

Appendix A

Macroinvertebrate Report



Australian Government

Department of the Environment, Water, Heritage and the Arts
Supervising Scientist

**An assessment of the effects of mine waste
waters arising from the Redbank copper mine
on downstream macroinvertebrate
communities, March 2008**

for

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November 2008

Registry File SG2008/0069

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Acknowledgments

We thank Dr James Searle of Redbank Mines Ltd for instigating this consultancy with **eriss** and for organising all aspects of the field work associated with the study. We are also grateful to Rob Sowerby from the neighbouring Lagoon Creek Resources P/L exploration camp for arranging the hiring of a helicopter on lease to his company for access to a number of the Redbank receiving water sites.

We are particularly grateful to Cyrus Edwards of the NT Department of Regional Development, Primary Industry, Fisheries and Resources (DRDPIFR) for general advice including advice on sampling locations, access to sampling sites and for historic water quality and macroinvertebrate data gathered from Redbank sites by NT DRDPIFR for contextual comparison.

David Jones of **eriss**, and Cyrus Edwards and Michael Walsh from NT DRDPIFR provided critical comments and valuable suggestions on drafts of this report.

Executive summary

1. In March 2008, macroinvertebrate samples and accompanying water and sediment samples were collected from 15 stream sites in the vicinity of Redbank mine. There were 6 'exposed' sites (impacted or potentially impacted) located along Echo, 12 Mile and Settlement Creeks, and 9 reference sites located on Redbank, Echo, 12 Mile, Settlement, 7 Mile and Branch Creeks.

Water and sediment quality results

2. Multivariate analysis of the water and sediment quality data showed that the dominant influence on receiving waters and sediments was a mine disturbance gradient associated with elevated acidity, Cu, Mn, Al, Co, Zn, Ni and sulphate in waters, and elevated Cu, Co, Ni, S, Zn and Al in sediments. The next dominant water quality influence on receiving waters related to catchment geology: the influences of the Masterton sandstone in close contact with upland streams in the immediate vicinity of the mine site (soft, low solute concentration waters), and the mainly shale and volcanic geology associated with lowland streams (harder, higher solute concentration waters).
3. Water and sediment chemistry values from key sampling sites exceeded the current Australian Water Quality Guidelines toxicant triggers for ecosystem health for a number of metals – from numerous exceedances across a range of parameters just downstream of the minesite to much reduced contamination (by Cu only) 36 km downstream in lower Settlement Creek.
4. While surface waters followed a gradient of decreasing concentrations of mine-derived contaminants with increasing distance downstream of the minesite, highest sediment concentrations for Cu, Ni and Zn were observed at an intermediate site, 18 km downstream of the minesite (on 12 Mile Ck), and just upstream of the confluence of 12 Mile Creek with Settlement Creek. The formation of backed-up, slack waters at this site during high flow events, from the greater flows in Settlement Creek immediately downstream, most likely contributes to the deposition of finer (silt/clay), contaminant-laden sediment particles at this site.

Macroinvertebrate community response

5. Macroinvertebrate (family-level) taxa number and total abundance were substantially lower at mine-exposed stream sites compared with reference sites. There was a general increase, and hence recovery, downstream in taxa number and total abundance such that these summary values at Settlement Creek 36 km downstream of Redbank (site SC3) were consistent with those recorded at reference sites.
6. Multivariate ordination of taxa abundance data showed distinct separation of exposed and reference sites. However, exposed site SC3 on Settlement Creek plotted amongst reference sites, a pattern also observed in the corresponding water and sediment chemistry ordination, and consistent with taxa number and total abundance results reported in numbered point 5 above.
7. Macroinvertebrate taxa most influential in separating exposed and reference sites had greatly reduced abundances at the exposed sites. The dominant 10 taxa included two mayfly families (Caenidae, Baetidae), two non-biting midge subfamilies (Chironominae,

Tanypodinae), two microcrustacean groups (Ostracoda, Cladocera), two caddisfly families (Philopotamidae, Hydroptilidae), mites (Oribatidae) and worms (Oligochaeta).

8. Significant negative relationships were observed between community summaries and key metals in water and sediment, indicating the adverse impacts of mine waste water dispersion to receiving water health. The strongest negative relationships were generally found for Cu in water and sediment. Significant relationships were also found between community summaries and percent of substrate cover comprising filamentous algae, and two riparian descriptors, proportion of the sampled stream length with overhanging riparian vegetation and proportion of the sampled stream length with riparian vegetation draped in water. These metal-habitat relationships also appeared to reflect adverse effects of mine water input on receiving waters. Two of the strongest environmental correlates of the macroinvertebrate ordination space (depicting community structure) were Zn in water and Cu in sediment.
9. Species-level data were acquired from the three Redbank Creek sites. These data will provide important ecological baseline and conservation assessment information to assess future mining that is planned for the Redbank, Azurite and Bluff copper deposits. The data also expand the knowledge of distributions of macroinvertebrate taxa for northern Australia generally and provide useful contextual information for future conservation assessments for the region. None of the species present at the three Redbank sites appeared to be restricted in distribution and/or locally-endemic.

Interannual observations

10. NT Department of Regional Development, Primary Industry, Fisheries and Resources (DRDPPIFR) have assessed water quality and macroinvertebrate communities in receiving waters downstream of Redbank in past years. The contaminant concentration gradients observed in 2008 were also evident in NT DRDPPIFR data from 2003 and 2006. Further and similarly, macroinvertebrate communities sampled in Settlement Creek in this 2008 study and by NT DRDPPIFR in 2003 and 2004 displayed much lower taxa number and total abundance at the exposed site, SC2, compared with reference site values at SC1, just upstream. For both 2008 and 2003/2004 sampling periods, the two mayfly families, Caenidae and Baetidae, and non-biting midge subfamily, Chironominae, were observed to be influential in distinguishing reference sites from exposed sites (i.e. were dominant taxa in reference sites).
11. Given the general similarity in results of this study compared with those reported by NT DRDPPIFR in past years, there is no evidence for any improvement in water quality and stream health in recent years.

Recommendations

1. Macroinvertebrate assemblages sampled in the March 2008 study clearly demonstrated mine-related impacts arising from the Redbank mine upon receiving waters. To this end, periodic (end-of-wet season) macroinvertebrate sampling should continue in future, using the general configuration of sites used in the current survey. Over time, the results can be used to monitor system recovery.
2. Improvements to the design of future sampling at Redbank receiving water sites could include the relocation of sites immediately below reference-exposed creek confluences – such as ECDS, 12MDEC and SC2 – to locations further and sufficiently downstream so as to avoid mixing zones and artefacts arising from drift of organisms from the reference

stream immediately upstream that gives the appearance of better-than-expected macroinvertebrate diversity and stream health.

3. A zone of recovery in stream health was evident in this study for Settlement Creek between 18 km (SC2) and 36 km (SC3) downstream of the Redbank minesite. Should significant remedial works be undertaken at the minesite in future, further downstream recovery would presumably be first detected in Settlement Creek. To this end, future surveys should focus on Settlement Creek; better definition of the extent and degree of impact between sites SC2 and SC3 would provide an improved basis for detecting and assessing system recovery.
4. The current Australian Water quality Guidelines recommend that ecological baseline data be gathered for stream sites for a minimum of three years prior to planned developments. It is recommended, therefore, that annual sampling continue in Redbank Creek, a receiving water potentially exposed to any mine wastes arising from future development of the Redbank, Azurite and Bluff copper deposits.
5. Redbank receiving waters offer a variety of different habitats from which to sample macroinvertebrate communities for monitoring. A dedicated study should be conducted in future at selected stream sites, sampling different habitats at each site and examining results from samples processed separately from the different habitats. This comparison would identify the most appropriate habitat(s) to sample and monitor in future.
6. Sediment samples collected from sites RC2, ECU12MC, 12MUEC, 7MC1 and BC1 were not analysed. These archived samples should be chemically analysed in the near future and statistical analyses re-run to more accurately characterise the impact of sediment contamination arising from inputs of water from the the Redbank mine.

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An assessment of the effects of mine waste waters arising from the Redbank copper mine on downstream macroinvertebrate communities, March 2008

1. INTRODUCTION

1.1 Location of study site

The Redbank copper mining operation is located in the Gulf region of the Northern Territory, just inside the border with Queensland (Figure 1), and in the central-west of the Wollogorang pastoral lease. While copper mining commenced in the Redbank area as early as 1916, it was not until the mid 1990s that larger-scale operations were carried out with the development of the Sandy Flat pit (Earthsciences 2007). Development and mining of the Sandy Flat pit led to significant downstream pollution of receiving waters by acidic, copper-laden wastes, a legacy the current operator, Redbank Mines Ltd, inherited in 2006 and has committed to remediating.

