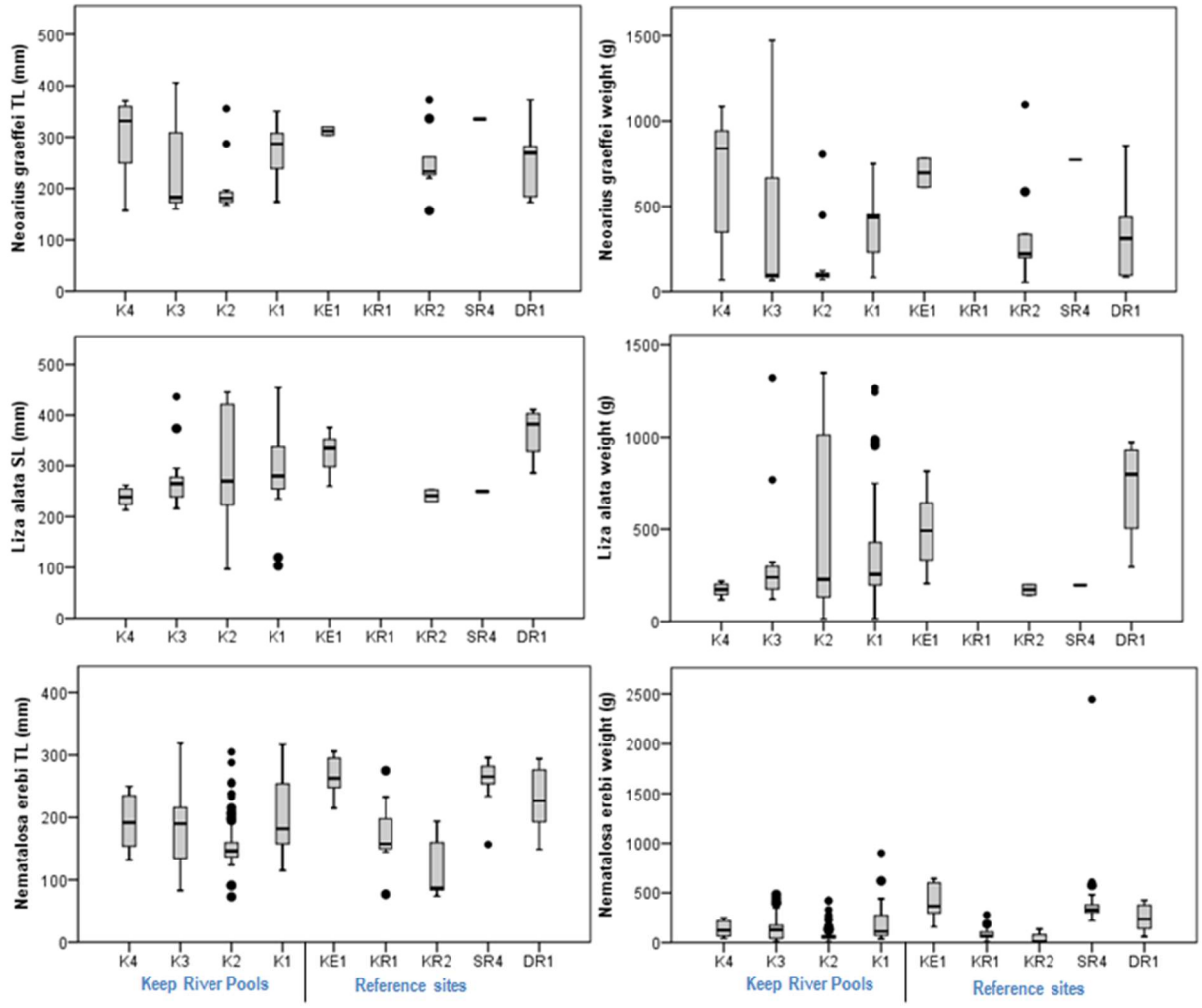

Figure 23. Boxplots of total length (left) and weight (right) of selected fish species at each site. Plots show minimum, 20%ile, median (50%ile), 80%ile and maximum sizes of each species for each site. Plots are provided for *Neoarius graeffei* (top), *Liza alata* (middle), and *Nematalosa erebi* (bottom).

5.4 Discussion

This study presents baseline data from the second round of sampling of the Keep River under the Ord Stage 2 Expansion Aquatic Fauna Monitoring program, and provides some comparison with earlier data collected in 2011 (i.e. WRM 2013). The data provided here form part of the initial baseline for

the system, against which future changes in water quality and aquatic fauna assemblages (macroinvertebrates and fish) may be assessed. Additional water quality (monthly samples) and flow data (continuous measurement) are being collected by DAFWA (2011), using the same suite of analytes as this program, and 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. The current report also presents initial data on distribution, relative abundance and population structure of listed sawfish species. To-date no *Glyphis* sharks have been captured in the system.

Overall, water quality was found to be significantly different between pools, with a longitudinal gradient present along the Keep River. The downstream pool, K1, separated from other pools and reference sites based on its higher pH, dissolved oxygen, EC and concentrations of ions such as magnesium, calcium and chloride. This reflects the estuarine/tidal influence at this site, with this influence decreasing progressively upstream (i.e. into pools K2 and K3). Water quality of the upstream pool, K4, was most similar to reference sites Milligans Lagoon (KE1) and Alligator Waterhole (KR1). In general, aquatic macroinvertebrate and fish assemblages were found to be influenced by these differences in water quality. River condition, as determined by the AusRivAS outputs, 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. Preliminary biotic TVs were developed for each Keep River pool, based on the 20th percentile of O/E scores from each site recorded in 2011 and 2012. These TVs will be updated once data from the 2013 sampling round become available. Future monitoring data can then be compared against these TVs statistically, using a Wilcoxons Test.

In many respects 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 probably sets them beyond the bounds of habitats to which the AusRivAS model should be applied. However, when run through the relevant model, the sites were not 'rejected' as being outside the bounds of the model, and therefore the outputs appear valid. 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 current condition of each pool sets current baseline condition against which future changes will be assessed once irrigation commences.

The Keep River system is highly dynamic between wet and dry seasons, as are many northern Australian river systems, receding from extreme high flows to zero or very low base flows. Many water quality attributes change dramatically (i.e. TSS and turbidity, as well as 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 system due to flooding and road conditions, and even if access was possible, it would be extremely difficult to sample under high flows. Therefore, the decision to standardise sampling to the late dry season was made for this sampling program. It is acknowledged that this provides only a snap-shot of the system each year, but by standardising to the late dry season, it is anticipated this will minimise seasonal effects on aquatic fauna and water quality data, allowing inter-annual comparisons, and allow any changes in water quality or aquatic fauna as a result of the development, should they occur, to be detected.

The baseline provides data on spatial differences in surface water and sediment quality, macroinvertebrate assemblages and fish assemblages. It provides a measure of the relative differences in taxa richness and assemblage structure across pools in the system. Additional sampling in 2013, as required under Commonwealth conditions for project approval, will add to the baseline and allow spatial and temporal variability to be characterised further. This will enable any impacts that may be as a result of the stage 2 development, if any, to be differentiated from climatic or other

system-level changes. Further sampling will also provide additional data on relative abundance, distribution and population structure of listed species in the upper estuary and upstream pools. Future catch returns of tagged individuals will also provide information on sawfish movements and growth rates in the Keep system.

