LOWER ORD RIVER

INVERTEBRATE HABITAT SURVEY

FINAL REPORT

To

Water and Rivers Commission

by

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CONTENTS

Frontispiece: Taking a kick-sample with an FBA pond-net from a gravel run on the Lower Ord River

1 EXECUTIVE SUMMARY

Future increased allocation from the Ord River for Stage II irrigation will likely result in decreased dry season flows, with a concomitant reduction in dry season water levels in the Lower Ord River (LOR). Under this scenario, the loss of key habitats and any dependent fauna was identified as a potential risk to the ecological health and biodiversity of the LOR. To address this concern, aquatic macroinvertebrate communities of the Lower Ord River were intensively sampled in late October (late dry season) 2001 to identify key habitats, the critical physico-chemical parameters that describe each habitat, the macroinvertebrate assemblages from each habitat, and the occurrence and preferences of each species of macroinvertebrate for each habitat.

The study clearly demonstrated that different dominant habitats in the LOR could be very accurately differentiated on the basis of their physical properties, with depth, velocity and substrate composition being the primary parameters to distinguish between habitat types.

In addition, the different habitat types also could be clearly distinguished on the basis of their macroinvertebrate assemblages, with most macroinvertebrate taxa demonstrating a preference for one or several habitats, with some habitats being more highly preferred. There were also significant differences in biodiversity between habitats. From these data it may be inferred that a loss of key habitats will result in a loss of macroinvertebrate biodiversity for the LOR.

These results support the world literature on the relationships between aquatic macroinvertebrates and habitat diversity, whereby there is a close association between functional habitats (as described principally by flow velocity and depth, as well as other inter-dependent descriptors) and biodiversity (as described by aquatic macroinvertebrates). This supports the underlying precepts of the Functional Habitat concept. This concept will likely prove to be a very useful tool in managing the ecological health of the LOR.

In a provisional assessment of the likelihood of each habitat to be affected by reduced flows, habitat types were subjectively ranked on biodiversity, macroinvertebrate habitat preferences, areal extent in the system, and likelihood of each habitat to be modified through changes in stage height. This assessment made several assumptions which may or may not apply. For example, the relative areal extent of each habitat was based on a visual assessment and not mapping, the areal extent of submerged macrophytes would increase as this habitat recovered following recent spates, the susceptibility for each habitat to change following changes in water level was subjectively assessed. Based on this very preliminary assessment, Rapids, Gravel bars, Submerged Macrophyte beds and Emergent Macrophytes appeared to be the most important and susceptible habitats to reduced flows.

From results of this study, it is assumed that so long as each habitat type is well represented in the LOR then the macroinvertebrate fauna will be protected. Therefore, any future monitoring of the effects of reduced dry season flows should target habitat availability and condition, rather than macroinvertebrate assemblages, with effort aimed at developing capability to predict effects of a lowered dry season water level on each habitat, particularly the priority habitats.

It was recommended that future work aims to:

- Assess the suitability of the Functional Habitat concept as a tool for managing the ecological health of the Lower Ord River
- Survey the extent of habitat types, particularly those supporting high diversity and/or unique taxa, and those most susceptible to modification under reduced flows
- Develop capability to predict the response of abiotic and biotic habitats to reduced dry season flows, and,
- Establish an ongoing monitoring program that will detect changes in the extent of different habitats.

2 BACKGROUND

The Ord River has been used for irrigation for more than thirty years, but only a small proportion of the water resource has been used to date. However, over the last decade proposals to expand the area under irrigation with a concomitant increase in the amount of water required have arisen. Most recently this has been in the form of the Ord Stage II Irrigation Development. Over the same period, the ecological, recreational, social and cultural values of the river system have also gained greater importance within the community and in the State legal system. As a result a Water Allocation Plan is required for any proposed expansion.

A water allocation plan for a major resource such as the Ord River requires considerable scientific, technical and cultural investigation and input, and extensive consultation before it can be finalised. To facilitate planning for Ord Stage II, an Interim Allocation Strategy was developed in 2000 to make initial provisions for water-dependent ecological values. With input from a Scientific Panel and a Community reference panel the Interim Strategy allowed for water to be allocated for ecological, cultural and social values before making water available for Stage II. Following-on from the Interim Strategy, channel surveys provided data on wetted perimeter which was used to estimate the effect of changed flow on in-stream habitat availability for aquatic fauna. For this purpose, shallow (< 1 m) and deep (> 1 m) areas were partitioned on the assumption that these zones would support different faunal assemblages, rather than a specific understanding of habitat preferences. This process indicated that reduced discharge likely would result in a change in proportion of shallow and deep areas. It was recognised as part of this process that more detailed information was needed on the habitat requirements of aquatic macroinvertebrates (and fish) of the Lower Ord River (LOR).

The need to consider habitats when studying the ecology of aquatic macroinvertebrates has long been recognised (Barmuta, 1989; Plafkin, *et al*. 1989, Humphries *et al*. 1996, Pardo & Armitage, 1997, Harper & Everard, 1998), and has influenced the development of approaches for rapid bioassessment of river health using aquatic macroinvertebrates (Wright *et al*, 1984, Davies, 1994, Parsons & Norris, 1996, Smith *et al*., 1999).

More recently, the association between habitat type and macroinvertebrate fauna composition has lead to the development of the 'Functional Habitat Concept' for river management (Harper *et al*. 1995, Harper & Everard, 1998). This Concept assumes it is possible to manage habitats in rivers far more easily than it is to manage species (Harper *et al*, 1995, cited Buffagni *et al*. 2000), especially in species-rich systems. Pardo & Armitage (1997) and Buffagni *et al*. (2000) reported the successful application of the Functional Habitat Concept in northern hemisphere upland streams, and Armitage & Pardo (1995) and Buffagni *et al* (2000) successfully applied the habitat approach to larger lowland rivers. To date, this approach has not been trialed in Australia.

The application of the Functional Habitat Concept to the LOR is an obvious choice given the lack of knowledge on the species of macroinvertebrates found in the system, let alone the biology of those species. However, the applicability of the Functional Habitat approach must first be affirmed by testing for concordance between easily recognisable physical habitat types and the macroinvertebrate fauna they support.

To this end, the University of Western Australia was contracted by the Water and Rivers Commission to determine habitat requirements of aquatic macroinvertebrates occurring on the Lower Ord River (LOR).

The objectives of the study were to:

- Undertake detailed surveys of the aquatic macroinvertebrate communities of the Lower Ord River in dry season 2001;
- Identify key habitat types and sample the invertebrate fauna from each habitat using techniques similar to that used in the AusRivAS protocol;
- Undertake detailed description of each habitat using appropriate habitat descriptors;
- Identify invertebrate taxa to species level where possible;
- Determine invertebrate composition and relative abundance in relation to habitat;
- Determine critical habitat parameters;
- Make recommendations for longer term monitoring of invertebrate communities.

3 METHODS

3.1 Habitat selection

To meet the objectives of this study, replicated sampling was undertaken of each dominant, distinct habitat type present in the Lower Ord River (LOR) between Lake Kununurra and The Rocks.

Based on previous experience of the river system, seven physically distinct dominant meso-habitats were identifiable:

- pools,
- gravel runs,
- edges with banks of coarse sand,
- turbulent rock rapids,
- fine unconsolidated silts and muds,
- submerged macrophyte beds, and
- flooded riparian zones along margins.

Upon commencement of sampling, several modifications to the provisional sampling regime were made to allow for logistical constraints and changes observed in the field:

1. Due to the large size and indistinct nature of Pool habitat, which was difficult to physically define longitudinally and laterally on a reach (i.e. at what point does a pool change to a run), and also because within any individual pool several other habitat types could be present (i.e. Sand, Mud, Submerged Macrophyte or Flooded Riparian Vegetation), pools were not sampled as a habitat.

2. Emergent macrophyte although distinct from submerged macrophyte, and likely to provide different habitat conditions for invertebrates, was not included as a habitat in the initial design. This was because this habitat, predominantly comprised by *Typha orientalis* had been flushed from the LOR following the floods in the 1999/2000 and 2000/2001 wet seasons. However, another emergent macrophyte, *Phragmites australis* has now become well established in sections along the length of the river system (Plate 1). Therefore, to replace Pool habitat, this dominant emergent species was sampled as ‘Emergent Macrophyte’ habitat in the late dry season. The floating emergent macrophyte *Persicaria attenuata* has also become established, forming extensive beds in some areas. This species

was still present along the river, but was not inundated at the end of the dry season, water levels having receded from the plants (Plate 2). Therefore, it was not possible to sample this emergent habitat in the late dry season – but from observations and sampling undertaken for the Ord EFI project (Storey, unpub. dat.), this emergent macrophyte is an important habitat for aquatic invertebrates when inundated.

3. It was anticipated that 'Flooded Margins' would be present only during and following the wet season when water levels were elevated. However, the previous floods had resulted in extensive bank slumping along the LOR and as a result there was inundated, but degraded riparian vegetation present in all reaches (Plate 3). The inundated vegetation formed a narrow band (~ 5 m wide) of dead or stressed trees which had 'slumped' into the channel. Although this would provide habitat for invertebrates, it would be different from the riparian vegetation inundated during the wet-season (Plate 4). However, it was considered to be flooded riparian vegetation and was sampled in all reaches.

4. Prior to the large floods in the preceding two wet seasons, the LOR supported extensive beds of submerged macrophyte, dominated by the ribbon weed *Vallisneria americana*. However, the recent floods had flushed most submerged macrophyte from the system. Ribbon weed was becoming re-established with numerous small areas of regrowth of short stems (< 10 cm) (Plate 5), however, there were few areas of established beds with stems > 50 cm. Where present, these established beds were sampled to provide data on 'Submerged Macrophyte' habitat. Full replication of this habitat was not possible because there were few areas present, especially in the lower reach, and some areas were in poor condition exhibiting dieback, possibly from low water levels during the "shutdown" in mid October[1]. However, this habitat type was retained because if and when it becomes re-established in the system, it is possible that this habitat may be very important, supporting large populations of prawns and small fish, and feeding areas for larger species of fish.

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[1] Approx. 6 days prior to this study, water levels in the LOR were lowered for three days (8th – 10th October 2001), to facilitate maintenance of Ivanhoe Crossing. Initially, discharge and water levels increased in the LOR for at least one day as Lake Kununurra was lowered to increase storage to accommodate Ord Dam spillway flows. The hydroelectric scheme was then shutdown, and the diversion dam closed, gradually lowering levels in the three reaches of Diversion Dam to Tarrara Bar, Tarrara Bar to Carlton Crossing, and Carlton Crossing to The Rocks by 0.65, 0.5 and approx. 0.2 m respectively. Sampling in the most upstream and affected reach (KDD to Tarrara Bar) did not commence until 23rd October, approx 2 weeks after the shutdown, and it is assumed that macroinvertebrate distributions had re-established prior to sampling.

5. The majority of rapids in the system are situated in the upper reach (Kununurra Diversion Dam to Tarrara Bar). At the flow rates that occurred during this study, the only rapids in the lower parts of the river were situated either side of Carlton Crossing. As a result the full replication of rapids was not possible for the middle and lower reaches. Due to fast flows, sampling tended to be along the margins of the rapids.

Examples of each habitat type are shown on Plates 1 – 9.

Plate 1 Emergent Macrophyte habitat: beds of *Phragmites australis* are now well established along lengths of the Lower Ord River

Plate 2. Beds of *Persicaria attenuata* above the water level at the end of the dry season, but will be inundated in the wet

Plate 3. Flooded Riparian Vegetation habitat: dead and stressed flooded riparian vegetation at the end of the dry season, where vegetation was inundated following bank slumping.

Plate 4. Flooded Riparian Vegetation, predominantly *Melaleuca* spp near House Roof Hill in June 2001, more typical of this habitat following the wet season

Plate 5 Submerged Macrophyte habitat: bed of *Vallisneria americana* (foreground), a submerged macrophyte becoming re-established in the LOR

Plate 6 Sand habitat: sand edge downstream of House Roof Hill.

Plate 7. Rapid habitat: Turbulent rapids downstream of Buttons Crossing

Plate 8. Gravel Run habitat: measuring in situ water quality parameters on a gravel run upstream of House Roof Hill

Plate 9 Mud/Silt habitat: mud banks beside 'The Rocks' in the tidally-influenced reaches of the Lower Ord River (above).

Plate 10 Mud/Silt habitat: Mud banks along the waters edge downstream of House Roof Hill (right).

To provide even coverage of the system, the LOR was stratified into three reaches:

- Kununurra Diversion Dam (KDD) to Tarrara Bar,
- Tarrara Bar to Carlton Crossing and
- Carlton Crossing to The Rocks.

Replicate samples from each habitat were then stratified across the three reaches. This ensured all replicate samples were not taken from the same part of the LOR, which could give a biased representation of the system. The distribution of samples by habitat and reach are presented in Table 1. Logistical constraints such as daily travel time by boat from base camps, and limited boat access to some parts of the upper reach due to impassable rapids and no road access, meant that samples within each reach tended to be clumped rather than evenly distributed along the length of each reach.

Sampling was conducted in the late dry season 2001 (16th – 27th October 2001 incl), commencing in the middle and lower reaches to allow the upper reach time to equilibrate after the drawdown (sampling in the upper reach did not commence until 23rd October, approx 2 weeks after the drawdown). Conditions were hot (39° - 43°C) and humid, with occasional isolated thunderstorms, as is typical in the lead-up to the wet season. The location of each replicate habitat sample was recorded by GPS to allow accurate re-sampling of the same locations in future investigations (Figure 1, Appendix 1).

Table 1. Number of replicate samples of each habitat type in each reach collected for the invertebrate habitat survey of the Lower Ord River

Reach	Emergent macrophyte	Gravel Runs	Rapids	Submerged Macro-phytes	Edge sand banks	Deposits of mud/ silt	Flooded riparian	**Total per Reach**
KDD to Tarrara Bar	3	3	3	5	3	3	3	**23**
Tarrara Bar to Carlton Xing	3	3	1	3	3	3	3	**19**
Carlton Xing to the Rocks	3	3	1	0	3	3	3	**16**
Total per habitat	**9**	**9**	**5**	**8**	**9**	**9**	**9**	**58**

3.2 Macroinvertebrate Fauna

Sampling was conducted following the Western Australian AusRivAS macroinvertebrate collection protocols, using a 250 μm mesh net to kick/sweep over 10m of the selected habitat. Exceptions included:

a.) flooded riparian vegetation (as in Plate 3) was sampled by vigorous sweeping up and down submerged branches/trunks.

b.) soft, unconsolidated mud was sampled from shallow areas by passing the substrate from approx 0.075 m^2 through a 250 μm sieve by washing and elutriation in the water. Mud was defined as inorganic material < 250 μm (i.e. the sample was discarded if sand was retained in the sieve)

Samples were preserved in formalin and freighted to the laboratory in Perth where they were washed and preserved in 70% alcohol, and then sorted under low power microscope to remove animals. Specimens were then identified to species level (where possible) using available keys and expert taxonomic assistance, and all taxa added to a ‘Kimberley’ voucher collection held in the Zoology Department and duplicated at the Dept CALM, Wildlife Research Centre. All taxa were enumerated to six abundance classes (i.e. 0 = 0, 1 = 1, 2-10 = 2, 11-100 = 3, 101 – 1000 = 4, and >1000 = 5) and entered onto spreadsheet.

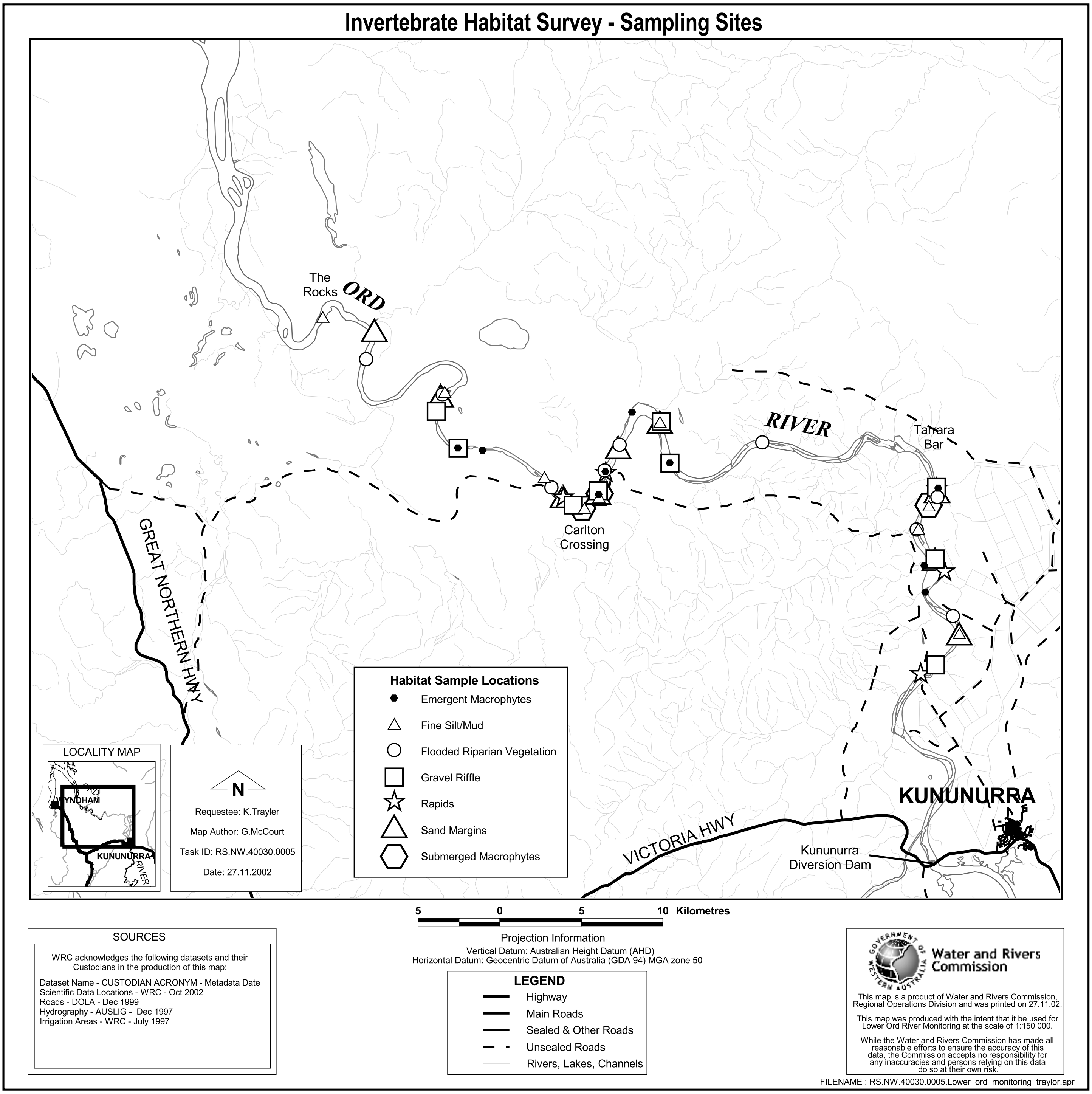

Figure 1. Locations of individual habitats sampled for aquatic macroinvertebrates in the Lower Ord River in October 2001

Table 2. Proforma detailing physico-chemical parameters measured at each site to describe habitat structure

INVERTEBRATE HABITAT ASSESSMENT SHEET - LOWER ORD RIVER

HABITAT TYPE:

i.e. Sand Gravel Runs Rapid Submerged Macrophyte Mud/silt Flooded riparian Emergent Macrophyte

REACH (upper/middle/lower)

REPLICATE

METHOD (kick/grab)

DATE

LATITUDE

LONGITUDE

PH

TEMPERATURE (^{O}C)

CONDUCTIVITY (µs/cm)

SALINITY (mg/l)

TURBIDITY

REDOX

RIPARIAN VEG COVER

SECCHI DEPTH

Mineral Substrate	**%**	**Breakdown of habitat surface area**	**%**	**Density (1 = sparse; 5=dense)**
Bedrock		Mineral substrate		
Boulders (phi –9.0) (>256 mm)		Emergent Macrophyte		**1 2 3 4 5**
Cobbles (phi –6.5) (64 – 256 mm)		Submerged Macrophyte		**1 2 3 4 5**
Pebbles (phi –4.5) (16 – 64 mm)		Floating Macrophyte		**1 2 3 4 5**
Gravel (phi –2.0) (4 – 16 mm)		Algal Cover		**1 2 3 4 5**
Sand (phi 2.0) (1 – 4 mm)		Detritus		**1 2 3 4 5**
Silt (phi 6.6) (< 1mm)		Riparian veg. draped in water		**1 2 3 4 5**
Clay (phi 9.5)		Large Woody Debris		**1 2 3 4 5**
Total		Other:		**1 2 3 4 5**
		Total		

DEPTH (cms)

VELOCITY (cms/sec)

DISS. OXYGEN:

Top of water column		Bottom of water column	
% saturation	mg/l	% saturation	mg/l

BED COMPACTION	Armoured, array of sizes, tightly packed & overlapping, hard to dislodge	Packed but not armoured, array of size, tightly packed, overlapping, can be dislodged	Moderate compaction, array of sizes, some packing, little overlap, can be dislodged	Low compaction, poor grading, some packing, little overlap, can be dislodged easily	Low compaction, loose array, no packing, no overlap, easily moved

GENERAL COMMENTS ON SITE CONDITION/DISTURBANCE ETC

3.3 Physico-chemical parameters

A range of physico-chemical parameters were recorded at each site (Table 2) to adequately describe the physical attributes of each habitat. This would allow discrimination between habitat types and thereby assist in determining physical characteristics preferred or avoided by different species. Parameters selected for measurement were based on the AusRivAS habitat descriptors. Data collected at each site were manipulated to produce 42 measured or derived parameters (Table 3).

