ORIA STAGE II EXPANSION
KEEP RIVER

BASELINE AQUATIC FAUNA & TARGETED SAWFISH SURVEYS SEPTEMBER/OCTOBER 2011

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Disclaimer

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Frontispiece (left to right): water lilies at Milligan's Lagoon; freshwater sawfish *Pristis microdon*; and, Alligator Waterhole (all photos by WRM staff ©).

CONTENTS

LIST OF TABLES, FIGURES & PLATES

TABLES

FIGURES

PLATES

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 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) then excess pumped groundwater will be collected in a storage reservoir and/or discharged.

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 ans 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

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 microdon*) and dwarf sawfish (*Pristis clavata*) from the system by anglers
- recording of *P. microdon* 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)
- suspicions that the listed Speartooth sharks (*Glyphis* spp) may occur in the system as well as the freshwater whiprays.

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*).

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. 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 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/October 2011 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) for establishing baseline conditions and surface water trigger values for assess 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; 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**

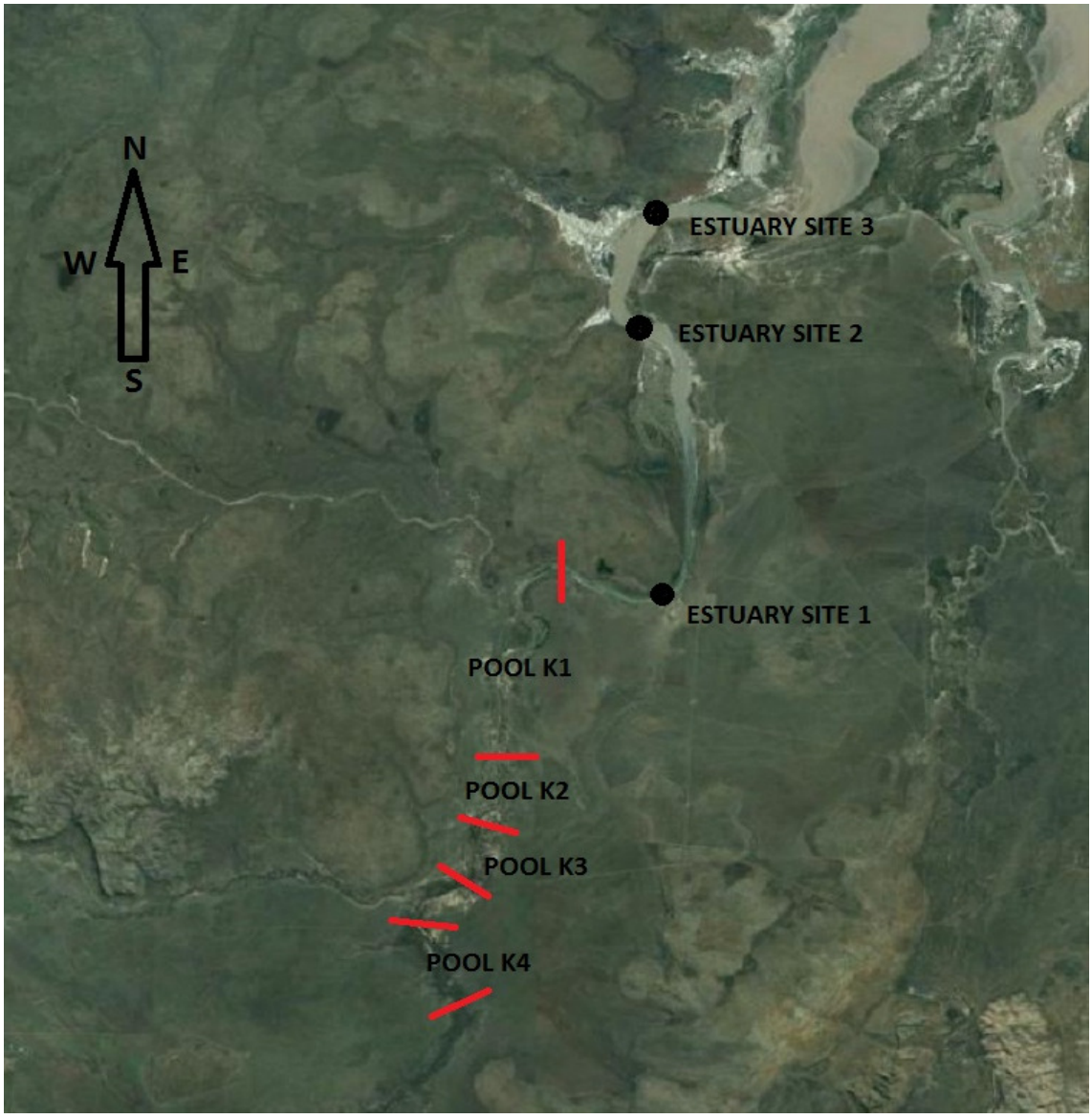

Figure 1. Location of sediment sampling and targeted sawfish/shark survey sites in the Keep River (pools and estuary sites).

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 that if exceeded, should trigger further study. The ISQG-High value corresponds to the median effect concentration as detailed in Long *et al.* (1995). 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, ANOVA was undertaken comparing concentrations of each parameter measured between sites. 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 across sites and replicates. 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. Permutational multivariate analysis of variance (PERMANOVA) was undertaken to determine whether there were any significant differences in sediment quality between site (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 and Appendix 3). Variation within replicates (i.e. between left, middle and right-of-bank samples) was also evident (Figure 2). The greatest average TOC content was recorded from K3-4 (0.91%) and the lowest from K4-2 (0.30%). There was no significant difference in total organic carbon between sites.

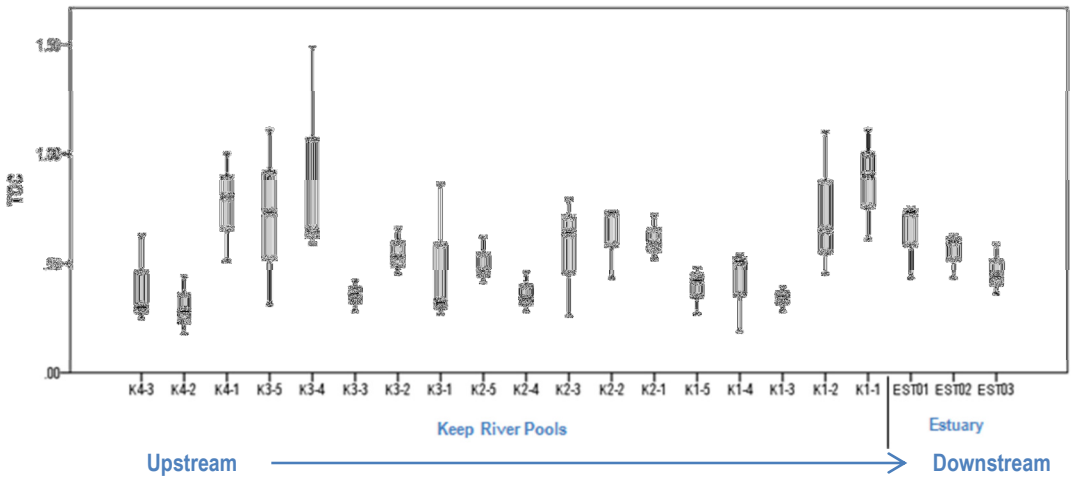

Figure 2. Box plot of total organic carbon content (%) within sediments from potentially exposed sites. Plots show minimum, 20%ile, median (50%ile), 80%ile and maximum concentrations for each site, using variance between left bank, mid-channel and right bank.

Ionic composition of sediments was generally dominated by calcium cations and chloride anions at both Keep River pools and estuary sites (Figure 3 and Appendix 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. 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).

Nutrient concentrations were also highly variable within- and between-site (Figure 4, Appendix 3). The average concentration of ammonia ranged from 1 mg/kg dry weight at EST02 and EST03 to 20 mg/kg dry weight at K3-5 (Figure 4). Ammonia concentrations were generally lower from the estuary sites (Figure 4), although this difference was not significant. Nitrate was generally low, and below detection limits at a number of sites. The highest average nitrate concentration was recorded from K4-2 (1 mg/kg dry weight). Differences in nitrate between sites were not significant. Average phosphorus concentrations were lowest at K4-2 (72.67 mg/kg dry weight) and highest at EST02 (223.33 mg/kg dry weight; Figure 4). Phosphorus in sediments was highest in the estuary. This difference was significant (Appendix 3). Again, within-replicate variation of nutrient concentrations was high (Figure 4).

Generally, concentrations of heavy metals within sediments were low and well below the Interim Sediment Quality Guidelines (Figure 5 and Appendix 3). 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, K1-5, K2-3 and K4-3 (Figure 5). Interestingly, all exceedances of the high ISQG for mercury were from sediment samples collected in the centre of the river. 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 most sites, with the exception of K4-1, K3-5, K3-4, K2-2, K1-2, K1-1, EST02 and EST03.

Concentrations of nickel exceeded the ISQG-low trigger value of 21 mg/kg dry weight at K2-1 (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.

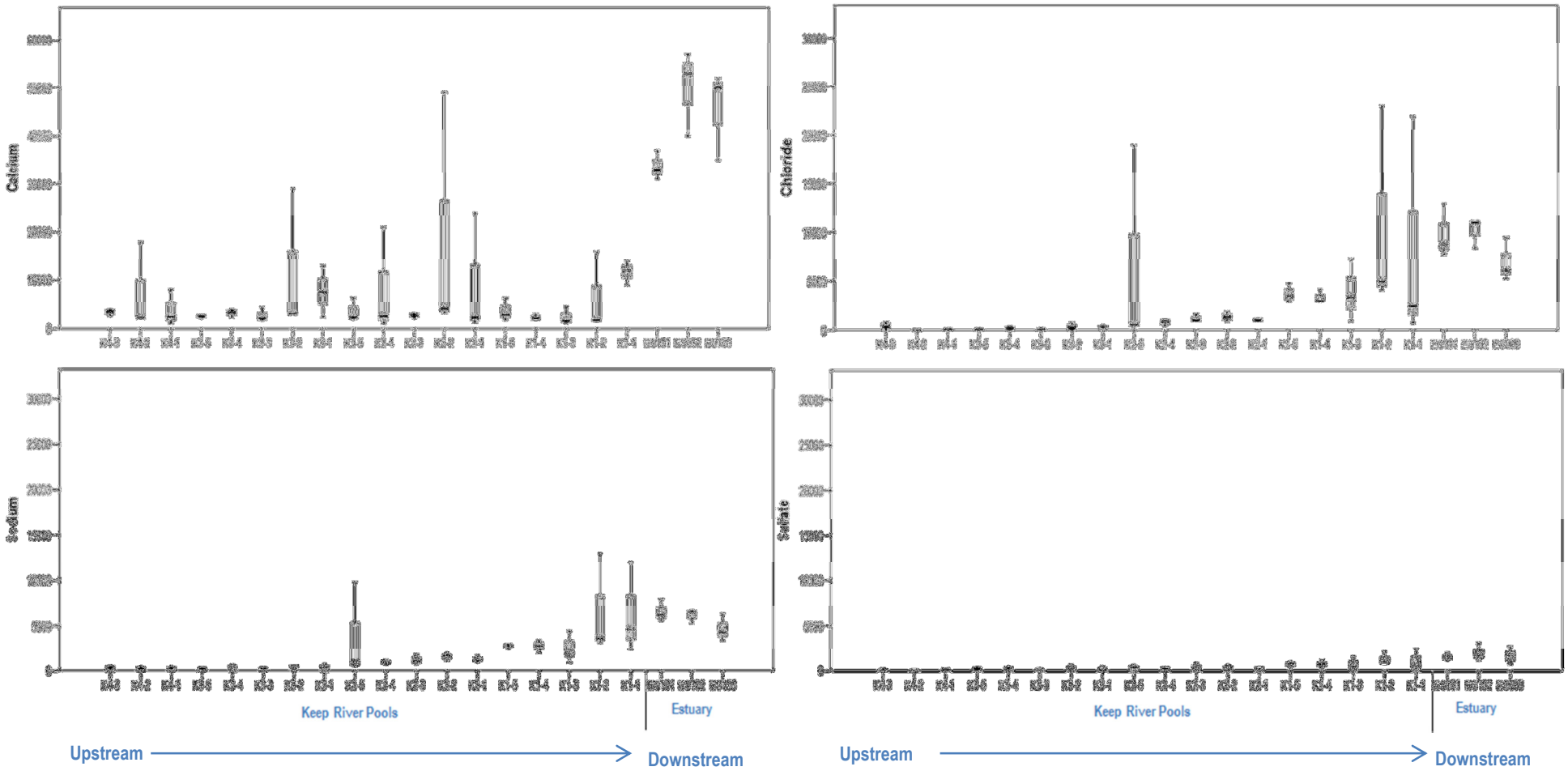

Figure 3. Boxplots of some selected ions within sediments (mg/kg dry weight). Plots show minimum, 20%ile, median (50%ile), 80%ile and maximum concentrations for each replicate within a site. Boxplots of calcium, chloride, sodium and sulfate are shown. NB – the scale for calcium is different, due to the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

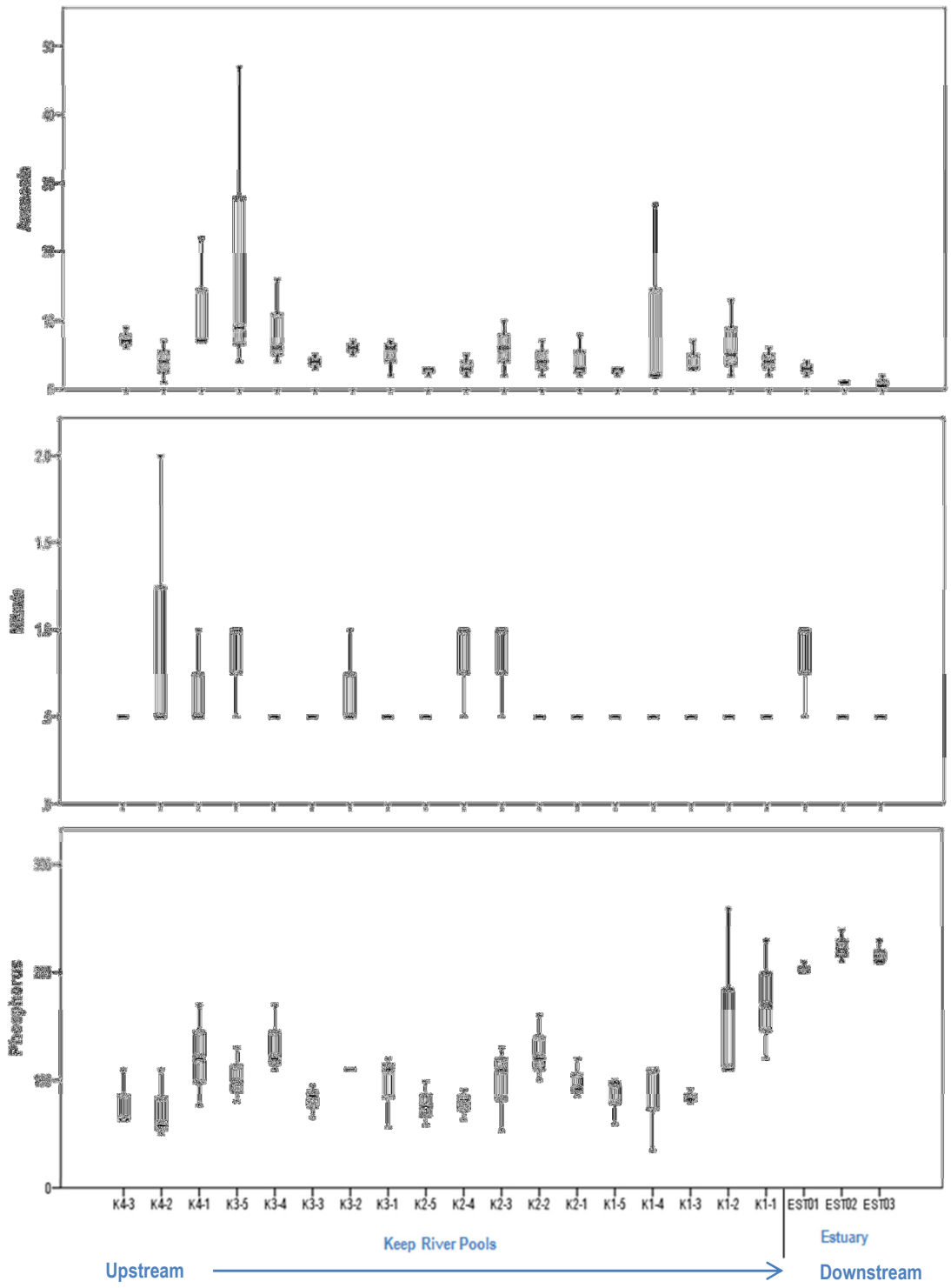

Figure 4. Boxplots of nutrient composition within sediments (mg/kg dry weight). Plots show minimum, 20%ile, median (50%ile), 80%ile and maximum concentrations for each replicate within a site. Boxplots of ammonia, nitrate and phosphorus are shown. NB – scales are not the same between plots.