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APPENDICES

Appendix 1. Site photographs

POTENTIALLY EXPOSED SITES

K1

K2

K3

K4

REFERENCE SITES

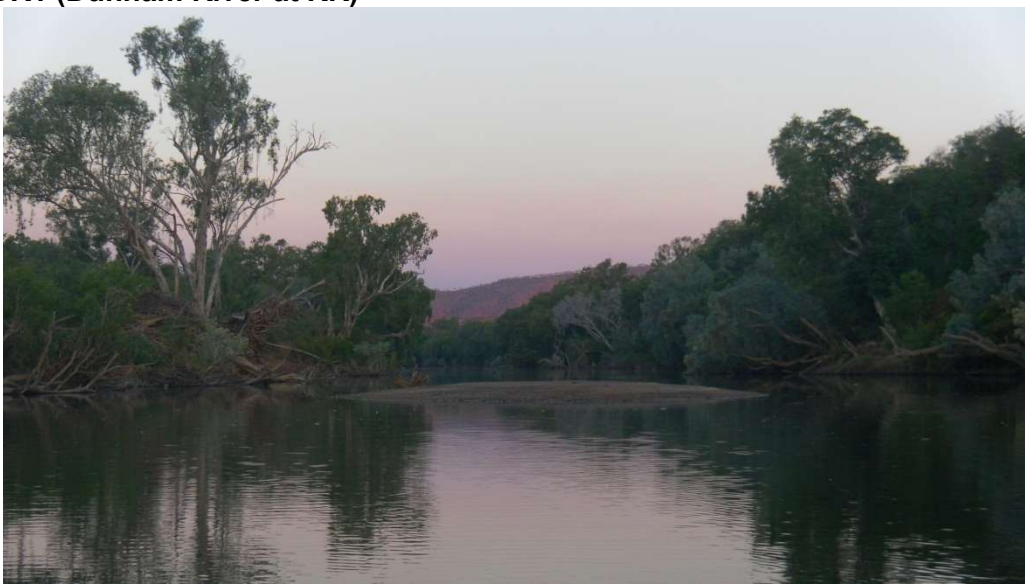
KE1 (Milligan's Lagoon)

KR1 (Alligator Waterhole)

KR2 (Policeman's Waterhole)

SR4 (Augustus Waterhole)

DR1 (Dunham River at KR)



ESTUARY SITES

ESTO1

No picture taken of EST02

EST03

Appendix 2. Interim Sediment Quality Guidelines

The recommended guideline values are tabulated as 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.

Table A2-1. Recommended sediment quality guidelines (adapted from Long *et al.* 1995).

Contaminant	*ISQG-Low (trigger value)*	*ISQG-High*
METALS (mg/kg dry wt.)		
Antimony	2	25
Cadmium	1.5	10
Chromium	80	370
Copper	65	270
Lead	50	220
Mercury	0.15	1
Nickel	21	52
Silver	1	3.7
Zinc	200	410
METALLOIDS (mg/kg dry wt.)		
Arsenic	20	70
ORGANOMETALLICS		
Tributyltin (µg Sn/kg dry wt.)	5	70
ORGANICS		
Low Molecular Weight PAHs	552	3160
High Molecular Weight PAHs	1700	9600
Total PAHs	4000	45000
Total DDT	1.6	46
Total PCBs	23	-

Appendix 3. Sediment Quality ANOVA Results

Table A3-1. Two-way ANOVA results comparing ionic composition in sediments between sites and between years. Degrees of freedom, f-value, p-value, and Tukeys post-hoc results are shown. Only significant results are tabulated. Tukey's results are presented in ascending order, with groups of no difference in means joined by a black line.

Parameter	Source	df	F	p	Tukeys post-hoc (low – high mean)
Ca	Site	4	77.02	0.000	K4 K3 K1 K2 EST
	Year	1	1.07	0.309	2011 2012
	Site*Year	4	2.79	0.043	
	Corrected total	41			
Cl	Site	4	28.80	0.000	K4 K3 K2 K1 EST
	Year	1	1.40	0.246	2012 2011
	Site*Year	4	0.38	0.820	
	Corrected total	41			
K	Site	4	8.26	0.000	K4 K3 K2 EST K1
	Year	1	2.72	0.109	2011 2012
	Site*Year	4	0.28	0.888	
	Corrected total	41			
Mg	Site	4	8.45	0.000	K4 K3 K2 K1 EST
	Year	1	4.89	0.034	2011 2012
	Site*Year	4	0.38	0.818	
	Corrected total	41			
Na	Site	4	34.78	0.000	K4 K3 K2 K1 EST
	Year	1	0.00	0.998	2012 2011
	Site*Year	4	0.108	0.979	
	Corrected total	41			
SO4	Site	4	46.55	0.000	K4 K3 K2 K1 EST
	Year	1	1.00	0.324	2012 2011
	Site*Year	4	2.00	0.119	
	Corrected total	41			

Table A3-2. One-way ANOVA results comparing sediment nutrient data by site. Degrees of freedom, f-value, p-value, and Tukeys post-hoc results are shown. Only significant results are tabulated. Tukey's results are presented in ascending order, with groups of no difference in means joined by a black line.

Parameter	Source	df	F	p	Tukeys post-hoc (low – high mean)
N_NH4	Site	4	3.02	0.032	EST K2 K1 K3 K4
	Year	1	2.97	0.095	2012 2011
	Site*Year	4	0.51	0.728	
	Corrected total	41			

N_NO3	Site	4	4.92	0.003	**K1 K4 K2 EST K3**
	Year	1	13.48	0.001	**2011 2012**
	Site*Year	4	3.23	0.024	
	Corrected total	41			
P	Site	4	23.44	0.000	**K2 K4 K3 K1 EST**
	Year	1	1.65	0.209	**2011 2012**
	Site*Year	4	0.12	0.976	
	Corrected total	41			

Table A3-3. One-way ANOVA results comparing sediment metals composition data by site. Degrees of freedom, f-value, p-value, and Tukey's post-hoc results are shown. Only significant results are tabulated. Tukey's results are presented in ascending order, with groups of no difference in means joined by a black line.