Table 3. Measured and derived physico-chemical parameters, giving names, abbreviations and units of measurement.

Type	Parameter	Abbreviation	Unit
PHYS/CHEM PARAMETERS	pH Top	pHT	#
	pH Bottom	pHB	#
	meanpH	pHM	#
	conductivity	conductivity	us/cm
	salinity	salinity	mg/l
	turbidity Top	TurbT	ntu
	turbidity Bottom	TurbB	ntu
	mean turbidity	TurbM	ntu
	temperature Top	tempT	^{0}C
	temperature Bottom	tempB	^{0}C
	mean temperature	tempM	^{0}C
	redox Top	redoxT	#
	redox Bottom	redoxB	#
	mean redox	redoxM	#
	mean velocity	veloM	cms/sec
	Mean depth	depthM	cms
	Variance in depth	depthV	cms
	Dissolved Oxygen Top	DO%T	%
	Dissolved Oxygen Bottom	DO%B	%
	mean Dissolved Oxygen	DO%M	%
	Oxygen Concentration Top	DOmgT	mg/l
	Oxygen Concentration Bottom	DOmgB	mg/l
	mean Oxygen Concentration	DOmgM	mg/l
MINERAL SUBSTRATE[1]	Bedrock	Bedrock	%
	Boulders	Boulders	%
	Cobbles	Cobbles	%
	Pebbles	Pebbles	%
	Gravel	Gravel	%
	Sand	Sand	%
	Silt	Silt	%
	Clay	Clay	%
	mean particle size[2]	mean phi	
SUBSTRATE SURFACE AREA[1]	Mineral	Mineral	%
	Emergent macrophyte	Emergent	%
	Submerged macrophyte	Submerged	%
	Algae	Algal	%
	Detritus	Detritus	%
	Riparian Vegetation	RipVeg	%
	Large woody debris	LWD	%
	Other (i.e. root mats etc)	Other	%
	Habitat diversity[3]	subdiv	#
DESCRIPTION	Riparian Cover	ripvegcov	%
	Substrate compaction	compaction	1 - 5

[1]. Mineral substrates and Substrate surface areas were estimated visually.

[2] mean particle size calculated as the mean phi value weighted by the percentage cover of each mineral substrate type (clay = phi 9.5, silt = phi 6.5, sand = phi 2.0, gravel = phi –2.0, pebbles = phi –4.5, cobbles = phi – 6.5, boulders = phi –9.0). Where bedrock was present, it was given the same phi value as boulders.

[3] Substrate diversity calculated as the total number of substrate types present.

In situ physico-chemical parameters (i.e. pH, conductivity, salinity, turbidity, water temperature, redox, and dissolved oxygen as percentage saturation and concentration) were measured using a Yeo-kal Model 611 multiprobe water quality analyser. Water velocity was measured with a Marsh-McBirney velocity meter, with velocity recorded for approx. 0.6 of water depth. Water depths were measured with a graduated staff (< 1.5 m) or a Garmin Model 135 GPSMAP sounder and GPS (> 1.5 m). Site locations were also recorded with the Garmin sounder/GPS. Measurements of physico-chemical parameters were taken at approximately 10 cms below the water surface and approx. 10 cms above the river bed at each site. Surface and bottom measurements were analysed separately and as an average. Mineral substrate composition, substrate surface area and riparian cover at each site were estimated visually. Mean particle size at a site was calculated as the mean phi value (clay = phi 9.5, silt = phi 6.5, sand = phi 2.0, gravel = phi –2.0, pebbles = phi –4.5, cobbles = phi – 6.5, boulders = phi –9.0) weighted by the percentage cover of each mineral substrate type. Where bedrock was present, it was given the same phi value as boulders. Habitat diversity was calculated as the total number of substrate types present. Substrate compaction was estimated on a scores of 1 – 5 using a visual assessment where, 1 = Low compaction, loose array, no packing, no overlap, easily moved, 2 = Low compaction, poor grading, some packing, little overlap, can be dislodged easily, 3 = Moderate compaction, array of sizes, some packing, little overlap, can be dislodged, 4 = Packed but not armoured, array of size, tightly packed, overlapping, can be dislodged, and, 5 = Armoured, array of sizes, tightly packed & overlapping, hard to dislodge.

3.4 Data Analyses

Analyses were undertaken to:

a.) define the physio-chemical structure of different habitats and determine the physical distinctiveness of each habitat,

b.) determine the distinctiveness of the macroinvertebrate fauna of each habitat in terms of biodiversity and assemblage composition, and

c.) determine the preference of each taxon to specific habitats.

In the first instance, one-way analysis of variance was applied to test for between habitat differences in physico-chemical parameters and in macroinvertebrate species richness. Prior to analysis, appropriate transformations were applied to conform with the assumptions of the test. Tukey’s HSD multiple range test was applied to locate between-habitat differences where there was a significant main effect. Results were tabulated and representative significant variables graphed.

The CSIRO Pattern Analysis package PATN (Belbin, 1995) was then used to investigate physico-chemical characteristics and macroinvertebrate assemblages of each habitat using ordination and classification techniques. This approach identified:

- habitats with similar physico-chemical characteristics, with a measure of this dissimilarity,
- habitats with similar macroinvertebrate assemblages, with a measure of dissimilarity, and
- relationships between macroinvertebrate assemblages and physico-chemical characteristics of the samples.

All replicates were classified and ordinated to identify between-site differences in physico-chemical composition and macroinvertebrate assemblage structure. Physico-chemical variables were first standardised whereby within each parameter each value was transformed {$xnew = (x – xmin)/xrange$} to produce a scale 0 – 1 and thereby give each parameter an equal weighting in the analysis and so avoid variables on a higher scale having an over-bearing influence on the analysis. Macroinvertebrate data were analysed using the $\log_{10}$ abundance categories and only taxa that occurred at greater than 10% of samples were included to avoid ‘low-occurrence’ taxa having a disproportionate effect on the results.

Replicates were classified using **U**nweighted **P**air**g**roup Arith**m**etic **A**veraging (UPGMA), an agglomerative hierarchical fusion technique which produces a dendrogram in which sites with similar physico-chemistry/macroinvertebrate assemblages group together. Sites were then ordinated using **S**emi-**S**trong **H**ybrid **M**ulti**d**imensional **S**caling (SSH MDS) to produce an n-dimensional scatter plot of sites. For each analysis, similarity between sites was determined using the Bray-Curtis association measure. *A priori* habitat types and *a posteriori* groupings from the UPGMA classification were superimposed on the physico-chemical and macroinvertebrate ordination plots to assess the distinctiveness of the separation of samples into habitats or UPGMA groupings. To test the significance of the separation of these groups of sites in ordination space, the ANOSIM option in PATN (Belbin, 1995) was used.

The Principal Axis Correlation (PCC) option in PATN was then used to place gradients of:

- physico-chemical parameters through the ordination of sites on physico-chemical data, and
- physico-chemical parameters through the ordination of sites on macroinvertebrate data.

This test indicates physico-chemical parameters that assist in differentiating amongst habitat types and which may be driving macroinvertebrate assemblage composition of each habitat. Monte Carlo randomisations (n=100) of the data were performed to test the significance of these gradients.

The preference of each species for each habitat type was examined using Chi-squared contingency table analysis on presence/absence data. Deviation of the observed from the expected frequency (i.e. the preference of a species for a habitat type) was taken as significant is $p < 0.05$. For significant tests, the preferred habitat(s) was determined as the habitat with the highest contribution to the Chi-square statistic.

Multiple Discriminant Analysis (MDA) was used to investigate relationships amongst groupings, defined by *a priori* habitat types and by *a posteriori* UPGMA groupings, and physico-chemical parameters measured for each replicate habitat sample (Storey *et al*, 1990). The technique allocates samples to selected groups using the physico-chemical parameters. If samples are correctly allocated to the groups, it suggests a close relationship between groupings (*viz*. habitat types or UPGMA groupings) and physico-chemical parameters.

3.5 Ecosystem Health Monitoring

Finally, species-level data were reduced to family level presence/absence data and each replicate sample run through an AusRivAS model to assess the ecological health of each habitat type. Output comprises a.) the ratio of the number of taxa predicted to occur at a site (Expected) to the number of these taxa actually recorded at the site (Observed), and b.) the O/E ratio converted to a model Banding (Halse *et al*. 2001):

X	O/E Score	>0.15	Enriched (i.e. slightly disturbed or biological hotspot)
A	O/E Score	0.85 – 1.15	Undisturbed
B	O/E Score	0.55 – 0.84	Significantly impaired
C	O/E Score	0.25 – 0.54	Severely impaired
D	O/E Score	0.00 – 0.24	Extremely impaired

The most current and robust northern WA AusRivAS model available on the AusRivAS website is a “spring” (*viz* late dry) Channel Habitat model. This model is suitable for running samples from sand, rapid and gravel habitat types (Stuart Halse, Dept CALM, pers. com.) There is no appropriate model to run macroinvertebrate samples from submerged or emergent macrophyte, flooded riparian or mud/silt habitats.

The model requires predictor variables of discharge category, latitude, longitude, $\log_{10}$ of maximum velocity (cm/sec), and average annual rainfall. These parameters were determined from physico-chemical data collected as part of this study, summary of discharge data from Water & Rivers Commission (WRC, 1998; average current discharge at mouth = 3200 GL) and Bureau of Meteorology (long term average annual rainfall for Kimberley Research Station = 789.5 mm).

Based on the findings of the current study, an ongoing monitoring approach was proposed to provide a cost effective approach that has sufficient sensitivity (*viz*. statistical power) to detect change, and targets habitats of high biological diversity and which are most likely to show a response to modifications in flow regime.

4 RESULTS

4.1 Physico-chemical description of habitats

Analysis of variance on physico-chemical parameters detected significant between-habitat differences in 20 of the 42 measured and derived parameters (Table 4). Chemical parameters, generally indicative of water quality (i.e. pH, conductivity, turbidity, temperature, redox and dissolved oxygen) showed no significant between-habitat differences, reflecting that the flowing water was well mixed both vertically and laterally across all habitat types. All significant differences were recorded for physical attributes of the different habitat types, including water depth, velocity, mineral composition, cover by organic substrates and degree of compaction (Table 4).

Table 4 One-way ANOVA to test for differences in physico-chemical parameters amongst habitat types (EM = emergent macrophyte, FL = flooded riparian, GR = gravel run, MU = mud/silt, RA = rapids, SA = sand, SU = submerged macrophyte)(degrees of freedom = 6,51). Data transformations are indicated where applied. Tukeys HSD multiple comparison test was applied to locate differences between habitats where there was a significant main effect. Levels joined by a common line are not significantly different at p = 0.05, and groups are arranged in descending order.

Parameter	p	Tukey's HSD multiple range test						
pHT	ns							
pHB	ns							
pHM	ns							
Cond	ns							
Salinity	ns							
TurbT	ns							
TurbB	ns							
TurbM	ns							
TempT	ns							
TempB	ns							
TempM	ns							
RedoxT	ns							
RedoxB	ns							
RedoxM	ns							
VeloM (log10)	<0.0001	RA	GR	SA	EM	FL	MU	SU
DepthM (log10)	<0.0001	FL	EM	SUB	GR	RA	SA	MU
DepthV (log10)	0.0011	FL	EM	SU	GR	SA	RA	MU
DO%T	ns							
DO%B	ns							
DO%M	ns							
DOmgT	ns							
DOmgB	ns							
DOmgM	ns							
Bedrock	ns							
Boulders (log10)	<0.0001	RA	EM	FL	MU	GR	SA	SU
Cobbles (log10)	<0.0001	RA	GR	EM	FL	MU	SA	SU
Pebbles	<0.0001	GR	RA	EM	FL	SA	SU	MU
Gravel	<0.0001	GR	RA	EM	FL	SA	SU	MU
Sand (log10)	<0.0001	SA	FL	EM	GR	SU	MU	RA
Silt (log10)	<0.0001	MU	SU	FL	EM	SA	GR	RA
Clay	ns							

Parameter	p	Tukey's HSD multiple range test						
mean phi	<0.0001	MU	SU	FL	SA	EM	GR	RA
Mineral (log10)	<0.0001	SA	GR	RA	MU	FL	SU	EM
Emergent (log10)	<0.0001	EM	SU	FL	MU	RA	SA	GR
Submerged (log10)	<0.0001	SU	MU	EM	FL	RA	SA	GR
Algae (log10)	0.016	RA	GR	FL	MU	EM	SA	SU
Detritus (log10)	<0.0001	MU	SU	FL	RA	SA	EM	GR
Ripveg (log10)	<0.0001	FL	EM	GR	MU	RA	SA	SU
Large Woody Debris (log10)	<0.0001	FL	MU	EM	GR	RA	SA	SU
Other substrate	ns							
Habitat Diversity (log10)	<0.0001	FL	SU	MU	EM	RA	SA	GR
Riparian veg. cover (log10)	<0.0001	FL	RA	MU	EM	GR	SA	SU
Compaction	<0.0001	RA	GR	FL	MU	EM	SA	SU

Many of the habitat differences were intuitive and reflected the readily observed physical differences that were used to characterise habitat types in the first instance. For example, percentages of boulder and cobble substrates were highest in Rapid habitat, pebble and gravel substrate was greatest in Gravel habitat, sand in Sand habitat, and silt in Mud/silt habitat. Highest coverage of emergent and submerged macrophyte were recorded from Emergent and Submerged Macrophyte habitats respectively, and the highest cover of riparian vegetation and large woody debris was recorded from Flooded Riparian habitat. Less obvious differences were highest velocities recorded in Rapid and Gravel habitats, with minimum velocities recorded from Flooded Riparian, Mud and Submerged Macrophyte habitats, and deepest water recorded from Flooded Riparian and Emergent Macrophyte habitats (Figure 2). To allow differentiation amongst habitat types, mean, standard error, maximum and minimum values for each descriptive parameter are tabulated in Appendix 2.

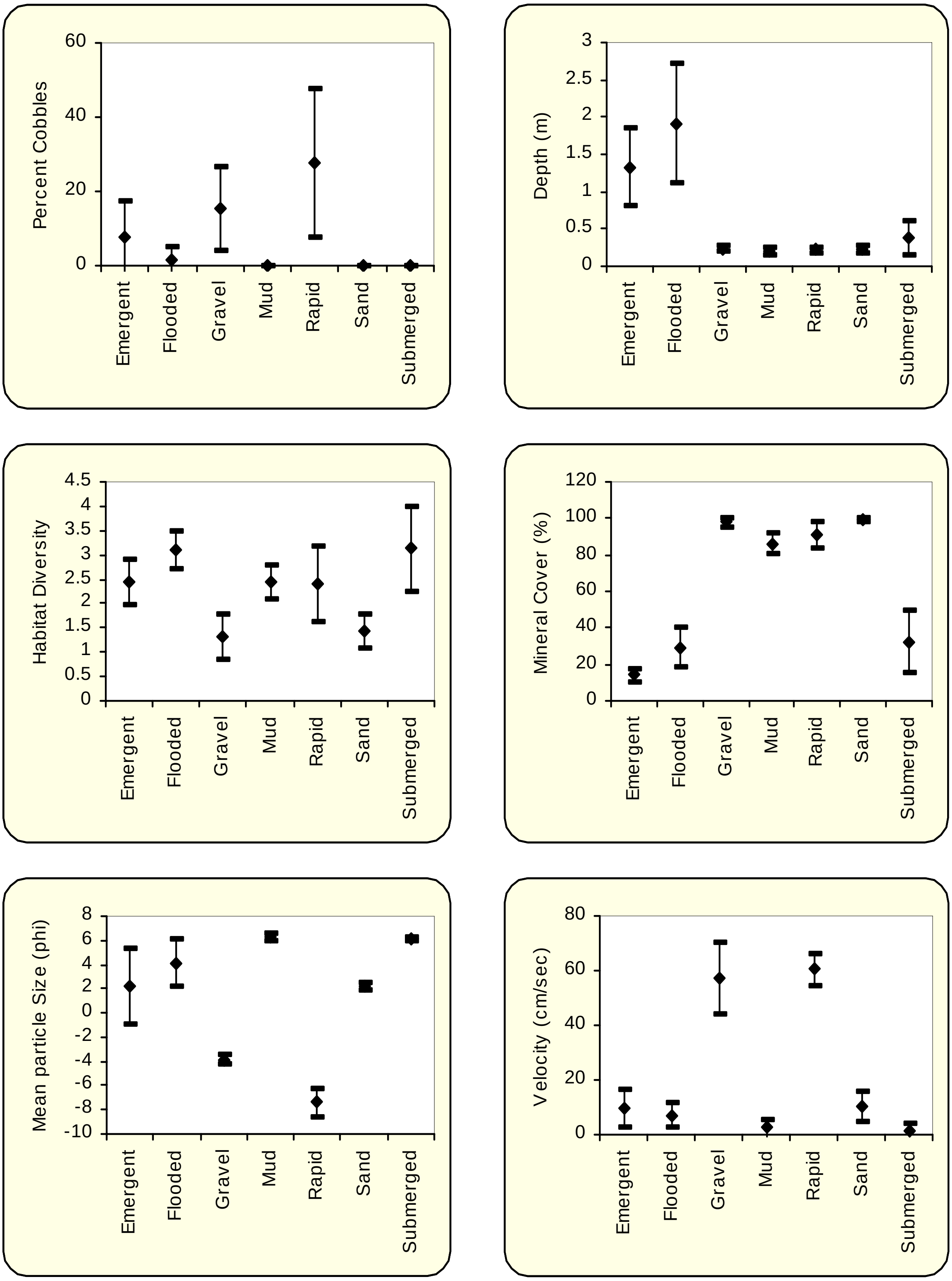

Figure 2. Mean (+ 95% CI) of selected physico-chemical parameters by habitat types to illustrate between habitat type differences

UPGMA classification of all samples using physico-chemical parameters that had significant between-habitat differences (Table 4) demonstrated very good concordance between classification groupings and habitat types. The classification produced six distinct groups, each comprised of samples from one or two habitats (Figure 3). Three of the 58 samples mis-classified to the incorrect groupings. These mis-classifications were all from the upper reach, and consisted of one Flooded riparian and two Emergent macrophyte samples. These replicates were in deeper and higher velocity areas, with a coarser substratum than other replicates of the same habitat type, which probably resulted in the samples grouping closer to Riffle and Rapid samples.