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 site for a number of metals, including:

- Arsenic – significantly higher in the estuary
- Boron - significantly higher in the estuary
- Barium – lowest in the estuary and highest at the most upstream pool K4

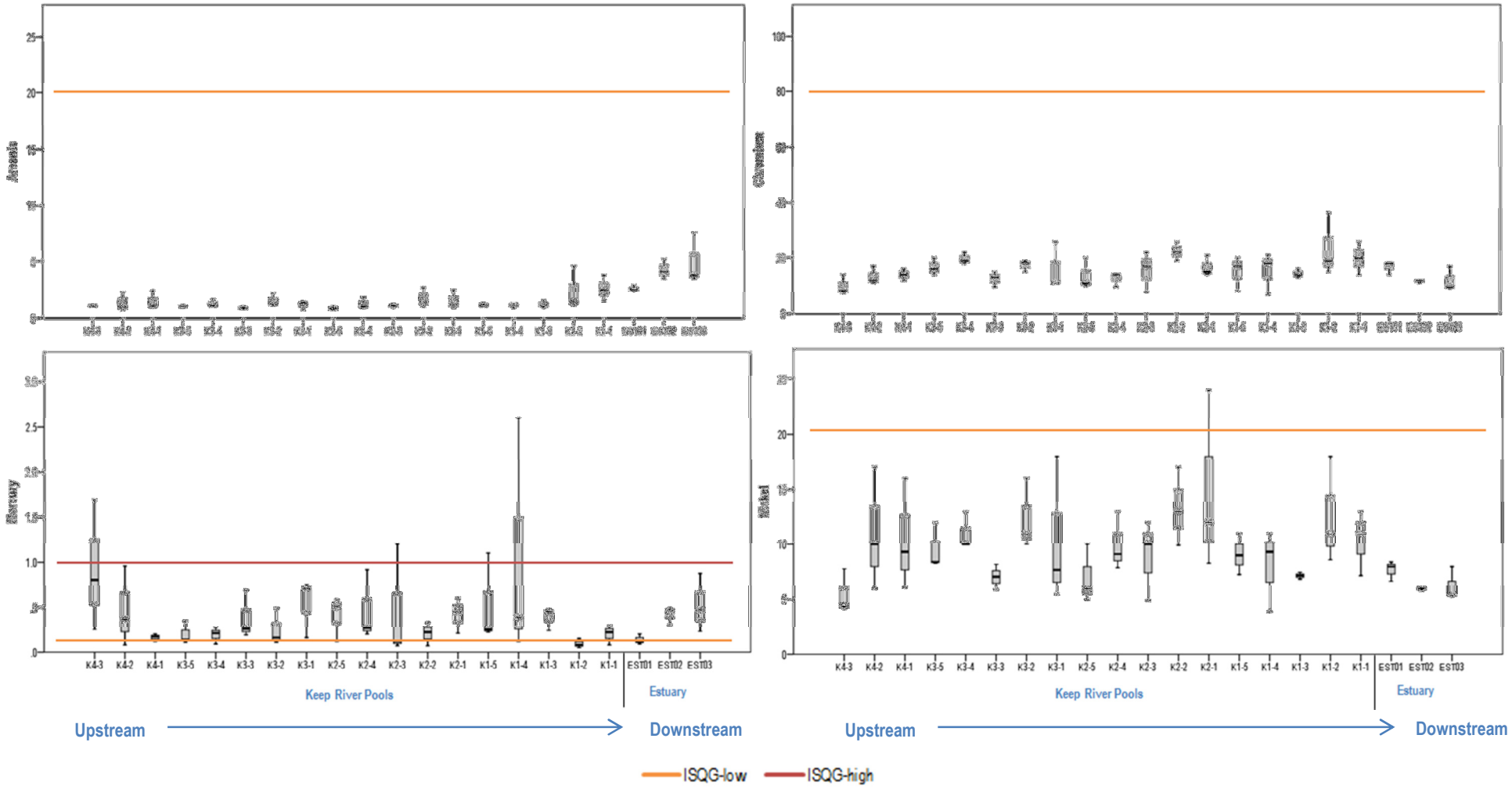

Figure 5. Boxplots of concentration of some selected metals within sediments (mg/kg dry weight). Plots show minimum, 20%ile, median (50%ile), 80%ile and maximum concentrations for each replicate within a site. Boxplots of arsenic, chromium, mercury and nickel are shown. The low and high trigger values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

- Copper – lowest in the estuary and highest at K3
- Lithium – lowest at the upstream K4 and highest in the estuary
- Lead – lowest in the estuary and highest at K3
- Titanium – significantly higher in the estuary and lowest at K4
- Vanadium – lowest in the estuary and highest at K3 (see Appendix 3).

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).

3.3.2 Patterns in sediment quality

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; 0.99 along CAP1 and 0.94 along CAP2.
- Separations between sites were evident in the CAP ordination (Figure 6). Estuary sites separated from Keep River pools along CAP1. There was considerable overlap in sediment quality between K3 and K4 upstream pools (Figure 6).
- Vector overlay of analytes with Spearman Rank correlations > 0.5 indicated separation of estuary sites was due to the higher concentrations of calcium, sulfate, potassium, sodium, magnesium, phosphorus, boron, arsenic and titanium (Figure 6). Upstream Keep River pools (K3 and K4) separated from other sites due to their higher concentrations of ammonia and barium (Figure 6). The middle Keep River pool (K2) separated based on its higher concentrations of lead, vanadium and silica (Figure 6). The lower pool (K1) separated from other sites due to its higher concentration of beryllium (Figure 6).
- 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 6).
- Differences in overall sediment quality between sites were significant (PERMANOVA; df = 6, Pseudo F = 4.11, p = 0.0001) (Table 3).

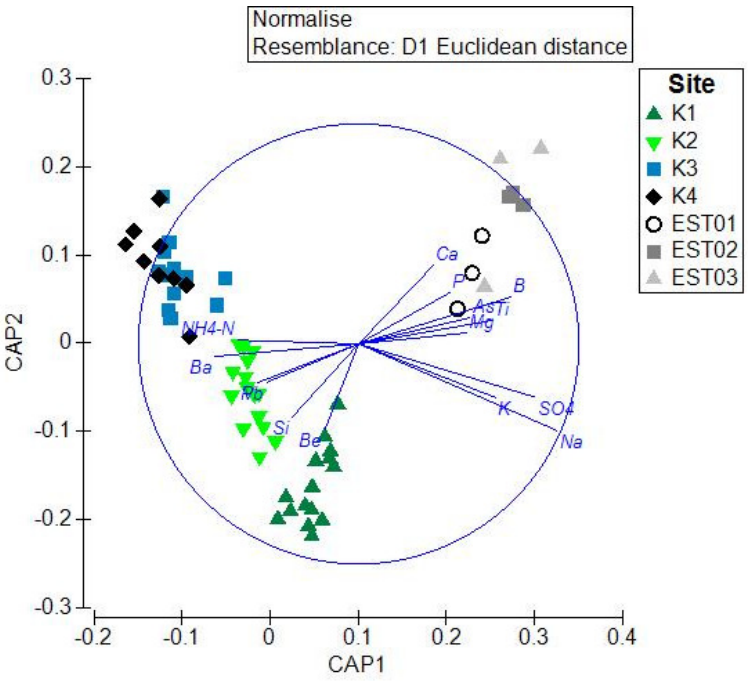

Figure 6. Constrained CAP plot of sediment quality data between site, with vectors of Spearman rank correlations overlain (correlation >0.5).

Table 3. PERMANOVA post-hoc results showing t-values for all pairwise comparisons. * = sites significantly different.

	K1	K2	K3	K4	EST01	EST02
K1						
K2	1.33					
K3	1.71*	0.92				
K4	1.85*	1.37	1.22			
EST01	1.74	2.19*	2.70*	2.38*		
EST02	2.22*	2.65*	3.27*	2.66*	2.48	
EST03	2.05*	2.45*	3.00*	2.43*	1.55	0.52

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, K1-5, K2-3 and K4-3. Concentrations of nickel exceeded the ISQG-low TV at K2-1. 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. Measurement of total organic carbon content of the current and future samples will allow relationships between metals levels and organic content to be investigated.

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 two years 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

There are records of *Pristis* sawfish from the Keep River, in areas which may be potentially impacted by the ORIA Stage II development. These fish are listed on national and international conservation lists. Therefore, baseline sampling was undertaken to document the current occurrence, distribution, population size, and population structure of listed species (*Pristis* sawfish and *Glyphis* sharks) in the Keep River pools and upper estuary. Sampling will be conducted annually for three years (this study, 2012 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 microdon* from pool K2 (photo by WRM staff ©).

Listed species were processed and returned to the water alive as rapidly as possible. Sampling was undertaken at the same site 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.

4.3 Results

4.3.1 Species recorded

Three species of *Pristis* sawfish were recorded during the current study, including the freshwater sawfish *Pristis microdon* (Plate 3), dwarf sawfish *Pristis clavata* (Plate 3) and green sawfish *Pristis zijsron* (Table 4). *Pristis microdon* was the most common species in the Keep River pools, while *Pristis clavata* was more common in the estuary (Table 4). The estuary site EST01 recorded the greatest number of *Pristis* individuals (8 individuals tagged, two others released without processing, and numerous individuals seen feeding in shallows; Table 4). Sawfish were also recorded from two sites during sampling on the Ord River; downstream of Ivanhoe Crossing and upstream of Carlton Crossing (Table 4). One freshwater sawfish was also caught and tagged from Policeman's Waterhole in the Keep River National Park.

Due to the high abundance of *Pristis* sawfish caught in gillnets at EST01, combined with inclement weater (hot, humid with afternoon storms), nets were removed early from this site, and fewer nets were set, and for a shorter duration, at EST02 and EST03. No sawfish were subsequently caught in nets at the latter two sites, however, individuals were observed feeding along the bank (Andrew Storey, WRM, pers. obs.).

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

Of the *Pristis microdon* recorded from the Keep River pool K2, the majority were female. In contrast, the *Pristis clavata* from the estuary site EST01 were mostly males. Sawfish of all species ranged in

size from 950 cm TL to 1925 cm TL. Juveniles were recorded from the Ord River downstream of Ivanhoe, and at Carlton Crossing (Table 4).

Table 4. 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	K2	*Pristis microdon*	301	1150	260	240	21	21	M
		Pristis microdon	302	1100	275	265	22	21	F
		Pristis microdon	303	1040	250	230	19	18	F
		Pristis microdon	304	1130	280	265	21	21	F
		Pristis microdon	305	1480	350	330	23	23	F
	KR2 (Policeman's)	*Pristis microdon*	306	950	240	220	20	19	F
Keep River Estuary	EST01	*Pristis clavata*	309	1870	368	352	22	21	M
		Pristis zijsron	310	1905	395	372	23	24	F
		Pristis clavata	311	1445	305	290	22	21	M
		Pristis clavata	312	1925	425	395	21	22	M
		Pristis clavata	313	~2000	Not measured but tagged & DNA taken				
		Pristis clavata	314	1900	418	400	20	20	M
		Pristis clavata	315	1500	305	290	22	22	M
		Pristis clavata	316	1650	340	322	21	21	F
Ord River	Ord d/s Ivanhoe	*Pristis microdon*	307	965	248	235	19	20	juvenile
	Carlton Crossing	*Pristis microdon*	308	1100	270	260	19	20	juvenile

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

4.3.2 Conservation significance of *Pristis* species recorded

Freshwater sawfish *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. microdon* 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 microdon* 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). No specific recovery, conservation or threat abatement plans have been developed for *P. microdon* although it is 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. microdon*. 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. microdon* 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). No specific conservation or threat abatement plans have been developed for *P. clavata.*

Even less is known of the biology of *P. clavata* than *P. microdon*. Preferred habitat appears to be shallow (2 - 3 m) coastal and estuarine waters. Unlike *P. microdon*, *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 a Keep River estuary site. 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 hass not been documented, it is likely to occur within estuarine rather than marine environments, probably at a similar time of year as *P. microdon*. 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.

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

Green sawfish *Pristis zijsron*

The green sawfish is a tropical Indo-Pacific species with a range from eastern Australia and Papua New Guinea, through Southeast Asia to western India, and with a disjunct population off eastern South Africa (Paxton *et al*. 1989, Compagno *et al*. 2006b, Last and Stevens 1994). It is mainly recorded in inshore marine habitats, but it is also reported from freshwater. Freshwater records

have been made from Thailand (Tachin River and Songkhla Lake) (Cook and Compagno 1994), Malaysia, Indonesia and Australia (Paxton *et al*. 1989, Last and Stevens 1994). Within Australia, the green sawfish is mainly found in the northern tropics, but records have been made from Byron Bay, Clarence River, Richmond River and the Parramatta River in NSW (Last and Stevens 1994). Recent studies suggest that *P. zijsron* no longer occurs in freshwaters of Thailand or NSW, Australia. In fact, it has recently been proposed by the Fisheries Scientific Committee that *P. zijsron* be listed as 'Presumed Extinct' in NSW, under Part 4 of Schedule 4 of the *Fisheries Management Act 1994* (NSW DPI 2005). The green sawfish is currently listed as:

- **Vulnerable** under the *Territory Parks and Wildlife Conservation Act 2000*
- **Endangered** under the NSW *Fisheries Management Act 1994* (although it has been proposed to be changed to 'Presumed Extinct' in NSW
- **Vulnerable** under the *Environment Protection and Biodiversity Conservation Act 1999*
- **Endangered** in the Australian Society for Fish Biology 2001
- **Critically Endangered** under the IUCN Red List of Threatened Species (Compagno *et al.* 2006).

Throughout its range, *Pristis zijsron* has been exploited, both as a target species and incidental by-catch in commercial, sport or shark-control net fisheries and for aquarium display. It is considered a good eating species for human consumption (Last and Stevens 1994), the fins command a high price in the shark fin trade (Rose and McLoughlin 2001), and their saws are used in traditional medicine. As well as effects from fishing, this species is also susceptible to pollution, habitat loss and degradation. As a result, contraction of its range has been observed in Australia, where it no longer occurs in NSW, it is rarely recorded south of Townsville, and has not been reported from the Moreton Bay area since the 1960s (Johnson 1999). The species appears to have experienced a contraction in range of around 30% in Australian waters (Stevens *et al.* 2005). In Thailand, it has not been recorded in Songkhla Lake for some 30 to 40 years (Cook and Compagno 1994), and in South Africa it appears to be extinct from areas such as Lake St Lucia (Compagno *et al.* 2006b).