Parameter	*Source*	*df*	*F*	*p*	*Tukeys post-hoc (low – high mean)*
As	Site	4	20.14	0.000	**K3 K2 K4 K1 EST**
	Year	1	18.11	0.000	**2011 2012**
	Site*Year	4	1.11	0.371	
	Corrected total	41			
Al	Site	4	3.06	0.030	**EST K4 K3 K2 K1**
	Year	1	23.86	0.000	**2011 2012**
	Site*Year	4	1.04	0.402	
	Corrected total	41			
B	Site	4	38.69	0.000	**K3 K4 K2 K1 EST**
	Year	1	13.25	0.001	**2011 2012**
	Site*Year	4	3.16	0.027	
	Corrected total	41			
Ba	Site	4	9.26	0.000	**EST K1 K3 K2 K4**
	Year	1	0.49	0.488	**2012 2011**
	Site*Year	4	0.67	0.615	
	Corrected total	41			
Co	Site	4	5.98	0.001	**EST K1 K3 K4 K2**
	Year	1	0.14	0.715	**2011 2012**
	Site*Year	4	0.42	0.790	
	Corrected total	41			
Cr	Site	4	3.19	0.026	**EST K4 K3 K2 K1**

Parameter	Source	df	F	p	Tukeys post-hoc (low – high mean)
					2011 2012
	Year	1	15.78	0.000	
	Site*Year	4	0.97	0.435	
	Corrected total	41			
					EST K4 K1 K3 K2
Cu	Site	4	9.04	0.000	
					2011 2012
	Year	1	2.05	0.162	
	Site*Year	4	0.88	0.488	
	Corrected total	41			
					EST K1 K3 K4 K2
Ni	Site	4	5.74	0.001	
					2011 2012
	Year	1	32.09	0.000	
	Site*Year	4	1.00	0.423	
	Corrected total	41			
					EST K1 K4 K2 K3
Pb	Site	4	11.35	0.000	
					2011 2012
	Year	1	4.77	0.036	
	Site*Year	4	0.493	0.741	
	Corrected total	41			
					EST K1 K3 K2 K4
Se	Site	4	4.26	0.007	
					2011 2012
	Year	1	63.84	0.000	
	Site*Year	4	1.22	0.320	
	Corrected total	41			
					K4 K2 K3 K1 EST
Ti	Site	4	42.50	0.000	
					2011 2012
	Year	1	27.80	0.000	
	Site*Year	4	1.00	0.423	
	Corrected total	41			
					EST K1 K4 K3 K2
U	Site	4	3.83	0.012	
					2011 2012
	Year	1	6.98	0.013	
	Site*Year	4	1.09	0.376	
	Corrected total	41			
					EST K1 K4 K2 K3
V	Site	4	14.03	0.000	
					2011 2012
	Year	1	1.02	0.319	
	Site*Year	4	0.54	0.709	
	Corrected total	41			

Appendix 4. ANZECC/ARMCANZ (2000) trigger values for the protection of aquatic systems in tropical northern Australia

Table A4-1. Default trigger values for some 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; NH4+ = 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).

	TP ($\mu g\ L^{-1}$)	*FRP* ($\mu g\ L^{-1}$)	*TN* ($\mu g\ L^{-1}$)	*NOx* ($\mu g\ L^{-1}$)	*NH_4^+* ($\mu g\ L^{-1}$)	*DO* % saturation[f]	*pH*
Aquatic Ecosystem							
Upland River[e]	10	5	150	30	6	90-120	6.0-7.5
Lowland River[e]	10	4	200-300[h]	10[b]	10	85-120	6.0-8.0
Lakes & Reservoirs	10	5	350[c]	10[b]	10	90-120	6.0-8.0
Wetlands[3]	10-50[g]	5-25[g]	350-1200[g]	10	10	90[b]-120 [b]	6.0-8.0
Estuaries	20	5	250	30	15	80-120	7.0-8.5

b = Northern Territory values are $5\mu gL_{-1}$ 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.

Table A4-2. Default trigger values for salinity and turbidity for the protection of aquatic ecosystems, applicable to tropical systems in Australia (ANZECC/ARMCANZ 2000).

Aquatic Ecosystem		*Comments*
Salinity	***(µs/cm)***	
Aquatic Ecosystem		
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)***	
Aquatic Ecosystem		
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.

Table A4-3. Default trigger values for toxicants at alternative levels of protection for the protection of aquatic ecosystems, applicable to tropical systems in Australia (ANZECC/ARMCANZ 2000). All values in µg/L.

	Trigger values for freshwater Level of protection (% species)			
Compound	***99%***	***95%***	***90%***	***80%***
METALS & METALLOIDS				
Aluminium pH > 6.5	27	55	80	150
Aluminium pH < 6.5	ID	ID	ID	ID
Arsenic (As III)	1	24	94	360
Arsenic (As IV)	0.9	13	42	140
Boron	90	370	680	1300
Cadmium	0.06	0.2	0.4	0.8
Cobalt	ID	ID	ID	ID
Chromium (Cr III)	ID	ID	ID	ID
Chromium (Cr VI)	0.01	1	6	40
Copper	1	1.4	1.8	2.5
Iron	ID	ID	ID	ID
Manganese	1200	1900	2500	3600
Molybdenum	ID	ID	ID	ID
Nickel	8	11	13	17
Lead	1	3.4	5.6	9.4
Selenium (Se total)	5	11	18	34
Selenium (Se IV)	ID	ID	ID	ID
Uranium	ID	ID	ID	ID
Vanadium	ID	ID	ID	ID
Zinc	2.4	8	15	31
NON-METALLIC INORGANICS				
Ammonia	320	900	1430	2300
Chlorine	0.4	3	6	13
Nitrate	17	700	3400	17000

Appendix 5. Water quality data recorded from Keep River pools, reference sites and the estuary in Sep-12.

Table A5-1. *In situ* and turbidity data.

	Site	pH	Redox	DO %	EC µS/m	Turbidity NTU
Keep River Pools	K4-3	6.92	-19.6	59.8	817	7.4
	K4-2	6.90	-15.9	66.3	817	5.9
	K4-1	6.85	-12.2	63.7	816	7.2
	K3-5	8.03	-85.9	89.6	942	5.3
	K3-4	7.88	-79.2	85.4	957	5.9
	K3-3	7.96	-83.4	85.3	962	6
	K3-2	8.03	-88.5	88.3	950	4.9
	K3-1	8.07	-90.3	87.3	953	4.1
	K2-5	7.99	-86.9	92.7	2640	6
	K2-4	8.06	-92.0	100.5	3780	6.3
	K2-3	8.10	-92.1	99.5	3840	6.6
	K2-2	8.00	-86.7	89.8	3870	8.5
	K2-1	8.02	-86.2	90.7	3900	6.9
	K1-5	8.13	-89.6	89.2	23300	5.1
	K1-4	7.91	-84.1	96.0	23600	2.7
	K1-3	8.02	-86.2	97.3	24200	3.1
	K1-2	7.97	-84.1	99.1	27400	3.5
	K1-1	8.01	-89.7	88.4	28100	3
Reference	KE1	7.05	-27.4	48.6	347	2.8
	KR1	7.34	-45.0	74.4	206	3.8
	KR2	7.79	-73.7	85.1	275	8
	SR4	7.88	-78.6	73.7	297	1.4
	DR1	8.15	-94.6	98.0	386	3.3
Estuary	EST01	8.11	-92.3	86.1	47300	27
	EST02	8.05	-88.7	94.3	53800	12
	EST03	7.98	-84.6	86.8	55400	390

Table A5-2. Alkalinity, hardness, dissolved organic carbon and ionic composition data. All values in mg/L.