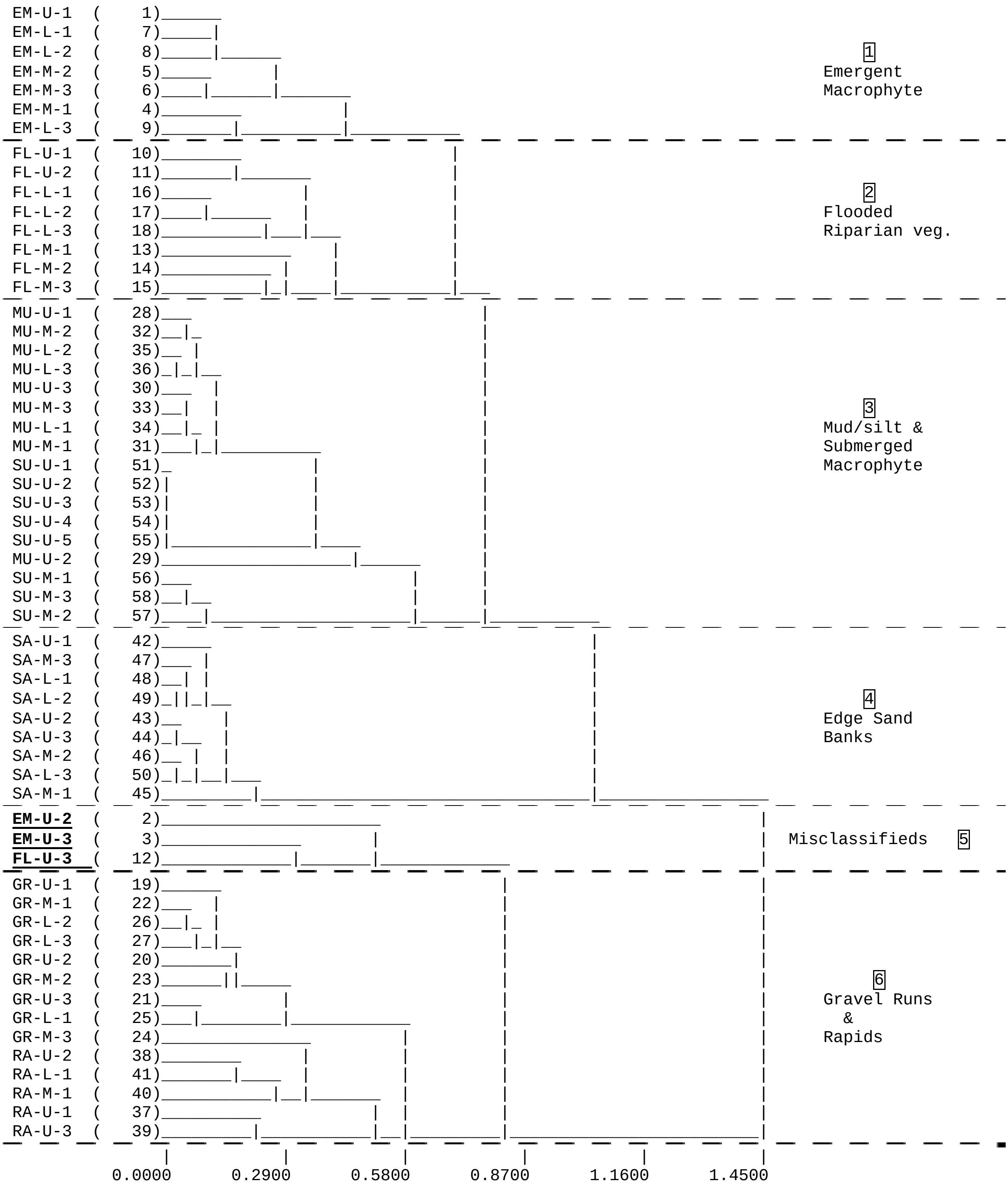

Figure 3. UPGMA classification of replicate samples on physico-chemcial parameters (Table 4). Samples are labelled by habitat type (EM = emergent macrophyte, FL = flooded riparian, GR = gravel run, MU = mud/silt, RA = rapids, SA = sand, SU = submerged macrophyte), reach (U = upper, M = middle, L = lower) and replicate number. Samples which 'misclassified' are in **BOLD** and underlined

Ordination of samples on physico-chemical data, with habitat types and UPGMA classification groups superimposed on scatter plots demonstrated a clear separation of habitats in ordination space, and a good concordance between *a priori* habitat types and *a posteriori* classification groups (Figure 4). ANOSIM detected highly significant separation of habitat types and UPGMA groups in ordination space ($p < 0.0001$).

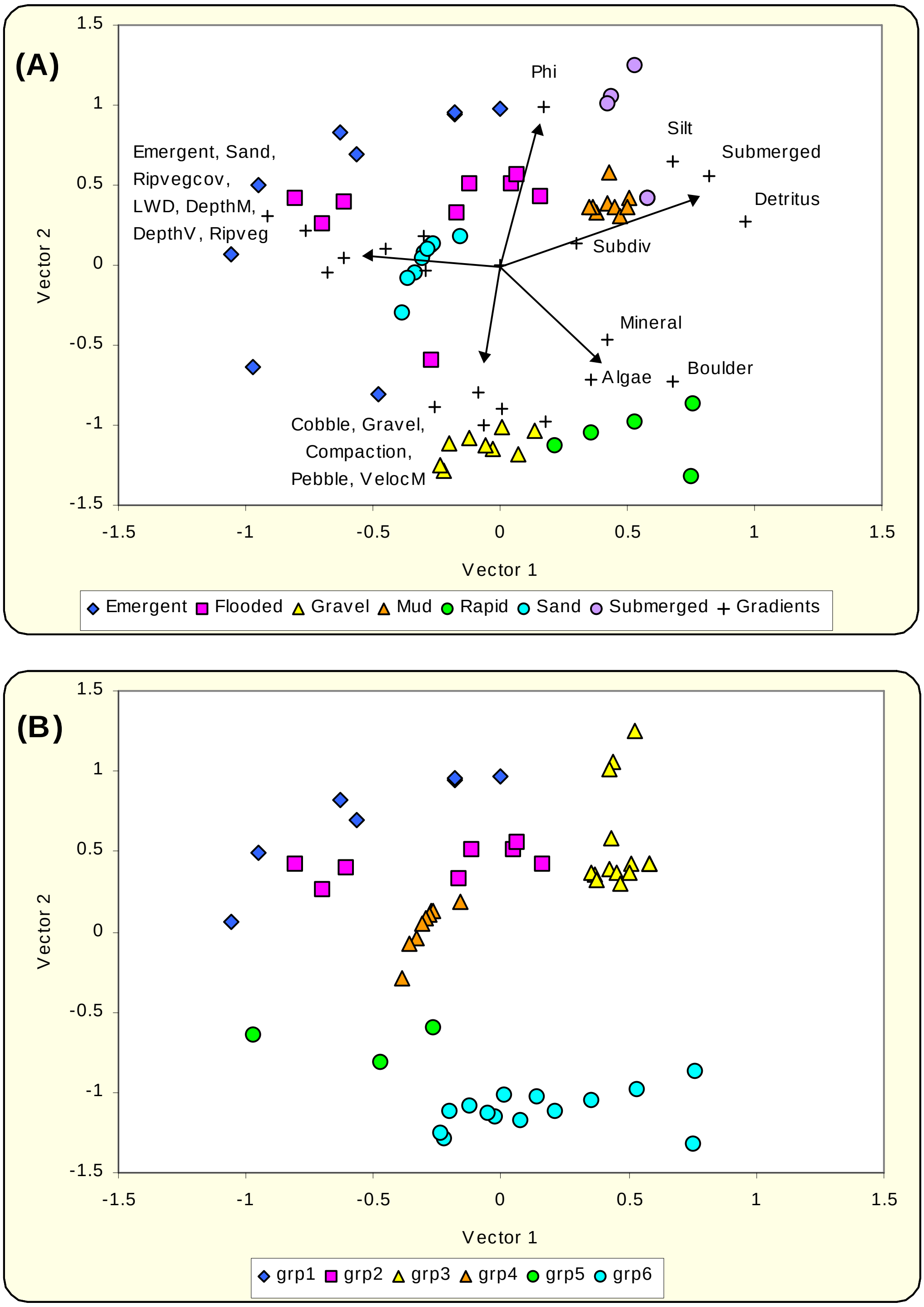

Figure 4. MDS ordination of samples on physico-chemical parameters with samples grouped (A) by habitat type, and (B) by UPGMA classification groupings taken from Figure 3. Significant gradients in physico-chemical variables through ordination space are indicated on (A). Optimum solution for the ordination was three dimensions with a stress of 0.108

Gradients of parameters through ordination space supported results of ANOVAs (Table 4). Gravel runs and Rapids were characterised by high values of mineral cover, algal cover, boulders, cobbles, gravel, compaction, pebbles and velocity (i.e. fast flowing water, with coarse particle size and high epiphytic algal cover) (Figure 4a). Mud/silt and Submerged macrophyte habitats were characterised by low levels of the above parameters and high values of detritus, silt, mean particle size (*viz*. mean phi), and submerged macrophyte (i.e. low velocity, small particle size, submerged macrophyte and high detritus/CPOM levels). Emergent macrophyte, Flooded Riparian, and to a lesser extent Sand habitats were characterised by high values for emergent vegetation, depth, sand, riparian vegetation cover, and large woody debris, however, Sand habitat tended to separate from Emergent and Riparian habitats on a third dimension (not shown). The most widely dispersed habitats in ordination space were Emergent macrophyte and Flooded riparian, with depth, velocity and substrate variable across replicates (Figure 4) (ref Appendix 2 for actual values for each habitat).

MDA using physico-chemical data was able to predict 100% of samples to the correct group, for both the *a priori* habitat types and *a posteriori* classification groups (Table 4). Six and five discriminant functions contributed significantly to the explained variance in MDA to habitat and UPGMA groupings respectively (Appendix 3 & 4). In both instances, the first three discriminant functions explained > 95% of the total variation. This reflects that the physico-chemical parameters are good predictors (viz. descriptors) of the physically distinct habitat types (ref. Appendix 2).

4.2 Macroinvertebrate assemblages of habitats

Sampling across all habitats recorded 171 taxa of macroinvertebrates, the majority of which were identified to named species or species-level vouchers. A full taxonomic listing by habitat type is presented in Appendix 5 and summarised by broad taxonomic groups in Figure 5. Not all groups could be identified to species level due to lack of suitable taxonomic keys (i.e. many Diptera families, some families of Trichoptera and Coleoptera), and some groups were not considered as macroinvertebrates and so not taken further (i.e. micro-crustacea), therefore, the total species richness is likely greater than 171. Allowing for the limitations above, the Insecta comprised 80% of the taxa recorded, with the remaining 20% consisting of Mollusca, Annelida, Crustacea and Arachnida. The Insecta were dominated by Coleoptera (48 taxa), Chironomid midge larvae (30 taxa) and Hemiptera (18 taxa) (Figure 5). Generally, most taxa were distributed along the length of the LOR, with the exception of occasional records of Nereid polychaetes and the freshwater crab *Holthuisana transversa* (family Sundathelphusidae) only from the lower tidally-influenced reach.

Table 4. Percent of samples predicted by MDA to each group, with error rates for mis-classifications to each group and over all error rates for MDA on physico-chemical variables to (a) *a priori* habitats, and (b) *a posteriori* groups from UPGMA classification (Figure 3).

(a)

Habitat	emergent	flooded	gravel	mud	rapid	sand	submerg	Total
emergent	9	0	0	0	0	0	0	9
	100	0	0	0	0	0	0	100
flooded	0	9	0	0	0	0	0	9
	0	100	0	0	0	0	0	100
gravel	0	0	9	0	0	0	0	9
	0	0	100	0	0	0	0	100
mud	0	0	0	9	0	0	0	9
	0	0	0	100	0	0	0	100
rapid	0	0	0	0	5	0	0	5
	0	0	0	0	100	0	0	100
sand	0	0	0	0	0	9	0	9
	0	0	0	0	0	100	0	100
submerg	0	0	0	0	0	0	8	8
	0	0	0	0	0	0	100	100
Total	9	9	9	9	5	9	8	58
Error Rate	0	0	0	0	0	0	0	0

(b)

UPGMA	1	2	3	4	5	6	Total
1	**7**	0	0	0	0	0	7
	100	0	0	0	0	0	100
2	0	**8**	0	0	0	0	8
	0	**100**	0	0	0	0	100
3	0	0	**17**	0	0	0	17
	0	0	**100**	0	0	0	100
4	0	0	0	**9**	0	0	9
	0	0	0	**100**	0	0	100
5	0	0	0	0	**3**	0	3
	0	0	0	0	**100**	0	100
6	0	0	0	0	0	**14**	14
	0	0	0	0	0	**100**	100
Total	7	8	17	9	3	14	58
Error rate	0	0	0	0	0	0	0

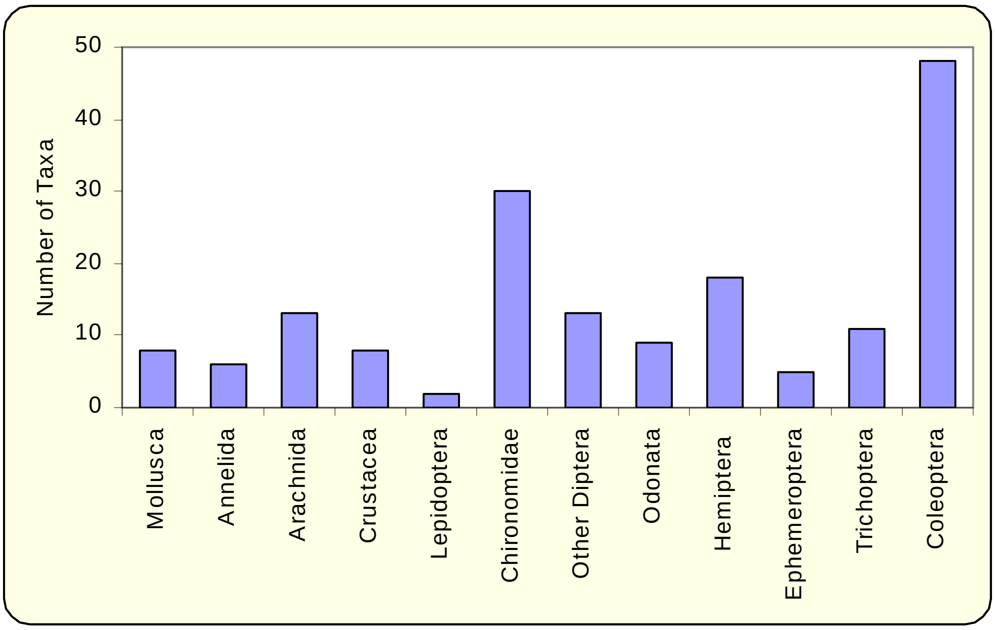

Figure 5. Number of taxa recorded from each broad taxonomic group across all habitats

ANOVA detected a highly significant difference in species richness between habitats. The greatest number of taxa was recorded from Emergent macrophyte, Submerged macrophyte and Rapid habitats, with taxa richness at Emergent macrophyte habitat greater than Flooded riparian and Gravel runs. Taxa richness in Sand and Mud habitats was similar, and lower than all other habitats (Table 5; Figure 6).

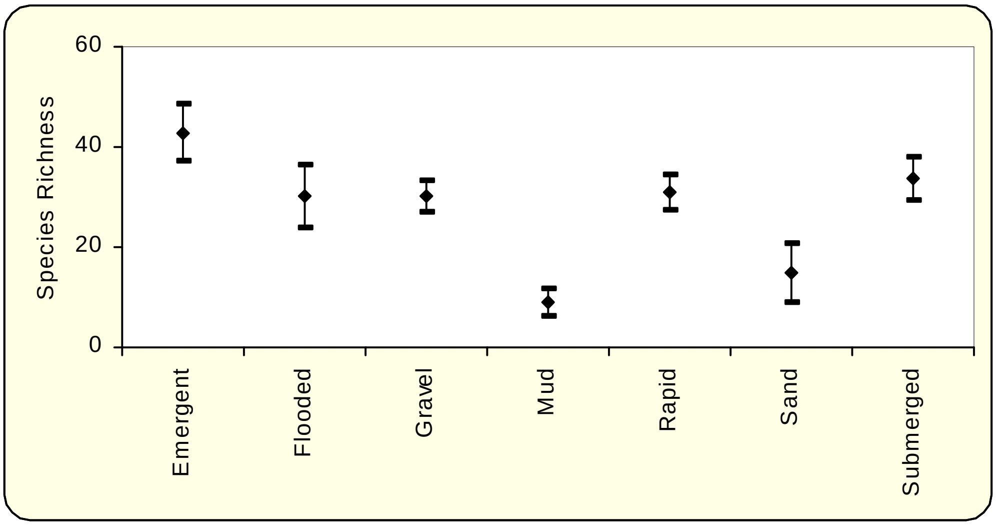

Figure 6. Mean (+ 95% CI) taxa richness for each habitat type

The distinctiveness of macroinvertebrate assemblages in each habitat type was investigated using classification and ordination. UPGMA produced a classification with six groups (Figure

7). Different habitats tended to separate in the classification, although this was not as consistent as for the UPGMA classification on physico-chemical parameters (*cf* Figure 3 and 7). For instance, the majority of samples from Emergent macrophyte and Flooded riparian habitats classified into Group 1, and all samples from Gravel and Rapid habitats classified into Group 2, but samples from Mud/silt, Sand and Submerged macrophyte habitats were interspersed across Groups 3 – 6.