The green sawfish is a benthic species found in muddy bottom areas. It tends to be found more frequently in shallow water (Stead 1963). As with other species of Pristidae, little is known about the reproductive biology of *P. zijsron*. The reproductive mode involves internal fertilisation and live birth. Stevens *et al*. (2005) suggested that it is likely they are long-lived, produce few pups and mature late in life. From direct observation, it appears they reach size at maturity in 9 years and 95% of their maximum length (~5.08 m) at around 24 years of age (Stevens *et al*. 2005). They are the largest species of sawfish and may reach up to 7.30 m, but are more reliably recorded up to 5.00 m. Anecdotal evidence from elsewhere indicates they may have up to 20 young. Some data detailing the presence of pups in inshore coastal waters of WA, NT and QLD suggests pupping may occur during the wet season (Peverell 2005). Given their low fecundity and slow maturation, green sawfish are highly susceptible to anthropogenic disturbance, and their ability to recover from population declines is limited (Stobutzki *et al.* 2002).

Green sawfish feed on slow-moving shoaling fish such as mullet, as well as molluscs and small crustaceans which are swept out of the mud using their saw.

4.3.3 Population size estimate for K2

The Keep River Pool K2 was the only site where tagged individuals were re-captured. Using the Ricker Equation the estimated population size of ***Pristis microdon*** at K2 is **6** individuals, i.e.

$$N = \frac{(M+1)(C+1)}{R+1} \qquad \frac{(5+1)(2+1)}{(2+1)}$$

However, Ricker (1975) stated that the probability of a systematic statistical bias in the population estimate cannot be ignored if recaptures number less than 3. In this case only two individuals were recaptured.

4.4 Discussion

Listed sawfish species were recorded from the Keep River at K2, Policeman's Waterhole (KR2), the Keep River estuary at EST01, and from the Ord River at Carlton Crossing and downstream of Ivanhoe Crossing. The greatest abundance of *Pristis clavata* was recorded from the estuary (EST01), while the greatest number of *P. microdon* was recorded from the Keep River pool site K2.

Although sawfish were not caught at EST02 and EST03, they were observed feeding in the shallows along the bank. It is likely that the presence of a gravel/sand bar between EST01 and EST02 limits movement between these sites. It is hypothesised that sawfish are able to move in over the bar when the tide is rising, as they feed on baitfish on the incoming tide, but they would become stranded in the extensive pool by the sandbar as the tide goes out. This may explain, at least in part, the high numbers of sawfish present at EST01.

It is interesting to note here, that since this fieldwork was conducted, two tagged individuals have been re-caught by local fisherman. *Pristis clavata* #314 was recaptured not long after release, on the 27th of October 2011. It was caught approximately 7 km downstream from where it was originally caught and tagged. *Pristis clavata* #311 was re-caught recently, on the 30th of June 2012, approximately 13 km downstream of its original location (see Figure 7 and Box 1).

Box 1. Notes on recapture of tagged sawfish by local fisherman.

Sawfish recapture reported 13/7/12 (caught 30/6/12) – VIA phone to David Morgan
TAG Number: 311
Where: Keep River 15°14'12";129°06'43"
TL: about 3 m
Method: R&L - released
When: 4:30pm, 30/6/12
Notes: Looked healthy, released

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

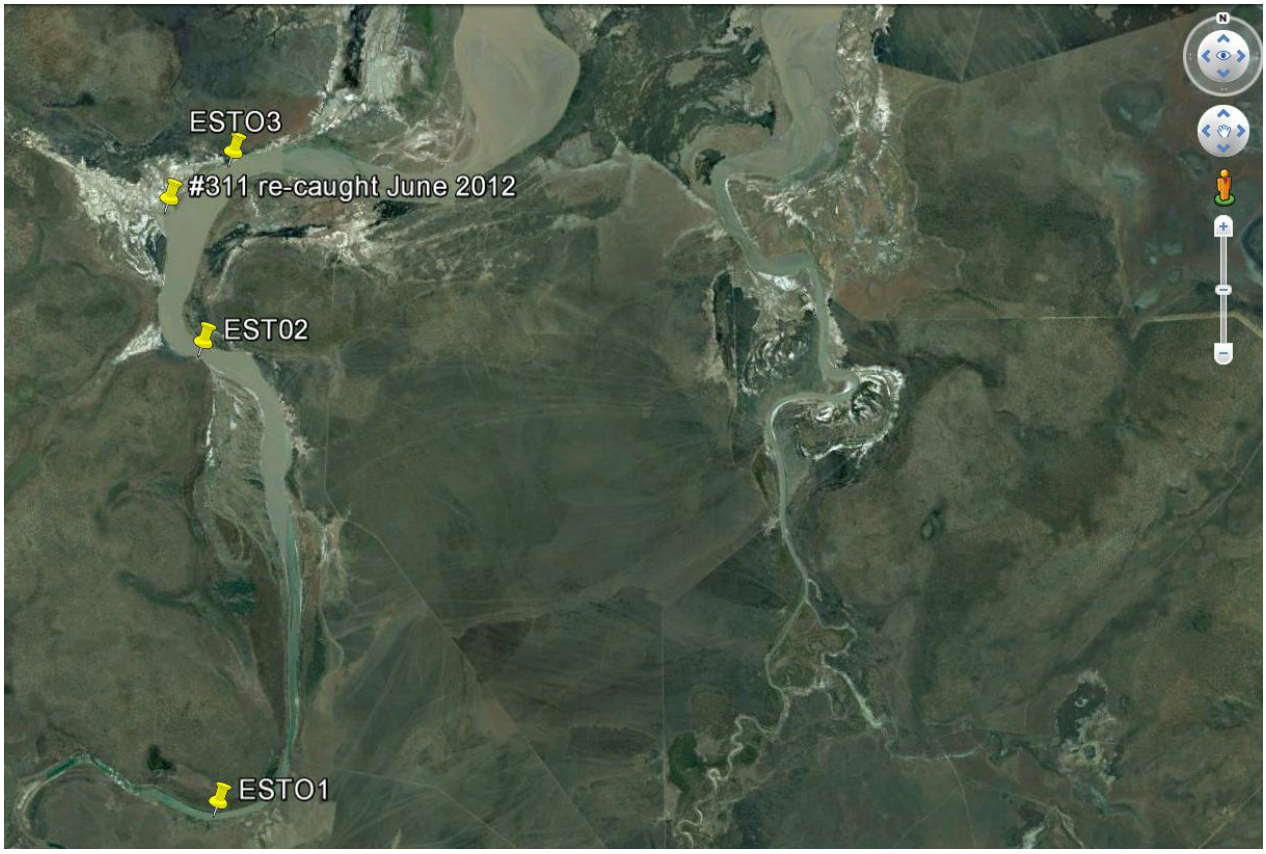

Figure 7. Location of the recapture of #311 in June 2012, close to EST03. It was originally caught and tagged at EST01.

5 BASELINE AQUATIC FAUNA SURVEYS

5.1 Rationale

The aim of this aspect of the aquatic fauna monitoring program is 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 (2011, 2012 and 2013), 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.

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 8).

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 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.

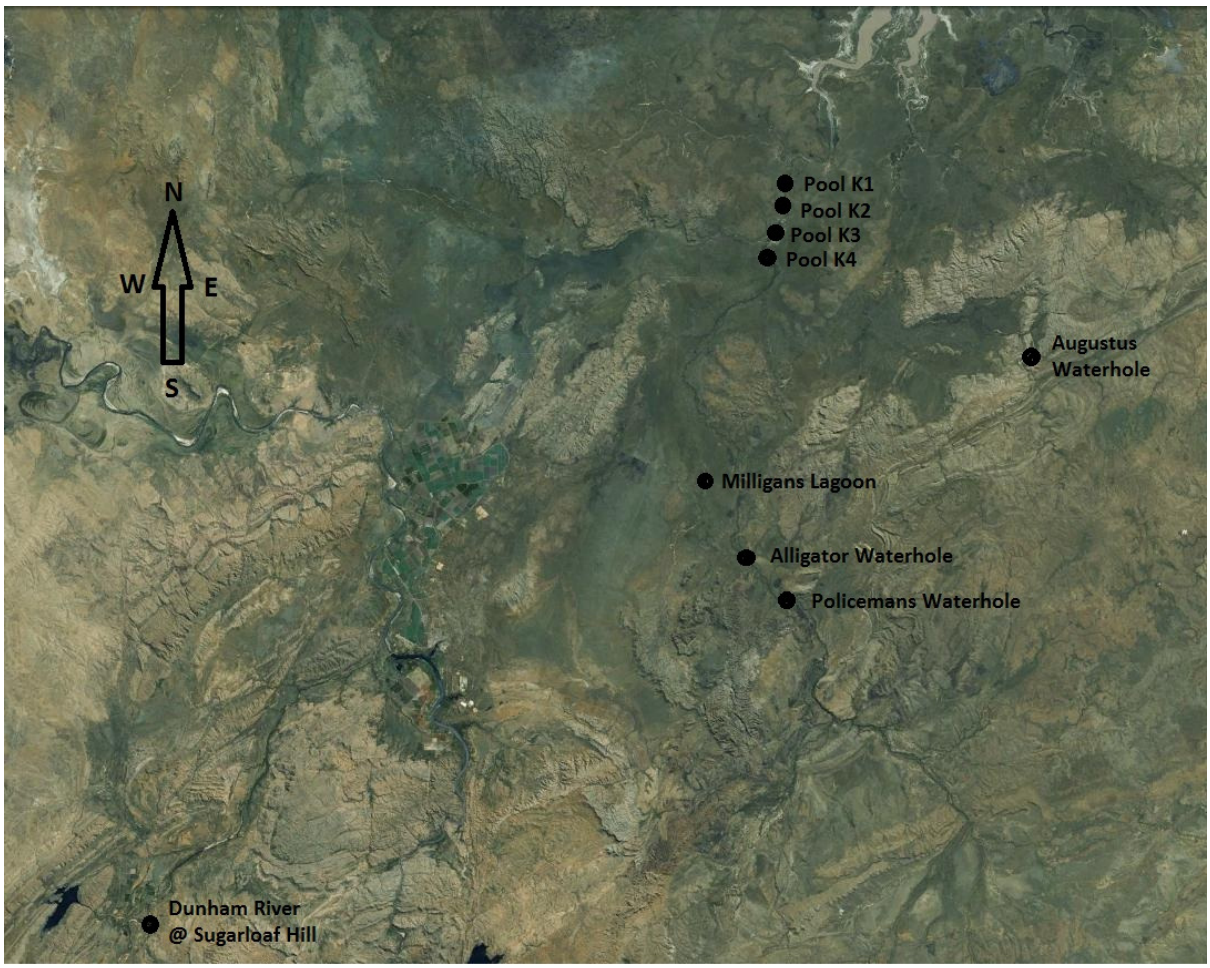

Figure 8. Location of the baseline aquatic survey potentially exposed Keep River pool sites and the five reference sites.

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 and nutrient concentrations. Nutrient samples were filtered through 0.45 µm Millipore nitrocellulose filters, kept cool on ice whilst in the field and then frozen as soon as possible for subsequent transport to the laboratory. All laboratory analyses were conducted by the Chem Centre WA (a NATA accredited laboratory). The suite of analytes were those selected 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 the wet season of 2011 and subsequent recharge of the aquifer, permanent flows were established in 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 2011 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, upstream of pool K3 and close to where Border Creek enters the main channel. 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), with additional riffle samples collected from sites in the Ord and Pentecost rivers. 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.

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 - 10 individuals, 2 = 11 - 100 individuals, 3 = 101-1000 individuals, 4 = >1000). 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).

5.2.5 Data analysis

Univariate

To examine spatial variation in water quality and species diversity between Keep River pools and reference sites, boxplots were produced, and ANOVA used to test for significant 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 amongst sites. Analyses applied to the water quality 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. Permutational multivariate analysis of variance (PERMANOVA) was undertaken to determine whether there were any significant differences in water quality or faunal assemblages between sites (Anderson 2001a, b, McArdle and Anderson 2001, Anderson and ter Braak 2003, Anderson *et al.* 2008).

AusRivAS River Health Assessment

Condition 11F of the Storm Water and Groundwater Discharge Management Plan requires development of "AusRivAS trigger levels for aquatic macroinvertebrates". This entails converting macroinvertebrate species data from each site to family level, and running the data through the AusRivAS dry season edge habitat model to determine observed to expected (O/E) scores and model bands which provide current ecological health ratings. The model outputs will then be used to develop trigger values for each site, as per ANZECC/ARMCANZ (2000) protocols. This aspect is still to be conducted for the 2011 data, and will be reported in the 2012 annual monitoring report.

5.3 Results

5.3.1 Water quality

Keep River pools were characterised by circum-neutral pH, high alkalinity (well buffered against rapid changes in pH) and generally low nutrient levels (Figures 9 to 12; 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. This is a result of regular tidal influence on water quality in the lower pools. Dissolved oxygen was also much higher from the downstream pools (both K1 and K2). Turbidity and concentrations of silicon dioxide increased with increasing distance upstream in pools K1 to K4, but was low in the reference sites (Figure 10).

Generally, water quality parameters 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 recommended guidelines, with values lower than the guidelines being recorded from the upstream pool K4 (Figure 9). 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). 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. DO values in excess of ANZECC/ARMCANZ (2000) trigger values were recorded from some replicate sites at K2 and K1 (Figure 9). Super-saturated DO levels occur when net photosynthesis exceeds total oxygen consumption, and is common in areas of high macrophyte and algal growth. Such sites often experience oxygen stress overnight, as respiration by plants, algae, bacteria and other aquatic fauna deplete DO. Super-saturated DO can lead to fish bubble disease. It can occur in systems with good light penetration and nutrient inputs which lead to excessive algal and macrophyte growth.

While electrical conductivity (EC) exceeded ANZECC guidelines at all Keep River pools (Figure 9), 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)[1]. 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

[1] 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).

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, EC at all K3 sites was lower than the interim water quality TV[2] developed for this pool by WRM (2010b). In 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 1800 µS/cm to 2160 µS/cm (Figure 9). As noted above, this pool, as well as K3 receives occasional inputs from high spring tides (DAFWA, 2011). In contrast, the lower tidally-influenced pool was highly saline, with EC ranging from 9640 µS/cm to 17,300 µS/cm (Figure 9).