	Site	Alkalinity	Hardness	DOC	Ca	Cl	Mg	HCO_3
Keep River Pools	K4-3	132	200	1.2	35.8	132	26.5	161
	K4-2	134	210	1.2	37.8	130	28	162
	K4-1	133	200	1.5	36.8	133	27.4	163
	K3-5	144	220	1.9	39.8	159	29.6	175
	K3-4	147	240	2.7	43.3	174	31.7	179
	K3-3	146	230	2.1	42	168	30.5	179
	K3-2	146	220	2.1	40.9	197	29.8	179
	K3-1	146	220	2.1	40.4	191	29.7	177
	K2-5	144	410	3	56.4	712	64.6	176
	K2-4	147	560	3	72.2	1040	91.8	179
	K2-3	147	550	3	72	1070	91	179
	K2-2	148	560	2.9	72.5	1060	91.1	180
	K2-1	148	560	3.1	71.8	1070	92	180
	K1-5	155	2800	4.2	212	7870	543	189
	K1-4	154	2800	3.7	211	8150	545	188
	K1-3	156	2900	3.7	218	8190	566	190
	K1-2	162	3200	4.3	237	9310	633	198
	K1-1	164	2900	4.2	213	8630	569	200
Reference	KE1	124	120	9.3	23.6	32	15.2	152
	KR1	68	75	4.4	15	14	9.2	83
	KR2	110	110	3.5	22.1	13	14.5	134
	SR4	150	150	2.1	26.8	4	20	183
	DR1	198	170	1.7	28.1	13	24.3	233
Estuary	EST01	175	5500	3.9	380	16900	1120	213
	EST02	185	6100	2.7	422	20000	1230	226
	EST03	156	7000	1.8	455	19300	1420	191

Table A5-3. Nutrient data.

	Site	N_NH3	N_NOx	N_total	P_SR	P_total
Keep River Pools	K4-3	0.005	0.005	0.14	0.005	0.01
	K4-2	0.005	0.005	0.13	0.005	0.01
	K4-1	0.01	0.005	0.27	0.005	0.01
	K3-5	0.005	0.005	0.15	0.005	0.005
	K3-4	0.01	0.005	0.39	0.005	0.005
	K3-3	0.005	0.005	0.20	0.005	0.005
	K3-2	0.005	0.005	0.18	0.005	0.005
	K3-1	0.005	0.005	0.18	0.005	0.005
	K2-5	0.005	0.005	0.31	0.005	0.01
	K2-4	0.005	0.005	0.27	0.005	0.01
	K2-3	0.005	0.005	0.25	0.005	0.01
	K2-2	0.005	0.005	0.22	0.005	0.005
	K2-1	0.005	0.005	0.29	0.005	0.005
	K1-5	0.01	0.005	0.41	0.005	0.005
	K1-4	0.005	0.005	0.26	0.005	0.005
	K1-3	0.005	0.005	0.29	0.005	0.005
	K1-2	0.02	0.005	0.58	0.005	0.01
	K1-1	0.01	0.005	0.41	0.005	0.005
Reference	KE1	0.02	0.005	0.86	0.005	0.01
	KR1	0.005	0.005	0.34	0.005	0.005
	KR2	0.01	0.005	0.41	0.005	0.005
	SR4	0.005	0.005	0.15	0.005	0.005
	DR1	0.005	0.005	0.15	0.01	0.01
Estuary	EST01	0.07	0.005	0.65	0.005	0.005
	EST02	0.02	0.005	0.32	0.005	0.005
	EST03	0.01	0.005	0.26	0.005	0.005

WATER QUALITY ANOVA RESULTS

Table A5-4. Two-way ANOVA results comparing *in situ* water quality data between sites and between years. Degrees of freedom, f-value, p-value, and Tukeys post-hoc results are shown. Only significant results are tabulated. Tukey's results are presented in ascending order, with groups of no difference in means joined by a black line.

	Source	df	F	p	Tukeys post-hoc (low – high mean)
pH	Site	5	38.14	0.000	K4 REFS K3 EST K1 K2
	Year	1	20.55	0.000	2012 2011
	Site*Year	5	1.84	0.127	
DO %	Site	5	22.73	0.000	K4 REFS K3 EST K2 K1
	Year	1	10.07	0.003	2012 2011
	Site*Year	5	3.26	0.015	
EC µS/cm	Site	5	758.35	0.000	REFS K4 K3 K2 K1 EST
	Year	1	17.82	0.000	2011 2012
	Site*Year	5	12.85	0.000	
Turbidity NTU	Site	5	5.70	0.000	K1 REFS K3 K2 K4 EST
	Year	1	0.02	0.894	2011 2012
	Site*Year	5	0.003	1.000	

Table A5-5. Two-way ANOVA results comparing ionic composition data between sites and between years. Degrees of freedom, f-value, p-value, and Tukeys post-hoc results are shown. Only significant results are tabulated. Tukey's results are presented in ascending order, with groups of no difference in means joined by a black line.

	Source	df	F	p	Tukeys post-hoc (low – high mean)
Alkalinity	Site	5	2.23	0.070	K4 REFS K3 K2 K1 EST
	Year	1	0.504	0.482	2012 2011
	Site*Year	5	0.628	0.679	
	Corrected total	51			
Ca	Site	5	834.76	0.000	REFS K4 K3 K2 K1 EST
	Year	1	14.10	0.001	2011 2012
	Site*Year	5	10.66	0.000	
	Corrected total	51			
Cl	Site	5	1278.63	0.000	REFS K4 K3 K2 K1 EST
	Year	1	17.31	0.000	2011 2012
	Site*Year	5	23.95	0.000	
	Corrected total	51			
Mg	Site	5	565.13	0.000	REFS K4 K3 K2 K1 EST
	Year	1	6.84	0.013	2011 2012
	Site*Year	5	8.64	0.000	
	Corrected total	51			

Table A5-6. Two-way ANOVA results comparing nutrient data between sites and between years. Degrees of freedom, f-value, p-value, and Tukeys post-hoc results are shown. Only significant results are tabulated. Tukey's results are presented in ascending order, with groups of no difference in means joined by a black line.

	Source	df	F	p	Tukeys post-hoc (low – high mean)
N_NH_3	Site	5	4.69	0.002	K2 K4 K3 REFS K1 EST
	Year	1	1.31	0.260	2011 2012
	Site*Year	5	0.240	0.943	
	Corrected total	51			
Total nitrogen	Site	5	6.48	0.000	K4 K3 K2 K1 REFS EST
	Year	1	6.63	0.014	2011 2012
	Site*Year	5	1.35	0.264	
	Corrected total	51			
Total phosphorus	Site	5	1.67	0.164	K1 K3 REFS K2 K4 EST
	Year	1	4.93	0.032	2012 2011
	Site*Year	5	1.73	0.149	
	Corrected total	51			

Appendix 6. List of macroinvertebrate taxa recorded from each site recorded in Sep-12.

Table A6-1. Edge habitat. Numbers represent $\log_{10}$ abundance categories, where 1 = 1 - 10 individuals, 2 = 11 - 100 individuals, 3 = 101-1000 individuals, 4 = >1000.