MDS ordination on macroinvertebrate fauna, with habitat types and UPGMA classification groups superimposed on scatter plots showed a good separation of habitats in ordination space, with good concordance between *a priori* habitat types and *a posteriori* classification groups (Figure 8). ANOSIM detected highly significant separation of habitat types and UPGMA groups in ordination space ($p < 0.0001$). Gradients of physico-chemical parameters through ordination space reflected the gradients observed through the ordination of samples on physico-chemical data (*cf* Figure 4a and 8a). Gravel runs and Rapids were characterised by high values of compaction, pebbles and velocity (i.e. fast flowing water, with coarser particle size). Mud/silt habitat was characterised by high values of detritus and mineral cover, Sand habitat had a high sand cover and high phi, and Emergent macrophyte and Flooded Riparian habitats were characterised by high values for emergent vegetation and mean depth. The most widely dispersed samples in ordination space were from Mud/Silt and Sand habitats (Figure 8).

Table 5 One-way ANOVA to test for differences in taxa richness amongst habitat types (EM = emergent macrophyte, FL = flooded riparian, GR = gravel run, MU = mud/silt, RA = rapids, SA = sand, SU = submerged macrophyte)(degrees of freedom = 6,51). Tukeys HSD multiple comparison test was applied to locate differences between habitats where there was a significant main effect. Levels joined by a common line are not significantly different at p = 0.05, habitats are arranged in descending order and mean number of taxa is in parenthesis.

Parameter	**F**	**p**	**Tukey’s HSD multiple range test**						
Taxa richness	22.9	<0.0001	EM (42.8)	SU (33.8)	RA (31.0)	GR (30.3)	FL (30.2)	SA (14.8)	MU (9.0)

```
 EM-U-1  (    1)______
 EM-U-2  (    2)___  |
 EM-U-3  (    3)__|__|____
 FL-U-1  (   10)____     |
 FL-U-3  (   12)___|__   |
 FL-U-2  (   11)_____|___|______
 EM-M-1  (    4)_________      |
 EM-M-2  (    5)______  |      |
 EM-M-3  (    6)_____|__|      |                                                   Group 1
 EM-L-2  (    8)_____  ||      |
 EM-L-3  (    9)____|__||____  |
 EM-L-1  (    7)____________|__|
 FL-M-1  (   13)__________     |
 FL-M-2  (   14)______   |     |
 FL-M-3  (   15)_____|___|___  |
 FL-L-1  (   16)____________|__|_____
 SU-M-1  (   56)_____               |
 SU-M-3  (   58)____|_____          |
 SU-M-2  (   57)_________|__________|__________
 FL-L-3  (   18)__________                    |
 GR-M-1  (   22)_______  |                    |
 GR-M-3  (   24)______|__|                    |
 GR-M-2  (   23)___      |                    |
 GR-L-1  (   25)__|___   |                    |
 GR-L-2  (   26)_____|   |                    |
 RA-M-1  (   40)___  |   |                    |                                    Group 2
 RA-L-1  (   41)__|__|__ |                    |
 GR-L-3  (   27)_______|_|__                  |
 GR-U-1  (   19)______     |                  |
 GR-U-2  (   20)_    |     |                  |
 RA-U-2  (   38)|__  |     |                  |
 RA-U-3  (   39)__|__|__   |                  |
 GR-U-3  (   21)_______|   |                  |
 RA-U-1  (   37)_______|___|__________________|_____
 MU-U-1  (   28)______________                     |
 MU-U-2  (   29)_____        |                     |
 MU-U-3  (   30)____|_____   |                     |                               Group 3
 MU-M-2  (   32)_________|___|____________         |
 SA-U-1  (   42)_                        |         |
 SA-U-2  (   43)|_                       |         |
 SA-U-3  (   44)_|___________            |         |
 SA-M-3  (   47)____________|__________  |         |
 SU-U-1  (   51)_____                 |  |         |                               Group 4
 SU-U-2  (   52)___ |                 |  |         |
 SU-U-4  (   54)__|_|                 |  |         |
 SU-U-5  (   55)____|_                |  |         |
 SU-U-3  (   53)_____|________________|__|_________|_________________________
 FL-L-2  (   17)________________                                            |
 SA-L-2  (   49)_______________|___________________________________         |      Group 5
 MU-M-1  (   31)______                                            |         |
 MU-L-1  (   34)_____|___                                         |         |
 MU-L-2  (   35)________|______________                           |         |
 MU-M-3  (   33)_________             |                           |         |
 SA-M-1  (   45)________|__           |                           |         |      Group 6
 SA-L-1  (   48)__________|_____      |                           |         |
 MU-L-3  (   36)_______________|___   |                           |         |
 SA-M-2  (   46)__________        |   |                           |         |
 SA-L-3  (   50)_________|________|___|___________________________|_________|
                |           |           |           |           |           |
           0.1580      0.4984      0.8388      1.1792      1.5196      1.8600
```

Figure 7. UPGMA classification of replicate samples on macroinvertebrate fauna. Samples are labelled by habitat type (EM = emergent macrophyte, FL = flooded riparian, GR = gravel run, MU = mud/silt, RA = rapids, SA = sand, SU = submerged macrophyte), reach (U = upper, M = middle, L = lower) and replicate number.

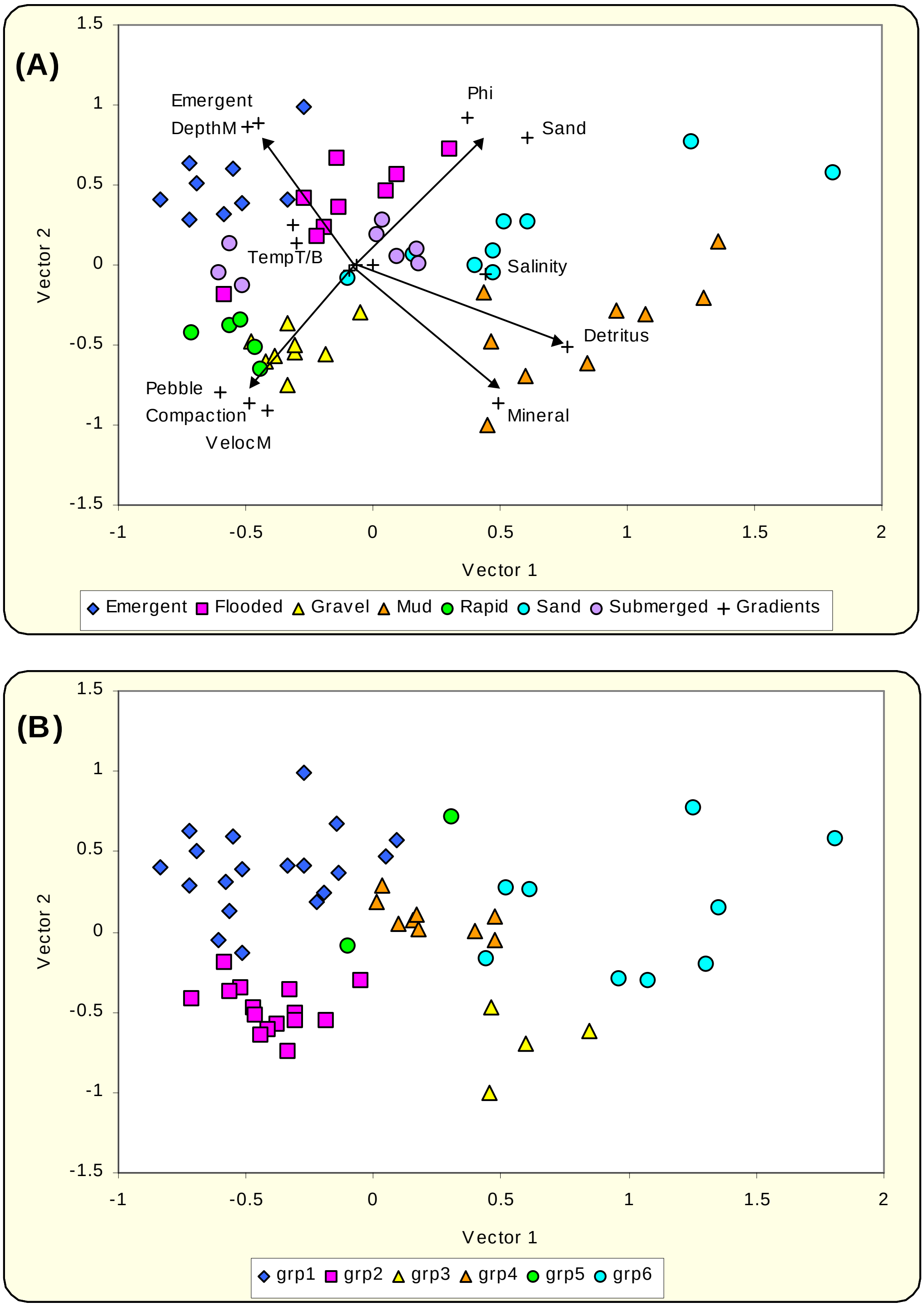

Figure 8. MDS ordination of samples on macroinvertebrate fauna with samples grouped (A) by habitat type, and (B) by UPGMA classification groupings taken from Figure 7. Significant gradients in physico-chemical variables through ordination space are indicated on (A). Optimum solution for the ordination was three dimensions with a stress of 0.137

MDA using physico-chemical data was able to correctly predict all but five (9 % error) of samples to the correct group from UPGMA classification on macroinvertebrates (Table 6). Five discriminant functions contributed significantly to the explained variance in MDA to macroinvertebrate UPGMA groupings (Appendix 6). The first three discriminant functions explained 93% of the total variation, and % mineral, mean velocity, mean depth and % detritus were the highest scoring parameters on the first two discriminant functions. This reflects that the physico-chemical parameters are good predictors (*viz.* descriptors) of the UPGMA groups derived from macroinvertebrates.

Table 6. Percent of samples predicted by MDA to each group from UPGMA classification on macroinvertebrate fauna (Figure 7), with error rates for mis-classifications to each group and over all error rates.

UPGMA	1	2	3	4	5	6	Total
1	**19**	0	0	0	0	0	19
	100	0	0	0	0	0	100
2	**1**	**14**	0	0	0	0	15
	6.67	**93.33**	0	0	0	0	100
3	0	0	**3**	**1**	0	0	4
	0	0	**75**	**25**	0	0	100
4	0	0	0	**9**	0	0	9
	0	0	0	**100**	0	0	100
5	0	0	0	0	**2**	0	2
	0	0	0	0	**100**	0	100
6	0	0	**2**	0	**1**	**6**	9
	0	0	**22.22**	0	**11.11**	**66.67**	100
Total	20	14	5	10	3	6	58
Error rate	0	6.7%	25.0%	0	0	33.0%	8.6%

The occurrence and preference of each taxon for each habitat type is tabulated in Table 7. Preference was determined by chi-square contingency table analysis, where a significant chi-square statistic indicates a deviation of the observed from the expected frequency of occurrence and thereby a preference of a taxon for one or more habitat types. Table 7 is summarised in Figure 9 to show taxa preferences for each habitat type, and frequency of preferences for one or more habitat types. As can be seen, Emergent Macrophyte was the most preferred habitat type, with lower levels of preference for Flooded Riparian, Gravel, Rapid, and Submerged macrophyte. Sand and Silt habitats were preferred by the fewest number of taxa. Fifteen percent of taxa (13 taxa) showed no preference for any habitat type, 67 % (59 taxa) had a significant preference for one or two habitat types, and 18% of taxa (16 taxa) had a preference for three or more habitats (Figure 9). Most taxa occurred across two or more habitat types, with only 7 taxa restricted to only one habitat type, predominantly Submerged Macrophyte.

Table 7. Occurrence of each taxon in each habitat type, whereby values represent the percentage of the samples from each habitat type in which each taxon was recorded (number of samples taken from each type is in parenthesis). Significance of chi-square tests are indicated, and percentage occurrences highlighted in **BOLD** indicate preferred habitats for each taxon.

Order	**Family**	**Species/Taxon**	**Emergent (9)**	**Rapids (5)**	**Gravel (9)**	**Submerged (8)**	**Flooded (9)**	**Sand (9)**	**Mud/silt (9)**	**Chi-sq p-value**
EPHEMEROPTERA	**Baetidae**	Genus 1 WA sp1.	**100**	**100**	**100**	38	**78**	22	22	0.0001
EPHEMEROPTERA	**Leptophlebidae**	*Tasmanocoenis arcuata*	**100**	**100**	**100**	50	78	67	33	0.0049
DIPTERA	**Chironomidae, Orthocladinae**	*Cricotopus* sp.	**100**	**100**	**100**	63	**89**	78	11	0.0001
DIPTERA	**Chironomidae, Tanypodinae**	*Paramerina* sp.	**100**	60	56	63	56	44	0	0.0044
COLEOPTERA	**Hydrophilidae**	*Hydrochus* sp.	**100**	0	0	0	56	0	0	0.0001
COLEOPTERA	**Hydrophilidae**	*Paracymus pygmaeus*	**100**	0	0	25	44	11	0	0.0001
COLEOPTERA	**Hydrophilidae**	*Regimbartia attenuata*	**100**	0	0	0	22	0	0	0.0001
HEMIPTERA	**Pleidae**	*Plea brunni*	**100**	0	0	25	33	0	0	0.0001
HEMIPTERA	**Corixidae**	Micronecta sp. UK1	**100**	0	0	**88**	**78**	**89**	11	0.0001
DIPTERA	**Chironomidae, Tanypodinae**	*Nilotanypus* sp. nov.	**89**	**80**	**78**	38	**89**	0	11	0.0001
DIPTERA	**Chironomidae, Chironominae**	*Cladotanytarsus* sp.	89	60	100	75	89	67	56	ns
DIPTERA	**Chironomidae, Tanypodinae**	*Larsia ?albiceps*	**89**	60	33	**75**	**89**	11	33	0.0026
DIPTERA	**Un Id Diptera sp**	Pupae UK2	**89**	0	0	0	44	44	0	0.0001
LEPIDOPTERA	**Pyralidae**	*Pyralidae* sp.	**78**	**100**	**67**	**100**	22	0	0	0.0001
ODONATA, Zygoptera	**Austrocorduliidae**	*Nanophlebia risi*	**78**	**100**	56	0	33	11	0	0.0001
DIPTERA	**Chironomidae, Chironominae**	*Dicrotentipes* sp.	**78**	**80**	**67**	63	**89**	0	11	0.0002
HEMIPTERA	**Mesoveliidae**	*Mesovelia* sp.	**78**	0	0	13	33	0	0	0.0001
ODONATA, Zygoptera	**Coenagrionidae**	*Pseudagrion microcephalum*	**78**	0	0	**75**	22	0	0	0.0001
DIPTERA	**Chironomidae, Chironominae**	*Tanytarsus* sp.	67	100	89	75	56	44	56	ns
DIPTERA	**Ceratopogonidae**	Ceratopogonidae spp	67	80	100	88	89	89	78	ns
CRUSTACEA	**Palaemonidae**	*Machrobrachium rosenbergii*	**67**	**80**	33	38	22	0	0	0.0033
DIPTERA	**Chironomidae, Chironominae**	*Rheotanytarsus* sp.	**67**	**60**	**44**	0	33	0	0	0.0020
DIPTERA	**Chironomidae, Chironominae**	*Parachironomus* sp.	**67**	40	33	38	33	0	0	0.0275
COLEOPTERA	**Hydreanidae**	Hydraena sp2	**67**	0	0	0	44	0	11	0.0004
COLEOPTERA	**Hydreanidae**	?Octhebius sp. UK1	**67**	0	0	13	11	0	0	0.0002
HEMIPTERA	**Naucoridae**	*Aphelocheirus australicus*	**67**	0	0	25	11	0	0	0.0004
HEMIPTERA	**Gerridae**	*Limnogonus (L) fossarum*	**67**	0	0	0	0	0	0	0.0001
CRUSTACEA	**Atyidae**	*Caradina nilotica*	**67**	0	0	38	**78**	0	0	0.0001
DIPTERA	**Chironomidae, Orthocladinae**	*Parakiefferiella* sp.	56	**100**	**78**	0	44	0	0	0.0001

Order	Family	Species/Taxon	Emergent (9)	Rapids (5)	Gravel (9)	Submerged (8)	Flooded (9)	Sand (9)	Mud/silt (9)	Chi-sq p-value
TRICHOPTERA	**Ecnomidae**	*Ecnomus* sp.	56	**100**	**67**	50	**67**	22	0	0.0044
ANNELIDA	**OLIGOCHAETA**	Oligochaeta spp.	**56**	**80**	**100**	**63**	**89**	44	**100**	0.0268
EPHEMEROPTERA	**Baetidae**	*Cloeon sp.*	**56**	20	11	**88**	**56**	0	0	0.0002
DIPTERA	**Chironomidae, Chironominae**	*Stenochironomus watsoni*	**56**	20	0	0	**78**	0	0	0.0001
COLEOPTERA	**Limnichidae**	Linmnichidae sp. UK1	**56**	0	0	0	**67**	0	11	0.0002
DIPTERA	**Chironomidae, Orthocladinae**	*Nanocladius* sp.1 (Cranston)	**44**	40	22	**50**	**78**	0	0	0.0037
CRUSTACEA	**Atyidae**	*Caradina serratirostris*	44	20	11	13	11	0	0	ns
COLEOPTERA	**Hydrophilidae**	*Helochares* marreensis	**44**	0	0	0	**33**	0	0	0.0057
COLEOPTERA	**Hydrophilidae**	UD sp B	**44**	0	0	0	22	0	0	0.0083
HEMIPTERA	**Corixidae**	Micronecta sp. UK2	44	0	0	**50**	33	33	0	0.0415
HEMIPTERA	**Veliidae**	*Microvelia* sp.	**44**	0	0	13	**67**	0	0	0.0004
HEMIPTERA	**Gerridae**	*Rhagadotarsus anomalus*	**44**	0	0	0	**44**	0	0	0.0021
HEMIPTERA	**Hebridae**	*Merragata hackeri*	**44**	0	0	0	11	0	0	0.0051
ODONATA, Zygoptera	**Coenagrionidae**	*Austroagrion cyane*	**44**	0	0	**88**	11	0	0	0.0001
TRICHOPTERA	**Leptoceridae**	*Triaenodes* sp.	**44**	0	0	13	11	0	0	0.0201
DIPTERA	**Chironomidae, Tanypodinae**	*Ablabesmyia* sp.	**44**	0	0	13	0	22	0	0.0279
DIPTERA	**Tabanidae**	*Tabanus* sp.	33	**80**	**67**	0	0	0	0	0.0001
DIPTERA	**Chironomidae, Chironominae**	*Polypedilum watsoni*	33	60	67	50	78	11	33	ns
CRUSTACEA	**Copepoda**	Copepoda	33	40	33	**100**	**89**	56	11	0.0017
CRUSTACEA	**Ostracoda**	Ostracoda	33	20	33	75	56	33	44	ns
CRUSTACEA	**Palaemonidae**	*Machrobrachium bullatum*	33	0	**44**	**63**	22	0	0	0.0127
COLEOPTERA	**Dytiscidae**	*Hydroglyphus leai*	33	0	0	13	22	0	0	ns
COLEOPTERA	**Hydrophilidae**	UD sp A	33	0	0	0	**44**	0	0	0.0057
COLEOPTERA	**Carabidae**	Carabidae sp. UK1	**33**	0	0	0	**33**	0	0	0.0213
DIPTERA	**Simulidae**	*Simulium ornatipes*	22	**100**	**100**	13	44	56	11	0.0002
TRICHOPTERA	**Hydropsychidae**	*Cheumatopsyche* sp.	22	**100**	**89**	0	11	11	0	0.0001
BIVALVIA	**Corbiculidae**	*Corbicula* sp. UK1	22	**80**	**100**	**100**	22	44	0	0.0001
ANNELIDA	**NEMATODA**	Nematoda sp.	22	**80**	**100**	50	33	33	**56**	0.0158
DIPTERA	**Empididae**	*Hemerodrominae* sp.	22	**80**	**33**	0	0	0	0	0.0004
TRICHOPTERA	**Hydroptilidae**	*Orthotrichia* sp.	22	**60**	**33**	0	0	0	0	0.0062
ODONATA, Anisoptera	**Gomphidae**	*Austrogomphus mjobergi*	22	**40**	**33**	0	0	0	0	0.0041
ODONATA, Anisoptera	**Libellulidae**	*Diplacodes haematodes*	22	0	11	**63**	0	0	0	0.0014
DIPTERA	**Chironomidae, Chironominae**	*Polypedilum* (*Pentapedilum*) *leei*	22	0	11	13	33	0	0	ns
HEMIPTERA	**Corixidae**	Micronecta sp. UK3	22	0	0	**63**	11	0	0	0.0014