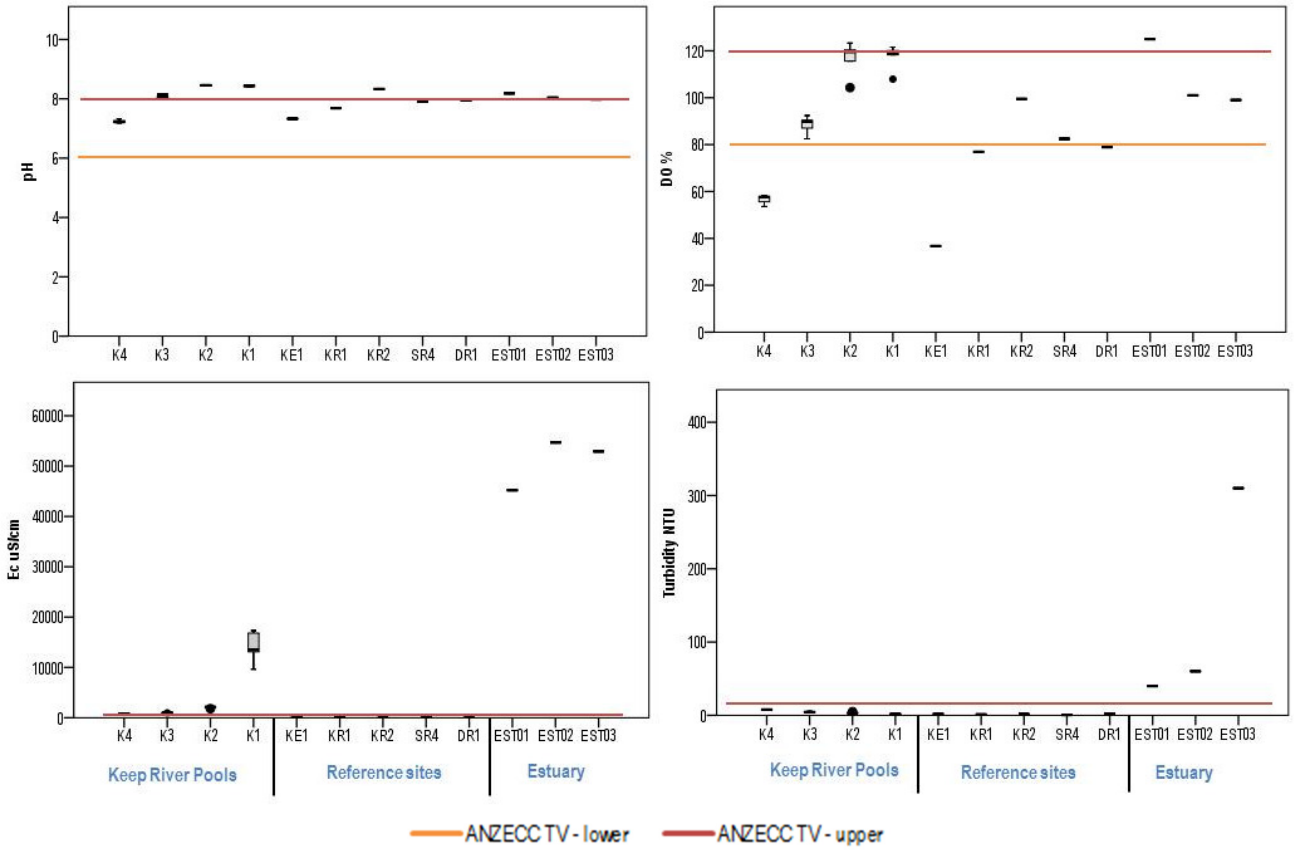

Figure 9. Boxplots of some water quality parameters, including pH, dissolved oxygen (%), electrical conductivity (µS/cm) and turbidity (NTU). Plots show minimum, 20%ile, median (50%ile), 80%ile and maximum concentrations for each site. The corresponding ANZECC/ARMCANZ (2000) water quality trigger values are also indicated.

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

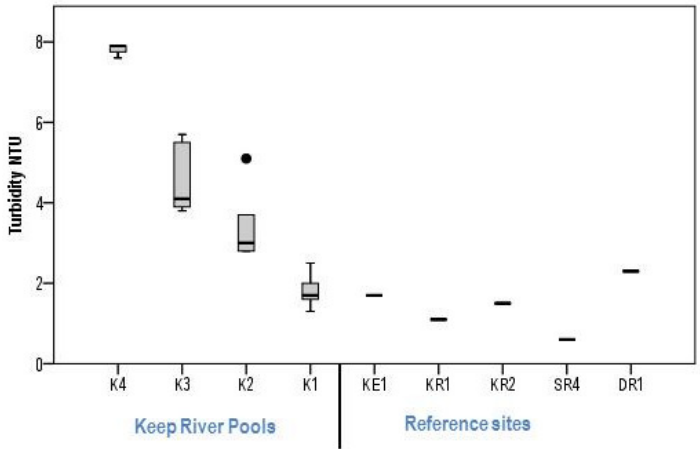

Figure 10. Boxplot of turbidity at Keep River pools and reference sites. The minimum, 20%ile, median (50%ile), 80%ile and maximum concentrations are shown for each site.

Total nitrogen was low at all Keep River pools and within default ANZECC guidelines. The interim TV for pool K3 also deferred to the default ANZECC value, so total nitrogen at this pool was also within the interim water quality TVs developed by WRM (2010b). Total phosphorus exceeded ANZECC/ARMCANZ (2000) guidelines at the most upstream Keep River pool (K4; Figure 12). Total phosphorus at K3 was within both the ANZECC/ARMCANZ (2000) and interim water quality TVs (WRM 2010b). Once sufficient baseline data are obtained, and before project commencement, system-specific water quality trigger values will be developed and proposed, and future monitoring will be against these TVs, rather than the default ANZECC/ARMCANZ (2000) TVs.

Reference sites also recorded circum-neutral pH, high alkalinity (well buffered) and generally low nutrient levels, but they were also characterised by low electrical conductivity, low turbidity and low ionic concentrations (Figures 9 to 11). Concentrations of silicon dioxide varied greatly between reference sites, with the lowest levels being recorded from Milligan's Lagoon (KE1) and highest from the Dunham River (DR1; Figure 10).

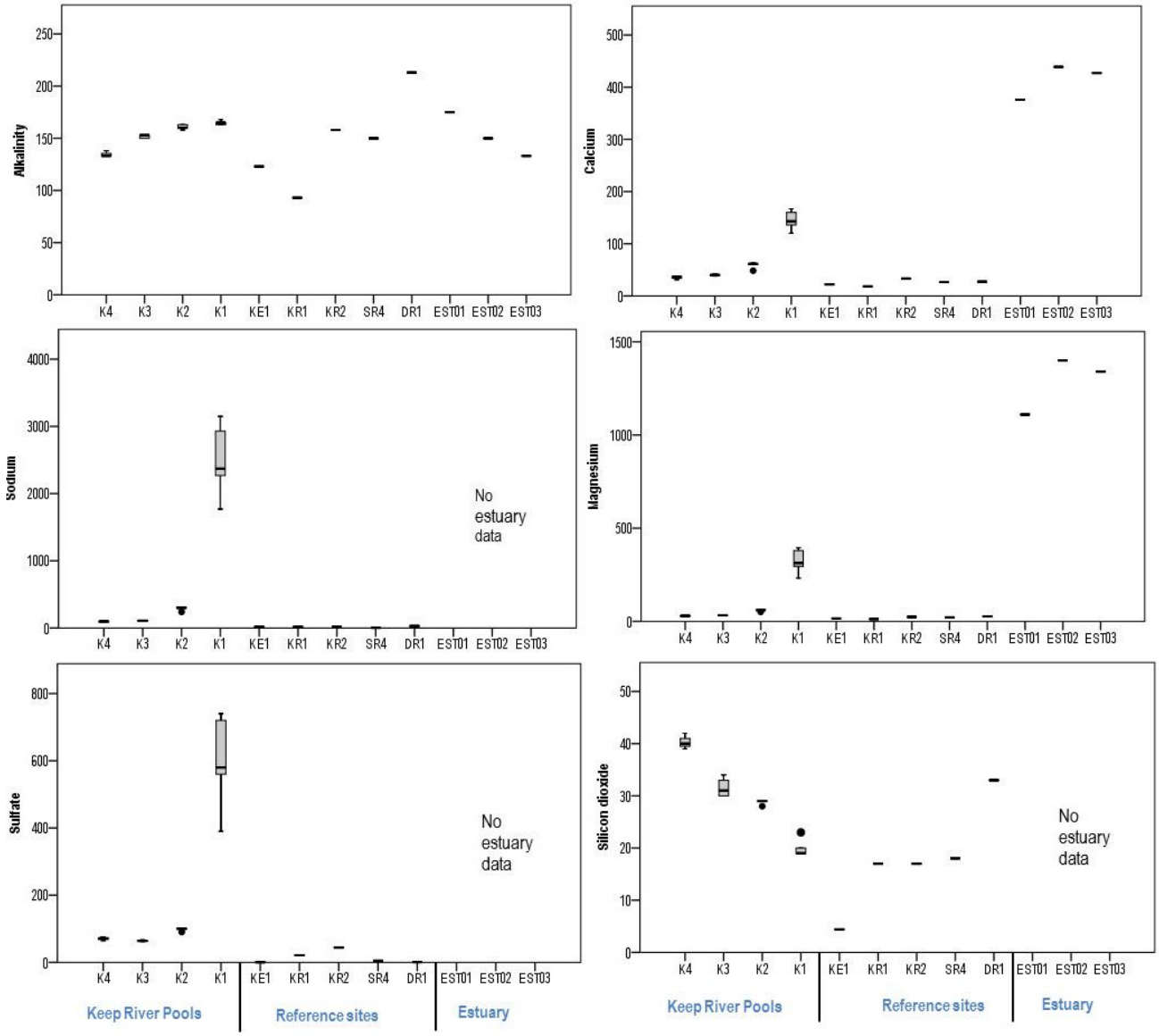

Figure 11. Boxplots of alkalinity and ionic composition (mg/L). Plots show minimum, 20%ile, median (50%ile), 80%ile and maximum concentrations for each site. NB – scales are not the same between plots.

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, total nitrogen and total phosphorus (Figures 10 and 12). Dissolved oxygen levels lower than the guidelines were recorded from Milligan's Lagoon (KE1), Alligator Waterhole (KR1) and the Dunham River (DR1), however, no levels were considered low enough to cause severe ecological impact to biota. As with the upper Keep River pools, reference sites exceeded guidelines for electrical conductivity but waters at all sites were fresh as defined by the DoE (2003). Electrical conductivity ranged from 277 µS/cm at Alligator Waterhole to 453 µS/cm at Policeman's Waterhole (KR2). Therefore, the elevated EC with respect to ANZECC/ARMCANZ (2000) trigger value were not considered to be of ecological consequence at these reference sites. Lastly, nutrient levels were elevated at two reference sites; total nitrogen exceeded guidelines at Milligan's Lagoon and total phosphorus was considerably elevated at the Dunham River (i.e. concentrations were twice the ANZECC trigger value).

As would be expected, water quality at the Keep River estuary sites was considerably different to the upstream pools and reference sites (see Figures 9, 11 and 12). The estuary sites were characterised

by circum-neutral pH, high dissolved oxygen and high EC (saline waters). Water temperatures were high (between 29.7 °C and 33.2 °C)

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, including dissolved oxygen (Figure 9), turbidity (Figure 9), total nitrogen (Figure 12) and total phosphorus (Figure 12). Dissolved oxygen marginally exceeded the guidelines at EST01 (124% DO). Total nitrogen was elevated at all sites, with concentrations from EST01 and EST03 being more than twice the ANZECC trigger value. EST03 also recorded elevated concentrations of total phosphorus. Finally, turbidity was above ANZECC/ARMCANZ (2000) guidelines at all sites. Turbidity recorded from EST03 was much higher than that recorded from the other estuary sites, reflecting the dynamic nature of this area, with high tidal energy.

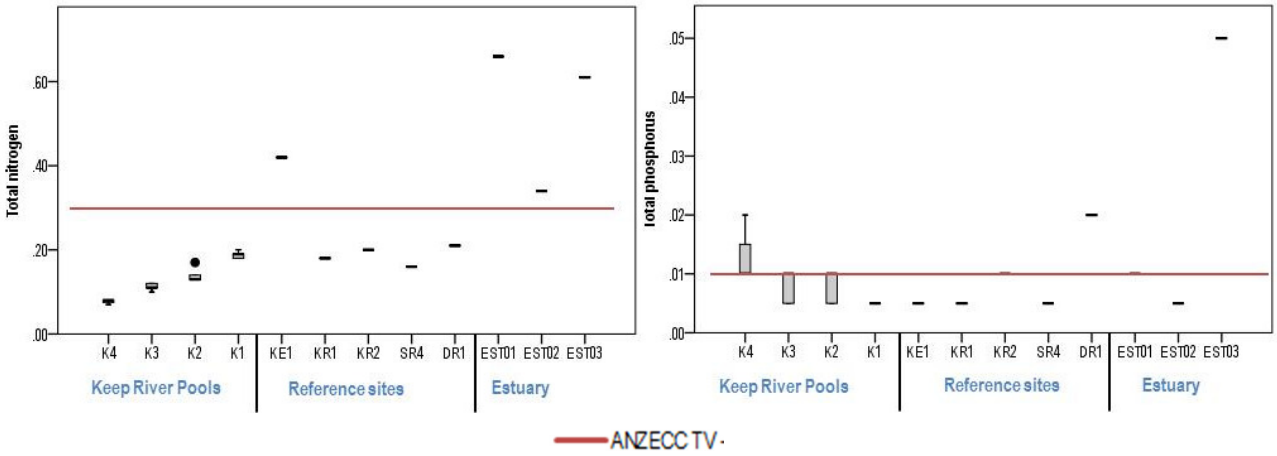

Figure 12. Boxplots of total nitrogen and total phosphorus concentrations (mg/L). Plots show minimum, 20%ile, median (50%ile), 80%ile and maximum concentrations for each site. The corresponding ANZECC/ARMCANZ (2000) water quality trigger values are also indicated.

Dissolved oxygen (%) depth profiles for Keep River pools and reference sites are provided in Figure 13. Reference sites generally showed greater change in DO with depth, particularly Milligan's Pool and Alligator Waterhole which recorded extremely low DO at 3.5 metres from the water surface (Figure 13). There was little change in DO with depth at Keep River pools K1, K2, K3 and K4 (Figure 13). 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).

Given the large variation in water quality amongst estuary sites, coupled with the large variation between the estuary and Keep River/reference sites, the estuary sites were removed from further analyses to enable patterns between Keep River pools and reference sites to become apparent. Multivariate analyses of Keep River 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; 0.99 along CAP1 and 0.98 along CAP2.
- Separations between sites were evident in the CAP ordination (Figure 14). All Keep River pools separated from each other in ordination space 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 14).

- Vector overlay of water quality parameters with Spearman Rank correlations > 0.5 indicated separation of K1 from the upper Keep River pools and reference sites was primarily due to the higher EC, DO, alkalinity and concentrations of Mg, SO_4, Ca and Na. The upstream Keep River pool (K4) separated from all other sites based on its higher turbidity and silicon dioxide levels (Figure 14).
- Differences in overall water quality between site[3] were significant (PERMANOVA; df = 4, Pseudo F = 11.82, p = 0.0001). Post-hoc results revealed that all sites were significantly different from each other (Table 5).

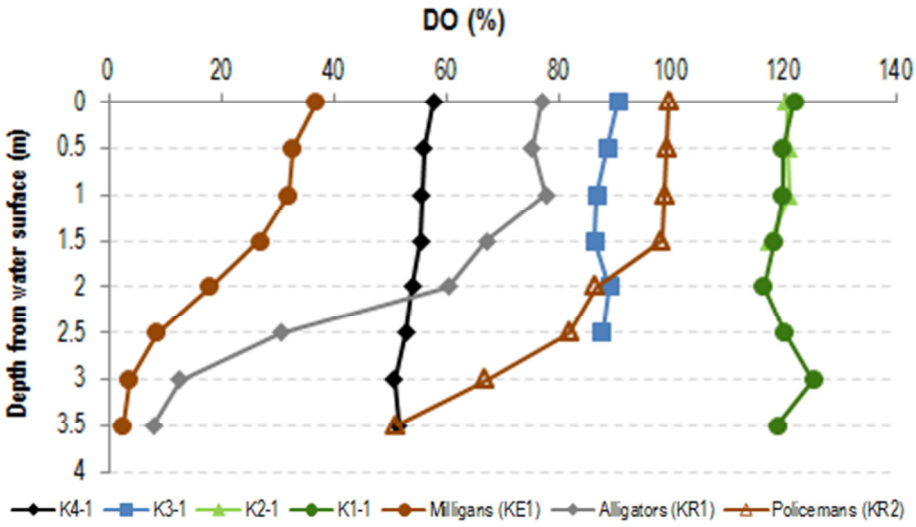

Figure 13. Dissolved oxygen (%) depth profiles.