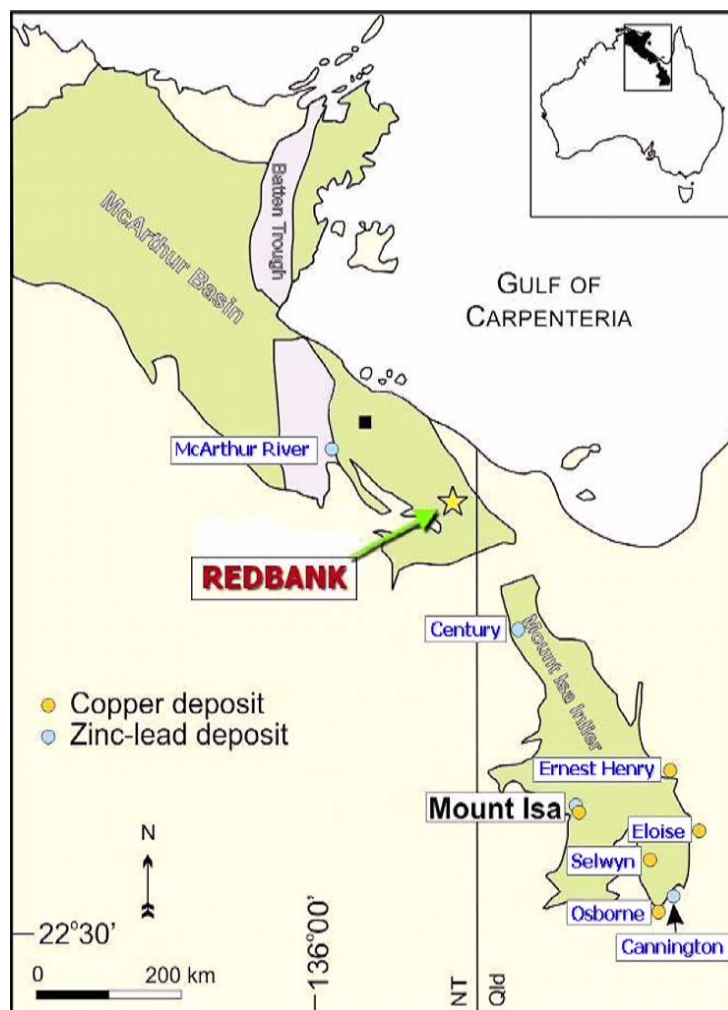


Figure1 Location of Redbank copper mine in the Northern Territory (from Earthsciences 2007)

1.2 Project scope and objectives

In March 2008, Redbank Mines Ltd commissioned **eriss** to conduct a program of biological monitoring for local receiving water streams adjacent to the mining operations using aquatic macroinvertebrates as indicators. The results of the study were required for two purposes: (i) to assess the health of streams as part of NT Government license conditions to release treated mine waters to the environment, and (ii) to provide an ecological baseline to assess future impacts of expanded mining that is planned by the company for its Redbank, Azurite and Bluff copper deposits located on or near the current mining operations. (See <http://www.nt.gov.au/nreta/environment/assessment/register/redbank/pdf/finalredbankguidelinesoct08.pdf> for further background on the expanded mining proposal.)

1.3 Technical background

The technical basis for the use of aquatic macroinvertebrates for biological monitoring of water quality is well established (ANZECC & ARMCANZ 2000) and to this end, macroinvertebrates have been selected as the key indicator group for bioassessment of the health of Australia's streams and rivers under the National River Health Program (Schofield & Davies 1996). Active state/territory agency programs using the so-called 'AUSRIVAS'¹ approach, underpinned by extensive Research and Development, are well established across the country. Staff from NT Department of Regional Development, Primary Industry, Fisheries and Resources (DRDPIFR) have undertaken similar but limited macroinvertebrate sampling in the streams around Redbank in 2003 and 2004, thus providing a time series of data for comparison with the results from this current project.

The NT DRDPIFR has conducted its earlier macroinvertebrate sampling and laboratory sample processing (subsampling, sorting and macroinvertebrate identifications) according to AUSRIVAS methodology, though data analysis and reporting have employed traditional, non-AUSRIVAS techniques for assessment of site health and condition (Cyrus Edwards, pers comm) because of the lack of AUSRIVAS models relevant to eastern portions of the NT (see item (ii) below). In the present study, the following modifications to, or departures from, AUSRIVAS methodology were made in sample collection and reporting of results:

- (i) AUSRIVAS models used throughout Australia are specific to particular habitats. In the NT, different habitats have been sampled in the past (edge, riffle, sand) but models have been based only on 'edge' habitat. In the present study, samples from each site were collected from both edge and riffle habitat before being combined into a composite site sample. Sampling both edge and riffle habitats was undertaken in order to maximise macroinvertebrate diversity for conservation and biodiversity assessment (in particular, Redbank Creek baseline), as well as potential response to contaminants given that each habitat will both support taxa common to all habitats as well as those that may be more unique to a particular habitat.

¹ The basis of AUSRIVAS is the development of predictive models of the macroinvertebrate community composition expected at a site in the absence of significant human disturbance. The predictor variables are environmental, and the models are derived from multivariate classification and multiple discriminant analysis procedures. The model outputs, based upon input of several predictor environmental variables, are the expected macroinvertebrate families (type and number) at the site in the absence of disturbance. Thus, to assess impairment of environmental quality, the *observed* (O) macroinvertebrate composition is compared with the *expected* (E) composition viz. a O/E ratio. Bands across the 0-1 scale of resulting values define the level of site impairment.

- (ii) Laboratory processing of samples differed from that described in the current NT AUSRIVAS manual (Lamche 2007) in that (a) the animals present in the 250-500 μm fraction of samples, and (b) microcrustaceans, were recovered and included in taxa counts (both omitted in the NT protocol). As for (i) above, the rationale at the time for these modifications was to maximise macroinvertebrate diversity.
- (iii) Reliable AUSRIVAS models for eastern NT locations have not yet been developed because of a general paucity of sampling that has been conducted in this part of the NT (G Lamche pers comm).

In other respects and similar to NT DRDPFR's studies at Redbank in past years, key aspects of the AUSRIVAS protocol were adhered to closely in the present study. These included the sampling of 10 m of habitat (5 m for each of edge and riffle habitat in the present study) and most of the procedures involved in the laboratory processing of samples (subsampling, sorting and identifications).

When compared with earlier NT DRDPFR results, the compositing of habitat samples in the present study could lead to (i) higher taxa numbers (since two habitats were sampled), (ii) higher abundances (since riffle habitat often harbours higher densities of macroinvertebrates than other habitats), (iii) different community structures (as a consequence of (i) and (ii)), and (iv) similar *relative* differences reported amongst sites. The effects of different sampling times and flow conditions (March 2008 versus May 2003 and 2004), however, could confound these expectations. This assessment would need to be confirmed by way of a future, dedicated study at Redbank examining results from samples collected and processed separately from different habitats. This assessment would most benefit the design of future sampling and monitoring at Redbank.

2. METHODS

2.1 Sites and sampling design

The location of the Redbank mine site in relation to local streams and sampling sites is shown in Figure 2. Metal-rich water from the Sandy Flat mine drains to the adjacent small, seasonally-flowing stream, Hanrahans Creek, which joins Echo Creek about 1.5 km downstream of the mine. A further 3.6 km downstream of the Echo-Hanrahans junction Echo Creek joins with 12 Mile Creek. A further 12 km downstream, 12 Mile Creek joins Settlement Creek which flows past Wollogorang Station then into Queensland before discharging to the Gulf of Carpentaria (Earthsciences 2007). According to Earthsciences (2007), there is very little groundwater expression into these catchments² and so all creeks cease flowing in the early dry season at about the same time. However, Echo and Settlement Creeks appear to cease flowing later than 12 Mile Creek (upstream of Echo Creek). As a consequence, the prolonged flow into Settlement Creek increases concentrations of mine water contaminants in Settlement Creek during the recessional flow period (Earthsciences 2007).

With this background, stream sites were selected from within and outside the Redbank mine lease and encompassed, as best as possible, a full gradient of potential Cu concentrations in water and sediment, as well as a sufficient suite of non-mine influenced reference sites for comparison.

² Dr David Jones of *eriss*, however, observes that groundwater flow in the alluvials down-gradient of the Sandy Flat mine pit typically extends well into the dry season.

Table 1 List of exposed and reference sites in the vicinity of Redbank Mine used to monitor and assess effects of mine waste water dispersion upon macroinvertebrate communities

Site code	Site	Site co-ordinates (decimal degrees)		Date sampled	Exposure type and additional rationale
		Latitude	Longitude		
RC1	Redbank Ck Site 1	17.16642	137.76572	15/03/2008	Reference; Baseline to assess future mining on and around the current mine site
RC2	Redbank Ck Site 2	17.1638	137.7758	15/03/2008	As for RC1
RC2A	Redbank Ck site 2A. Track crossing	17.16339	137.78732	17/03/2008	As for RC1
RC3	Redbank Ck Site 3	17.15749	137.79791	15/03/2008	As for RC1
ECUS	Echo Ck upstream of Hanrahans Ck confluence	17.20275	137.72537	16/03/2008	Reference
ECDS	Echo Ck downstream of Hanrahans Ck confluence	17.20331	137.72482	16/03/2008	Exposed
ECU12MC	Echo Ck upstream of 12 Mile Ck confluence	17.22712	137.71336	18/03/2008	Exposed
12MUEC	12 Mile Ck upstream Echo Ck confluence	17.22713	137.71301	18/03/2008	Reference
12MDEC	12 Mile Ck downstream of Echo Ck confluence	17.22758	137.71362	18/03/2008	Exposed
12MC1	12 Mile Ck site 1, upstream of Settlement Ck confluence	17.2787	137.79703	17/03/2008	Exposed
SC1	Settlement Ck site 1, upstream of 12 Mile Ck confluence	17.27955	137.79795	17/03/2008	Reference
SC2	Settlement Ck site 2, downstream of 12 Mile Ck confluence	17.27896	137.7981	17/03/2008	Exposed
SC3	Settlement Ck site 3, Wollogorang Road crossing	17.21723	137.93147	16/03/2008	Exposed
7MC1	Seven Mile Ck, Wollogorang Road crossing	17.21731	137.80729	16/03/2008	Reference
BC1	Branch Ck (QLD), Wollogorang Road crossing	17.21149	138.01994	16/03/2008	Reference