Order	Family	Species/Taxon	Emergent (9)	Rapids (5)	Gravel (9)	Submerged (8)	Flooded (9)	Sand (9)	Mud/silt (9)	Chi-sq p-value
ACARINA	**Hygrobatidae**	Australiobates mutatus	11	**80**	**89**	**50**	22	0	0	0.0001
COLEOPTERA	**Gyrinidae**	Gyrinidae sp. (L)	11	**40**	**33**	0	0	0	0	0.0310
TRICHOPTERA	**Leptoceridae**	*Oecetis* sp1	11	20	33	63	22	22	0	ns
DIPTERA	**Chironomidae, Tanypodinae**	*Procladius* spp.	11	20	33	75	22	33	33	ns
ACARINA	**Hygrobatidae**	Dropursa babinda Cook	11	0	44	25	0	22	0	ns
CRUSTACEA	**Cladocera**	Cladocera	11	0	0	**50**	11	11	0	0.0293
COLEOPTERA	**Elmidae**	Austrolimnius sp. (L)	0	**80**	**100**	13	11	0	11	0.0001
COLEOPTERA	**Elmidae**	*Austrolimnius* sp. UK1	0	**80**	**67**	0	0	0	0	0.0001
TRICHOPTERA	**Philopotamidae**	*Chimmara uranka*	0	**80**	**44**	0	0	0	0	0.0001
LEPIDOPTERA	**Pyralidae**	*Pyralidae* sp. pupae	0	**80**	33	0	0	0	0	0.0001
EPHEMEROPTERA	**Leptophlebidae**	*Genus Z*	0	**40**	**56**	0	0	0	0	0.0002
DIPTERA	**Chironomidae, Chironominae**	*Cryptochironomus ?griseidorsum*	0	20	**100**	38	0	**56**	0	0.0001
DIPTERA	**Chironomidae, Chironominae**	*Harnischia* sp.	0	20	33	**88**	22	44	44	0.0132
DIPTERA	**Chironomidae, Chironominae**	*Chironomini* ?genus	0	20	22	13	22	56	22	ns
DIPTERA	**Chironomidae, Chironominae**	*Polypedilum nubifer*	0	20	11	38	22	0	22	ns
DIPTERA	**Chironomidae, Chironominae**	*Paracladopelma* nr. M1 (Cranston)	0	0	33	0	0	**78**	0	0.0001
DIPTERA	**Chironomidae, Chironominae**	*Chironomini* ?genus	0	0	11	**38**	0	0	33	0.0413
COLEOPTERA	**Dytiscidae**	*Laccophilus* sp. (L)	0	0	0	**50**	0	0	0	0.0002
COLEOPTERA	**Hydrophilidae**	Berosus sp. (L)	0	0	0	**63**	0	0	0	0.0001
ODONATA, Anisoptera	**Libellulidae**	*Orthetrum caledonicum*	0	0	0	**38**	0	0	11	0.0206
MOLLUSCA	**Thiaridae**	*Thiara* (*Plotiopsis*) sp.	0	0	0	**38**	0	0	0	0.0030
MOLLUSCA	**Lymnaeidae**	*Austropeplea lessoni*	0	0	0	**50**	0	0	0	0.0002
DIPTERA	**Chironomidae, Tanypodinae**	*Coelopynia pruinosa*	0	0	0	**50**	0	0	22	0.0032
ACARINA	**Arrenuridae**	Arrenurus sp.	0	0	0	**38**	0	0	0	0.0030
ACARINA	**Eylaidae**	Eylais sp.	0	0	0	**38**	0	0	0	0.0030

Across broad taxonomic levels, there were tendencies for groups of taxa to have preferences to specific habitat(s). For example, the Trichoptera tended to prefer Emergent vegetation, Rapids and Gravel, although the Ecnomids occurred across all habitat types. The Odonata preferred Emergent and Submergent vegetation. The Gastropoda only occurred in Submerged macrophytes, and the Acarines also had a preference to this habitat. The Lepidoptera, Ephemeroptera and Palaemonid prawns occurred across all habitats except Sand and Mud. The Diptera tended to occur across all habitat types with no single habitat preferred or avoided by this group, probably reflecting the broad range in tolerances within this diverse group. The Coleoptera tended to prefer Emergent and Macrophtes and Flooded Riparian vegetation, although several species also occurred in Rapids, Gravel runs and Submerged macrophytes; Sand and Mud/Silt habitats tended to be avoided by Coleoptera. Finally, the Annelids and Bivalves were broadly distributed across all habitats.

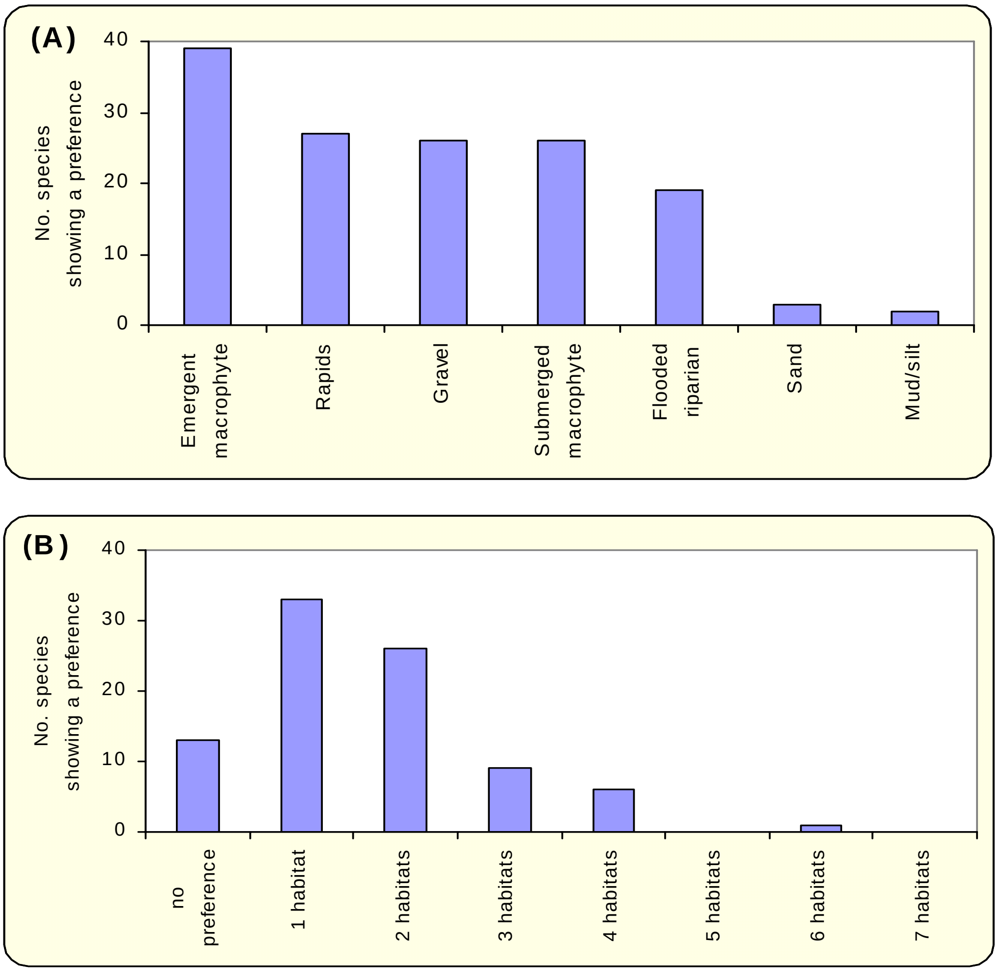

Figure 9. Summary of taxa preferences for habitat types, showing a.) number of taxa showing a preference for each habitat type, and b.) frequency of preferences for 1 or more habitat types.

4.3 Ecosystem Health Monitoring

Output from running all replicate samples from Gravel, Rapid and Sand habitats through the AusRivAS Spring Channel habitat model are summarised in Figures 9 and 10 and detailed in Appendix 7. Several Rapid habitat samples had a maximum velocity which exceeded the upper bound for the model. To facilitate running of these samples through the model, the mean, rather than the maximum velocity was used.

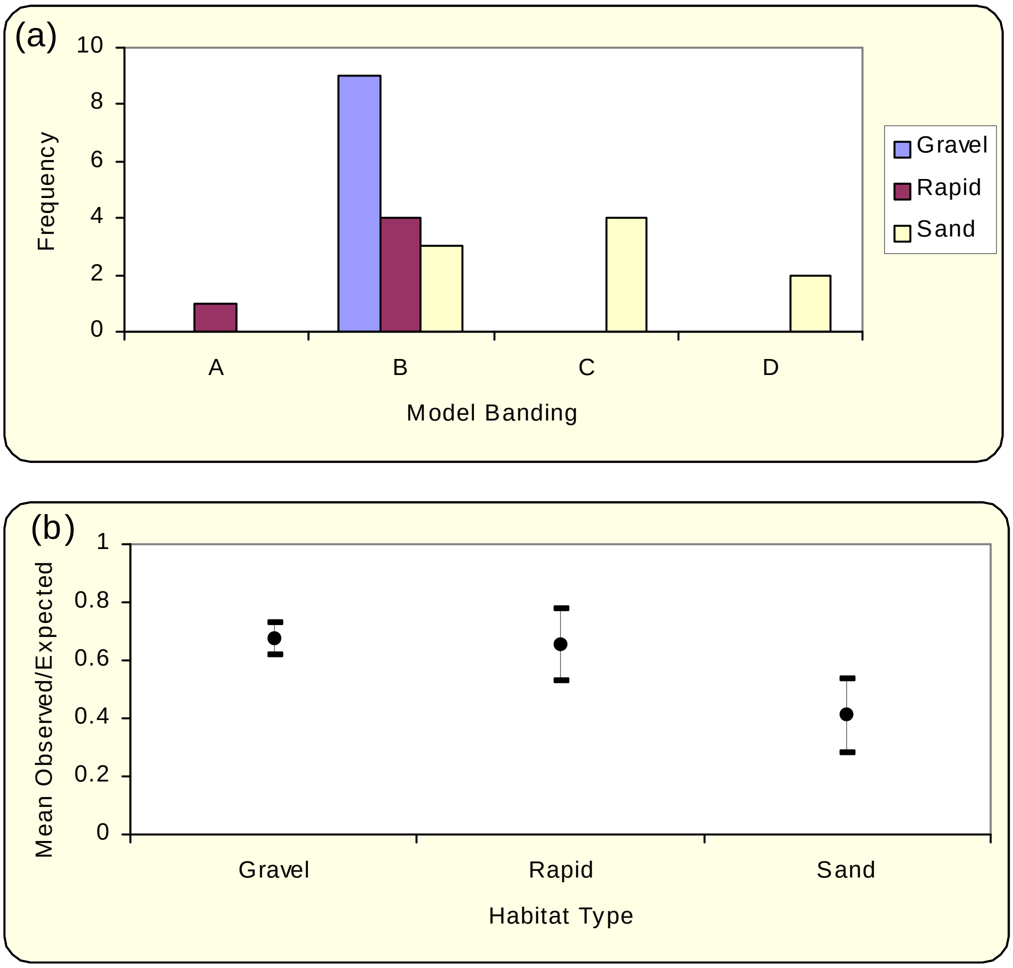

Figure 9. AusRivAS model output for Gravel, Rapid and Sand habitats summarised as (a) Frequency of samples in each model banding for each habitat type (where band A = Undisturbed, B = Significantly impaired, C = Severely impaired, and D = Extremely impaired), and (b) mean (± 95% CI) O/E score for each habitat.

All Gravel habitat samples had a Band Score of B (significantly impaired), one Rapid habitat sample was Band A (Undisturbed) and all others were Band B, and for Sand habitat 3 were Band B, 4 Band C (Severely Impaired), and 2 Band D (Extremely Impaired). Using ANOVA on O/E(50) scores, there was no significant difference in the condition of Gravel and Rapid habitats, but both had a significantly higher O/E score than Sand habitat (Figure 9 & 10, Table 7). Plots of family and species richness against O/E scores demonstrated highly significant correlations (correlation coefficients > 0.9) (Figure 10), indicating strong relationships between biodiversity in samples and model outputs.

Table 7 One-way ANOVA to test for differences in O/E(50) amongst habitats. Tukeys HSD multiple comparison test was applied to locate differences between habitats where there was a significant main effect. Levels joined by a common line are not significantly different at p = 0.05, habitats are arranged in descending order and mean O/E is in parenthesis.

	df	**F**	**P**	**Tukeys HSD**		
Habitats	2,20	8.14	0.0026	Gravel (0.68)	Rapid (0.66)	Sand (0.41)

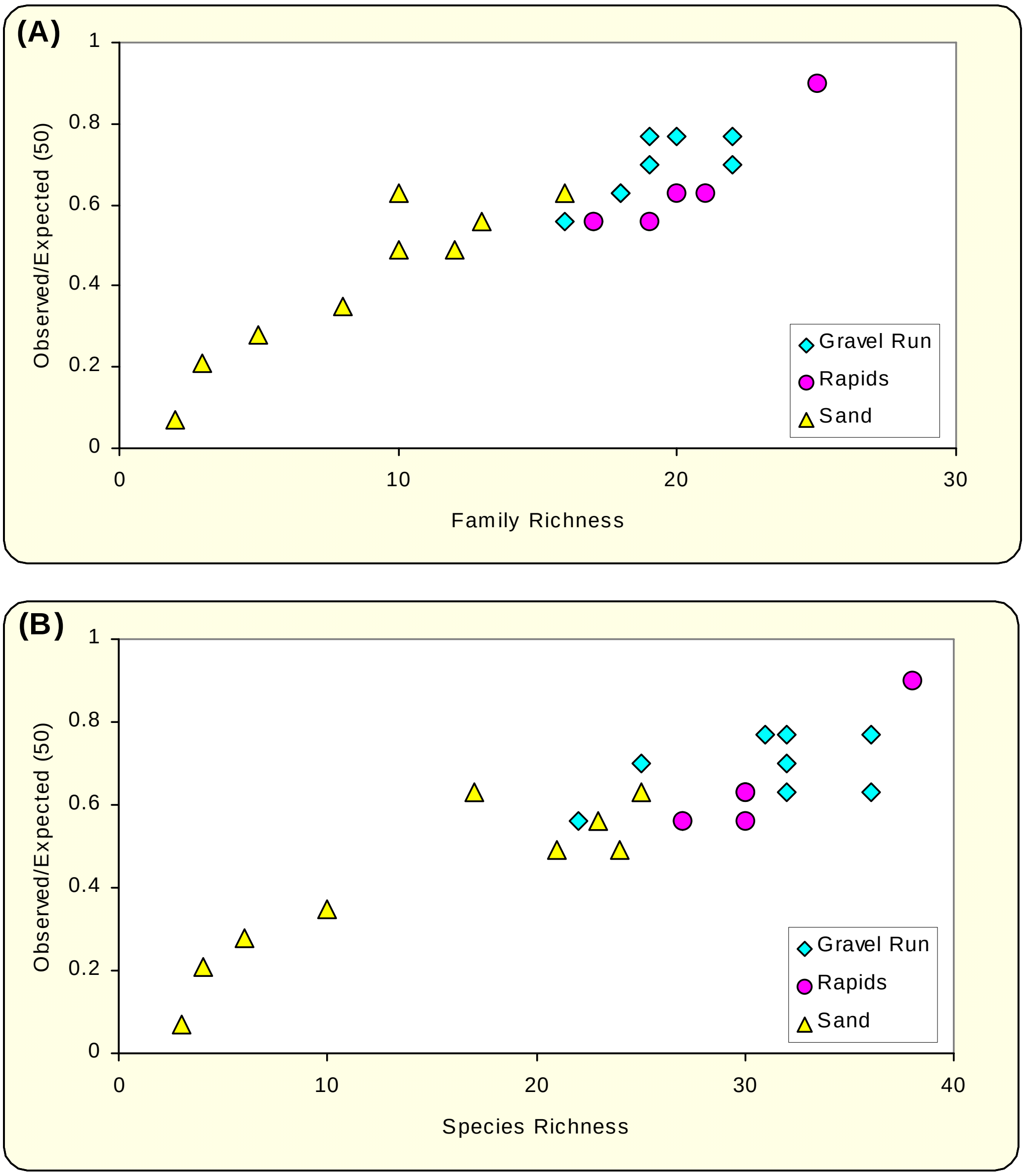

Figure 10. Plots of Observed/Expected ratio against (A) family richness and (B) species richness for each habitat type

5 DISCUSSION

5.1 Macroinvertebrate Usage of Habitats

The current study clearly demonstrated that different dominant habitats in the Lower Ord River could be differentiated on the basis of their physical properties, with water depth, water velocity and substrate properties being the primary parameters to distinguish between habitat types.

In addition, the different habitat types also could be clearly distinguished on the basis of their macroinvertebrate assemblages, with most macroinvertebrate taxa demonstrating a preference for one or several habitats. There were also significant differences in biodiversity between habitats. From these data it may be inferred that a loss of key habitats will concomitantly result in a loss of biodiversity for the Lower Ord River.