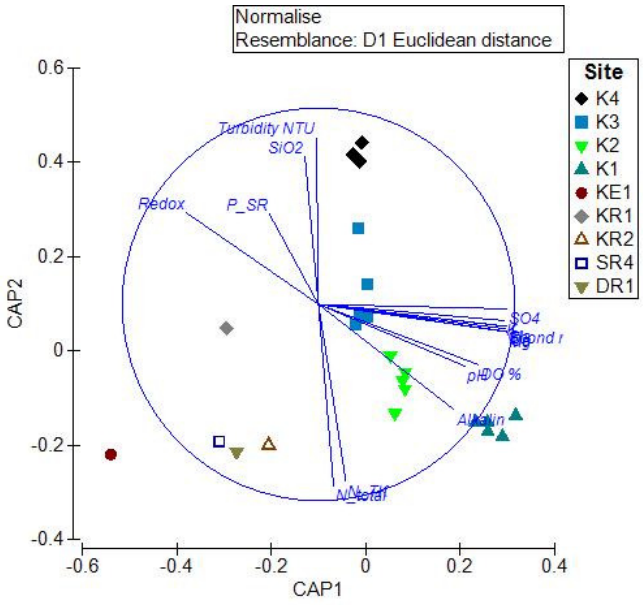

Figure 14. Constrained CAP plot comparing water quality between site. Vectors of Spearman rank correlations > 0.5 are overlain.

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

Table 5. PERMANOVA post-hoc results for comparisons of water quality between site, showing t-value. * = pairwise comparison of sites are significantly different.

	K1	K2	K3	K4
K1				
K2	6.20*			
K3	6.22*	2.17*		
K4	11.87*	5.15*	2.40*	
Refs	4.04*	2.55*	2.04*	2.21*

5.3.2 Macroinvertebrates

A total of 249 macroinvertebrate taxa was recorded from all sites and habitats sampled (Appendix 6). 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 249. Of the edge habitat samples, reference sites recorded a greater number of Hemiptera and Diptera taxa than Keep River pools, despite a much lower number of sites being sampled (Table 6). In contrast, the number of Coleoptera and Diptera from riffle samples of Keep River pools was greater than riffles of reference sites (Table 6). A greater number of Ephemeroptera were recorded from reference site riffle habitats (Table 6).

All macroinvertebrate taxa recorded during the current study were common, ubiquitous species, with distributions extending across northern Australia (northern WA, NT and northern QLD) or across Western Australia and the Northern Territory.

Table 6. 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	1+	0	0
Platyhelminthes (flat worms)	0	0	1+	0
Nematoda (round worms)	1+	0	0	0
Oligochaeta (aquatic segmented worms)	1+	1+	1+	1+
Polychaeta (aquatic bristle worms)	1+	0	0	0
Cnidaria (freshwater hydra)	0	1	1	0
Mollusca (snails & bivalves)	5	5	2	1
Crustacea (side swimmers)	10	6	2	1
Acarina (water mites)	0	1+	1+	1+
Collembolla (spring tails)	1	1	1	0
Ephemeroptera (mayflies)	8	12	5	10
Odonata (dragonflies & damselflies)	7	11	3	8
Hemiptera (true bugs)	24	27	5	5
Coleoptera (aquatic beetles)	41	34	16	10
Diptera (two-winged flies)	32	43	31	29
Trichoptera (caddis-flies)	11	11	11	8
Thysanoptera (thrips)	1	0	0	0
Lepidoptera (moths)	0	0	5	7
Total number of taxa	**143+**	**154+**	**85+**	**81+**

The number of taxa recorded varied between site and habitat, and ranged from 14 taxa (from K1-1 edge habitat) to 80 (from KR1 edge habitat; Figure 15). Of the edge habitat samples, taxa richness

was generally higher from reference sites in comparison to Keep River pools (Figure 15). 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. Pools K1 and K3 had significantly lower taxa richness than the reference sites, but were not significantly different to species richness at K2 and K4, and taxa richness at the latter two sites was not significantly different to richness at the reference sites (One-way ANOVA; see Table 7). The low taxa richness at K1 likely reflects the effects of higher conductivity, combined with lower habitat diversity at the most downstream pool. Taxa richness from riffle habitats ranged from 50 at DR1 to 60 at both K4 and SR4 (Figure 15).

Table 7. One-way ANOVA results comparing macroinvertebrate taxa richness in edge habitat between each Keep River pool and reference sites. 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*		
Sites	4,18	8.537	0.000	K1	K3	K4	K2	Reference
				23.80	41.20	42.67	46.80	65.80

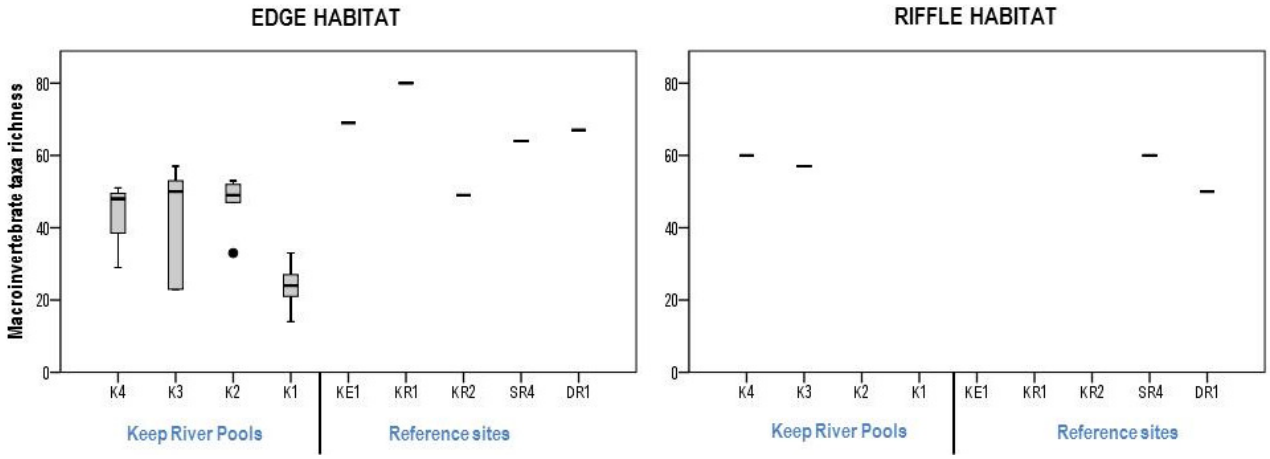

Figure 15. Boxplots of macroinvertebrate taxa richness from edge and riffle habitats. Plots show minimum, 20%ile, median (50%ile), 80%ile and maximum values, where applicable, for each site.

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; 0.99 along CAP1 and 0.98 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 16). CAP2 separated the remaining Keep River pools from the reference sites (Figure 16). The upstream Keep pool (K4) was most similar to the reference sites, while K2 and K3 clustered together at the top of the ordination (Figure 16).
- Vector overlay of water quality parameters with Spearman Rank correlations > 0.5 indicated that the macroinvertebrate assemblages of K1 were influenced by the higher EC (viz. salinity), calcium, sulfate, magnesium, sodium, pH and dissolved oxygen at this site (Figure

16). The assemblages of the brackish K2 and K3 sites were influenced by the higher turbidity characteristic of these sites (Figure 16).

- The BVSTEP routine indicated that water quality variables which had a significant influence on the macroinvertebrate assemblages were alkalinity, calcium, EC, magnesium, sodium and turbidity (BVSTEP; Rho = 0.72, p = 0.001).
- A number of species influenced the separation of K1, most of which were species known to tolerate estuarine/saline waters. Such taxa included the prawns *Macrobrachium rosenbergii* and *M. bullatum*, shrimp *Caridina nilotica*, Polychaeta spp. and snail Hydrobiidae spp.
- The separation of reference sites from Keep River pools was influenced by higher abundances of a high number of taxa, including the snails *Ferrissia petterdi*, *Leichhardtia* sp. and *Notopala* sp., the watermites Hydracarina spp., chironomids *Larsia* ?*albiceps*, *Clinotanypus crux* and pupae, odonates *Antipodogomphus neophytus*, *Austroepigomphus turneri*, *Diplacodes haematodes*, *Orthetrum caledonicum* and *Pseudagrion lucifer* and caddisfly *Leptocerus* sp. AV2.
- PERMANOVA concurred with these patterns, and found that macroinvertebrate assemblages were significantly different between site[4] (PERMANOVA; df = 4, Pseudo F = 3.93, p = 0.0001). Post-hoc results revealed that the only sites which were NOT significantly different from each other were K2 and K3 (Table 8 and see Figure 16).

Table 8. PERMANOVA post-hoc results for comparisons of macroinvertebrate assemblages between site, showing t-value. * = sites are significantly different.

	K1	K2	K3	K4
K1				
K2	2.30*			
K3	2.11*	1.34*		
K4	2.20*	1.70*	1.09	
Refs	2.68*	1.94*	1.96*	1.69*

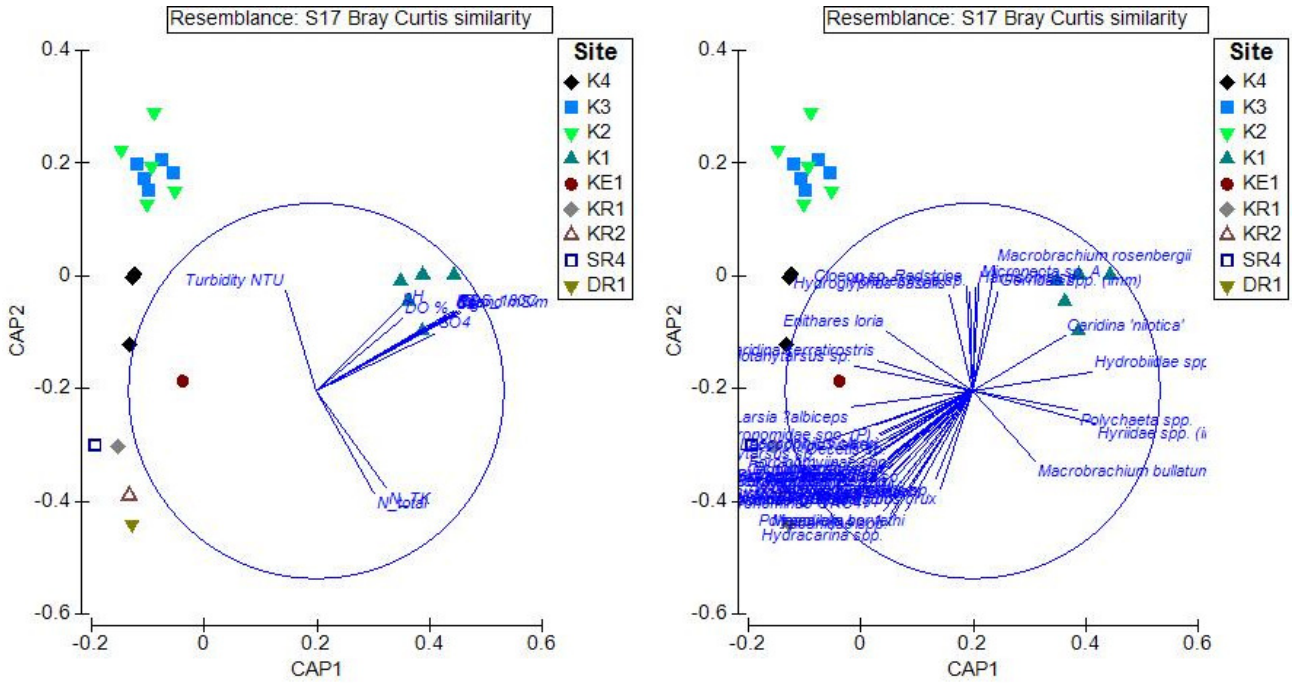

Figure 16. Constrained CAP plot of macroinvertebrate abundance data between site. Vectors of water quality Spearman Rank Correlations (correlation >0.5) (left) and species correlations (right) are overlain on the ordination.

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

5.3.3 Fish

A total of 27 species of fish were recorded during the current study, including 18 freshwater species and 9 marine/estuarine species (Table 9). Freshwater species included bony bream *Nematalosa erebi*, blue catfish (or lesser salmon catfish) *Arius graeffei* (Plate 5), shovel-nosed catfish *Arius midgleyi*, toothless catfish *Anodontiglanis dahli*, narrow-fronted tandan *Neosiluris ater*, freshwater longtom *Strongylura kreffti* (Plate 5), giant glassfish *Parambassis gulliveri*, barramundi *Lates calcarifer* (Plate 5), barred grunter *Amniataba percoides*, Jenkins' grunter *Hephaestus jenkinsi* (Plate 5), Butler's grunter *Syncomistes butleri*, long-nose grunter *Syncomistes trigonicus*, mouth almighty *Glossamia aprion*, seven-spot archerfish *Toxotes chatareus*, two species of mullet *Liza alata* and *Liza* sp., empire gudgeon *Hypseleotris compressa*, and the northern trout gudgeon *Mogurnda mogurnda*. Estuarine species included the bull shark *Carcharhinus leucas*, anchovy *Thyrssa kammalensis*, giant herring *Elops australis*, oxeye herring *Megalops cyprinoides*, common ponyfish *Leiognathus equulus*, mangrove jack *Lutjanus argentimaculatus*, snub-nosed garfish *Arrhamphus sclerolepis*, long-spined glassfish *Ambassis interruptus* and giant threadfin *Polydactylus macrochir* (Table 9).

Plate 5. Some of the fish recorded during the current study, including Jenkin's grunter *Hephaestus jenkinsi* (top left), barramundi *Lates calcarifer*, blue catfish *Arius graeffei* (middle left), freshwater longtom *Strongylura kreffti* (middle right), oxeye herring *Megalops cyprinoides* (bottom left), and long-spined glassfish *Ambassis interruptus* (bottom right). All photos by WRM staff, except the *Ambassis* (photo by Gerry Allen).

Bony bream and lesser salmon catfish were the most commonly encountered species, being recorded from 22 of the 23 sites (Table 9). This was followed by mullet *Liza alata* and seven-spot archerfish, recorded from 21 and 14 sites, respectively (Table 9). A number of species were only recorded from one site, including the shovel-nosed catfish, giant glassfish, Jenkin's grunter, long-nose grunter, empire gudgeon, northern trout gudgeon, and the estuarine mangrove jack (Table 9).

All species recorded are known to be common throughout the north of Australia. There were no species of conservation significance recorded.

The greatest number of fish recorded from any given site was 11 species, which was recorded from the reference site DR1 (Dunham River at KR; Figure 17). This was followed by nine species, recorded from the Keep River pool sites K4-1, K3-5, K4-4 and K1-1 (Figure 17). The lowest number of fish species was recorded from K4-3 (three species). Fish species richness at reference sites ranged from 4 (at Alligator Waterhole KR1) to 11 (at the Dunham River at KR; Figure 17).

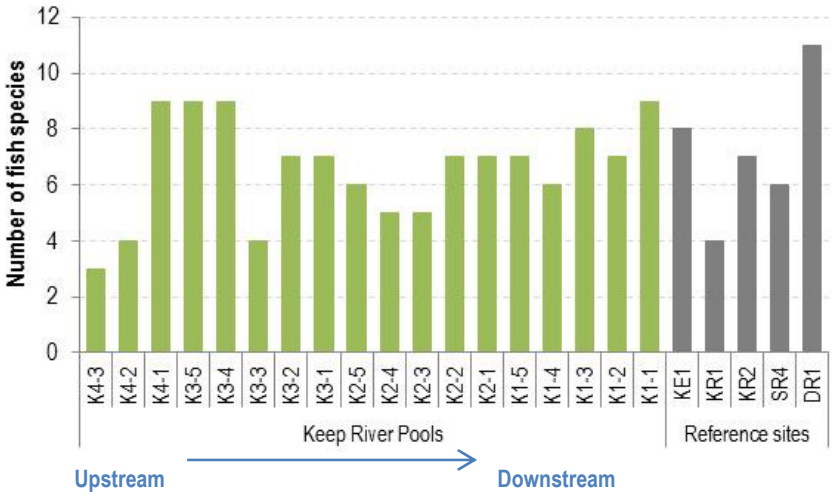

Figure 17. Number of fish species recorded from each site.