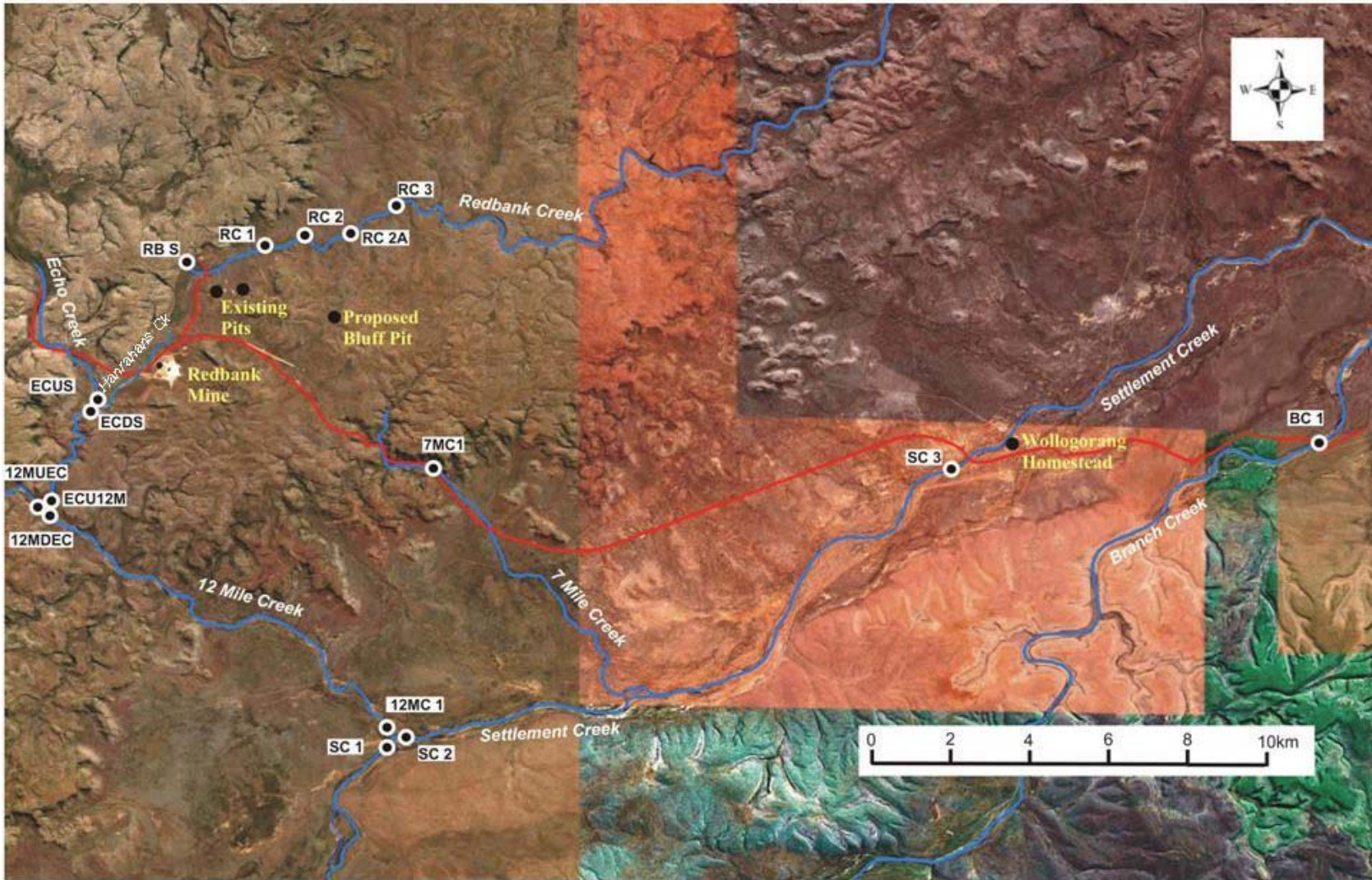


Figure 2 Location of Redbank sampling sites. Refer to Table 1 for site codes

Fifteen sites were sampled. These comprised 6 ‘exposed’ (impacted or potentially impacted) sites: two on each of Echo, 12 Mile and Settlement Creeks; and 9 reference sites: four on Redbank Creek, one each on Echo, 12 Mile and Settlement Creeks, as well as one each on 7 Mile and Branch Creeks, additional tributaries of Settlement Creek (Table 1 & Figure 2). Photographs of each of the 15 sites are contained in the plates of Appendix C. As indicated in Table 1, data from all sites were gathered to assess the impacts to receiving waters from legacy or current operations. Results from Redbank Creek sites will also provide an ecological baseline to assess future mining that is planned by the company for its Redbank, Azurite and Bluff copper deposits. Two of the sites sampled for macroinvertebrates in the present study, SC1 and SC2 (Table 1), were also sampled by NT DRDPFR in May 2003 and 2004.

Sampling was conducted during the late wet-recessional flow period of 2008 (March 15-18). While rainfall in the wet season to this point had been below average (Table 2), there were adequate to good flow conditions at all sites at the time of sampling (see discharge estimates in Appendix A, Table A1-B).

Table 2 Monthly and annual rainfall measured at Wollongorang Station: average data for 1967-2008 and totals for 2007-08 (Bureau of Meteorology, 2008)

Average rainfall, 1967-2008												
Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Annual
0.7	3.8	22.4	64.6	167.1	210.1	249.4	165.7	38	7.1	3.3	1.4	963.2
2007-2008												
Aug 07	Sep	Oct	Nov	Dec	Jan 08	Feb	Mar	Apr	May	Jun	Jul	Total
10.4	0	16.7	58.7	169.0	140.5	194.2	124	0	0	0	0	713.5

Sampling was conducted in the recessional flow period so as to capture the integrated effects of mine site runoff over the preceding wet season. Even without pre-mining (‘Before’) data, the configuration of replicate exposed and reference sites enables formal statistical comparisons to be made between sites of the different exposure types over time. Macroinvertebrates subjected to unfavourable conditions, such as exposure to high metal concentrations during the wet season, should display differing responses (taxa number, abundances and assemblage structure) than those of reference sites. It was intended that all, or a selection of, sites from those sampled in 2008 would be selected for use in ongoing monitoring.

2.2 Sampling of macroinvertebrate communities

2.2.1 Habitat selection

As stated above, samples from each site were collected from both edge and riffle habitat before being combined into a composite site sample. Habitats were defined as follows:

Riffles: Selected on the basis of ‘rapid’ stream velocity usually ($> 0.1\text{m/sec}$) over coarse-grained sediments (gravel-cobbles, 4–256 mm diameter sediment particles) in shallow ($< 0.4\text{ m}$) waters at the downstream end of pools;

Edge: Stream edges, typically just upstream of riffle zones, and dominated mainly by sandy substrates that may also have included root matting, and/or large tree roots. Sampling amongst aquatic plants and logs was avoided as far as possible. Water velocities were lower, and stream widths greater, than those recorded across riffles.

2.2.2 Macroinvertebrate sampling and sample processing

At each site, macroinvertebrate samples were collected using a composite-habitat modification to the standard national AUSRIVAS protocol. A kick sample was taken using a dip net (250 µm mesh), disturbing the substrate, benthos and overlying habitat by foot or hand, generally in a progressive upstream direction. Each sample represented the equivalent total of 10 m x 0.3 m of disturbed habitat, with equal (50:50) effort in each of riffle and edge habitat. After collection, the samples were washed through nested sieves (8 mm and 250 µm) to remove excess organic matter and detritus. Samples were placed in 500 or 1,000 mL pots and preserved in 80-90% ethanol for later laboratory sorting and identification.

In the laboratory, preserved samples were sub-sampled using a multi-cell subsampler and sorted under a stereo microscope, until a target of 200 animals was reached. The percentage subsample of the sample examined was recorded so that animal numbers could later be scaled up to those equivalent of the full sample size. All sorted samples were identified to family (or higher taxonomic) level, consistent with AUSRIVAS 'family-level' taxonomic resolution (Lamche 2007) with the exception that microcrustacean taxa (Cladocera, Copepoda and Ostracoda), were *included* in the taxa lists and counts from the present study. Three Redbank Creek sites were further identified to species level for conservation and biodiversity assessment (pre-mining, baseline data).

2.3 Sampling of environmental variables

At each site, a range of water and sediment quality and habitat variables was measured and assessed in association with macroinvertebrate sampling – see Table 3. The exception to this was sediment chemistry analyses which were not performed for samples collected from sites RC2, ECU12MC, 12MUEC, 7MC1 and BC1.

Field measurements of water temperature, pH, electrical conductivity, dissolved oxygen and turbidity were performed at all sites using a calibrated TPS 90-FL multi-parameter water quality meter. Water chemistry and sediment samples were collected in accordance with existing, in-house protocols. Filtered water samples (< 0.45 µm) were collected and analysed. Sediments were collected from 'edge' habitat and their characterisation also focused on the < 63 µm (bioavailable) fraction (Table 3) using a weak acid (1M HCl) digest method. The environmental data were collected in order to assess the degree and extent of chemical contamination in receiving waters and also to assist in interpreting differences in biological assemblage structure and associated community summaries.