These results support the world literature on the relationships between aquatic macroinvertebrates and habitat diversity in which the preferential use of different habitats by aquatic macroinvertebrates has long been recognised, especially for faster-flowing, upland, mid-order and small lowland streams and rivers (Barmuta, 1989; Humphries *et al*. 1996, Pardo & Armitage, 1997, Harper & Everard, 1998), with riffle/run habitat usually supporting the greatest diversity and abundance of macroinvertebrates (Plafkin, *et al*. 1989). It is similarly recognised that the quality of habitats determines species richness in an ecosystem, and consequently, an assessment of habitat quality should provide an indication of biodiversity, and the maintenance of habitat quality therefore should protect biodiversity (Harper & Everard, 1998).

The recognition of the importance of habitat has influenced the development of various approaches for the rapid bioassessment of river health using aquatic macroinvertebrates. In the UK, the River Invertebrate Prediction and Classification System (RIVPACS) stratified sampling across all habitats at a site to maximise fauna richness (Wright *et al*, 1984). In Australia, Parsons & Norris (1996) reported that unless comparisons of ecological health between sites were based on the same habitats, results may be confounded by the occurrence of different habitats at each site. Therefore, the Australian River Assessment Scheme (AusRivAS) adopted habitat-specific sampling (Davies, 1994, Smith *et al*., 1999), with models developed for specific habitats (i.e. channel, riffle, macrophyte, edge etc). These approaches further emphasise the importance of considering habitats and their diversity. The importance of habitat was recognised by Wright *et al*. (1994) who examined the richness of biota in named habitats and the association between certain invertebrate families and habitat classes (e.g. 'non-macrophytes', 'submerged macrophytes', 'emergent macrophytes'). This and other habitat approaches have allowed scientists to identify and highlight to river managers the biologically important features of a river channel which should be conserved if present, or enhanced if degraded or absent (Harper & Everard, 1998).

This acknowledged association between habitat type and macroinvertebrate fauna composition has lead to the development of the 'Functional Habitat Concept' for river management, particularly in relation to the determination of environmental flows (Harper *et al*. 1995, Harper & Everard, 1998). Initially, habitat preference curves, as used in the In-stream Flow Incremental Methodology (IFIM) and other similar habitat assessment techniques for freshwater fishes (see review by Storey, 2000) were used to determine environmental flows. However, habitat preference curves are species-specific, requiring detailed information on the biology and habitat use of each species. It is time consuming and therefore expensive to obtain such data, and so is not suitable for species-rich communities, such as macroinvertebrate communities. The Functional Habitat Concept has arisen as an alternative to the habitat preference curves. The approach treats the river as being composed of distinct habitat units, recognisable and classifiable both on the basis of their physical and their biological attributes (Buffagni *et al*. 2000). It is assumed that it is possible to manage habitats in rivers far more easily than it is to manage species (Harper *et al*, 1995, cited Buffagni *et al*. 2000), especially in species-rich systems, for which there may be little information on the biology of the individual species. Therefore, by having easily recognisable habitats, which support distinct communities, managing the river to maintain habitats is assumed to be an indirect way of maintaining the communities.

Harper & Everard (1998) argue that habitats are the most convenient scale for management because they can be used in a simple building-block approach to restoration, and importantly, they are the interface between organisms and the physical processes of a river. Harper *et al*. (1992; cited Harper & Everard, 1998) introduced the term '*functional* habitats' because the units reflect the physical functioning of the river ecosystem. Examples of functional habitats include sediment separated into certain particle classes, and plants separated into shape and location classes as opposed to species; between them reflecting the power spectrum of a river. The distribution and frequency of functional habitats within a natural river channel is a predictable consequence of the physical continua (Vannote et al., 1980), and can thus be related to the principal power-related features, being discharge, the pool-riffle sequence and the meander pattern (Harper *et al.,* 1997; cited Harper & Everard, 1998). This means that habitat frequency and abundance for any river section should be predictable from basic geomorphological information: discharge, altitude, geology, stream order. This has been achieved for lowland rivers in the UK and the predictive power successfully used in river restoration (Harper *et al*., 1998, cited Harper & Everard, 1998, Kemp *et al*. 1999).

In a review of the hydrological, geomorphological and chemical factors shaping and influencing habitats in rivers Harper & Everard (1998) comment that functional habitats have occurrence frequencies which can be defined by flow velocity and depth, and there is a clear relationship between flow types (which are surrogates of velocity/depth) and functional habitats.

The concept of functional habitats has been mainly tested in North Europe, especially in upper and middle-order streams and small, lowland rivers where the habitats are, for the most part, distinguished by the in-channel vegetation (i.e. Pardo & Armitage, 1997, Buffagni *et al*. 2000). There are few examples where the concept has been applied to large lowland rivers and this probably reflects the difficulties of defining physical habitats in these systems, but also in sampling the aquatic invertebrate fauna of lowland rivers (Humphries *et al*. 1998). Where applied to lowland rivers, the functional habitat approach has been productive. For example, Armitage & Pardo (1995) assessed the impacts of flow regulation by sluice gates on a lowland river and reported the habitat approach as more sensitive than conventional biological assessment techniques, and Buffagni *et al* (2000) successfully applied the habitat approach to a large lowland river, in Italy.

The application of the Functional Habitat Concept to the LOR is an obvious choice given the lack of detailed knowledge on the species of macroinvertebrates found in the system, or the biology of those species. However, the applicability of the Functional Habitat approach must first be affirmed by testing for concordance between easily recognisable physical habitat types and the macroinvertebrate fauna they support. The current study has demonstrated a clear association between functional habitats (as described principally by flow velocity and depth, as well as other inter-dependent descriptors) and biodiversity (as described by aquatic macroinvertebrates). Therefore, it seems likely that the Functional Habitat concept will prove to be a very useful tool in managing the ecological health of the Lower Ord River.

5.2 Habitat Response to Reduced Flows

In lieu of applying the Functional Habitat concept to the LOR, a preliminary assessment of the potential effects of a reduced dry season water level on macroinvertebrates and their habitats was undertaken by considering four attributes of the habitats:

- biodiversity,
- macroinvertebrate habitat preferences,
- areal extent in the system, and
- likelihood of each habitat to be modified through changes in stage.

This study has demonstrated that high biodiversity habitats include Emergent macrophyte, Submerged macrophyte, Flooded riparian vegetation, Rapids, and Gravel runs. Habitats which are most highly preferred by macroinvertebrates include Emergent macrophyte, followed by Rapids, Gravel runs and Submerged macrophyte, and then Flooded riparian vegetation.

Mapping of the extent of different habitats is yet to be undertaken, however, subjectively, Sand, Emergent macrophyte and Flooded riparian vegetation are currently greatest in areal extent, and Gravel runs and Rapids have least cover, with most rapids located in the upper reach (KDD to Tarrara Bar). Submerged macrophyte currently has low cover, but will likely rapidly increase in extent if the system returns to pre-flood state (i.e. a channel with broad, shallow banks of sand and silt stabilised by dense beds of ribbon weed, as opposed to the current (May 2002) predominantly trapezoidal-shaped channel). The Mud/silt habitat is predominantly in low-velocity areas (backwaters, slow-flowing parts of wide reaches etc) with a relatively low aerial extent.

The riparian vegetation along the LOR has a relatively high cover but is restricted to a narrow zone along both banks of the river. The Flooded Riparian habitat sampled in the dry season consisted predominantly of dead or highly stressed riparian vegetation, smothered by sand that had been deposited on the banks during recent floods, but which had subsequently slumped into the channel (see Plate 3). This habitat is unlikely to persist as erosion from future wet season flows and biological processes breakdown and remove this habitat/material.

But in the longer term this habitat will likely be replaced by healthy riparian vegetation as the banks are recolonised. However, this habitat is unlikely to be inundated in future dry seasons, especially with a lower water level, but will be an important habitat in the wet season.

The final attribute, the likelihood of each habitat to be modified through changes in stage height due to a decrease in dry season water levels is perhaps the most difficult to determine. The susceptibility of physical/non-biological habitats (i.e. Gravel Runs, Rapids, Sand) to change was subjectively assessed based on the spatial extent of the habitat in the LOR combined with the likelihood of this cover to be modified by a change in water level (i.e. does a decline in dry season water level change the area of the habitat inundated). However, it is difficult to predict changes to this habitat without knowing either the extent of this substrate currently inundated, or future geomorphological changes to the habitats. For ‘biotic’ habitats (i.e. Submerged or Emergent Macrophyte or Riparian vegetation) the sensitivity to a decreased dry season flow depends upon the not so well understood ability of the vegetation to a.) adapt to a lower dry season water level (i.e. does it re-establish at a new, lower level in the channel), and b.) survive a greater seasonal change in water level (i.e. ability to survive longer/deeper inundation in the wet season and potentially a higher, drier position in the channel if unable to re-establish at a lower stage). This aspect of the provisional ranking will no doubt require further investigation and refinement.

Table 8. Preliminary ranking of each habitat to determine Priority Habitats with greatest susceptibility to change under reduced dry season flows. The approach scores four properties of each habitat to derive an overall mean score, upon which habitats are ordered. The properties include biodiversity of aquatic macroinvertebrates in each habitat (1 = high biodiversity, 6 = low biodiversity), areal extent in the system (l = low areal extent, 6 = high areal extent), subjective likelihood to be modified (1 = large change likely, 6 = small change likely), and taxa preferences (1 = preferred by a large number of taxa, 6 = preferred by a small number of taxa). Overall susceptibility was derived by ranking habitats using the mean of the rankings across all properties.

Habitat Type	Biodiversity	Areal extent[1]	Sensitivity[2]	Taxa preferences	Susceptibility to Change
Rapid	2	2	1	2	1.75
Gravel	4	1	1	2	2.00
Submerged	2	4	1[3]	2	2.25
Emergent	1	5	4	1	2.75
Flooded	4	5	4[4]	5	4.50
Mud/silt	6	3	5	6	5.00
Sand	6	5	5	6	5.50

1. Subjectively assessed during field studies in late dry season 2001, highest ranking (1) given to habitat with lowest areal extent, and lowest ranking (6) given to most common habitat
2. Refers to sensitivity to a further reduction in dry season water level, encompassing areal extent in the system, ability to re-establish at a lower stage and susceptibility to stranding/ isolation/reduction in area.
3. Likely to show short-term sensitivity, with loss of growth in shallows, but would persist at greater depths
4. Riparian vegetation will likely have a reduced duration of inundation during the wet season

In addition to the above unknowns, some additional unknowns are a.) the morphological response of the river to a reduction in dry season flows, whereby it is likely that a change in hydrology alters channel morphology which determines the extent and distribution of abiotic (and biotic) habitats (*sensu* the Functional Habitat concept), and b.) the future incidence of unpredictable high wet season flows, as seen in 1999 and 2000, which may result in large changes in the distribution of different habitats in the LOR.

With these assumptions and shortcomings in mind, each habitat type was scored using the above criteria to determine habitats of highest value and which are most likely to be modified (Table 8). Based on this very preliminary assessment, Rapids, Gravel bars, Submerged and Emergent Macrophytes appear to be the most important and susceptible habitats and therefore a survey of Functional Habitats should focus on these habitat as a minimum.

5.3 Ecosystem Health Monitoring

For future management of the LOR, especially when subjected to additional allocation, it is important to develop an effective monitoring program that will detect change in ecological condition. Increased allocation for irrigation will likely result in a greater amplitude in water levels in the LOR. Average/above average wet season flows will essentially remain unchanged as overflows from the Ord Dam and discharge from the Dunham River are uncontrolled. However, dry season flows will likely be reduced. Therefore, monitoring will essentially assess effects of reduced dry season flows/levels on habitat availability and greater drawdown from wet season habitat located higher on the bank.

The effectiveness of the AusRivAS package was tested in assessing ecosystem health for individual habitats. The package has been used previously on the Ord River for the First National Assessment of River Health, which provided input to State of the Environment reporting (Halse *et al*. 2001). Replicate samples from Gravel (9), Rapid (5) and Sand (9) habitats sampled in this study were run through the AusRivAS Spring season, Channel habitat model. Of the 23 samples, one was scored as Undisturbed (A), and 16, four and two were scored as Significantly (B), Severely (C) and Extremely Impaired (D) respectively. NB. Ecological health of other dominant habitats identified in this study (i.e. submerged and emergent macrophytes, mud/silt and flooded riparian vegetation) could not be assessed using the AusRivAS package because an appropriate, robust model does not exist for these habitat types.

Halse *et al.* (2001) reported that most rivers of the Kimberley showed little sign of disturbance, however, the Ord River was noted as one of the most disturbed, with an average O/E score in Spring of 0.83 (top end of Band B), and an overall basin condition of C_c for State of the Environment reporting; a system that graded basins from highest condition (A) to poorest condition (D). The disturbance was attributed mostly to cattle grazing and associated erosion/siltation. The assessment by Halse *et al*. (2001) was based on 10 sites distributed throughout the Ord basin, only three of which were downstream of the Ord Dam (scored as Bands A and B in Spring and Autumn 1998). In comparison, all sites in the current study were downstream of the Ord dam and had an overall average O/E score of 0.57 (Gravel = 0.68, Rapid = 0.66, Sand = 0.41).

The lower than expected scores in this study could be interpreted as indicative of further degradation. This may be the case, however, several confounding factors must be considered. In the first instance, prior to this study, but after the sampling by Halse *et al*. (2001) the LOR was subjected to two successive large wet season floods, which, although small relative to pre-dam floods, they were the largest events in the last ~20 years, and importantly, they had a long duration because the Ord Dam spillway over-topped for most of the following dry season. The floods caused considerable mobilisation of fine and coarser sediment in the LOR to such an extent that habitat structure was severely modified. Prior to the floods there were extensive areas of broad, shallow gravel and sand banks with low velocity and a good cover of algae, detritus and leaf pack material) (Plates 10 – 12). These areas were sampled as Channel habitat in AusRivAS sampling. However, during the floods this habitat was redistributed within the system with the majority of mud and fine silt, detritus and leaf pack material washed down to the estuary, and sand from the upper reach washed down to the middle and lower reaches and deposited along the edges (*ref* sand banks in Plate 6). As a result much of the channel is now trapezoidal in shape, with edges consisting of vertical consolidated mud banks, steep banks of clean, sorted sand, dense stands of emergent and floating macrophytes, or degraded riparian vegetation, smothered in sand and slumping into the channel. The remaining habitats are uniform and simplified in structure, with reduced micro-diversity and now likely to support fewer taxa. What may be regarded as Channel habitat is now present in deeper water (i.e. > 1 m) and tends to be characterised by armoured gravel/pebble substrate, with higher velocity, and generally too deep to sample with AusRivAS protocols, especially given the threat from estuarine crocodiles.

The same 'reset' phenomenon was observed at WillyWally (Fortescue River, east Hamersley Range), where a major flood six months previous to sampling had washed much accumulated sediment from the site, leaving a much wider channel, with greatly simplified habitat containing little detritus, algae or leaf pack material. As a result, the macroinvertebrate fauna was depauperate, and the site had a lower than expected O/E score (Stuart Halse, Dept CALM, pers. com.).

Such floods are a natural phenomenon in arid and wet-dry tropical systems. Therefore apparent changes in ecological health need to be interpreted with care, as they may merely reflect a different state of a naturally variable system, recovering from an episodic natural disturbance. The fauna that is present may be quite healthy and existing at a low level of risk, but is limited by habitat availability/condition.

Plate 10. Lower Ord River downstream of Kununurra airport showing established beds of submerged macrophytes across much of the channel (Oct. 1995)

Plate 11. Lower Ord River at Button's Crossing showing extensive shallows (during hydro shutdown, October 1999)

Plate 12. Well developed benthic community in shallows at Button's Crossing (during hydro shutdown, October 1999)

The other confounding factor is that sampling in the current study was very specific, targeting habitats characterised by substrate type or particle size, with sampling restricted to the exact habitat type. In some instances, the habitat had very uniform structure, with little diversity and subsequently supported few taxa (i.e. sand and mud/silt areas). Sampling for AusRivAs would normally consist of composite samples across several of the habitats that were sampled separately in the current study. This may also account for the lower scores in the current study.

Based on these results, it seems likely that the AusRivAS protocol, when applied to very specific habitats will under-estimate ecological health and may not have the sensitivity to detect future change. Habitat differences in macroinvertebrate assemblages, biodiversity and taxa preferences were performed at the species level. It is suggested that any future monitoring should be undertaken at this lowest taxonomic level to achieve greatest sensitivity.

However, it could be assumed that so long as each habitat type is well represented in the LOR then all macroinvertebrate taxa will be represented. Therefore, future monitoring should target habitat availability and condition, rather than macroinvertebrate assemblages, with most effort aimed at developing capability to predict effects of a lowered dry season water level on each habitat, particularly the priority habitats identified in section 5.2. To this end, the potential to use the Functional Habitat concept as a management approach for the LOR should be investigated.

6 RECOMMENDATIONS

- Assess the suitability of the Functional Habitat concept as a tool for managing the ecological health of the Lower Ord River
- Survey the extent of habitat types, particularly the priority habitats identified by this study
- Develop a capability to predict the response of abiotic and biotic habitats to reduced dry season flows
- Establish an ongoing monitoring program that will detect changes in the extent of different habitats.