			Keep River pools																		Reference sites				
Class/Order	Family	Lowest taxon	K1-1	K1-2	K1-3	K1-4	K1-5	K2-1	K2-2	K2-3	K2-4	K2-5	K3-1	K3-2	K3-3	K3-4	K3-5	K4-1	K4-2	K4-3	KE1	KR1	KR2	SR4	DR1
ANNELIDA																									
OLIGOCHAETA		Oligochaeta spp. (dam/imm.)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	3	0	1	0
	Naididae	*Dero furcata*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
		Naidinae spp.	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2	0	0	3	0	0	0	0
		Pristina sp.	0	0	0	0	0	0	0	0	1	0	1	0	0	2	2	1	2	0	0	0	0	0	0
		Tubificinae spp.	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
POLYCHAETA	**Eunicidae**	Eunicidae spp.	0	1	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Nereididae	Nereididae spp.	3	3	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TURBELLARIA	**Temnocephalidae**	*Temnocephala* sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
CNIDARIA																									
HYDROZOA	**Hydridae**	*Hydra* sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	0	0
MOLLUSCA																									
BIVALVIA		Bivalvia spp. (?estuarine)	3	2	2	3	0	0	3	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Hyriidae	*Velesunio* sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	Sphaeriidae	Sphaeriidae spp. (dam/imm.)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
		Pisidium sp.	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GASTROPODA		Gastropoda spp. (?estuarine)	3	2	2	3	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
	Thiaridae	*Thiara* sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
	Planorbidae	*Amerianna* sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0
		Ferrissia petterdi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0
		Gyraulus hesperus	0	0	0	0	0	1	0	0	0	0	2	0	0	0	0	2	0	0	4	3	3	2	1
	Bithyniidae	Bithyniidae spp. (imm.)	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Gabbia sp.	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	3	0	0	0	0
	Tateidae	Tateidae spp.	0	0	0	3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ARTHROPODA																									
CRUSTACEA																									

Class/Order	Family	Lowest taxon	Keep River pools																		Reference sites				
			K1-1	K1-2	K1-3	K1-4	K1-5	K2-1	K2-2	K2-3	K2-4	K2-5	K3-1	K3-2	K3-3	K3-4	K3-5	K4-1	K4-2	K4-3	KE1	KR1	KR2	SR4	DR1
AMPHIPODA		Amphipoda sp. (stygofauna)	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Aoridae	*Grandidierella* sp.	3	0	0	2	0	2	2	2	2	3	1	2	0	2	0	0	1	0	0	0	0	0	0
DECAPODA	**Brachyura**	Brachyura sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	Atyidae	*Caridina* spp. (dam/imm.)	1	0	0	2	0	2	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0
		Caridina nilotica	2	3	4	3	0	3	3	3	3	3	3	3	3	3	3	2	0	0	0	3	2	3	0
		Caridina serratirostris	0	0	2	0	0	0	2	2	0	0	3	1	2	3	2	3	3	3	2	3	2	0	2
	Hymenosomatidae	*Amarinus lacustris*	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Palaemonidae	*Macrobrachium bullatum*	3	2	3	3	3	1	0	3	0	0	1	1	3	2	2	3	3	3	1	1	3	0	2
		Macrobrachium lar	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
		Macrobrachium rosenbergii	0	2	0	0	0	2	0	0	0	1	0	2	1	2	0	0	2	0	0	0	1	0	0
		Macrobrachium spp. (dam/imm.)	3	0	0	0	3	0	0	0	0	0	0	0	0	0	0	3	2	0	2	1	2	0	2
	Penaeidae	*Penaeus* spp.	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ARACHNIDA																									
SARCOPTIFORMES		Oribatida spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
TROMBIDIFORMES		Hydracarina spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	3	2	3	1
		Trombidioidea spp.	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
COLLEMBOLLA																									
ENTOMOBRYOMORPHA		Entomobryoidea spp.	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
INSECTA																									
COLEOPTERA	**Carabidae**	Carabidae spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
	Dytiscidae	*Allodessus bistrigatus*	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Tribe Bidessini sp. (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
		Clypeodytes feryi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0
		Copelatus nigrolineatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
		Hydroglyphus basalis	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1	2	0	0	0	0	1	1	0
		Hydroglyphus daemeli	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
		Hydroglyphus leai	0	0	0	0	2	1	0	2	2	2	0	2	2	0	0	1	1	1	0	0	0	2	0
		Hydroglyphus trifasciatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
		Hydroglyphus trilineatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0
		Hydrovatus opacus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
		Hydrovatus parallelus	0	0	0	0	0	1	0	0	0	0	1	0	2	0	0	2	0	0	0	0	0	0	0
		Hyphydrus elegans	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
		Hyphydrus lyratus	0	0	0	0	0	2	0	0	0	0	0	2	0	1	1	0	1	0	2	0	0	0	0
		Hyphydrus sp. (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
		Laccophilus cingulatus	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	3	2	0	2

Class/Order	Family	Lowest taxon	Keep River pools																			Reference sites				
			K1-1	K1-2	K1-3	K1-4	K1-5	K2-1	K2-2	K2-3	K2-4	K2-5	K3-1	K3-2	K3-3	K3-4	K3-5	K4-1	K4-2	K4-3	KE1	KR1	KR2	SR4	DR1
		Laccophilus clarki	0	0	0	0	0	3	0	3	2	3	1	2	2	3	3	2	3	2	2	3	3	2	1
		Laccophilus religatus	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Laccophilus sharpi	0	0	0	0	0	2	0	2	2	1	0	2	0	2	0	0	2	0	2	2	2	1	1
		Laccophilus sp. (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0
		Laccophilus walkeri	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0
		Limbodessus compactus	0	0	0	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	1	2	0
		Megaporus ruficeps	0	0	0	0	0	3	0	2	3	1	1	0	2	2	2	1	2	0	3	0	0	0	0
		Onychohydrus sp. (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
	Elmidae	*Austrolimnius* sp. (L)	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2
	Gyrinidae	*Macrogyrus* sp. (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	Hydraenidae	*Hydraena* sp.	0	0	0	0	0	0	0	0	1	2	0	0	2	1	0	0	2	0	3	0	0	0	0
		Ochthebius sp.	0	0	2	0	0	2	0	2	0	1	0	0	0	1	0	0	1	1	0	0	0	0	0
	Hydrochidae	*Hydrochus* sp.	0	0	2	0	0	2	1	2	2	3	0	2	0	2	1	0	1	2	0	3	1	2	2
	Hydrophilidae	*Amphiops australicus*	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
		Amphiops sp. (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	2	0
		Berosus josephenae	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
		Berosus pulchellus	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
		Enochrus deserticola	0	0	0	0	0	0	0	2	1	0	0	0	0	0	2	0	0	0	2	1	0	1	0
		Paracymus pygmaeus	0	0	0	0	1	2	0	3	2	2	0	2	2	0	2	0	2	2	0	1	0	2	1
		Regimbartia attenuata	1	2	1	2	0	0	1	2	0	3	0	2	0	2	2	0	2	2	3	2	1	1	0
	Limnichidae	Limnichidae spp.	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0
	Noteridae	*Hydrocanthus micans (waterhousei)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
		Neohydrocoptus subfasciatus	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
	Scirtidae	Scirtidae spp. (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1	2
DIPTERA	**Ceratopogonidae**	Ceratopogonidae spp. (P)	0	0	0	0	0	0	2	0	0	2	0	0	0	2	2	0	0	0	2	0	2	2	1
		Ceratopogoninae spp.	2	1	1	2	2	2	2	0	0	2	3	2	3	2	1	2	2	2	2	2	1	3	2
		Dasyheleinae spp.	0	0	0	0	0	2	3	2	0	3	2	1	1	3	2	0	2	2	0	0	0	3	0
		Forcipomyiinae spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0
	Chironomidae	Chironomidae spp. (P)	0	0	0	0	0	2	2	2	2	3	2	2	2	0	2	1	3	2	2	2	2	3	3
		Chironomini spp. (ORC36)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
		Chironomini spp. (ORC43)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2
		Chironomini spp. (ORC47)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2
		Chironomus aff. *alternans*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
		Cladopelma curtivala	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
		Cladotanytarsus sp. (ORC2)	1	0	0	1	2	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2	3
		Cryptochironomus ?griseidorsum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
		Dicrotendipes sp. 1	0	0	0	0	0	2	2	2	0	1	2	2	3	2	0	3	2	3	3	2	2	2	2