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 high along both canonical axes; 0.97 along CAP1 and 0.91 along CAP2.
- Patterns were evident in the CAP ordination. Keep River pools generally separated from the reference sites, and the fresh upstream Keep River pool also separated from the lower Keep River pools (Figure 18). There was considerable overlap in fish assemblage samples from the lower Keep River pool sites (K3, K2 and K1; Figure 18).
- Variation amongst reference sites was high. Fish assemblages of KE1 (Milligan's Lagoon) and KR2 (Policemen's Waterhole) were similar to the Keep River Pool K2 (Figure 18).
- Vector overlay of fish species with Spearman Rank correlations > 0.5 indicated the lower Keep River pools separated from other sites based on their higher abundance of *Leiognathus equulus*, *Toxotes chatereus*, *Liza* sp. and *Elops australis* (Figure 18).
- Environmental variables which influenced the fish assemblage CAP ordination included pH, alkalinity, chloride concentration, total phosphorus and turbidity (BVSTEP; Rho = 0.51, p = 0.001).
- Differences in fish assemblages between site[5] were significant (PERMANOVA; df = 4, Pseudo F = 3.80, p = 0.002). Post-hoc results revealed that the lower, more saline, Keep River pools were not significantly different from one another (i.e. K1, K2 and K3; Table 10).

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

Table 9. Fish species recorded from each site (* indicates species was not caught in nets, but was observed at that site).

	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.
Freshwater	Clupeidae	*Nematalosa erebi*	Bony bream	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	22
	Ariidae	*Arius graeffei*	Blue catfish	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	22
	Ariidae	*Arius midgleyi*	Shovel-nosed catfish																							✓	1
	Plotosidae	*Anodontiglanis dahli*	Toothless catfish																			✓			✓		2
	Plotosidae	*Neosilurus ater*	Narrow-fronted tandan																✓	✓	✓					✓	4
	Belonidae	*Strongylura kreffti*	Freshwater longtom						✓								*							✓		✓	4
	Ambassidae	*Parambassis gulliveri*	Giant glassfish																✓							✓	2
	Centropomidae	*Lates calcarifer*	Barramundi				✓	✓	✓					✓	✓		✓	✓	✓			✓		✓			10
	Terapontidae	*Amniataba percoides*	Barred grunter																				✓	✓	✓	✓	4
	Terapontidae	*Hephaestus jenkinsi*	Jenkins' grunter																						✓		1
	Terapontidae	*Syncomistes butleri*	Butler's grunter									✓													✓	✓	3
	Terapontidae	*Syncomistes trigonicus*	Long-nose grunter																							✓	1
	Apogonidae	*Glossamia aprion*	Mouth almighty				✓															✓					2
	Toxotidae	*Toxotes chatareus*	Seven-spot archerfish	✓	✓	✓		✓	✓				✓	✓	✓	✓	*	✓	*			✓		✓			14
	Mugilidae	*Liza alata*	Mullet	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓	21
	Mugilidae	*Liza* sp.	Mullet	✓		✓								✓	✓			✓									5
	Eleotridae	*Hypseleotris compressa*	Empire gudgeon														*										1
	Eleotridae	*Mogurnda mogurnda*	Northern trout gudgeon																*								1
Estuarine/Marine	Carcharhinidae	*Carcharhinus leucas*	Bull shark	✓	✓	✓											✓										4
	Engraulidae	*Thryssa kammalensis*	Anchovy							✓	✓	✓	✓		✓			✓									6
	Elopidae	*Elops australia*	Herring	✓		✓		✓		✓							✓										5
	Megalopidae	*Megalops cyprinoides*	Oxeye herring																✓			✓	✓			✓	4
	Leiognathidae	*Leiognathus equulus*	Common ponyfish	✓	✓	✓		✓	✓	✓			✓	✓				✓									9
	Lutjanidae	*Lutjanus argentimaculatus*	Mangrove jack				✓																				1
	Hemiramphidae	*Arrhamphus sclerolepis*	Snub-nosed garfish		✓					✓																	2
	Ambassidae	*Ambassis interruptus*	Long-spined glassfish							✓								✓									2
	Polynemidae	*Polydactylus macrochir*	Giant threadfin	✓							✓																2
			Number of species	9	7	8	6	7	7	7	5	5	6	7	7	4	9	9	9	4	3	8	4	7	6	11	

Table 10. PERMANOVA post-hoc results for comparisons of fish assemblages between site, showing t-value. * = sites are significantly different.

	K1	K2	K3	K4
K1				
K2	1.49			
K3	0.85	1.53		
K4	2.17*	2.03*	2.31*	
Refs	2.26*	2.16*	2.26*	1.77*

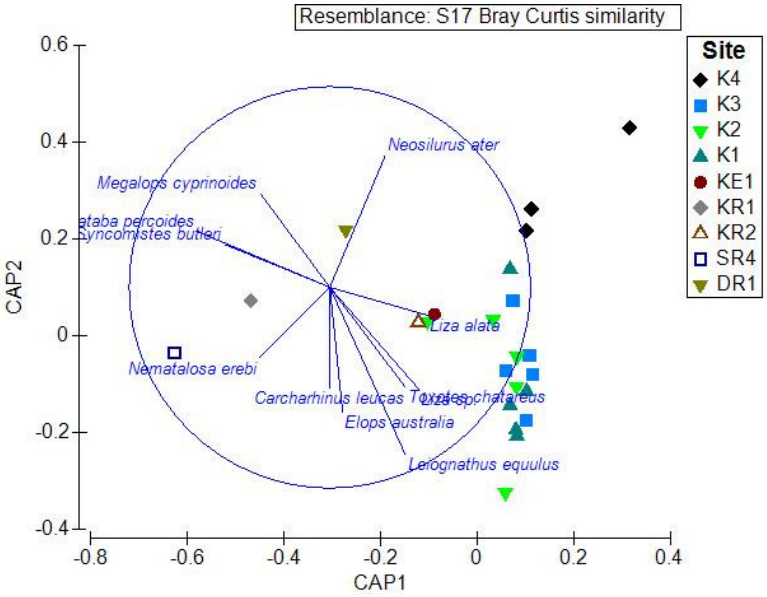

Figure 18. Constrained CAP plot of fish presence/absence data between site, with vectors of Spearman rank correlations overlain (correlation >0.5).

Blue catfish, *Arius graeffei*, recorded from SR4, KE1 and K4 were slightly longer and heavier than those recorded elsewhere (Figure 19). However, there was considerable within-site variation in length and weight of blue catfish. The mullet, *Liza alata* were of a similar size and weight from most sites, with much greater variability in total length and weight from Keep River pool sites K3, K2 and K1 (Figure 19).

5.4 Discussion

This study presents baseline data from the first round of sampling of the Keep River under the Ord Stage 2 Expansion Aquatic Fauna Monitoring program. 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, 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 sulfate, magnesium, calcium and sodium. 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 significantly different to other sites due to its higher turbidity and silicon dioxide concentration, and absence of any tidal influence. Turbidity at this site appears to be due to zooplankton blooms, which have been prevalent at this site since sampling commenced in 2000 (WRC, 2003a). In general, aquatic macroinvertebrate and fish assemblages were found to be influenced by these differences in water quality.

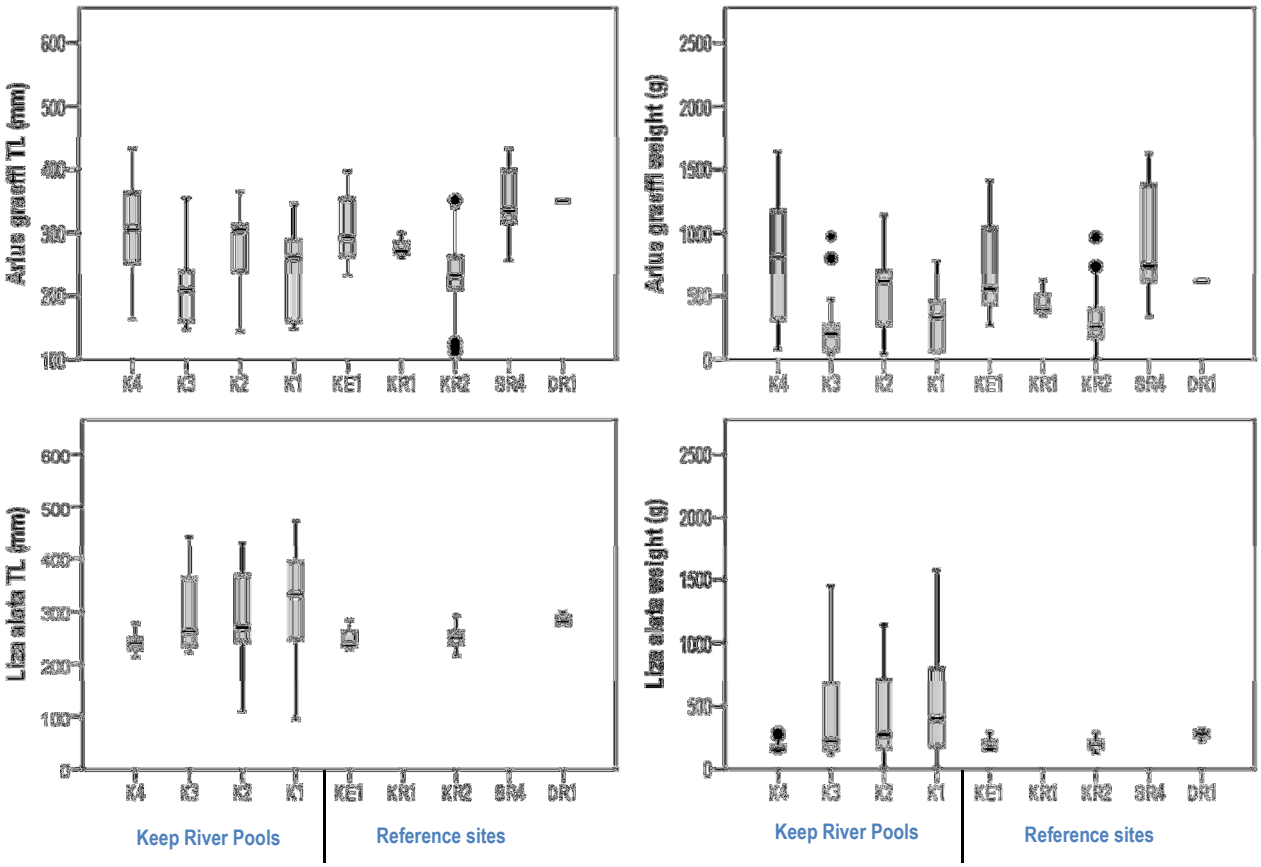

Figure 19. Boxplots of total length (left) and weight (right) of selected fish species at each site. Plots show minimum, 20%ile, median (50%ile), 80%ile and maximum sizes of each species for each site. Plots for *Arius graeffei* (top) and *Liza alata* (bottom) are shown.

Future sampling in 2012 and 2013, as required under Commonwealth conditions for project approval, will further develop this baseline dataset, along with data being collected by DAFWA, as mentioned above. This will provide additional data on water quality, and 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.

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 there was access, it would be extremely difficult to sample under high flows. Therefore, the decision was taken for the current study to standardise sampling to the late dry season. It is acknowledged that this

provides only a snap-shot of the system each year, but by standardising to 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 2012 and 2013 will add to the baseline by providing a measure of temporal variability in diversity and similarity within each pool. These data will characterise baseline spatial and temporal variability, against which it will be possible to differentiate any impacts that may be as a result of the stage 2 development, as opposed to climatic or other system-level changes.

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APPENDICES

Appendix 1. Site photographs

POTENTIALLY EXPOSED SITES

K1


K2


K3

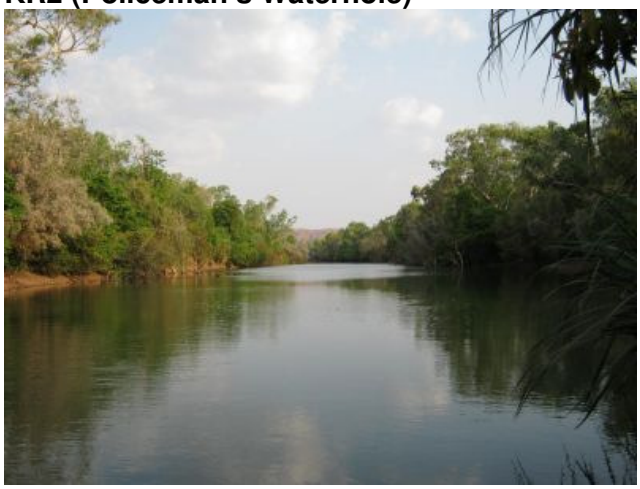

K4


REFERENCE SITES

KE1 (Milligan's Lagoon)

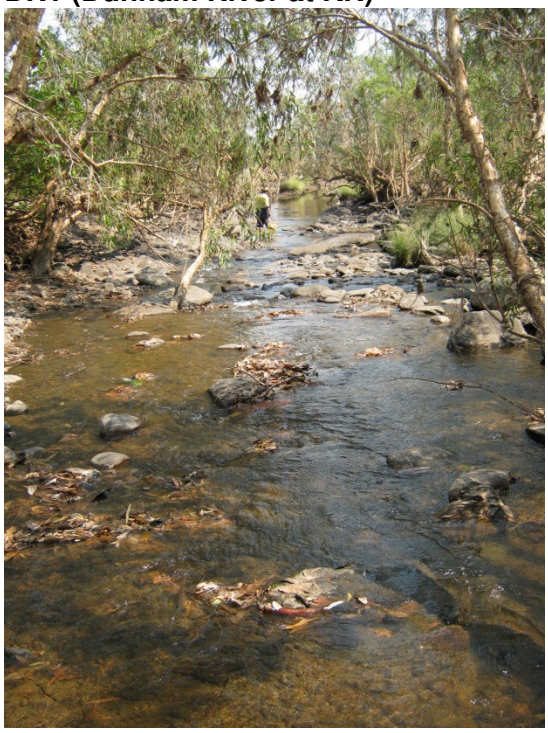

KR1 (Alligator Waterhole)


KR2 (Policeman's Waterhole)



SR4 (Augustus Waterhole)

DR1 (Dunham River at KR)



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 Results – September 2011.

ANOVA RESULTS

Table A3-1. One-way ANOVA results comparing ionic composition in sediments between 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.

	Source	df	F	p	Tukeys post-hoc (low – high mean)				
Ca	Between groups	4	31.93	0.000	K4	K1	K3	K2	EST
	Within groups	16							
	Total	20							
Cl	Between groups	4	11.39	0.000	K4	K3	K2	K1	EST
	Within groups	16							
	Total	20							
K	Between groups	4	4.13	0.017	K4	K3	K2	K1	EST
	Within groups	16							
	Total	20							
Mg	Between groups	4	4.37	0.014	K4	K3	K2	K1	EST
	Within groups	16							
	Total	20							
Na	Between groups	4	14.05	0.000	K4	K3	K2	K1	EST
	Within groups	16							
	Total	20							
SO4	Between groups	4	53.09	0.000	K4	K3	K2	K1	EST
	Within groups	16							
	Total	20							

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.

	Source	df	F	p	Tukeys post-hoc (low – high mean)				
P	Between groups	4	10.39	0.000	K4	K2	K3	K1	EST
	Within groups	16							
	Total	20							

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.