2.4 Macroinvertebrate data compilation and analysis

2.4.1 Community summaries

All results, including taxonomic lists, abundance data, physico-chemical measurements (Table 3) and GPS locations, were entered onto a Microsoft 'Excel' spreadsheet. Raw data are provided in the appendices to this report. Community summaries were derived for number of taxa and total number of organisms (= total abundance), and plotted according to site and habitat. Cross-correlation of community summaries with environmental data was conducted

using the correlation analysis tool of Excel. Preparation of environmental data for correlation analysis is described below ('Multivariate analysis' step 4b). The population correlation calculation (also equivalent to Pearson's correlation coefficient) returns the covariance of two data sets divided by the product of their standard deviations. Regression analysis was performed on selected significant correlations to examine the nature of the relationships.

Table 3 Site variables measured or collected at each site at the time of sampling.

Category	Feature/analyte	Units
Water quality variables	Water temperature ¹	°C
	pH ¹	
	Electrical conductivity ¹	µS/cm
	Dissolved oxygen ¹	mg/L
	Turbidity ¹	NTU
	Alkalinity	mg/L
	Ca, K, Mg, Na, SO ₄	mg/L (filtered)
	Al, Co, Cu, Fe, Mn, Ni, Pb, U, Zn	µg/L (filtered)
Sediment quality variables (<63 µm fraction)	Al, Cu, Fe, Mg, S, Zn, Pb	mg/kg
	Approx proportion of sediment <63 µm	%
Habitat variables: General	Stream velocity at riffle ²	m/sec
	Stream velocity at riffle (average from X-section profile) ^A	m/sec
	Discharge estimate	L/sec
	Stream width - pool	m
	Stream width - riffle	m
	Avg depth at riffle	m
	Max depth in pool	m
	Bank angle (shelving-undercut)	1-4
	Distance of overhang riparian vegetation	%
	Cover riparian vegetation	%
	Coarse organics omitted from sample	%
Habitat variables: Mineral substrate (%) and compaction	Bedrock	%
	Boulders (>256 mm)	%
	Cobbles (64-256 mm)	%
	Pebbles (16-64 mm)	%
	Gravel (4-16 mm)	%
	Sand (1-4 mm)	%
	Silt (< 1 mm)	%
	Clay	%
	Particle size graphic mean	mm
	Bed compaction (high-low)	1-5
Habitat variables: Site habitat area (%) and macrophyte composition	Mineral substrate	%
	Emergent macrophyte	%
	Submerged Macrophyte	%
	Floating Macrophyte	%
	Filamentous Algal Cover	%
	Detritus	%
	Riparian veg. draped in water	%
	Root mats	%
	Large Woody Debris	%

Superscripts: 1 = water quality variables measured in the field only; 2 = stream velocity measured as the time taken for a floating object to pass a set linear distance

2.4.2 Multivariate analysis

Abundance data from the community results were analysed using multivariate procedures from the PRIMER (v6) software package (Clarke & Gorley 2006). Four levels of multivariate analysis were applied to the data:

1. Describing pattern amongst the assemblage data using ordination. The basis of these analyses was Bray-Curtis similarity matrices performed on $\log(X+1)$ transformed data. The ordination method used was Multi-Dimensional Scaling (MDS) (Clark & Warwick 2001). Ordinations were depicted as two-dimensional plots based on the site by site similarity matrices.
2. For comparison of exposed versus reference site groupings, Analysis of Similarity (ANOSIM) – effectively an analogue of the univariate ANOVA – was conducted to determine if these were significantly different from one another. The ANOSIM test statistic compares the observed differences *between* groups (exposure type) with the differences amongst replicates *within* the groups. The test is based upon rank similarities between samples in the underlying Bray-Curtis similarity matrix. The degree of separation between groups is denoted by the R-statistic, where R-statistic > 0.75 = groups well separated, R-statistic > 0.5 = groups overlapping but clearly different, and R-statistic < 0.25 = groups barely separable. A significance level $< 5\%$ = significant effect/difference.
3. The SIMPER routine was used to examine which taxa were contributing to the differences of exposure groups that were found to be different according to the ANOSIM procedure.
4. The relationship between the environmental and biotic data was assessed in two ways:
 - a. For visualization, the numeric value of key environmental data were superimposed onto MDS ordinations, as circles of differing sizes – so called ‘bubble plots’.
 - b. The BIOENV routine was used to calculate the smallest subset of environmental variables explaining the greatest percentage of variation in the ordination patterns.

The BIOENV routine produces similarity matrices of the environmental variables, selecting those that “best explain” patterns in the biological community data. In particular, the procedure takes combinations of the environmental variables, k at a time, and derives the best matches of biological and environmental similarity matrices for each k , as measured by (in this case) Spearman rank correlation. The routine performs best on a relatively small environmental data set and to this end, it is preferable to eliminate as many correlated variables as possible. To identify redundant variables, cross-correlation amongst environmental data was conducted using (i) draughtsman's displays (scatter plot matrix) using PRIMER, and (ii) correlation using the correlation analysis tool of Excel (described above, ‘Community summaries’). Draughtsman's plots were also used to determine whether transformations of variables (usually log) were required for correlation (and any subsequent) analyses. (Transformations were not applied to pH nor proportional/percentage data.) Prior to correlation (and any subsequent) analysis, chemical variables that were below the detection limit were assigned values of half the detection limit.

Generally, where a correlation coefficient was higher than 0.9 and there was a sound technical explanation for the high correlation, then one or more of the (redundant) variables was

eliminated from the data set for BIOENV analysis. This analysis showed the following correlations and redundant variables:

Correlated variable(s) to be eliminated:

- Water chemistry variables: Mg (correlated with EC), Ca (correlated with alkalinity) and Co, Mn, Ni and SO₄ (correlated with Cu);
- Sediment chemistry variables: U (correlated with Al), Ca and Mn (correlated with Mg) and Co and Ni (correlated with Cu);
- Habitat variables: Stream width at the riffle (correlated with stream discharge) and percentage of boulders in the riffle (correlated with PSGM – particle size graphic mean).

The final suite of variables included in the BIOENV routines was:

- Habitat and geo-reference variables: Latitude, longitude, stream velocity at riffle, discharge estimate, stream width across pool, average depth at riffle, maximum depth in pool, stream bank angle, proportion of riparian vegetation characteristics (cover, overhanging and draped in water), coarse organics omitted from sample, proportion of riffle substrate fractions (bedrock, cobbles, pebbles, gravel, sand and silt), particle size graphic mean, bed compaction, proportion of both mineral and detritus substrate, proportion of aquatic plants (emergents, submerged, floating and filamentous algae), and proportions of root mats and large woody debris.
- Water chemistry variables: field measurements of pH, EC, temperature, turbidity and dissolved oxygen, alkalinity, Al, Cu, Fe, K, Na, Pb, U and Zn (all metals filtered fraction).
- Sediment variables: Al, Cu, Fe, Mg, S, Zn, Pb and approximate % of sample <63 µm.

Sediment chemistry analysis was not performed for samples collected from sites RC2, ECU12MC, 12MUEC, 7MC1 and BC1 (see above). With the exception of site ECU12MC, the other four sites for which data were not obtained are reference sites. To complete the full site environmental dataset for both BIOENV and PCA analysis, missing sediment chemistry data were interpolated or extrapolated as follows: site RC2 data were taken as the average of RC1 and RC3 data; site ECU12MC data were copied from those measured upstream at site ECDS; site 12MUEC data were taken as the average of those calculated from reference sites RC1, RC2 and ECUS; and 7MC1 and BC1 data were copied from those measured SC1. While this in-filling of missing data constitutes pseudo-replication and would lead to inaccuracies, it was believed that the benefits in information obtained by completing the dataset in this way outweighed the removal of these sites from the analyses altogether. It is conceivable that inaccuracies are reduced given that four of the five sites are reference sites which, from the values of corresponding water chemistry data, display relatively low variability compared with data from exposed sites (Appendix A, Table A2-A). Moreover, the inter/extrapolations for reference sites lacking sediment data, as described above, were performed such that catchment geology was matched as closely as possible (see section 3.1.1). Notwithstanding and at this stage, results arising from BIOENV and PCA analysis are regarded as interim until processing and analysis of the additional sediment samples has been conducted, and the data analysis repeated.

For community summary and multivariate analyses involving the combination of earlier (NTDRDPIFR) and current macroinvertebrate data, microcrustaceans identified in the present study were excluded from analysis so that taxonomically-consistent datasets were

used. Unless indicated above, default values or procedures recommended in the PRIMER (v6) User Manual (Clarke & Gorley 2006) were employed for PRIMER routines.

2.5 Method of analysis of water and sediment data

Available water and sediment quality data were analysed to determine the degree of contamination and potential impact (viz comparison of values against published national guidelines) arising from Redbank Mine on receiving waters, including Settlement Creek. This analysis does not constitute a fully comprehensive water and sediment quality assessment in the sense that only those analytes, including metals, relevant to the Redbank mine have been considered here. The analysis aims to present an understanding of water and sediment quality conditions downstream of Redbank Mine.

Water and sediment variables were assessed using correlation-based Principal Components Analysis (PCA) (Clarke and Warwick 2001) using the PRIMER (v6) software package (Clarke & Gorley 2006). Like other ordination techniques, PCA reduces the dimensionality of complex data sets, mapping samples or sites, usually in two or three dimensions, so as to reflect the similarity of their biological or environmental attributes. The closer data points are together in the ordination, the more similar are the corresponding samples or sites. Specifically, PCA transforms a number of (possibly) correlated variables into a (smaller) number of primary (uncorrelated) variables called *principal components*. The first principal component accounts for as much of the variability in the data as possible, and each succeeding component accounts for as much of the remaining variability as possible. The starting point for a PCA is a correlation matrix based upon Euclidean distance.