Class/Order	Family	Lowest taxon	Keep River pools																			Reference sites				
			K1-1	K1-2	K1-3	K1-4	K1-5	K2-1	K2-2	K2-3	K2-4	K2-5	K3-1	K3-2	K3-3	K3-4	K3-5	K4-1	K4-2	K4-3	KE1	KR1	KR2	SR4	DR1
		Dicrotendipes sp. 2	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	2	1	3	2	2	2	2	2
		Harnischia sp. (ORC7)	0	0	0	0	0	0	0	0	0	0	1	2	2	0	1	0	0	0	2	2	1	0	0
		Kiefferulus ?intertinctus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0
		Parachironomus sp. (ORC11)	0	0	0	0	0	0	1	0	0	1	2	0	2	1	0	0	0	0	0	2	1	1	3
		Polypedilum (*Pentapedilum*) *leei*	0	0	0	0	0	3	3	3	3	3	2	3	3	3	2	0	2	2	3	2	1	3	2
		Polypedilum nubifer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	0	0	0	2
		Polypedilum sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	0	2	3	3	2	2	2
		Polypedilum watsoni	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	2	0	0	0	0	0
		Rheotanytarsus sp. (ORC15)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
		Rheotanytarsus sp. 3	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2	0	0	2	3	0	2
		Tanytarsus sp. (ORC1)	0	0	1	2	3	3	3	2	2	3	3	3	3	3	3	3	3	4	3	3	2	2	3
		Tanypodinae spp. (ORT15)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	0	0	0	0
		Tanypodinae spp. (ORT16)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
		Tanypodinae spp. (ORT20)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	3	2	2	2
		Procladius sp. (ORT2)	0	0	0	0	0	0	0	0	0	1	2	2	2	0	0	0	0	0	3	2	1	0	2
		Paramerina sp. (ORT5)	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	2	2	2	2	2	0	0	0
		Ablabesmyia sp. (ORT6)	0	0	0	0	0	2	1	2	0	0	0	0	0	0	1	2	0	0	0	0	0	1	2
		Larsia ?albiceps	0	0	0	0	0	3	2	3	1	2	2	3	3	2	3	3	2	0	2	3	2	3	3
		Clinotanypus crux	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	2
		Coelopynia pruinosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
		Corynoneura sp. (ORO4)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
		Cricotopus sp. (ORO1)	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	2	2	0	0	2	0
		Nanocladius sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2	3	2	3
		Parakiefferiella sp. 2	0	0	0	0	0	3	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
	Culicidae	Culicidae spp. (P)	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
		Aedes sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	2	0
		Anopheles sp.	0	0	0	0	0	2	0	0	0	2	2	2	2	1	2	0	2	2	1	2	0	2	0
		Culex sp.	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0
	Dolichopodidae	Dolichopodidae spp.	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Simuliidae	Simuliidae spp.	0	0	0	0	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0
	Stratiomyidae	Stratiomyidae spp.	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	2	3	0	2	1	0	0
	Tabanidae	Tabanidae spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	Tanyderidae	Tanyderidae spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	1	0	0	1
	Tipulidae	Tipulidae spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
EPHEMEROPTERA	**Baetidae**	Baetidae spp. (dam/imm.)	0	0	0	0	0	2	3	2	3	2	2	1	3	2	2	3	2	3	3	2	3	3	2
		Cloeon fluviatile	0	0	0	0	0	1	0	2	0	1	0	0	0	0	1	0	1	2	0	3	3	0	2
		Cloeon spp. (dam/imm.)	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	1	0	0	2	0	0	0
		Cloeon sp. Red Stripe	0	0	0	0	0	0	2	2	2	0	0	2	1	0	0	2	2	0	2	2	0	0	0

Class/Order	Family	Lowest taxon	Keep River pools																			Reference sites				
			K1-1	K1-2	K1-3	K1-4	K1-5	K2-1	K2-2	K2-3	K2-4	K2-5	K3-1	K3-2	K3-3	K3-4	K3-5	K4-1	K4-2	K4-3	KE1	KR1	KR2	SR4	DR1
		Platybaetis sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
		Pseudocloeon plectile	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Caenidae	Caenidae spp. (dam/imm.)	0	0	0	0	0	0	0	0	0	1	1	1	2	2	0	3	3	2	0	3	0	2	1
		Tasmanocoenis spp. (dam/imm.)	0	0	0	0	0	0	0	0	0	0	2	0	2	1	1	0	1	0	1	1	0	3	2
		Tasmanocoenis sp. E	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	2	3	2
		Tasmanocoenis sp. P/*arcuata*	0	0	0	0	0	0	0	0	0	0	0	2	1	0	1	3	2	0	0	3	2	2	2
		Wundacaenis dostini	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
	Leptophlebiidae	*Atalophlebia* sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
HEMIPTERA	**Belostomatidae**	Belostomatidae spp. (imm.)	0	0	0	0	0	0	0	2	1	1	0	0	0	1	0	0	0	1	3	0	0	0	0
		Diplonychus pp.	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0
	Gelastocoridae	*Nerthra* sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
	Gerridae	Gerridae spp. (dam/imm.)	0	0	2	0	1	2	2	2	0	0	0	1	2	0	0	0	0	1	0	0	0	0	0
		Limnogonus spp. (dam/imm.)	0	0	0	0	0	0	0	1	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0
		Limnogonus fossarum gilguy	0	0	0	0	0	2	2	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0
		Limnogonus hungerfordi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
		Rhagadotarsus anomalus	0	0	0	0	0	0	0	0	0	0	1	0	2	0	0	0	0	2	0	0	1	2	2
	Hebridae	Hebridae sp. (dam/imm.)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
	Hydrometridae	*Hydrometra* sp.	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	Mesoveliidae	Mesovelia spp. (F/imm.)	0	0	0	0	0	1	0	0	0	2	0	0	0	0	0	0	1	0	2	0	0	0	0
		Mesovelia ebbenielseni	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Mesovelia vittigera	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	Micronectidae	Micronectidae spp. (imm.)	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	2	1	3	1	0	0	0
		Austronecta bartzarum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	2	0	0	0
		Austronecta micra	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	3	2	0	0	1	3	2	3
		Micronecta annae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
		Micronecta ludibunda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	2	0	0	0	0
		Micronecta robusta	0	0	1	0	1	0	0	2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	Naucoridae	*Naucoris subopacus*	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Nepidae	*Ranatra occidentalis*	0	2	1	0	1	1	2	0	1	0	0	0	0	1	0	0	2	0	2	2	2	0	0
		Ranatra spp. (dam/imm.)	0	0	0	0	0	0	1	0	0	1	0	0	0	0	2	0	0	0	1	1	0	0	0
	Notonectidae	Notonectidae spp. (dam/imm.)	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	3	0	0	3	3
		Anisops sp. (F/imm)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
		Enithares loria	0	0	0	0	0	1	0	0	2	0	0	0	0	0	0	0	1	0	0	3	2	0	0
		Nychia sappho	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	3	0	2	3	3	3
	Pleidae	*Paraplea* sp.	1	0	0	1	0	3	3	3	3	3	3	2	3	3	3	3	2	2	3	3	3	2	2