	Source	*df*	*F*	*p*	*Tukeys post-hoc (low – high mean)*				
As	Between groups	4	12.08	0.000	K3	K2	K4	K1	EST
	Within groups	16							
	Total	20							
B	Between groups	4	25.42	0.000	K3	K4	K2	K1	EST
	Within groups	16							
	Total	20							
Ba	Between groups	4	4.83	0.010	EST	K1	K3	K2	K4
	Within groups	16							
	Total	20							
Cu	Between groups	4	3.55	0.029	EST	K4	K1	K2	K3
	Within groups	16							
	Total	20							
Li	Between groups	4	3.59	0.028	K4	K2	K3	K1	EST
	Within groups	16							
	Total	20							
Pb	Between groups	4	3.93	0.021	EST	K1	K4	K2	K3
	Within groups	16							
	Total	20							
Si	Between groups	4	7.19	0.002	EST	K4	K1	K3	K2
	Within groups	16							
	Total	20							
Ti	Between groups	4	276.62	0.000	K4	K2	K3	K1	EST
	Within groups	16							
	Total	20							
V	Between groups	4	5.99	0.004	EST	K1	K4	K2	K3
	Within groups	16							
	Total	20							

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

b = Northern Territory values are 5µgL^{-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.

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).

	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 and reference sites.

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

		pH	Redox	DO %	Econd µS/m	Turbidity NTU
Keep River Pools	K4-1	7.320	-27.2	57.6	850	7.6
	K4-2	7.217	-25.1	58.2	814	7.9
	K4-3	7.187	-18.0	53.6	819	7.9
	K3-5	8.042	-69.0	87.0	973	5.7
	K3-4	8.071	-70.6	92.4	989	3.9
	K3-3	8.058	-69.0	82.5	994	3.8
	K3-2	7.982	-64.4	89.9	992	4.1
	K3-1	8.140	-74.1	90.3	995	5.5
	K2-5	8.447	-91.9	104.3	1800	5.1
	K2-4	8.460	-93.4	123.3	2070	3.7
	K2-3	8.457	-93.4	119.6	2150	2.8
	K2-2	8.465	-92.7	115.6	2160	3.0
	K2-1	8.434	-93.5	120.4	2160	2.8
	K1-4	8.420	-90.9	118.3	9640	1.7
	K1-3	8.441	-91.0	119.3	13100	1.6
	K1-2	8.434	-91.1	120.1	16800	1.3
	K1-1	8.445	-93.1	121.6	17300	2.5
	K1-5	8.390	-89.8	107.9	13500	2.0
Reference	KE1	7.331	-26.1	36.7	314	1.7
	KR1	7.682	-47.0	76.9	277	1.1
	KR2	8.330	-85.8	99.5	453	1.5
	SR4	7.900	-78.4	82.5	317	0.6
	DR1	7.950	-81.2	78.9	451	2.3

Table A5-2. Ionic composition data.

		Alkalinity	Ca	Cl	K	Mg	Na	SO4	SiO2
Keep River Pools	K4-1	138	37.7	115	4.2	29.9	97.0	71	39
	K4-2	133	31.1	112	3.8	25.4	80.3	65	40
	K4-3	133	36.4	134	4.2	29.8	97.7	76	42
	K3-5	150	39.9	138	5.1	32.6	108.0	67	34
	K3-4	150	41.8	147	5.5	33.9	113.0	65	33
	K3-3	153	39.2	154	5.3	31.9	105.0	64	31
	K3-2	153	38.2	157	5.1	31.1	103.0	62	30
	K3-1	153	40.9	159	5.4	33.5	109.0	63	30
	K2-5	158	48.4	422	8.0	50.9	239.0	90	28
	K2-4	160	61.5	498	9.2	60.4	296.0	99	29
	K2-3	160	62.0	521	9.4	61.3	308.0	100	29
	K2-2	163	60.1	526	9.3	59.9	300.0	100	29
	K2-1	163	63.0	547	9.5	62.4	311.0	100	29
	K1-4	163	120.0	2800	64.0	232.0	1770.0	390	23
	K1-3	165	136.0	4000	81.8	295.0	2270.0	560	20
	K1-2	165	160.0	5230	118.0	380.0	2930.0	720	19
	K1-1	168	167.0	5350	124.0	395.0	3150.0	740	19
	K1-5	163	143.0	4030	88.0	313.0	2370.0	580	19
Reference	KE1	123	22.2	20	2.8	15.4	17.0	<0.5	4.4
	KR1	93	18.3	16	3.2	12.2	16.9	21	17
	KR2	158	33.4	21	3.0	23.5	21.9	44	17
	SR4	150	26.7	5	3.3	21.3	4.1	4.7	18
	DR1	213	27.5	18	1.8	26.6	28.6	0.6	33

Table A5-3. Nutrient data.

		N_NH3	N_NOx	N_TK	N_total	Na	P_SR	P_total
Keep River Pools	K4-1	<0.01	<0.01	0.07	0.07	97	0.01	0.02
	K4-2	<0.01	<0.01	0.08	0.08	80.3	0.01	0.01
	K4-3	<0.01	<0.01	0.08	0.08	97.7	0.01	0.01
	K3-5	0.01	<0.01	0.10	0.10	108	0.01	0.01
	K3-4	<0.01	<0.01	0.12	0.12	113	0.01	0.01
	K3-3	<0.01	<0.01	0.12	0.12	105	<0.01	<0.01
	K3-2	<0.01	<0.01	0.11	0.11	103	0.01	0.01
	K3-1	<0.01	<0.01	0.11	0.11	109	<0.01	<0.01
	K2-5	<0.01	<0.01	0.14	0.14	239	0.01	0.01
	K2-4	<0.01	<0.01	0.13	0.13	296	0.01	0.01
	K2-3	<0.01	<0.01	0.13	0.13	308	0.01	0.01
	K2-2	<0.01	<0.01	0.13	0.13	300	<0.01	<0.01
	K2-1	<0.01	<0.01	0.17	0.17	311	<0.01	<0.01
	K1-4	<0.01	<0.01	0.18	0.18	1770	<0.01	<0.01
	K1-3	<0.01	<0.01	0.19	0.19	2270	<0.01	<0.01
	K1-2	<0.01	<0.01	0.19	0.19	2930	<0.01	<0.01
	K1-1	<0.01	<0.01	0.18	0.18	3150	<0.01	<0.01
	K1-5	<0.01	<0.01	0.20	0.20	2370	<0.01	<0.01
Reference	KE1	<0.01	<0.01	0.42	0.42	17	<0.01	<0.01
	KR1	<0.01	<0.01	0.18	0.18	16.9	<0.01	<0.01
	KR2	<0.01	0.02	0.18	0.20	21.9	0.01	0.01
	SR4	<0.01	<0.01	0.16	0.16	4.1	<0.01	<0.01
	DR1	<0.01	0.01	0.20	0.21	28.6	0.01	0.02

Appendix 6. List of macroinvertebrate taxa recorded from each site.

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
NEMATODA		Nematoda spp.	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NEMERTEA		Nemertea spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
ANNELIDA																									
OLIGOCHAETA		Oligochaeta spp.	0	0	0	0	0	0	2	1	2	0	0	0	0	0	2	0	3	0	3	3	1	3	2
POLYCHAETA		Polychaeta spp.	0	0	2	2	3	0	0	0	0	0	0	0	0	0	0	0	0	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	0	0	3	0	0	0
MOLLUSCA																									
BIVALVIA	Hyriidae	Hyriidae spp. (imm)	0	4	3	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Corbiculidae	*Corbicula* sp.	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GASTROPODA		Gastropoda spp. (imm)	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Ancylidae	*Ferrissia petterdi*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
	Hydrobiidae	Hydrobiidae spp. (imm)	2	0	2	2	1	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Planorbidae	*Gyraulus* sp.	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	4	1	2	0	0
		Leichhardtia sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
	Viviparidae	*Notopala* sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
	Thiaridae	Thiaridae spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
CRUSTACEA																									
AMPHIPODA	Aoridae	*Grandidierella* sp.	0	0	0	0	0	1	2	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0
DECAPODA	Atyidae	Atyidae spp. (imm.)	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
		Caridina 'nilotica'	4	4	4	4	3	4	3	2	3	2	4	2	3	3	3	0	1	3	0	3	2	3	0
		Caridina serratirostris	0	0	0	0	0	3	2	2	2	2	3	2	2	2	3	3	2	3	2	3	3	0	2
		Caridina ?thermophila	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
		Caridina sp.	0	0	2	0	0	0	0	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0
	Hymenosomatidae	*Amarinus lacustris*	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Palaemonidae	*Macrobrachium australe*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
		Macrobrachium bullatum	2	3	3	2	3	1	0	0	0	1	2	2	2	2	2	2	2	2	2	2	3	1	1
		Macrobrachium rosenbergii	0	0	1	2	4	3	3	3	3	3	3	3	2	1	3	2	2	2	1	0	1	0	0
		Macrobrachium sp.	3	1	2	0	2	0	3	1	0	1	2	0	2	1	1	1	2	2	2	1	1	0	2
ARACHNIDA																									
ACARINA		Hydracarina spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	3
COLLEMBOLLA																									
ENTOMOBRYOIDEA		Entomobryoidea spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
PODUROIDEA		Poduroidea spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
INSECTA																									
COLEOPTERA	Curculionidae	Curculionidae spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0

			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
	Dytiscidae	*Clypeodytes feryi*	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0
		Clypeodytes migrator	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
		Copelatus clarki	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Copelatus nigrolineatus	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
		Hydaticus vittatus	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
		Hydaticus consanguineus	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	1	0	0	0	0	0	0	0
		Hydroglyphus basalis	1	1	0	1	1	1	2	0	3	3	2	2	2	2	2	2	3	3	2	0	0	0	0
		Hydroglyphus daemeli	0	0	0	0	0	0	0	0	1	1	0	1	1	1	0	0	1	0	0	1	0	0	0
		Hydroglyphus godeffroyi	0	0	0	0	0	0	0	0	1	1	0	1	1	2	0	2	2	0	0	0	0	0	0
		Hydroglyphus leai	0	0	2	0	1	2	2	0	1	0	2	1	2	1	0	0	0	0	0	0	0	1	1
		Hydroglyphus trifasciatus	0	0	0	0	1	0	0	1	2	2	0	0	2	0	0	0	0	2	1	1	0	0	0
		Hydrovatus ovalis	0	0	0	0	0	0	2	2	0	0	1	1	2	0	0	0	0	1	0	0	0	0	2
		Hyphydrus contiguus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
		Hyphydrus lyratus	1	0	0	0	0	2	0	0	1	0	0	1	1	0	0	0	0	0	2	1	0	1	0
		Laccophilus cingulatus	0	0	0	0	0	1	0	0	0	0	1	2	0	0	0	1	2	1	0	1	0	0	0
		Laccophilus clarki	0	0	0	0	2	2	1	0	0	1	2	2	2	2	0	3	2	2	1	3	3	1	2
		Laccophilus sharpi	0	0	0	0	0	2	1	1	2	0	1	0	0	0	1	2	0	1	0	0	2	0	0
		Laccophilus unifasciatus	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	1	0	0	0
		Laccophilus walkeri	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	1	0	2	2	0	0
		Limbodessus compactus	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
		Megaporus ruficeps	0	0	0	0	0	2	1	2	0	1	0	1	1	2	0	0	1	0	2	1	0	0	0
		Neobidessodes flavosignatus	0	1	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
		Neobidessodes mjobergi	0	0	0	0	0	0	0	0	2	2	0	1	0	0	0	0	0	0	2	0	0	0	0
		Neobidessodes sp.	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Elmidae	*Austrolimnius* sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
		Austrolimnius sp. (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3
		Notriolus sp.	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	Hydraenidae	*Hydraena* sp.	2	2	2	0	0	2	3	2	2	3	2	3	3	3	0	2	3	2	3	3	3	2	1
		Octhebius sp.	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	Hydrochidae	*Hydrochus* sp.	0	1	0	1	0	2	2	2	2	2	0	1	0	0	0	0	2	2	3	3	2	1	2
	Hydrophilidae	*Amphiops australicus*	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0
		Amphiops sp. (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0
		Berosus munitipennis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
		Coelostoma fabricii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
		Enochrus esuriens	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Enochrus eyrensis	0	0	1	0	0	0	0	0	1	0	0	0	0	2	0	2	2	1	2	2	0	0	0
		Helochares clypeatus	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
		Helochares sp. (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0
		Helochares tatei	0	0	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	2	1	0	0	1
		Helochares mareensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
		Paracymus pygmaeus	1	1	0	0	2	2	2	2	3	1	2	1	1	2	1	2	1	0	2	0	0	2	1
		Regimbartia attenuata	0	0	1	0	0	0	1	0	0	1	0	2	0	1	1	2	2	0	2	4	2	0	0
		Sternolophus marginatus	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0
		Sternolophus sp. (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
	Limnichidae	Limnichidae spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

			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
	Noteridae	*Hydrocanthus waterhousei*	0	0	0	0	0	0	0	0	0	1	0	1	0	2	0	0	0	0	0	0	0	0	1
		Neohydrocoptus subfasciatus	0	0	0	0	1	0	1	2	1	0	0	2	0	0	0	0	1	0	2	0	0	0	1
	Scirtidae	Scirtidae spp. (L)	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0
DIPTERA	**Ceratopogonidae**	Ceratopogonidae spp. (P)	0	2	0	0	0	0	0	2	2	1	0	0	1	0	0	0	1	0	2	0	2	2	2
		Ceratopogoninae spp.	2	2	3	2	0	1	2	2	2	3	0	2	2	2	2	2	3	3	2	2	3	3	3
		Dasyheleinae spp.	0	0	0	0	1	2	3	0	2	2	2	0	1	0	0	3	2	2	0	0	2	1	0
		Forcipomyiinae spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0
	Chironomidae	Chironomidae spp. (P)	0	0	0	1	0	0	0	3	3	2	0	2	2	3	0	1	1	0	2	3	2	3	3
	Chironominae	Chironominae ORC18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
		Chironominae ORC20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
		Chironominae spp. (ORC36)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		Chironominae ORC41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
		Chironominae ORC43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
		Chironominae ORC47	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	2
		Cladotanytarsus sp.	1	1	2	2	2	2	3	2	3	3	0	3	3	3	3	3	3	2	2	2	3	3	3
		Cryptochironomus ?griseidorsum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	2	0	1
		Dicrotendipes sp. 1	0	1	0	0	1	0	1	2	0	2	1	0	0	0	0	3	2	0	2	0	0	2	2
		Dicrotendipes sp. 2	0	0	0	0	1	0	1	0	0	2	0	0	2	2	0	0	0	0	2	0	2	0	2
		Harnischia sp.	0	0	2	0	0	1	1	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0
		Parachironomus sp.	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	2	0	0	0
		Paracladopelma sp. (nr 'M1')	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
		Paratendipes sp.'K1'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
		Polypedilum (Pentapedilum) leei	0	1	2	0	1	3	3	3	3	3	1	2	3	2	0	0	0	0	2	3	1	2	2
		Polypedilum nubifer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
		Polypedilum sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	2	2	2	2
		Polypedilum sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
		Polypedilum watsoni	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	2	0
		Rheotanytarsus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
		Rheotanytarsus sp. 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2
		Skusella ?subvittata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0
		Stenochironomus watsoni	0	0	0	0	0	0	0	2	2	0	0	1	0	0	0	0	0	0	0	0	0	0	2
		Tanytarsus sp.	0	0	0	0	0	2	1	2	2	3	2	2	3	1	3	3	3	2	2	3	3	3	3
	Orthocladiinae	*Corynoneura* sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
		Cricotopus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0
		Nanocladius sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	2	0
	Tanypodinae	*Ablabesmyia* sp.	0	0	2	0	0	2	2	2	2	0	0	1	0	2	0	0	0	0	0	0	0	2	0
		Coelopynia pruinosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		Clinotanypus crux	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	0	0	2
		Djalmabatista sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		Larsia ?albiceps	0	0	0	0	0	2	1	0	3	2	0	1	0	2	3	1	0	0	2	3	2	3	3
		Paramerina sp.	0	0	2	0	0	0	0	0	0	2	0	0	0	1	0	2	2	0	0	3	2	0	1
		Procladius sp.	0	0	2	2	0	0	0	1	0	2	0	0	0	0	0	0	0	0	2	2	0	2	3
		Tanypodinae ORT15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0
		Tanypodinae ORT20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	3	2	2	0
		Tanypodinae spp. (ORT21)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