PCA analyses used water and sediment physico-chemistry variables apart from water temperature data (from Appendix A, Table A2). The treatment of variables below the detection limit and those requiring transformation to reduce skewness is described above ('Multivariate analysis' step 4b). Prior to PCA analysis, all data were normalised to account for different measures and measurement scales within the data set.

For visualization, the numeric value of key environmental variables was superimposed onto the PCA ordinations, as 'bubble plots'.

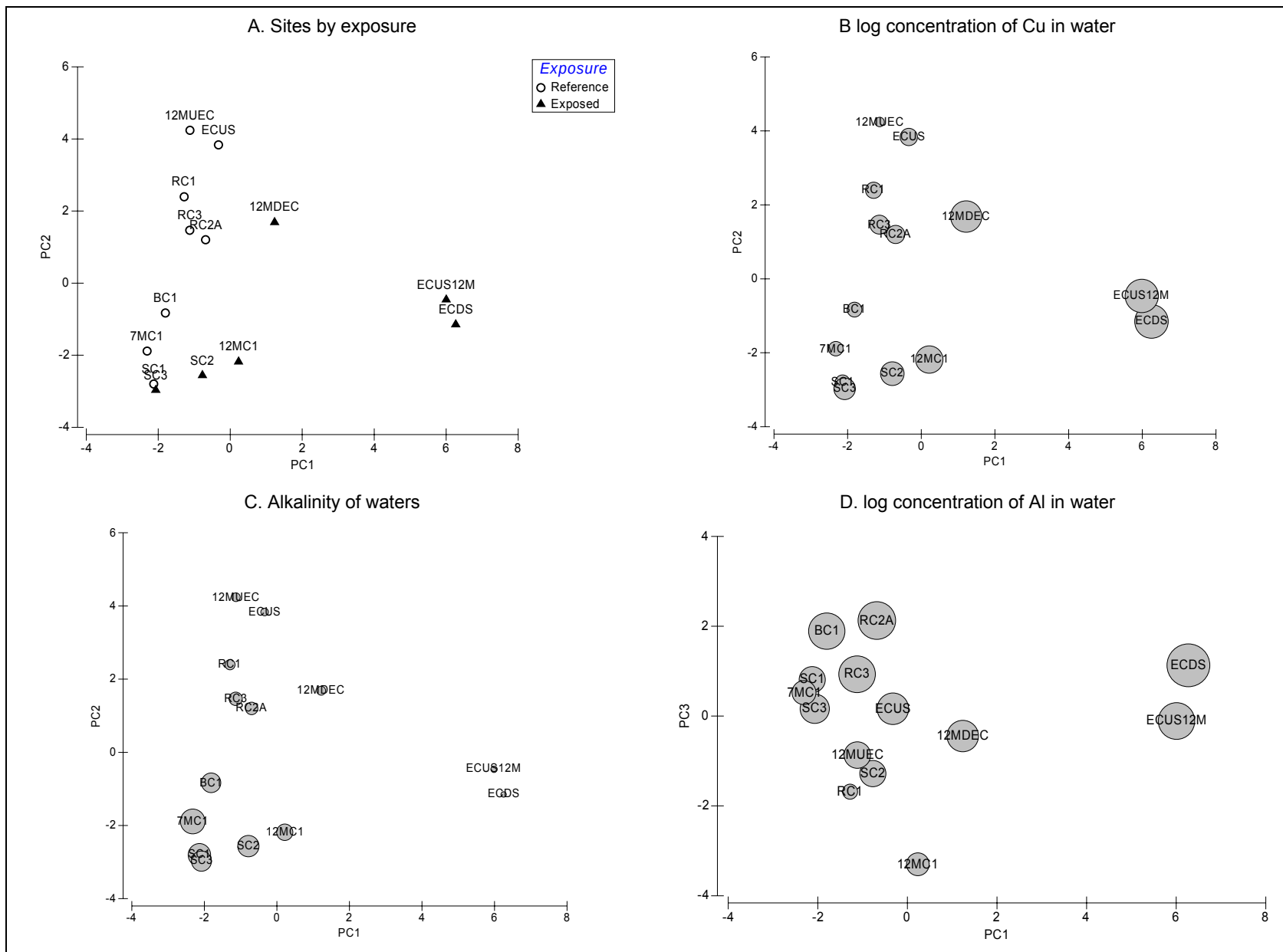
3. RESULTS AND DISCUSSION

3.1 Water and sediment physico-chemistry

Water and sediment data are summarised in Appendix A, Table A2, while habitat variables are summarized in Appendix A, Table A1.

3.1.1 Dominant water quality influences upon receiving waters

Complete results for the Principal Components Analysis conducted on water and sediment chemistry variables (from Appendix A, Table A2), are described in Appendix A, Table A3. Results for Axis 1, 2 and 3 of the analysis, accounting for 79% of the total variance (38, 30 and 11% respectively), are shown in Figure 3. This figure codes sites according to site and exposure type (Figure 3A) with major (exemplary) determinants of the observed gradients expressed by way of bubble plots. (The area of the bubble overlay is proportional to metal concentration.)



The dominant water quality influence upon receiving waters, representing most of the variation in the PCA ordination (38%), is shown along PC Axis 1 which represents a mine disturbance gradient. Axis 1 separates the five exposed sites downstream of Redbank, from right to left and in order of contaminant intensity (ECDS, ECUS12M, 12MDEC, 12MC1 and SC2), from reference sites and exposed site SC3 (Figure 3A). Analysis using bubble plots exemplifies the disturbance gradient in ordination space along Axis 1, using Cu concentrations in water of the respective sites (Figure 3B). A more detailed description of this mine-related spatial gradient is provided below.

The next dominant water quality influence upon receiving waters (30% of the ordination variation), is shown along PC Axis 2 which represents a mainly-natural separation of streams according to catchment geology (Earthsciences 2007): the influences of the Masterton sandstone in close contact with upland streams, Redbank, Echo and 12 Mile Creeks (upper portion of Axis 2), and the mainly shale and volcanic (rhyolite and trachyte) geology associated with lowland streams 7 Mile, Settlement and Branch Creeks to the south-east (lower portion of Axis 2). Typical sandstone influences upon Redbank, Echo and 12 Mile Creeks are reflected in soft, low solute concentration waters (low pH, EC, alkalinity, Ca, K, Na and Mg). The harder, higher solute concentration waters of 7 Mile, Settlement and Branch Creeks reflect the different geology of these catchments. The bubble plot shown in Figure 3C exemplifies the geological separation of sites in ordination space along Axis 2, using alkalinity in water of the respective sites. Both alkalinity and EC are highest in the negative range of Axis 2 and diminish increasingly towards the positive range of the axis. Thus, minewater influences upon Echo Creek at sites ECUS12M and ECDS on the one hand accentuate this gradient (low pH and low alkalinity) and on the other, counter the gradient (high EC) such that the sites lie in the 'neutral' (near-zero) range of Axis 2.

PC Axis 3 represents only 11% of the variation in the PCA ordination and is characterised by high Al and Pb in the waters of two Redbank Creek sites and in minewaters (as reflected in water quality in Echo and 12 Mile Creeks downstream of the minesite). Thus these influences reflect local mineralisation effects – natural and disturbance-related – around Redbank. The bubble plot shown in Figure 3D exemplifies the gradient amongst sites in ordination space along Axis 3, using Al in water of the respective sites.

3.1.2 Spatial and interannual variation in mine-related water and sediment chemistry

As shown in the PCA ordination, water and sediment chemistry results clearly indicate mine-related contamination at sites downstream of Redbank Mine. Metals are above concentrations recorded from reference sites, and water acidity, together with concentrations of Cu, Mn, Al, Co, Zn, Ni and sulfate in water, typically display a gradient of contamination, highest at ECDS closest to the mine site and decreasing downstream. Similar contaminant concentration gradients have also been recorded by NT DRDPIFR in past years, with Cu (in water) concentrations shown in Figure 4 for May 2003 and 2006, together with the March 2008 data from the present study. (The lower Cu concentrations measured in Settlement Creek sites, SC1, SC2 and SC3, in March 2008 compared with 2003 and 2006 may be a consequence of quite high flows (and hence increased dilution) recorded in 2008 as a consequence of overnight rains that occurred in the Settlement Creek catchment just prior to sampling.)

Receiving water sites also show high concentrations of Cu, Co, Ni, S, Zn and Al in the <63 µm fraction of sediments, though the highest sediment concentrations for Cu, Ni and Zn, and to a lesser extent Mn, are more typically observed at the 12 Mile Ck site, 12 MC1, located about 18 km downstream of the minesite and just upstream of its confluence with Settlement Creek. The formation of backed-up, slack waters at this site during high flow events, from the

greater flows in Settlement Creek immediately downstream, most likely contributes to deposition of finer (silt/clay) sediment particles at this site (Appendix A, Table A2-B, typically the fraction to which most metals bind).