7 ACKNOWLEDGMENTS

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9 APPENDICES

9.1 Appendix 1. Locations of sites sampled in October 2001

Appendix 1. Locations of replicates of individual habitats sampled in October 2001

Date	Code	Habitat	Reach	Rep	Latitude	Longitude
19/10/01	EML1	emergent	Lower	1	15 35.333	128 30.152
21/10/01	EML2	emergent	Lower	2	15 33.771	128 25.333
22/10/01	EML3	emergent	Lower	3	15 33.855	128 26.171
16/10/01	EMM1	emergent	Middle	1	15 32.587	128 31.311
16/10/01	EMM2	emergent	Middle	2	15 34.564	128 30.383
18/10/01	EMM3	emergent	Middle	3	15 34.285	128 32.594
23/10/01	EMU1	emergent	Upper	1	15 37.709	128 41.315
25/10/01	EMU2	emergent	Upper	2	15 35.145	128 41.798
26/10/01	EMU3	emergent	Upper	3	15 38.591	128 41.351
20/10/01	FRL1	flooded	Lower	1	15 35.077	128 28.524
21/10/01	FRL2	flooded	Lower	2	15 30.795	128 22.188
22/10/01	FRL3	flooded	Lower	3	15 31.979	128 24.797
17/10/01	FRM1	flooded	Middle	1	15 34.513	128 30.346
17/10/01	FRM2	flooded	Middle	2	15 33.662	128 30.871
18/10/01	FRM3	flooded	Middle	3	15 33.593	128 35.759
24/10/01	FRU1	flooded	Upper	1	15 36.496	128 41.054
25/10/01	FRU2	flooded	Upper	2	15 35.421	128 41.761
26/10/01	FRU3	flooded	Upper	3	15 39.385	128 42.284
20/10/01	GRL1	gravel run	Lower	1	15 35.677	128 29.276
21/10/01	GRL2	gravel run	Lower	2	15 33.771	128 25.333
22/10/01	GRL3	gravel run	Lower	3	15 32.548	128 24.581
16/10/01	GRM1	gravel run	Middle	1	15 35.192	128 30.145
18/10/01	GRM2	gravel run	Middle	2	15 34.288	128 32.595
18/10/01	GRM3	gravel run	Middle	3	15 32.907	128 32.300
24/10/01	GRU1	gravel run	Upper	1	15 37.484	128 41.678
25/10/01	GRU2	gravel run	Upper	2	15 35.111	128 41.733
26/10/01	GRU3	gravel run	Upper	3	15 41.001	128 41.696
20/10/01	ML1	mud	Lower	1	15 34.745	128 28.286
21/10/01	ML2	mud	Lower	2	15 29.398	128 20.706
22/10/01	ML3	mud	Lower	3	15 31.905	128 24.872
17/10/01	MM1	mud	Middle	1	15 35.401	128 30.152
17/10/01	MM2	mud	Middle	2	15 35.771	128 29.661
18/10/01	MM3	mud	Middle	3	15 32.924	128 32.247
24/10/01	MU1	mud	Upper	1	15 36.484	128 41.099
25/10/01	MU2	mud	Upper	2	15 35.714	128 41.473
26/10/01	MU3	mud	Upper	3	15 39.967	128 42.515
20/10/01	RL1	rapid	Lower	1	15 35.374	128 28.921
17/10/01	RM1	rapid	Middle	1	15 34.554	128 30.380
24/10/01	RU1	rapid	Upper	1	15 37.859	128 41.994
25/10/01	RU2	rapid	Upper	2	15 35.111	128 41.727
26/10/01	RU3	rapid	Upper	3	15 41.259	128 41.171
20/10/01	SL1	sand	Lower	1	15 35.373	128 28.921
21/10/01	SL2	sand	Lower	2	15 29.837	128 22.472
22/10/01	SL3	sand	Lower	3	15 32.014	128 24.742
16/10/01	SM1	sand	Middle	1	15 33.751	128 30.827
17/10/01	SM2	sand	Middle	2	15 35.263	128 30.122
18/10/01	SM3	sand	Middle	3	15 32.924	128 32.247
16/10/01	SMM1	submerged	Middle	1	15 35.305	128 30.180
19/10/01	SMM2	submerged	Middle	2	15 35.781	128 29.580
22/10/01	SMM3	submerged	Middle	3	15 35.305	128 30.180
26/10/01	SMU1	submerged	Upper	1	15 35.721	128 41.469
26/10/01	SMU2	submerged	Upper	2	15 35.721	128 41.469
26/10/01	SMU3	submerged	Upper	3	15 35.721	128 41.469
26/10/01	SMU4	submerged	Upper	4	15 35.721	128 41.469
26/10/01	SMU5	submerged	Upper	5	15 35.721	128 41.469
24/10/01	SU1	sand	Upper	1	15 37.484	128 41.678
25/10/01	SU2	sand	Upper	2	15 35.236	128 41.754
26/10/01	SU3	sand	Upper	3	15 39.967	128 42.515

9.2 Appendix 2. Values for each descriptive parameter for each habitat type

Appendix 2. Summary of physico-chemical parameters by each habitat type, presenting mean, 1 SE in parenthesis (in parentheses), with minimum and maximum values underneath (n = 9 for each habitat, except n=5 for Rapids and n = 8 for Submerged macrophytes).

Habitat	pHM	Cond	Salinity	TurbM	TempM	RedoxM	VelocM	DepthM	DO%M
emergent	7.7 (0.23)	313.8 (1.1)	172 (0.6)	17.4 (1.75)	30.1 (0.38)	6.6 (26.9)	9.6 (3.5)	1.33 (0.26)	83 (1.74)
	6.7 - 8.97	310 - 320	171 - 176	10.6 - 27.1	28.3 - 31.74	-77.5 - 163.5	1 - 35.7	0.34 - 2.5	76.1 - 90
flooded	8.2 (0.14)	330.9 (12.6)	181.2 (6.78)	23.7 (6.23)	30.2 (0.27)	-17.8 (12.8)	7.2 (2.16)	1.92 (0.41)	82.5 (1.2)
	7.5 - 9.02	310 - 424	170 - 231	10.2 - 71.05	28.9 - 31.41	-70 - 51.5	0 - 18	0.51 - 4.3	76.8 - 88.6
gravel	8 (0.12)	314.7 (2.5)	172.9 (1.25)	15.4 (1.72)	30 (0.26)	-44.1 (16.6)	57.3 (6.67)	0.24 (0.02)	82.4 (1.29)
	7.4 - 8.59	302 - 326	167 - 179	9.2 - 25.4	29 - 31.2	-142 - 15	31.7 - 87	0.17 - 0.39	76.8 - 89.2
mud	8.3 (0.22)	311.4 (21.3)	195.2 (16.1)	29.1 (7.21)	30.1 (0.28)	-10.4 (11.9)	2.6 (1.59)	0.2 (0.03)	82.2 (1.45)
	7.5 - 9.84	171 - 421	166 - 313	10.6 - 78.5	28.7 - 31.03	-94 - 27	0 - 14.3	0.13 - 0.38	73.6 - 87.5
rapid	8 (0.17)	310 (2.6)	170.2 (1.07)	16.3 (2.74)	29.9 (0.35)	-19.8 (10.6)	60.4 (2.9)	0.23 (0.02)	83.9 (0.92)
	7.4 - 8.42	300 - 314	166 - 172	10.7 - 25.9	29 - 30.8	-46 - 10	54 - 67.7	0.16 - 0.27	82.3 - 87.3
sand	8 (0.12)	324.7 (10)	178 (5.49)	25.7 (8.19)	30.3 (0.32)	11.5 (18.8)	10.3 (2.77)	0.23 (0.03)	83.1 (1.5)
	7.5 - 8.69	309 - 403	169 - 221	13.6 - 90.7	28.9 - 31.66	-78 - 104	1.3 - 22	0.15 - 0.42	77 - 91.1
submerged	8.1 (0.18)	330.1 (4.8)	181.3 (2.81)	17.5 (2.06)	29.4 (0.48)	3.9 (21.9)	1.7 (1.07)	0.38 (0.12)	83.1 (1.06)
	7 - 8.42	313 - 340	171 - 187	13.5 - 27.25	28.4 - 31.25	-34 - 125	0 - 8.5	0.15 - 0.94	81.4 - 89.9

Appendix 2 (cont.)

Habitat	DOmgM	Boulders	Cobbles	Pebbles	Gravel	Sand	Silt	phiMean	Mineral
emergent	6.2 (0.1)	6 (6)	7.7 (5.08)	4.8 (3.7)	4.8 (3.7)	32.2 (12.99)	44.4 (14.64)	2.2 (1.58)	14.1 (1.8)
	5.8 - 6.7	0 - 54	0 - 36	0 - 33	0 - 33	0 - 100	0 - 100	-6.55 - 6.5	8 - 25
flooded	6.2 (0.08)	1.1 (1.11)	1.7 (1.67)	3.3 (3.33)	3.3 (3.33)	30 (10.24)	60.6 (11.62)	4.1 (1)	29.4 (5.62)
	5.7 - 6.5	0 - 10	0 - 15	0 - 30	0 - 30	0 - 80	10 - 100	-3.08 - 6.5	15 - 65
gravel	6.2 (0.08)	0 (0)	15.6 (5.74)	58.6 (5.01)	18.4 (1.89)	6.3 (0.6)	0.8 (0.4)	-3.8 (0.19)	98.1 (1.38)
	5.9 - 6.6	0 - 0	5 - 50	30 - 80	10 - 25	5 - 10	0 - 3	-4.8 - -3.19	88 - 100
mud	6.2 (0.1)	0 (0)	0 (0)	0 (0)	0 (0)	4.7 (3.24)	95.3 (3.24)	6.3 (0.15)	86.3 (2.75)
	5.5 - 6.5	0 - 0	0 - 0	0 - 0	0 - 0	0 - 30	70 - 100	5.15 - 6.5	70 - 95
rapid	6.4 (0.04)	56.6 (15.65)	27.7 (10.26)	10.5 (3.54)	3.8 (1.69)	1.4 (0.6)	0 (0)	-7.4 (0.58)	90.8 (3.81)
	6.3 - 6.5	15 - 95	2.5 - 50	2.5 - 22	0 - 10	0 - 3	0 - 0	-8.83 - -5.73	78 - 100
sand	6.2 (0.1)	0 (0)	0 (0)	1.1 (1.11)	1.1 (1.11)	90 (2.2)	7.8 (2.06)	2.2 (0.18)	99.1 (0.54)
	5.7 - 6.7	0 - 0	0 - 0	0 - 10	0 - 10	80 - 100	0 - 20	0.95 - 2.9	95 - 100
submerged	6.3 (0.05)	0 (0)	0 (0)	1.3 (0.37)	1.9 (0.55)	2.5 (0.6)	94.4 (1.28)	6.1 (0.1)	32.5 (8.56)
	6.1 - 6.7	0 - 0	0 - 0	0 - 2	0 - 3	0 - 5	92 - 100	5.89 - 6.5	0 - 50

Appendix 2 (cont.)

Habitat	Emergent	Submerged	Algae	Detritus	RipVeg	LWD	Other substrate	Habdiv	Rip. Veg. Cov.
emergent	84.4 (2.12)	0 (0)	0 (0)	0.7 (0.55)	0.11 (0.11)	0.56 (0.56)	0 (0)	2.44 (0.24)	1.3 (0.73)
	75 - 90	0 - 0	0 - 0	0 - 5	0 - 1	0 - 5	0 - 0	2 - 4	0 - 5
flooded	0 (0)	0 (0)	0 (0)	2.8 (0.88)	4.44 (1.55)	63.33 (5.07)	0 (0)	3.11 (0.2)	25 (8.7)
	0 - 0	0 - 0	0 - 0	0 - 5	0 - 10	30 - 80	0 - 0	2 - 4	0 - 75
gravel	0 (0)	0 (0)	1.1 (1.11)	0.2 (0.22)	0 (0)	0 (0)	0.56 (0.56)	1.33 (0.24)	1.1 (0.73)
	0 - 0	0 - 0	0 - 10	0 - 2	0 - 0	0 - 0	0 - 5	1 - 3	0 - 5
mud	0 (0)	0.6 (0.56)	0 (0)	12.2 (2.65)	0 (0)	1 (0.58)	0 (0)	2.44 (0.18)	8.9 (7.67)
	0 - 0	0 - 5	0 - 0	5 - 30	0 - 0	0 - 5	0 - 0	2 - 3	0 - 70
rapid	0 (0)	0 (0)	3.4 (2.14)	2.6 (1.12)	0 (0)	0 (0)	3.2 (2.96)	2.4 (0.4)	8 (3.74)
	0 - 0	0 - 0	0 - 10	0 - 5	0 - 0	0 - 0	0 - 15	1 - 3	0 - 20
sand	0 (0)	0 (0)	0 (0)	0.9 (0.54)	0 (0)	0 (0)	0 (0)	1.44 (0.18)	0.6 (0.56)
	0 - 0	0 - 0	0 - 0	0 - 5	0 - 0	0 - 0	0 - 0	1 - 2	0 - 5
submerged	6.3 (1.83)	55 (12.21)	0 (0)	6.3 (1.83)	0 (0)	0 (0)	0 (0)	3.13 (0.44)	0 (0)
	0 - 10	30 - 100	0 - 0	0 - 10	0 - 0	0 - 0	0 - 0	1 - 4	0 - 0

9.3 Appendix 3. MDA for habitat groups

Appendix 3. Canonical discriminant function coefficients of physico-chemical variables against *a priori* habitats. Numbers in parentheses indicate the rankings of each variable on each discriminant function. The proportion of variation explained by each function is also presented.

Variable	DF1	DF2	DF3	DF4	DF5	DF6
Emergent	0.99 (1)	-0.02 (14)	0.01 (12)	0.12 (8)	-0.07 (11)	0.06 (13)
Mineral	-0.66 (2)	-0.46 (5)	0.43 (8)	0.18 (5)	-0.25 (3)	0.12 (7)
depthM	0.35 (3)	0.68 (2)	-0.01 (10)	-0.03 (14)	0.08 (10)	-0.07 (12)
Detritus	-0.24 (4)	-0.07 (13)	-0.45 (7)	-0.08 (10)	-0.01 (13)	0.63 (1)
LWD	-0.15 (5)	0.96 (1)	-0.01 (13)	-0.11 (9)	0.13 (7)	-0.08 (9)
velocM	-0.14 (6)	-0.30 (7)	0.78 (1)	-0.36 (2)	0.17 (5)	-0.13 (6)
ripVgCov	-0.14 (7)	0.50 (4)	0.01 (11)	-0.14 (7)	-0.01 (14)	0.15 (5)
habdiv	0.13 (8)	0.34 (6)	-0.46 (6)	-0.38 (1)	0.10 (8)	0.11 (8)
Pebble	-0.13 (9)	-0.26 (8)	0.69 (4)	0.06 (13)	0.61 (1)	-0.07 (10)
RipVeg	-0.09 (10)	0.67 (3)	0.00 (14)	-0.08 (11)	0.09 (9)	-0.07 (11)
Silt	0.03 (11)	0.16 (11)	-0.75 (3)	-0.06 (12)	0.21 (4)	0.48 (2)
Submerged	-0.03 (12)	-0.26 (9)	-0.64 (5)	-0.24 (4)	0.37 (2)	-0.34 (3)
phiM	0.01 (13)	0.25 (10)	-0.78 (2)	0.36 (3)	0.05 (12)	0.24 (4)
tempT	0.00 (14)	0.16 (12)	0.15 (9)	0.15 (6)	-0.16 (6)	0.06 (14)
Significance	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
% variance	85%	7%	5%	1%	1%	0.5%

9.4 Appendix 4. MDA for physico-chemical UPGMA groups

Appendix 4. Canonical discriminant function coefficients of physico-chemical variables against *a posteriori* UPGMA groupings derived from physico-chemical data. Numbers in parentheses indicate the rankings of each variable on each discriminant function. The proportion of variation explained by each function is also presented.

Variable	DF1	DF2	DF3	DF4	DF5
velocM	-0.83 (1)	0.08 (11)	0.05 (13)	0.23 (5)	0.41 (2)
Silt	0.62 (2)	-0.18 (7)	-0.19 (6)	-0.67 (2)	0.17 (9)
Sand	0.38 (3)	-0.11 (10)	0.12 (8)	0.82 (1)	-0.24 (5)
Emergent	0.36 (4)	0.71 (1)	0.55 (2)	-0.02 (10)	0.18 (8)
LWD	0.22 (5)	0.36 (3)	-0.85 (1)	0.11 (7)	-0.14 (10)
depthM	0.17 (6)	0.70 (2)	-0.27 (5)	-0.07 (8)	-0.41 (1)
Detritus	0.17 (7)	-0.33 (5)	-0.05 (12)	-0.62 (3)	-0.12 (11)
tempT	0.17 (8)	0.02 (13)	-0.07 (10)	0.30 (4)	0.24 (6)
salinity	0.16 (9)	-0.19 (6)	-0.11 (9)	-0.19 (6)	-0.06 (12)
ripVgCov	0.13 (10)	0.11 (9)	-0.54 (3)	0.01 (12)	0.05 (13)
RipVeg	0.08 (11)	0.34 (4)	-0.48 (4)	0.01 (13)	-0.29 (3)
DOmgB	0.07 (12)	-0.02 (12)	0.06 (11)	0.03 (9)	0.25 (4)
DOmgT	-0.01 (13)	-0.11 (8)	0.13 (7)	-0.02 (11)	0.23 (7)
Significance	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
% variance	65%	29%	4%	2%	1%

9.5 Appendix 5. Systematic list of macroinvertebrate fauna

Appendix 5. Systematic list of macroinvertebrate fauna, giving the mean of the log abundance values for each species across each habitat type, with total richness for each habitat and for the study.

			Emergent	Flooded	Gravel	Mud	Rapid	Silt	Submerged
MOLLUSCA									
GASTROPODA	**Viviparidae**	*Notopala* sp.	0.00	0.00	0.00	0.00	0.20	0.00	0.00
	Thiaridae	*Thiara* (*Plotiopsis*) sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.63
	Planorbidae	*Gyraulus* sp.	0.11	0.00	0.00	0.00	0.00	0.00	0.25
	Lymnaeidae	*Austropeplea lessoni*	0.00	0.00	0.00	0.00	0.00	0.00	0.88
	Ancylidae	*Ferrissia petterdi*	0.67	0.22	0.00	0.00	0.00	0.00	0.13
	Hydrobiidae	?Hydrobiidae sp.	0.00	0.33	0.00	0.11	0.00	0.00	0.00
	Neritidae	?Neritidae sp.	0.00	0.00	0.33	0.00	0.00	0.00	0.00
BIVALVIA	**Corbiculidae**	*Corbicula* (*corbiculina*) sp. UK1	0.33	0.44	2.00	0.00	2.00	0.67	1.50
ANNELIDA									
OLIGOCHAETA		Oligochaeta spp.	1.00	2.00	3.11	2.11	2.00	0.56	1.38
POLYCHAETA		Nereidae sp.	0.00	0.00	0.22	0.56	0.00	0.00	0.00
NEMATODA		Nematoda sp.	0.22	0.67	2.33	1.44	2.20	0.67	0.75
TURBELLARIA		Turbellaria sp	0.00	0.00	0.00	0.00	0.40	0.00	0.00
BRANCHIURA		Argulus sp. UK1	0.00	0.00	0.00	0.11	0.00	0.00	0.00
		Argulus sp. UK2	0.00	0.00	0.00	0.00	0.00	0.00	0.13
ARACHNIDA									
ACARINA	**Arrenuridae**	Arrenurus (Arr.) sp. cf pseudoaffinis	0.00	0.00	0.00	0.00	0.00	0.00	0.25
		Arrenurus sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.63
	Eylaidae	Eylais sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.50
	Hydrodromidae	Hydrodroma sp.	0.11	0.00	0.00	0.00	0.00	0.00	0.00
	Hygrobatidae	Australiobates mutatus K.O. Viets	0.11	0.22	2.44	0.00	2.20	0.00	0.63
		Hygrobatidae sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.13
		Coaustraliobates minor (Lundblad)	0.00	0.00	0.00	0.00	0.00	0.00	0.13
		Dropursa babinda Cook	0.22	0.00	0.78	0.00	0.00	0.22	0.25
	Limnesiidae	Limnesia parasolida K.O. Viets	0.11	0.00	0.00	0.00	0.00	0.67	0.00
	Torrenticolidae	Monatractides sp.	0.00	0.00	0.11	0.00	0.00	0.00	0.00
	Unionicolidae	Neumania sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.13
		Unionicola sp.	0.00	0.11	0.00	0.00	0.00	0.00	0.00
	Hydracarina sp.	Hydracarina sp	0.11	0.00	0.22	0.00	0.00	0.00	0.38
CRUSTACEA									
COPEPODA		Copepoda spp	0.78	1.67	0.56	0.11	0.60	1.22	1.75
OSTRACODA		Ostracoda spp	0.78	0.67	0.67	1.00	0.20	0.89	2.00
CLADOCERA		Cladocera spp	0.22	0.22	0.00	0.00	0.00	0.33	1.13
DECAPODA	**Atyidae**	*Caradina serratirostris*	1.11	0.22	0.22	0.00	0.40	0.00	0.13
		Caradina nilotica	2.00	0.89	0.00	0.00	0.00	0.00	1.38
	Palaemonidae	*Macrobrachium rosenbergii*	1.67	0.44	0.56	0.00	1.00	0.00	1.25
		Macrobrachium bullatum	0.67	0.44	0.67	0.00	0.00	0.00	1.50
	Sundathelphusidae	*Holthuisana transversa*	0.00	0.00	0.44	0.00	0.00	0.00	0.00
INSECTA									
LEPIDOPTERA	**Pyralidae**	*Pyralidae* sp.	1.33	0.33	1.33	0.00	2.80	0.00	2.63
		Pyralidae sp. pupae	0.00	0.00	0.56	0.00	1.60	0.00	0.00
DIPTERA	**Chironomidae**								