			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
		Tanypodinae spp. ORT14	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
		Thienemannimyia sp.	0	0	0	1	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
	Culicidae	*Aedes* sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
		Anopheles sp.	0	0	0	0	0	0	1	0	2	3	0	0	0	3	0	2	0	0	0	2	0	0	0
	Empididae	Empididae spp.	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	Simuliidae	Simuliidae spp.	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Stratiomyidae	Stratiomyidae spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	3	1	1	2
	Tabanidae	Tabanidae spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	2	0	2	2
	Tanyderidae	Tanyderidae spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
EPHEMEROPTERA	**Baetidae**	Baetidae spp. (imm.)	0	0	1	0	0	0	3	2	0	0	0	3	3	3	3	3	3	0	3	3	0	2	2
		Cloeon fluviatile	0	0	0	0	2	2	0	2	2	0	0	0	0	0	0	0	0	0	0	3	3	2	2
		Cloeon sp.	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	1	0	0	3	0	0	0	0
		Cloeon sp. NT2	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
		Cloeon sp. Redstripe	0	0	0	0	0	0	2	2	2	2	3	0	2	2	0	0	0	0	0	0	0	1	0
		Pseudocloeon hypodelum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
	Caenidae	*Caenidae* spp. (imm.)	0	0	0	0	0	0	2	0	0	0	0	2	2	2	2	2	3	2	2	3	0	0	2
		Tasmanocoenis arcuata	0	0	0	0	0	2	0	3	2	3	1	0	1	0	0	0	0	0	2	2	2	2	0
		Tasmanocoenis sp. E	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Tasmanocoenis sp. P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
	Leptophlebiidae	Leptophlebiidae spp. (imm)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
		Thraulus sp. AV1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
		Wundacaenis dostini	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	3
HEMIPTERA	**Belostomatidae**	*Diplonychus eques*	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	1	0	0	0
		Diplonychus sp. (imm)	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	2	0	0	2	2	0	1	1
	Corixidae	Corixidae spp. (imm)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	1
		Micronecta robusta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
		Micronecta sp. A	0	2	2	1	3	3	3	3	3	2	3	3	3	3	2	2	2	0	2	3	2	1	0
		Micronecta sp. B	0	0	0	0	0	1	0	0	2	0	0	2	0	0	0	1	0	0	2	3	3	3	3
	Gelastocoridae	*Nerthra* sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2	0	0	1	0
	Gerridae	Gerridae spp. (imm)	0	0	2	0	0	0	2	1	2	2	0	0	0	2	0	0	0	0	0	0	0	0	0
		Limnogonus fossarum gilguy	0	0	2	2	2	2	1	0	2	0	0	2	0	2	0	0	2	0	0	2	0	0	0
		Limnogonus hungerfordi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
		Limnogonus luctuosus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0
		Rhagadotarsus anomalus	0	0	0	0	0	0	0	0	2	0	0	0	1	2	0	0	0	0	0	2	0	1	0
	Hebridae	*Hebrus axillaris*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
		Hebrus nourlangiei	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
		Merragata hackeri	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0
	Mesoveliidae	*Mesovelia ebbenielseni*	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0
		Mesovelia horvathi	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	2	0	2
		Mesovelia sp. (imm./dam.)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	0	0	0	0
	Nepidae	*Ranatra occidentalis*	0	0	0	0	0	0	1	1	1	0	0	0	0	2	0	2	0	0	2	0	2	0	0
	Notonectidae	*Enithares loria*	0	0	0	0	0	0	1	2	2	1	0	2	1	1	2	2	1	0	0	1	2	0	0
		Notonectidae spp. (imm)	0	0	0	0	0	0	3	2	0	2	0	1	0	2	2	2	0	2	2	0	0	0	0
		Nychia sappho	0	0	0	0	0	0	2	2	0	0	0	2	2	2	0	2	3	2	3	3	3	3	3
	Pleidae	*Paraplea* sp.	2	2	3	2	2	3	3	3	3	3	3	3	3	3	2	3	3	3	3	4	3	0	0

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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
	Veliidae	*Microvelia herberti*	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	4	0	1	0
		Microvelia permanoena	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	2	0	0	0
		Microvelia sp. (F)	0	0	0	0	0	0	0	1	0	2	0	0	2	3	0	2	0	0	2	2	0	0	1
		Microvelia torresiana	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	1	0	0	0	0
		Microvelia (Petrovelia) katherinae	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
		Veliidae spp. (imm)	0	0	0	0	0	0	1	0	0	2	0	1	1	0	0	1	2	0	0	3	2	1	2
ODONATA																									
Anisoptera		Anisoptera spp. (imm)	0	2	0	0	0	0	0	2	0	0	0	1	0	1	0	0	1	0	0	2	0	0	1
	Gomphidae	*Antipodogomphus neophytus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		Austroepigomphus turneri	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2
	Libellulidae	*Diplacodes haematodes*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		Orthetrum caledonicum	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. (imm)	2	2	0	2	0	2	1	1	0	0	2	1	0	1	2	0	1	0	0	2	0	2	0
	Coenagrionidae	Coenagrionidae spp. (dam)	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
		Ischnura aurora	2	0	2	0	0	0	0	2	2	1	0	0	0	0	0	0	0	0	2	0	0	0	0
		Nososcticta sp.	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0
		Pseudagrion aureofrons	2	2	3	2	2	1	2	2	3	2	0	1	2	1	0	2	0	0	2	2	2	2	2
		Pseudagrion lucifer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
		Pseudagrion microcephalum	0	1	2	2	2	1	1	2	2	2	0	2	2	0	0	1	0	0	0	2	0	1	2
	Isostictidae	*Eurysticta kununurra*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
THYSANOPTERA		Thysanoptera spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	0	0	0	0	0	0
TRICHOPTERA	Ecnomidae	*Ecnomus* sp.	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0	3	0	3	2
	Hydropsychidae	*Cheumatopsyche wellsae*	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
		Hydropsychidae spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
	Hydroptilidae	*Orthotrichia* sp.	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	2	0	1	0
	Leptoceridae	Leptoceridae spp. (imm.)	0	0	0	0	0	0	0	0	0	2	0	2	1	0	0	0	2	0	0	2	0	0	0
		Oecetis sp.	0	0	2	0	0	0	1	2	2	0	0	0	1	0	0	0	0	0	0	3	2	3	2
		Leptocerus sp. AV2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
		Trianodes sp.	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	1	0	0	2
		Triplectides australicus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
		Triplectides australis	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Triplectides ciuskus seductus	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	2	0	3	2	0	1	0
		Triplectides helvolus	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
		Triplectides parvus	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Triplectides sp. (imm)	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0
		Taxa richness	**14**	**21**	**33**	**24**	**27**	**33**	**47**	**49**	**53**	**52**	**23**	**53**	**50**	**57**	**23**	**48**	**51**	**29**	**69**	**80**	**49**	**64**	**67**

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 Pools		Ref sites	
Class/Order	**Family**	**Lowest taxon**	**K3**	**K4**	**SR4**	**DR1**
PLATYHELMINTHES						
TURBELLARIA		Turbellaria sp.	0	4	0	0
ANNELIDA						
OLIGOCHAETA		Oligochaeta spp.	0	2	1	3
CNIDARIA						
HYDROZOA	**Hydridae**	*Hydra* sp.	0	4	0	0
MOLLUSCA						
GASTROPODA	**Hydrobiidae**	Hydrobiidae spp.	0	0	0	1
BIVALVIA	**Corbiculidae**	Batissa sp.	0	1	0	0
		Corbicula sp.	1	3	0	0
CRUSTACEA						
DECAPODA	**Atyidae**	*Caridina 'nilotica'*	1	2	1	0
	Palaemonidae	*Macrobrachium rosenbergii*	3	2	0	0
ARACHNIDA						
ACARINA		Hydracarina spp.	2	2	2	3
COLLEMBOLLA						
ENTOMOBRYOIDEA		Entomobryoidea spp.	1	0	0	0
INSECTA						
DIPTERA	**Athericidae**	Athericidae spp.	0	2	0	0
	Ceratopogonidae	Ceratopogonidae spp. (P)	0	1	0	0
		Ceratopogoninae spp.	0	2	2	2
		Dasyheleinae spp.	0	0	2	2
		Forcipomyiinae spp.	1	1	0	2
	Chironomidae	Chironomidae spp. (P)	3	3	3	0
	Chironominae	*Cladotanytarsus* sp.	2	0	2	0
		Cryptochironomus ?griseidorsum	0	2	0	0
		Dicrotendipes sp. 1	1	0	0	0
		Dicrotendipes sp. 2	2	2	0	0
		Kiefferulus ?intertinctus	1	0	0	0
		Paracladopelma sp. 'K2'	2	0	0	0
		Paratendipes sp. 'K1'	0	2	1	0
		Polypedilum (Pentapedilum) leei	0	2	0	0
		Polypedilum sp. 1	0	0	1	0
		Polypedilum watsoni	0	0	1	0
		Rheotanytarsus sp. 3	2	3	2	2
		Skusella ?subvittata	1	0	0	0
		Tanytarsus sp.	2	3	2	2
		Parachironomus sp.	0	0	0	2
		?*Parachironomus* sp.	0	0	0	2
		Chironominae ORC18	0	0	0	2
		Chironominae ORC47	0	0	2	3
	Tanypodinae	*Ablabesmyia* sp.	0	0	2	0
		Larsia ?albiceps	3	2	3	1
		Nilotanypus sp. nov.	3	2	2	3
		Paramerina sp.	3	2	2	2
		Procladius sp.	2	0	3	0
		Tanypodinae ORT20	2	0	0	0
	Orthocladiinae	*Cricotopus* sp.	0	2	2	0
		Nanocladius sp. 1	0	0	2	0

Class/Order	Family	Lowest taxon	Keep Pools		Ref sites	
			K3	K4	SR4	DR1
		Parametriocnemis ornaticornis	0	0	2	0
		Thienemanniella sp.	0	1	2	2
		Parakiefferiella sp. 2	3	3	2	3
		Orthocladiinae ORO9	0	0	2	0
	Culicidae	*Anopheles* sp.	1	0	0	0
	Dolichopodidae	Dolichopodidae spp.	2	3	0	0
	Empididae	Empididae spp.	0	1	0	0
		Empididae spp. (P)	0	1	0	0
	Simuliidae	Simuliidae spp.	3	1	3	3
	Stratiomyidae	Stratiomyidae spp.	0	1	1	0
	Tabanidae	Tabanidae spp.	3	3	2	3
	Tipulidae	Tipulidae spp.	0	0	2	0
COLEOPTERA	**Dytiscidae**	*Copelatus nigrolineatus*	0	1	0	0
		Hydroglyphus basalis	0	3	0	0
		Hydroglyphus leai	1	0	0	0
		Hydroglyphus trifasciatus	0	2	0	0
		Hydrovatus ovalis	0	0	2	0
		Megaporus sp. (L)	0	0	1	0
	Elmidae	*Austrolimnius* sp.	2	2	3	3
		Austrolimnius sp. (L)	3	3	3	3
	Gyrinidae	*Macrogyrus* sp. (L)	1	0	0	0
	Hydraenidae	*Hydraena* sp.	2	3	2	1
		Limnebius sp.	1	0	0	0
		Octhebius sp.	0	0	2	0
	Hydrochidae	*Hydrochus* sp.	0	2	2	0
	Hydrophilidae	*Amphiops australicus*	0	1	0	0
		Berosus reardoni	0	1	0	0
		Berosus sp. (L)	1	0	0	0
		Enochrus eyrensis	1	2	0	0
		Enochrus sp. (L)	0	0	0	1
		Paracymus pygmaeus	2	3	2	2
		Regimbartia attenuata	0	0	1	0
	Noteridae	*Neohydrocoptus subfasciatus*	1	0	0	0
HEMIPTERA	**Corixidae**	*Micronecta* sp. A	1	0	0	0
	Hebridae	*Hebrus axillaris*	0	0	0	1
		Hebrus nourlangiei	0	0	2	0
	Mesoveliidae	*Mesovelia* sp. (imm)	0	0	0	1
	Ochteridae	*Ochterus* sp.	0	0	0	1
	Pleidae	*Paraplea* sp.	0	1	1	0
	Veliidae	*Microvelia permanoena*	0	1	0	0
		Microvelia sp. (F)	0	2	0	0
		Veliidae spp. (imm)	1	2	0	0
EPHEMEROPTERA	**Baetidae**	Baetidae spp. (imm)	3	0	0	2
		Cloeon sp. Redstripe	0	0	1	0
		Pseudocloeon plectile	0	0	2	2
		Pseudocloeon hypodelum	2	0	3	3
		Pseudocloeon sp.	2	0	0	0
	Caenidae	Caenidae spp. (imm)	3	3	0	2
		Tasmanocoenis arcuata	3	2	3	3
		Tasmanocoenis sp. (M)	0	0	0	2
	Leptophlebidae	Leptophlebiidae spp. (imm)	0	0	0	3
		Austrophlebioides sp. AV10	0	0	0	3
		Atalophlebia sp. AV10	0	0	3	0
LEPIDOPTERA	**Crambidae**	Crambidae spp. (dam/imm)	2	2	2	0
		Eoophyla sp. 1	0	0	0	1
		Eoophyla triplaga	2	0	2	3
		Margarosticha euprepialis	0	0	2	0
		Margarosticha sp. 3	2	2	2	0
		Tetrernia sp. 1	1	2	2	2

Class/Order	Family	Lowest taxon	Keep Pools		Ref sites	
			K3	K4	SR4	DR1
		Tetrernia terminitis	1	0	2	0
ODONATA						
Anisoptera		Anisoptera spp. (imm)	0	0	0	1
	Austrocorduliidae	*Austrocordulia territoria*	0	0	1	0
	Gomphidae	*Austroepigomphus turneri*	0	0	2	3
	Hemicorduliidae	*Hemicordulia* sp. WRM02	0	0	0	1
	Libellulidae	Libellulidae spp. (imm)	0	0	1	0
		Diplacodes haematodes	0	0	1	0
		Nannophlebia sp.	3	2	0	3
		Orthetrum caledonicum	2	0	0	0
Zygoptera		Zygoptera spp. (imm)	0	1	0	1
TRICHOPTERA	**Ecnomidae**	*Ecnomus* sp.	1	1	2	3
	Helicopsychidae	*Helicopsyche* sp.	0	0	2	0
	Hydroptilidae	*Orthotrichia* sp.	2	0	2	2
	Hydropsychidae	*Cheumatopsyche wellsae*	4	4	3	3
		Cheumatopsyche sp. (dam/imm)	3	0	0	2
	Leptoceridae	*Oecetis* sp.	2	2	2	1
		Trianodes sp.	0	2	0	0
		Triplectides ciuskus seductus	2	0	0	0
	Philopotamidae	Philopotamidae spp.	3	0	0	0
		Chimarra sp. (dam/imm)	0	2	0	2
		Chimarra sp. AV18	0	2	0	0
		Chimarra uranka	3	3	3	3
		Taxa richness	**57**	**60**	**60**	**50**