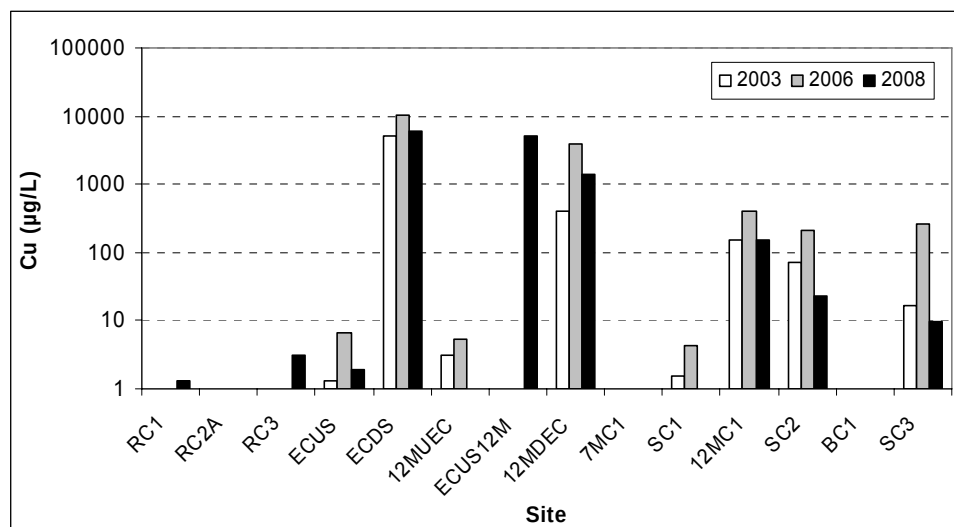


Figure 4 Cu concentrations measured in surface waters at sites sampled around Redbank Mine in May 2003 and 2006 (NT DRDPIFR data), and March 2008 (present study). Refer to Table 1 for site codes.

Water and sediment chemistry values from key sampling sites exceed recommended ANZECC & ARMCANZ (2000) toxicant triggers for a number of metals (Table 4). Since the water quality triggers are based on soft waters and are not site specific, they should only be used as a guide. (Toxicity of these metals is directly influenced by water hardness: increasing water hardness reduces toxicity.) Exceedances of published metal guidelines are consistent with the observation from above of a gradient in metal contamination in receiving waters, from numerous exceedances just downstream of the minesite (ECDS) to much reduced contamination (by Cu only) 36 km downstream in lower Settlement Creek (site SC 3).

Note that ANZECC & ARMCANZ (2000) provide two sets of guidelines for Al, 'high reliability' values for waters of pH >6.5 and another low reliability value for waters of pH <6.5. The exceedance of the mainly low-reliability Al guideline value for surface waters of both reference and mine-exposed sites clearly reflects naturally high background concentrations of Al in the region (apart from exposed sites ECDS and ECU12MC, Appendix A, Table A2-A) and may be inconsequential for most sites. The above-guideline value of Cu in surface waters at reference sites RC2, RC3 and ECUS, all located in, or close to, catchments containing Redbank, Azurite and Bluff copper deposits, also reflects, presumably, naturally high background. The moderately high sediment Cu observed at site ECUS, just upstream of the confluence of Echo Creek with Hanrahan's Creek, may possibly reflect deposition of mine wastes at this site from Hanrahan's Creek during past high flow events.

Table 4 Redbank site water and sediment metals that exceed recommended toxicant trigger values (ANZECC & ARMICANZ 2000). Italicised elements (Al, Co) indicate 'low reliability' trigger value. ND = no available data. ISQG = Interim Sediment Quality Guideline

Site	Water Quality trigger values ^A (95% Level of protection)	Sediment Quality guidelines	
		ISQG-high	ISQG-low
RC1	Al		
RC2	Al, Cu	ND	ND
RC3	Al, Cu		
ECUS	Al, Cu		Cu
ECDS	Al, Cu, Co, Ni, Zn	Cu,	Cu, Ni
ECU12MC	Al, Cu, Co, Ni, Zn	ND	ND
12MUEC	Al	ND	ND
12MDEC	Al, Cu, Co, Ni, Zn	Cu	Cu
12MC1	Cu, Co	Cu	Cu, Ni
SC1			
SC2	Cu		Cu
SC3	Cu		Cu
7MC1		ND	ND
BC1	Al	ND	ND

A: Not corrected for hardness

3.2 Macroinvertebrate community responses

3.2.1 Community summaries

Excluding different life forms of the same taxon and unidentified taxa, a total of 48 macroinvertebrate taxa, family or higher order, were collected from the 14 study sites (Appendix B, Table B1). Community summaries – taxa number and total abundance – are shown according to site in Figure 5.

Different patterns in number of taxa and total abundance were observed between Redbank exposed and reference sites, with both taxa number and total abundance being significantly lower at exposed sites compared with reference sites ($P < 0.05$, Student *t*-test). Two general observations may be made about community summaries in receiving waters (from Figure 5):

1. There is a general increase, and hence recovery, downstream in taxa number and total abundance such that the summary values at Settlement Creek 36 km downstream of Redbank (site SC3) are consistent with those recorded at reference sites. The only taxon missing from site SC3 of note is the mayfly family Leptophlebiidae, a particularly sensitive (to water quality) insect family (C Humphrey pers. observations, Chessman 2003).
2. Within the contaminated portions of Echo and 12 Mile Creeks, community summaries are higher at sites ECDS and 12MDEC (respectively), just downstream of confluences with mine-contaminated streams than they are at sites ECUS12M and 12MC1 (respectively), located further downstream and just above confluences with uncontaminated reference streams, despite water quality being poorer at the respective upstream sites. Rather than a tolerance of animals at these upstream sites to water of poorer quality, the observation is undoubtedly an artefact of the continuous

natural downstream drift of aquatic macroinvertebrates in streams, a major life-history strategy of in-stream fauna for colonisation and recruitment. In both streams, drift of healthy organisms from reference sites ECUS and 12MCUEC (respectively) has occurred to the adjacent contaminated sites (ECDS and 12MDEC respectively) just downstream of the reference-exposed stream confluence. It is likely that many of these organisms would not survive for long in the new exposed-site environment, nor contribute to successful reproduction and recruitment to the in-stream fauna. A more accurate reflection of species number and total abundance in the Echo and 12 Mile Creek stream sections, therefore, would be the values reported at the lower sites (ECUS12M and 12MC1 respectively).

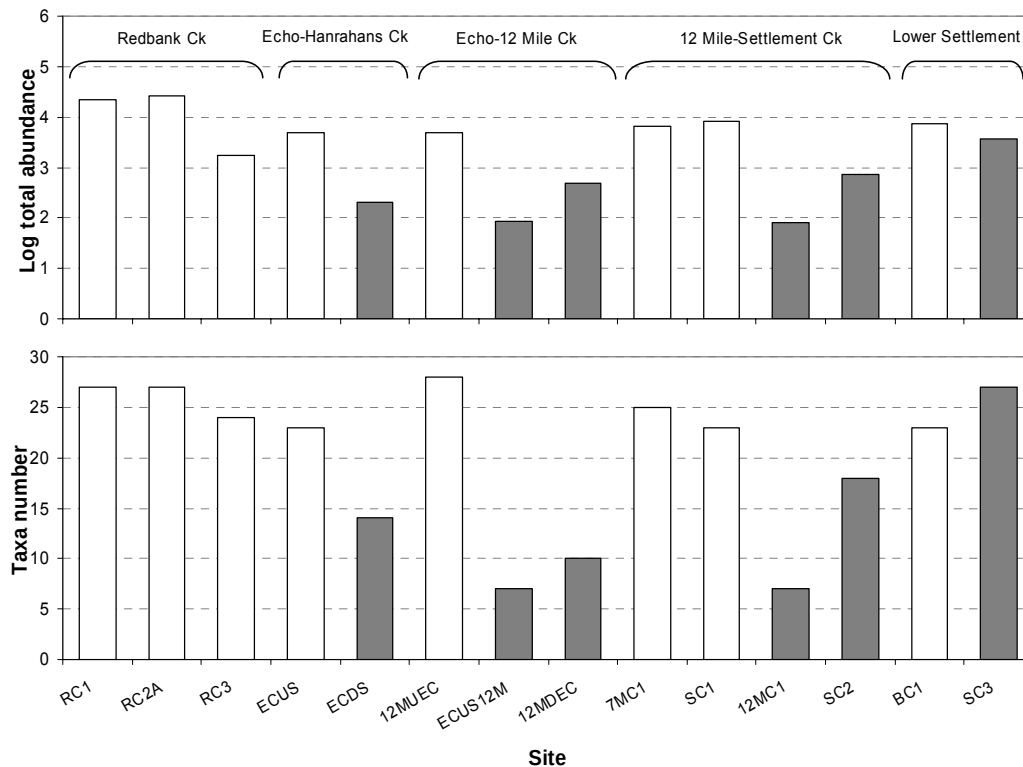


Figure 5 Histograms of macroinvertebrate abundance (total number per 10 m sweep) and taxa number for family-level data from 2008 Redbank sampling. Sites are shaded as exposed (■) and reference (□) and ordered from most upstream to most downstream within respective sub-catchments. Site codes are explained in Table 1.

Common sites near Redbank that were sampled for macroinvertebrates in this study (2008) and previous studies by NT DRDPFR (2003 and 2004) were Settlement Creek sites, SC1 and SC2. Community summaries for these two sites and for the three years for which there are data are shown in Figure 6. As discussed in the Introduction above, NT DRDPFR sampled edge habitat only whereas in this study a composite of edge and riffle habitats was sampled. It was suggested above that this could possibly lead to higher taxa numbers and total abundances being reported in the current study compared with earlier NT DRDPFR results, but similar relative differences reported between the two sites amongst years. The effects of different sampling times and flow conditions (March 2008 versus May 2003 and 2004), however, could confound (in particular, counter) these expectations. In the event, the relative difference in taxa number and total abundance between the two sites in 2008 was not dissimilar to that recorded in previous years. Importantly, in all three years, similar and lower

taxa number and total abundance were observed at the exposed site, SC2, compared with reference site values at SC1, just upstream (Figure 6).