Class/Order	Family	Lowest taxon	Keep River pools																			Reference sites				
			K1-1	K1-2	K1-3	K1-4	K1-5	K2-1	K2-2	K2-3	K2-4	K2-5	K3-1	K3-2	K3-3	K3-4	K3-5	K4-1	K4-2	K4-3	KE1	KR1	KR2	SR4	DR1
	Veliidae	*Microvelia* spp. (F/dam/imm.)	0	0	0	0	0	0	0	0	0	1	3	0	1	0	1	0	2	1	0	1	0	3	1
		Microvelia katherinae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
		Microvelia malipatili	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
		Microvelia peramoena	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
ODONATA																									
Anisoptera		Anisoptera spp. (dam/imm.)	0	0	0	0	0	0	0	0	1	0	2	0	2	2	0	1	2	1	2	0	0	2	0
	Aeshnidae	*Anax* sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
	Gomphidae	*Austrogomphus gordoni*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
		Ictinogomphus australis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
	Hemicorduliidae	*Hemicordulia intermedia*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2
		Hemicordulia sp. (dam/imm.)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2
	Libellulidae	Libellulidae spp. (dam/imm.)	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	1	2	0	0	0	0	1
		Crocothemis nigrifrons	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
		Diplacodes haematodes	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	2	1	2	1	1	0	2	2
		Macrodiplax cora	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
		Nannophlebia mudginberri	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
		Neurothemis stigmatizans	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
		Pantala flavescens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Zygoptera		Zygoptera spp. (dam/imm.)	0	2	2	0	2	3	2	2	0	1	2	2	0	2	0	1	1	2	3	3	2	2	0
	Coenagrionidae	Coenogrionidae spp. (dam/imm.)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
		Agriocnemis sp.	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0
		Argiocnemis rubescens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
		Austroagrion spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
		Ischnura aurora	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
		Pseudagrion aureofrons	2	1	0	0	0	1	2	1	1	0	2	1	2	1	1	1	1	2	0	1	2	2	2
		Pseudagrion microcephalum	0	2	2	0	0	2	2	2	2	2	0	2	0	0	0	2	2	0	0	0	2	2	2
		Pseudagrion spp. (dam/imm.)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2
	Protoneuridae	*Nososticta* sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
THYSANOPTERA		Thysanoptera sp.	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
TRICHOPTERA		Trichoptera spp. (dam/imm.)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
	Calamoceratidae	*Anisocentropus* spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	2	1	0	0
	Ecnomidae	*Ecnomus* sp.	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	1	0	2	1	1	2
	Hydropsychidae	*Cheumatopsyche wellsae*	0	0	0	0	0	2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
	Hydroptilidae	Hydroptilidae spp. (dam/imm.)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0

Class/Order	Family	Lowest taxon	Keep River pools																			Reference sites				
			K1-1	K1-2	K1-3	K1-4	K1-5	K2-1	K2-2	K2-3	K2-4	K2-5	K3-1	K3-2	K3-3	K3-4	K3-5	K4-1	K4-2	K4-3	KE1	KR1	KR2	SR4	DR1
		Hellyethira sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2	0
		Orthotrichia sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	3	0
	Leptoceridae	Leptoceridae spp. (dam/imm.)	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	1	0	0	0	1	2	2	1
		Leptocerus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		Oecetis sp.	0	0	0	0	0	0	0	2	1	1	0	0	0	0	0	0	1	1	2	3	3	3	2
		Triaenodes sp.	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	2	1	0	1	3	2	2	2
		Triplectides australis	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	1	2	2	0	0	0	1
		Triplectides ciuskus seductus	0	0	0	0	0	1	1	2	2	2	2	3	2	1	2	3	2	2	3	1	0	2	3
		Triplectides helvolus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
		Triplectides spp. (dam/imm.)	0	0	0	0	0	0	2	0	0	1	0	0	0	0	0	0	0	1	1	0	1	0	0
	Philopotamidae	*Chimarra* spp. (dam/imm.)	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
		Chimarra uranka	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Polycentropodidae	*Paranyctiophylax* sp. AV5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
		Taxa richness	**15**	**14**	**16**	**18**	**18**	**50**	**31**	**43**	**33**	**49**	**41**	**40**	**43**	**41**	**47**	**46**	**68**	**53**	**75**	**74**	**58**	**68**	**71**

Table A6-2. Riffle habitat. Numbers represent log_{10} abundance categories, where 1 = 1 - 10 individuals, 2 = 11 - 100 individuals, 3 = 101-1000 individuals, 4 = >1000.