			Emergent	Flooded	Gravel	Mud	Rapid	Silt	Submerged
	Tanypodinae	Larsia ?albiceps	2.44	2.44	0.67	0.44	1.40	0.11	2.88
		Procladius sp 1	0.22	0.33	0.56	0.67	0.40	1.00	2.13
		Coelopynia pruinosa	0.00	0.00	0.00	0.44	0.00	0.00	1.00
		Nilotanypus sp. nov.	2.44	2.00	2.11	0.11	1.80	0.00	1.13
		Paramerina sp.	1.89	0.78	1.33	0.00	1.20	0.89	1.75
		Ablabesmyia sp.	0.67	0.00	0.00	0.00	0.00	0.44	0.25
		Procladius sp 2	0.00	0.00	0.22	0.00	0.00	0.22	0.00
		Tanypodinae ?genus	0.00	0.00	0.00	0.33	0.00	0.44	0.00
	Chironominae	Tanytarsus spp.	0.89	1.22	2.00	1.00	2.40	1.11	2.13
		Cladotanytarsus sp.	1.89	1.89	3.00	1.11	1.60	1.67	2.00
		Dicrotendipes sp.	1.78	2.33	1.78	0.33	2.20	0.00	1.63
		Polypedilum (Pentapedilum) leei	0.22	0.56	0.22	0.00	0.00	0.00	0.38
		Chironomini ?genus sp.A	0.00	0.00	0.00	0.00	0.00	0.00	0.50
		Polypedilum nubifer	0.00	0.33	0.22	0.44	0.60	0.00	0.63
		Harnischia sp.	0.00	0.22	0.56	1.00	0.60	1.11	2.00
		Polypedilum watsoni	0.56	1.89	1.56	0.67	1.40	0.33	1.25
		Chironomini ?genus sp.B	0.00	0.00	0.22	0.78	0.00	0.00	0.75
		Cryptochironomus ?griseidorsum	0.00	0.00	2.33	0.00	0.60	1.22	0.63
		Parachironomus sp.	1.67	0.78	0.78	0.00	1.20	0.00	1.25
		Chironomini ?genus sp.C	0.00	0.44	0.44	0.33	0.40	1.11	0.25
		Paracladopelma nr. M1 (Cranston)	0.00	0.00	0.67	0.00	0.00	1.67	0.00
		Chironomini ?genus	0.00	0.00	0.44	0.44	0.00	0.00	0.00
		Rheotanytarsus sp.	1.00	0.67	1.22	0.00	1.60	0.00	0.00
		Chironomini ?genus sp.D	0.00	0.00	0.22	0.00	0.00	0.00	0.00
		Stenochironomus watsoni	1.22	1.67	0.00	0.00	0.40	0.00	0.00
		Xenochironomus sp.	0.00	0.00	0.00	0.00	0.40	0.00	0.00
	Orthocladinae	Cricotopus sp.	2.78	2.22	3.00	0.11	3.80	1.33	1.63
		Nanocladius sp. 1	0.67	1.11	0.56	0.00	0.80	0.00	1.25
		Parakiefferiella sp.	1.11	0.89	2.33	0.00	3.40	0.00	0.00
		Corynoneura sp.	0.22	0.00	0.22	0.00	0.00	0.00	0.00
	Ceratopogonidae	Ceratopogonidae spp	1.22	1.89	2.22	2.22	1.80	2.33	2.13
	Forcipomyiinae	*Atrichopogon* sp	0.00	0.00	0.00	0.00	0.20	0.00	0.00
	Stratiomyidae	Stratiomyidae spp	0.22	0.00	0.00	0.00	0.00	0.00	0.00
	Culicidae	*Anopheles* sp.	0.56	0.00	0.00	0.00	0.00	0.11	0.00
		Aedomyia catastica	0.00	0.00	0.00	0.00	0.00	0.00	0.25
	Tabanidae	*Tabanus* sp.	0.44	0.00	1.11	0.00	1.00	0.00	0.00
	Empididae	*Hemerodrominae* sp.	0.44	0.00	0.33	0.00	1.00	0.00	0.00
	Tipulidae	Tipulidae sp	0.00	0.00	0.00	0.22	0.00	0.00	0.00
	Simulidae	*Simulium ornatipes*	0.33	0.67	3.00	0.22	3.80	0.56	0.38
	Ephydridae	Ephydridae sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.13
	Un Id Diptera sp	Diptera sp UK1	0.00	0.22	0.00	0.00	0.00	0.00	0.00
		Pupae UK1	0.22	0.00	0.44	0.00	0.00	0.00	0.00
		Pupae UK2	1.78	0.89	0.00	0.00	0.00	0.78	0.00
ODONATA	**Zygoptera**	*Pseudagrion microcephalum*	1.67	0.33	0.00	0.00	0.00	0.00	2.25
		Austroagrion cyane	0.89	0.22	0.00	0.00	0.00	0.00	1.88
	Anisoptera	*Nanophlebia risi*	1.56	0.44	1.00	0.00	1.40	0.22	0.00
		Austrogomphus mjobergi	0.33	0.00	0.44	0.00	0.60	0.00	0.00
		Austrocordulia territoria	0.00	0.00	0.00	0.00	0.20	0.00	0.00

			Emergent	Flooded	Gravel	Mud	Rapid	Silt	Submerged
		Orthetrum caledonicum	0.00	0.00	0.00	0.11	0.00	0.00	0.88
		Antipodogomphus neophytus	0.00	0.00	0.00	0.00	0.00	0.11	0.00
		Diplacodes haematodes	0.33	0.00	0.22	0.00	0.00	0.00	2.00
		Unid early instars	0.00	0.00	0.56	0.00	0.40	0.44	0.25
HEMIPTERA	**Pleidae**	*Plea* sp.	0.33	0.11	0.00	0.00	0.00	0.00	0.13
		Plea brunni	2.11	0.44	0.00	0.00	0.00	0.00	0.38
	Naucoridae	*Aphelocheirus australicus*	1.22	0.11	0.00	0.00	0.00	0.00	0.50
	Notonectidae	*Nychia sappho*	0.22	0.44	0.00	0.00	0.00	0.00	0.00
		Notonectidae sp. (immature)	0.00	0.33	0.00	0.00	0.00	0.00	0.13
	Corixidae	Micronecta sp. UK1	2.89	2.33	0.00	0.22	0.00	3.22	2.13
		Micronecta sp. UK2	1.22	0.67	0.00	0.00	0.00	0.78	1.25
		Micronecta sp. UK3	0.56	0.11	0.00	0.00	0.00	0.00	1.50
		Agroptocorixa sp. UK1	0.00	0.00	0.00	0.00	0.00	0.00	0.50
		Micronecta juvenile	0.00	0.00	0.22	0.00	0.00	0.00	0.00
	Nepidae	*Ranatra* sp.	0.11	0.00	0.00	0.00	0.00	0.00	0.00
	Hydrometridae	*Hydrometra* sp.	0.11	0.00	0.00	0.00	0.00	0.00	0.00
	Veliidae	*Microvelia* sp.	0.78	1.56	0.00	0.00	0.00	0.00	0.13
	Gerridae	*Limnogonus (L) fossarum*	1.22	0.00	0.00	0.00	0.00	0.00	0.00
		Rhagadotarsus anomalus	0.67	0.89	0.00	0.00	0.00	0.00	0.00
	Mesoveliidae	*Mesovelia* sp.	1.56	0.56	0.00	0.00	0.00	0.00	0.25
	Hebridae	*Merragata hackeri*	0.67	0.22	0.00	0.00	0.00	0.00	0.00
		Hebrus woodwardi	0.11	0.00	0.00	0.00	0.00	0.00	0.00
EPHEMEROPTERA	**Baetidae**	Genus 1 WA sp1.	2.89	2.11	3.22	0.33	3.60	0.44	1.13
		Cloeon sp.	1.56	1.44	0.22	0.00	0.40	0.00	3.00
	Leptophlebidae	*Genus Z*	0.00	0.00	1.44	0.00	1.00	0.00	0.00
		Tasmanocoenis arcuata	2.89	1.89	3.22	0.67	3.40	1.56	1.50
		Wundacaenis dostini	0.44	0.00	0.00	0.00	0.40	0.00	0.00
TRICHOPTERA	**Leptoceridae**	*Triaenodes* sp.	0.67	0.11	0.00	0.00	0.00	0.00	0.25
		Oecetis sp1	0.11	0.22	0.56	0.00	0.60	0.22	0.88
		Oecetis sp2	0.00	0.11	0.00	0.00	0.00	0.00	0.00
		Triplectides helvolus	0.00	0.00	0.00	0.00	0.00	0.00	0.13
		Triplectides ciuskus seductus	0.00	0.00	0.00	0.00	0.00	0.00	0.13
	Hydroptilidae	*Orthotrichia* sp.	0.22	0.00	0.56	0.00	1.00	0.00	0.00
		Hellyethera ?ramosa	0.00	0.11	0.00	0.00	0.00	0.00	0.00
	Ecnomidae	*Ecnomus* sp.	1.00	1.00	1.67	0.00	2.40	0.22	0.50
	Polycentropidae	*Paranyctiophylax* sp. AV5	0.44	0.00	0.00	0.00	0.00	0.00	0.00
	Hydropsychidae	*Cheumatopsyche* sp.	0.33	0.22	2.67	0.00	3.60	0.11	0.00
	Philopotamidae	*Chimmara uranka*	0.00	0.00	0.67	0.00	1.40	0.00	0.00
COLEOPTERA	**Dytiscidae**	*Clypeodytes ?bifasciatus*	0.00	0.00	0.00	0.00	0.00	0.11	0.00
		Clypeodytes migrator	0.00	0.11	0.00	0.00	0.00	0.00	0.00
		Copelatus nigrolineatus	0.00	0.00	0.11	0.00	0.40	0.00	0.13
		Cybister sp. (L)	0.00	0.00	0.00	0.00	0.00	0.00	0.13
		Hydroglyphus basalis var. fuscolineatus	0.22	0.00	0.00	0.00	0.00	0.00	0.00
		Hydroglyphus leai	0.67	0.22	0.00	0.00	0.00	0.00	0.13
		Hydroglyphus trilineatus	0.00	0.00	0.00	0.00	0.00	0.33	0.13
		Hyphydrus lyratus	0.11	0.00	0.00	0.00	0.00	0.00	0.13
		Hyphydrus sp. (L)	0.00	0.00	0.00	0.00	0.00	0.00	0.38
		Hydrovatus ?ovalis	0.00	0.00	0.00	0.00	0.00	0.11	0.00

		Emergent	Flooded	Gravel	Mud	Rapid	Silt	Submerged	
	Laccophilus spA	0.11	0.00	0.00	0.00	0.00	0.00	0.00	
	Laccophilus spB	0.11	0.00	0.00	0.00	0.00	0.00	0.00	
	Laccophilus clarki	0.33	0.00	0.00	0.00	0.00	0.11	0.00	
	Laccophilus sp. (L)	0.00	0.00	0.00	0.00	0.00	0.00	0.63	
	Megaporus ruficeps	0.00	0.00	0.00	0.00	0.00	0.00	0.38	
Limnichidae	Linmnichidae sp. UK1	1.22	1.11	0.00	0.11	0.00	0.00	0.00	
Brentidae	Brentidae sp. UK1	0.22	0.00	0.00	0.00	0.00	0.00	0.00	
	Brentidae sp. UK2	0.33	0.00	0.00	0.00	0.00	0.00	0.00	
Curculionidae	Curculionidae sp. UK1	0.33	0.00	0.00	0.00	0.00	0.00	0.00	
Gyrinidae	*Macrogyrus ?paradoxus*	0.22	0.00	0.11	0.00	0.00	0.00	0.00	
	Gyrinidae sp. (L)	0.11	0.00	0.44	0.00	0.60	0.00	0.00	
Hydrophilidae	Laccobius ?bicuadatus	0.00	0.00	0.00	0.00	0.00	0.11	0.00	
	Laccobius sp.	0.00	0.00	0.00	0.00	0.00	0.22	0.00	
	Berosus australiae	0.00	0.11	0.00	0.00	0.00	0.00	0.00	
	Berosus sp. (L)	0.00	0.00	0.00	0.00	0.00	0.00	1.00	
	Enochrus deserticola	0.33	0.11	0.00	0.00	0.00	0.00	0.00	
	Helochares marreensis	1.00	0.56	0.00	0.00	0.00	0.00	0.00	
	Helochares sp. UK2	0.11	0.00	0.00	0.00	0.00	0.00	0.00	
	Helochares clypeatus	0.11	0.00	0.00	0.00	0.00	0.00	0.00	
	Georissus sp.	0.22	0.00	0.00	0.00	0.00	0.00	0.00	
	Hydrochus sp.	2.11	0.78	0.00	0.00	0.00	0.00	0.00	
	Paracymus pygmaeus	2.44	0.78	0.00	0.00	0.00	0.11	0.25	
	Regimbartia attenuata	1.67	0.22	0.00	0.00	0.00	0.00	0.00	
	Hydrophilidae sp. (L)	0.22	0.11	0.00	0.00	0.00	0.11	0.13	
	UD sp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	UD sp A	0.56	1.00	0.00	0.00	0.00	0.00	0.00	
	UD sp B	0.89	0.33	0.00	0.00	0.00	0.00	0.00	
	UD Coleoptera (L)	0.00	0.00	0.00	0.00	0.20	0.33	0.00	
Hydraenidae	*Hydraena ?impercepta*	0.00	0.11	0.00	0.00	0.00	0.00	0.00	
	Hydraena sp2	1.22	0.78	0.00	0.11	0.00	0.00	0.00	
	Hydraena trapezoidalis	0.89	0.00	0.00	0.00	0.00	0.00	0.13	
	Hydraena sp4	0.11	0.00	0.00	0.00	0.00	0.00	0.00	
	?Octhebius sp. UK1	1.33	0.22	0.00	0.00	0.00	0.00	0.13	
Staphylinidae	Staphylinidae sp. UK1	0.22	0.11	0.00	0.00	0.00	0.00	0.00	
	Staphylinidae sp. UK2	0.11	0.11	0.00	0.00	0.00	0.00	0.00	
	Staphylinidae sp. UK3	0.00	0.11	0.00	0.00	0.00	0.00	0.00	
Elmidae	*Austrolimnius* sp. UK1	0.00	0.00	0.89	0.00	1.20	0.00	0.00	
	Austrolimnius sp. (L)	0.00	0.11	2.78	0.22	1.80	0.00	0.13	
Carabidae	Carabidae sp. UK1	0.67	0.67	0.00	0.00	0.00	0.00	0.00	
	Total Richness	103	81	65	32	55	45	86	**171**

9.6 Appendix 6. MDA for macroinvertebrate UPGMA groups

Appendix 6. Canonical discriminant function coefficients of physico-chemical variables against *a posteriori* UPGMA groups derived from macroinvertebrate data. Numbers in parentheses indicate the rankings of each variable on each discriminant function. The proportion of variation explained by each function is also presented.

Variable	DF1		DF2		DF3		DF4		DF5	
Mineral	-0.90	(1)	0.15	(7)	0.17	(4)	0.00	(9)	0.17	(7)
depthM	0.75	(2)	0.04	(9)	-0.07	(6)	0.13	(6)	-0.02	(9)
velocM	-0.36	(3)	0.87	(1)	0.00	(9)	-0.14	(5)	-0.20	(6)
Detritus	-0.35	(4)	-0.55	(2)	-0.04	(8)	0.50	(1)	-0.33	(3)
habdiv	0.25	(5)	-0.35	(3)	0.04	(7)	-0.23	(3)	-0.21	(5)
tempT	0.24	(6)	0.22	(5)	0.37	(3)	0.44	(2)	0.47	(1)
Sand	0.12	(7)	-0.33	(4)	0.16	(5)	-0.21	(4)	0.34	(2)
salinity	-0.12	(8)	-0.16	(6)	0.60	(2)	-0.10	(8)	0.32	(4)
turbT	0.05	(9)	-0.10	(8)	0.95	(1)	0.11	(7)	-0.10	(8)
Significance	< 0.0001		< 0.0001		< 0.0001		< 0.0001		< 0.0028	
% variance	55%		28%		10%		4%		2%	

9.7 Appendix 7. AusRivAS spring channel habitat model output

Appendix 7. AusRivAS Spring channel habitat model outputs for each replicate sample from Gravel Runs, Rapids and Sand habitats (GR = gravel run, RA = rapids, SA = sand), reach (U = upper, M = middle, L = lower) and replicate number.

Site	NTE50	NTP50	NTC50	OE50	ESignal	OSignal	OESignal	Band
GR-L-1	14.38	18	11	0.77	4.86	5.73	1.18	B
GR-L-2	14.38	18	9	0.63	4.86	5.56	1.14	B
GR-L-3	14.38	18	9	0.63	4.86	5.56	1.14	B
GR-M-1	14.38	18	11	0.77	4.86	5.00	1.03	B
GR-M-2	14.38	18	10	0.70	4.86	5.50	1.13	B
GR-M-3	14.38	18	8	0.56	4.86	5.63	1.16	B
GR-U-1	14.38	18	8	0.56	4.86	5.63	1.16	B
GR-U-2	14.38	18	10	0.70	4.86	5.80	1.19	B
GR-U-3	14.38	18	11	0.77	4.86	5.73	1.18	B
RA-L-1	14.38	18	8	0.56	4.86	5.63	1.16	B
RA-M-1	14.38	18	9	0.63	4.86	5.56	1.14	B
RA-U-1	14.38	18	8	0.56	4.86	5.13	1.05	B
RA-U-2	14.38	18	13	0.90	4.86	5.38	1.11	A
RA-U-3	14.38	18	9	0.63	4.86	5.56	1.14	B
SA-L-1	14.38	18	5	0.35	4.86	4.60	0.95	C
SA-L-2	14.38	18	1	0.07	4.86	5.00	1.03	D
SA-L-3	14.38	18	3	0.21	4.86	3.33	0.69	D
SA-M-1	14.38	18	9	0.63	4.86	4.56	0.94	B
SA-M-2	14.38	18	4	0.28	4.86	3.50	0.72	C
SA-M-3	14.38	18	9	0.63	4.86	4.67	0.96	B
SA-U-1	14.38	18	8	0.56	4.86	5.13	1.05	B
SA-U-2	14.38	18	7	0.49	4.86	5.43	1.12	C
SA-U-3	14.38	18	7	0.49	4.86	4.57	0.94	C