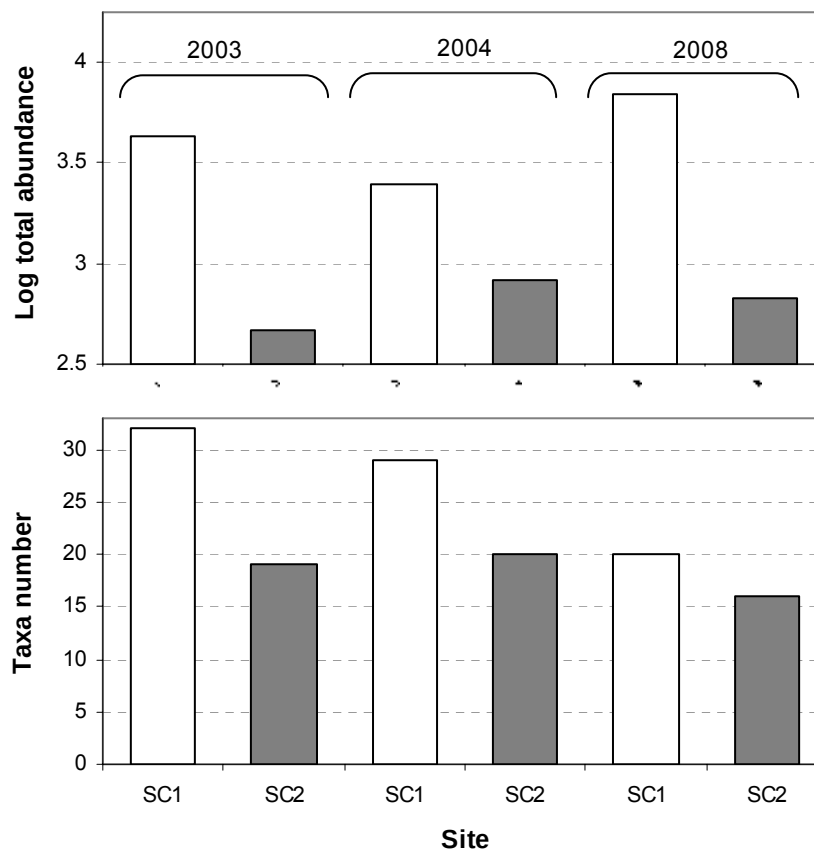


Figure 6 Histograms of macroinvertebrate abundance (total number per 10 m sweep) and taxa number for family-level data from Settlement Creek upstream (SC1, reference, □) and downstream (SC2, exposed ■) of 12 Mile Creek confluence. 2003 and 2004 data from NT DRDPFR and 2008 data from the present study. (Microcrustacean taxa recorded in 2008 excluded from analysis.)

Cross-correlations of the community summaries with environmental variables are shown in Table 5. It should be noted that the environmental dataset used in these correlations is that produced by the elimination of highly correlated variables for use in BIOENV analysis – see section “Multivariate analysis” from above. Hence any correlation shown in Table 5 will have similar associated correlations not shown because of the earlier removal of these variables (e.g. significant correlations between a community summary and copper in water will also be significant for that community summary and Co, Mn, Ni and SO₄ in water). The list of correlated and eliminated variables is provided above (see section 2.4.2 ‘Multivariate analysis’, subheading ‘Correlated variable(s) to be eliminated’).

Not surprisingly, all of the significant correlations observed between community summaries and metals in water or sediment were negative, indicating the adverse impacts of inputs of mine waters to receiving water health. The highest correlations were generally observed for Cu in water and sediment. The regression relationships derived between community summaries and ambient Cu are shown in Figure 7. Of the remaining significant correlations shown in Table 5 (Fe in water and habitat variables), only three appeared to have a sound ecological underpinning: (i) percent of substrate cover comprising filamentous algae or biofilm, and two riparian descriptors, (ii) proportion of the sampled stream length with overhanging riparian vegetation (Figure 8A) and (iii) proportion of the sampled stream length

with riparian vegetation draped in water. Relationships (ii) and (iii) appeared to reflect low percentage cover of riparian vegetation at mine-exposed sites, ECDS, ECU12MC, 12MDEC, 12MC1 and SC2 due in part to metal poisoning (eg see tree dieback evident at site ECU12MC, Appendix C, Plate 3-B). Possible direct adverse effects of loss of riparian vegetation upon macroinvertebrate communities may arise from loss of bank structure and habitat, loss of sources of food, or increased light penetration and surface water heating. Relationship (i) (Figure 8B) appeared to reflect in part the dense growth of filamentous algae – or “streamers” – at mine exposed sites, ECU12MC and SC2, a type of algae very common in AMD-impacted streams (D Jones, pers. comm.). (see Appendix C, Plate 3-E/F; because the filaments become coated with precipitated ferric hydroxides, they lose their green appearance.) The high densities of these filamentous biofilms on stony substrates downstream of Redbank may reduce habitat available for macroinvertebrates.

Table 5 Correlations (Pearson *r*) and their significance amongst macroinvertebrate community summaries and associated environmental variables at Redbank sites. For correlations involving macroinvertebrate total abundance, only the highest correlation (between transformed and untransformed data) is reported.

	<i>No. of taxa</i>	<i>Total abundance</i>	<i>log total abundance</i>
Total abundance	0.590 *		
log total abundance	0.919 ***	0.774 **	
log Cu in water	-0.873 ***		-0.859 ***
log Zn in water	-0.849 ***		-0.809 ***
Fe in water		0.552 *	
log Cu in sediment	-0.874 ***		-0.893 ***
log Al in sediment	-0.731 **		-0.802 ***
Zn in sediment	-0.662 **		-0.744 **
log S in sediment	-0.622 *		-0.655 *
Dist. overhang riparian veg	0.546 *		0.663 **
Riparian veg. draped in water		0.759 **	
Emergent macrophyte	0.581 *	0.657 *	
Pebbles	-0.651 *		
Sand		0.536 *	
Large Woody Debris	-0.559 *		
Filamentous Algal Cover	-0.536 *		

* = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$

3.2.2 Community structure

The MDS ordination conducted on log ($X+1$) transformed taxa abundance data (including different life forms of the same taxon but excluding unidentified taxa), is shown in Figure 9A. The ordination showed clear separation of exposed and reference sites along the vertical Axis 2 (ANOSIM, sample statistic (Global R) of 0.51 and $p = 0.2\%$), although Settlement Creek site SC3 plotted amongst reference sites (Figure 9A), a pattern also observed in the corresponding water and sediment chemistry ordination (Figure 3).

SIMPER analysis was conducted between (a priori) exposed and reference sites with summary results for the top 10 influential macroinvertebrate taxa shown in Table 6. The top 10 influential macroinvertebrate taxa had greatly reduced abundances at the exposed sites. These taxa included two mayfly families (Caenidae, Baetidae), two chironomid subfamilies (Chironominae, Tanypodinae), two microcrustacean groups (Ostracoda, Cladocera), two

caddisfly families (Philopotamidae, Hydroptilidae), oribatid mites and oligochaete worms (Table 5). Two influential taxa identified from SIMPER, as well as total abundance and taxa number, are presented as bubble plots over the MDS ordination in Figure 9).

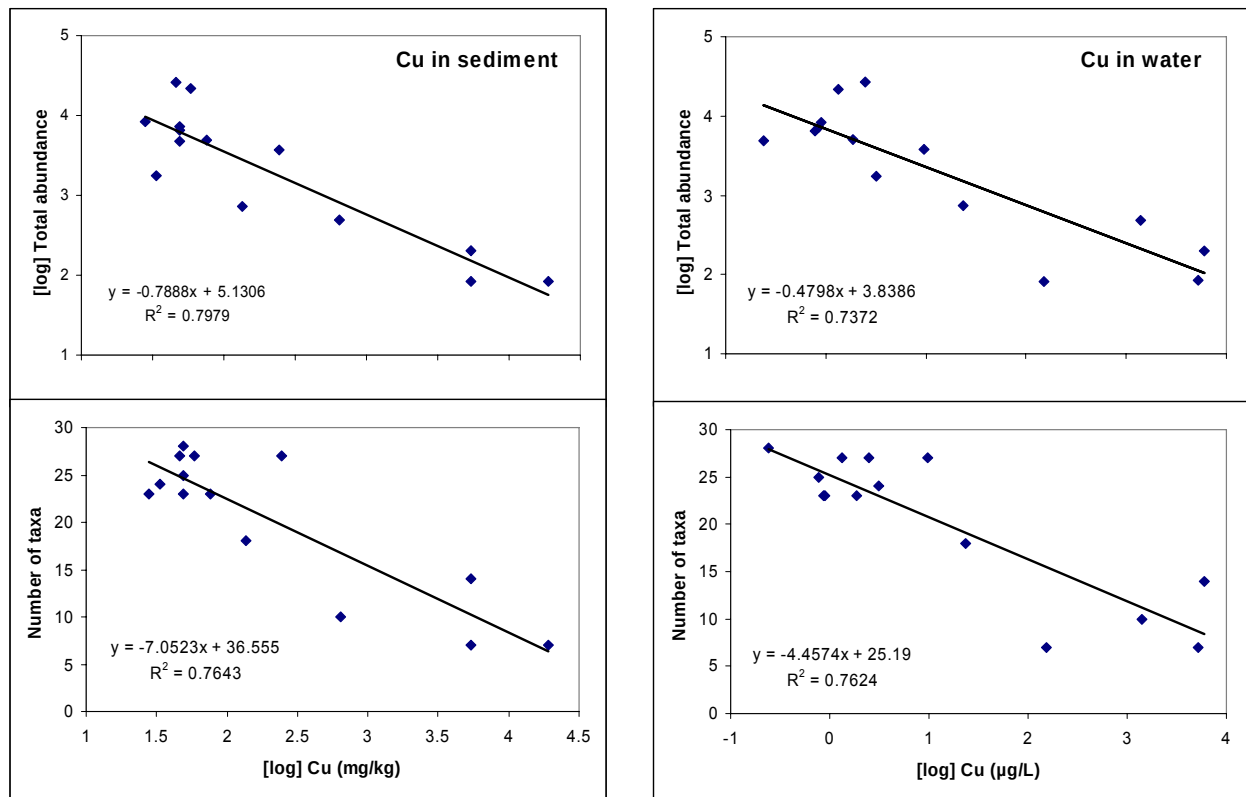


Figure 7 Regression relationships between macroinvertebrate community summaries and Cu in waters and sediments of Redbank sites