			Keep River		Reference	
Class/Order	**Family**	**Lowest taxon**	**K3**	**K4**	**SR4**	**DR1**
ANNELIDA						
OLIGOCHAETA		Oligochaeta spp. (dam/imm.)	0	0	2	2
	Naididae	Naidinae spp.	2	2	0	0
		Pristina sp.	3	0	2	0
		Tubificinae spp.	0	1	0	0
POLYCHAETA	**Nereididae**	Nereididae spp.	0	1	1	0
TURBELLARIA		Turbellaria spp.	0	1	1	0
CNIDARIA						
HYDROZOA	**Hydridae**	*Hydra* sp.	0	3	2	1
MOLLUSCA						
BIVALVIA	**Hyriidae**	*Velesunio* sp.	2	1	0	0
	Corbiculidae	*Corbicula* sp.	1	2	0	0
GASTROPODA	**Thiaridae**	*Melanoides* sp.	0	0	1	0
	Planorbidae	*Ferrissia petterdi*	0	1	0	0
ARTHROPODA						
CRUSTACEA						
DECAPODA	**Atyidae**	*Caridina nilotica*	0	2	0	0
ARACHNIDA						
SARCOPTIFORMES		Oribatida spp.	0	0	2	1
TROMBIDIFORMES		Hydracarina spp.	3	0	3	3
COLLEMBOLLA						
SYMPHYPLEONA		Symphypleona sp.	1	0	0	0
INSECTA						
COLEOPTERA	**Carabidae**	Carabidae sp.	0	0	0	1
	Dytiscidae	*Hydroglyphus basalis*	1	2	1	0
		Hydroglyphus daemeli	1	2	0	0
		Hydroglyphus trilineatus	0	2	0	0
		Megaporus ruficeps	1	0	0	0
		Neobidessodes mjobergi	0	1	0	0
		Platynectes sp. (L)	1	0	0	0
	Elmidae	*Austrolimnius* sp.	3	0	3	3
		Austrolimnius sp. (L)	3	0	3	2
	Gyrinidae	*Macrogyrus darlingtoni*	0	2	1	0
		Macrogyrus spp. (L)	2	0	1	0
	Hydraenidae	*Hydraena* spp.	0	0	0	2
		Ochthebius spp.	0	1	0	2
	Hydrochidae	*Hydrochus* spp.	2	2	2	2
	Hydrophilidae	*Berosus pulchellus*	2	2	0	0
		Enochrus deserticola	0	2	0	0
		Paracymus pygmaeus	1	0	2	0
	Limnichidae	Limnichidae sp.	0	0	1	0
	Scirtidae	Scirtidae spp. (L)	0	0	1	0
DIPTERA	**Ceratopogonidae**	Ceratopogonidae spp. (P)	0	1	1	1
		Ceratopogoninae spp.	3	3	2	2
		Dasyheleinae spp.	0	2	2	0
		Forcipomyiinae spp.	0	1	2	1
	Chironomidae	Chironomidae spp. (P)	3	2	3	2
		Chironomini spp. (ORC38)	0	0	2	0
		Chironomini spp. (ORC44)	0	0	0	1
		Chironomini spp. (ORC47)	0	1	0	3
		Cladotanytarsus sp. (ORC2)	0	2	2	1
		Clinotanypus crux	0	1	0	0
		Corynoneura sp. (ORO4)	2	0	2	0
		Cricotopus sp. (ORO1)	2	2	2	3
		Cryptochironomus ?griseidorsum	2	2	0	0
		Dicrotendipes sp. 1	0	2	0	0

			Keep River		Reference	
Class/Order	Family	Lowest taxon	K3	K4	SR4	DR1
		Dicrotendipes sp. 2	0	2	2	1
		Harnischia sp. (ORC7)	0	2	0	0
		Larsia ?albiceps	3	2	2	0
		Nanocladius sp. 1	0	0	2	0
		Nilotanypus sp. nov. (ORT4)	2	0	3	3
		Orthocladiinae spp. (ORO9)	0	0	2	0
		Parachironomus sp. (ORC11)	0	0	2	2
		Paracladopelma sp. K2	3	0	0	0
		Parakiefferiella sp. 2	4	0	3	3
		Paramerina sp. (ORT5)	2	3	0	1
		Parametriocnemis ornaticornis	0	0	2	0
		Polypedilum watsoni	0	1	0	0
		Procladius sp. (ORT2)	0	3	0	0
		Rheotanytarsus sp. (ORC15)	0	0	3	0
		Rheotanytarsus sp. 3	3	3	2	2
		Skusella ?subvittata	0	1	0	0
		Tanytarsus sp. (ORC1)	2	3	2	2
		Thienemanniella sp. (ORO5)	0	0	2	3
		Xenochironomus sp. (ORC18)	0	0	2	2
	Culicidae	*Anopheles* sp.	0	2	1	0
	Dolichopodidae	Dolichopodidae spp.	3	0	2	0
	Empididae	Empididae spp.	0	0	1	1
		Empididae spp. (P)	0	0	0	2
	Simuliidae	Simuliidae spp.	4	3	4	3
		Simuliidae spp. (P)	3	0	3	1
	Stratiomyidae	Stratiomyidae spp.	0	2	1	0
	Tabanidae	Tabanidae spp.	2	0	2	2
	Tanyderidae	Tanyderidae spp.	0	2	0	0
	Thaumaleidae	Thaumaleidae sp.	0	0	0	1
	Tipulidae	Tipulidae sp.	0	0	0	0
EPHEMEROPTERA	**Baetidae**	Baetidae spp. (dam/imm.)	2	2	2	0
		Offadens spp. (dam/imm.)	0	0	0	2
		Pseudocloeon hypodelum	3	2	0	2
		Pseudocloeon plectile	2	0	3	0
		Pseudocloeon spp. (dam/imm.)	0	0	2	0
	Caenidae	Caenidae spp. (dam/imm.)	2	2	3	0
		Tasmanocoenis sp. E	3	0	2	0
		Tasmanocoenis sp. P/*arcuata*	2	3	0	0
	Leptophlebiidae	Leptophlebiidae spp. (dam/imm.)	0	0	2	0
		Manggabora wapitja	0	0	3	0
HEMIPTERA	**Gerridae**	Gerridae spp. (dam/imm.)	2	0	2	0
		Limnogonus luctuosus	2	0	0	0
	Pleidae	*Paraplea* sp.	0	0	1	0
	Veliidae	*Microvelia* sp. (F/dam/imm.)	0	0	0	2
LEPIDOPTERA	**Crambidae**	Acentropinae spp. (dam/imm.)	2	0	0	3
		Eoophyla repetitalis	0	0	1	0
		Eoophyla triplaga	1	0	0	2
		Margarosticha spp.	2	0	0	0
		Tetrernia sp. 1	0	0	0	2
NEUROPTERA	**Sisyridae**	Sisyridae spp. (L)	0	0	0	2
ODONATA						
Anisoptera		Anisoptera spp. (dam/imm.)	0	0	2	2
	Austrocorduliidae	*Austrocordulia territoria*	0	0	1	0
	Gomphidae	*Austrogomphus pusillus*	0	0	2	0
		Austrogomphus sp.	0	0	0	2
	Libellulidae	*Diplacodes haematodes*	1	1	0	0
		Nannophlebia mudginberri	3	0	3	2
		Orthetrum caledonicum	0	2	0	0
TRICHOPTERA	**Ecnomidae**	*Ecnomus* sp.	2	0	2	3
	Hydropsychidae	*Cheumatopsyche* spp. (dam/imm.)	1	2	1	0
		Cheumatopsyche sp. AV12	0	0	2	0
		Cheumatopsyche wellsae	3	2	3	3
	Hydroptilidae	*Orthotrichia* spp.	0	0	2	3
	Leptoceridae	Leptoceridae spp. (dam/imm.)	0	0	0	1
		Oecetis spp.	2	0	2	0

Class/Order	Family	Lowest taxon	Keep River		Reference	
			K3	K4	SR4	DR1
		Triaenodes spp.	0	0	1	0
		Triplectides ciuskus seductus	1	2	0	1
		Triplectides spp. (dam/imm.)	0	1	2	0
	Philopotamidae	*Chimarra* spp. (dam/imm.)	0	0	3	1
		Chimarra sp. AV17	1	0	0	0
		Chimarra uranka	3	0	3	0
		Taxa richness	**50**	**48**	**66**	**48**