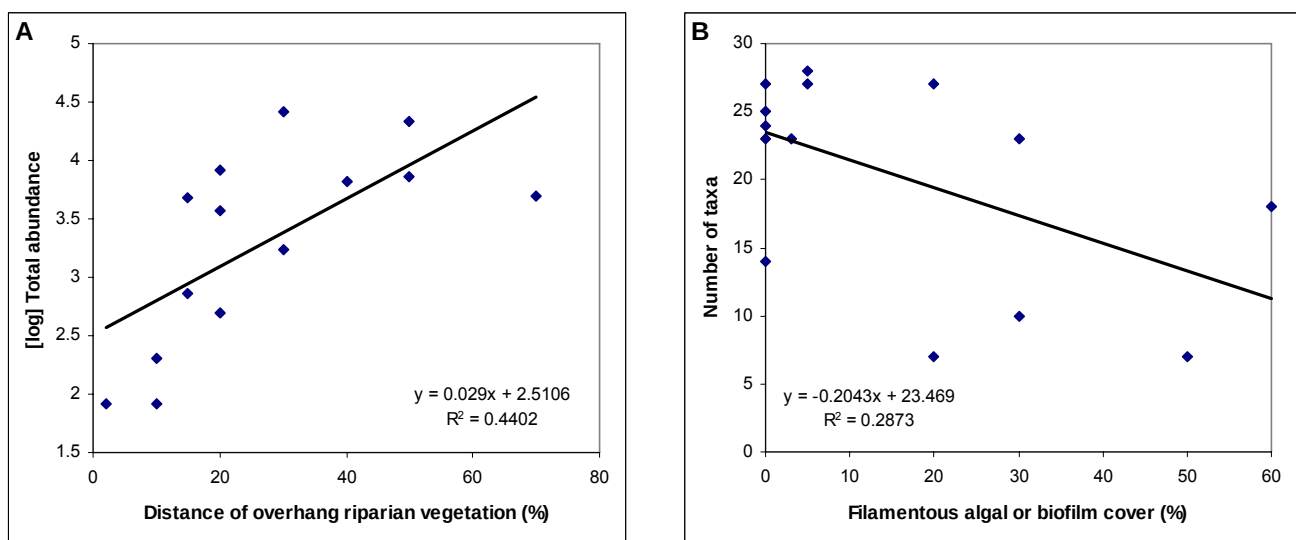


Figure 8 Regression relationships between macroinvertebrate community summaries and habitat variables at Redbank sites: A. (log) total abundance and proportion of the sampled stream length with overhanging riparian vegetation; and B. Number of taxa and percent of substrate cover comprising filamentous algae or biofilm

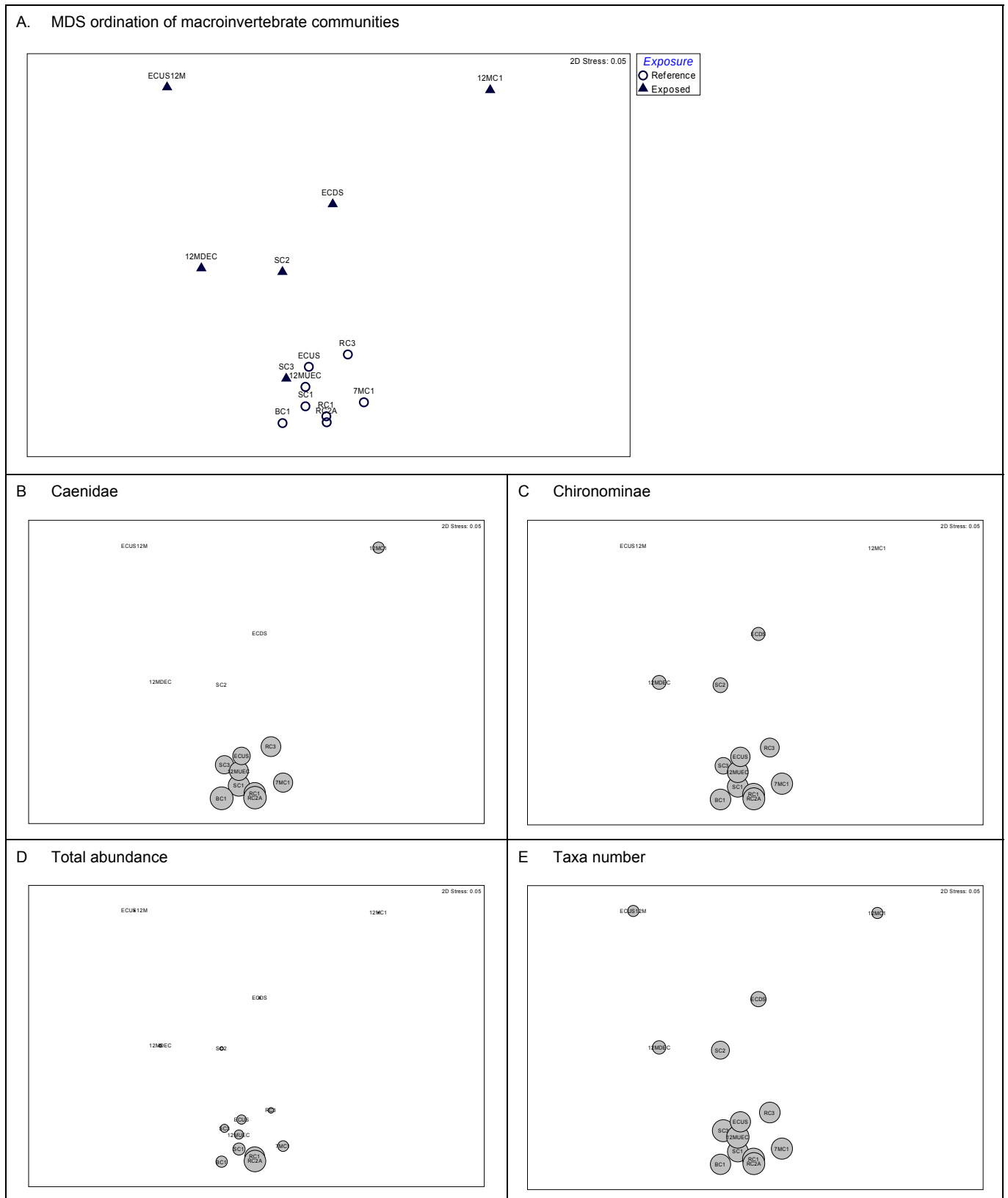


Figure 9 Bubble plots superimposed on the macroinvertebrate MDS ordination of influential taxa identified by SIMPER, as well as Total abundance and Taxa number. Site codes are explained in Table 1.

Table 6 SIMPER results for taxa discriminating exposed versus reference site groups around Redbank mine

Summary Statistics	Dominant taxa (top 10) in descending order contributing to separation of groups
	Caenidae, Chironominae, Baetidae, Ostracoda, Oribatida, Oligochaeta, Philopotamidae, Cladocera, Tanypodinae, Hydroptilidae
Average inter-group dissimilarity (%)	62.5
Cum. % of overall dissimilarity (top 10) contributed by dominant taxa	44.1

A key observation from the MDS ordination is that, despite measureable increases in Cu concentrations in water and sediment at exposed site SC3 compared with similar reference site data, macroinvertebrate communities at this site are not noticeably impaired.

An MDS ordination conducted on combined log (X+1) transformed taxa abundance data from the present *eriss* (2008) and previous NT DRDPIFR (2003 and 2004) studies is shown in Figure 10. ANOSIM and SIMPER results from the various group comparisons evident in the combined ordination are shown in Table 7. The ordination separated reference and exposed sites from both sampling periods (NT DRDPIFR and *eriss*) along horizontal Axis 1, and NT DRDPIFR and *eriss* sites along vertical Axis 2. Significant site group separation was observed for *eriss* reference versus *eriss* exposed, NT reference versus NT exposed, and *eriss* reference versus NT reference (Table 7). NT DRDPIFR sampled edge habitat in 2003 and 2004 whereas in 2008 *eriss* sampled a composite of edge and riffle habitats. This would explain higher proportions of flow-dependant taxa present in 2008 compared with 2003 and 2004 (eg Philopotamidae, Simuliidae) and higher proportions of still-water taxa present in 2003 and 2004 compared with 2008 (eg Hydrochidae, Pleidae, Hydraenidae). For both 2008 and 2003/2004 sampling periods, Caenidae, Chironominae and Baetidae were influential in distinguishing reference sites from exposed sites (i.e. dominant taxa in reference sites) (Table 7).

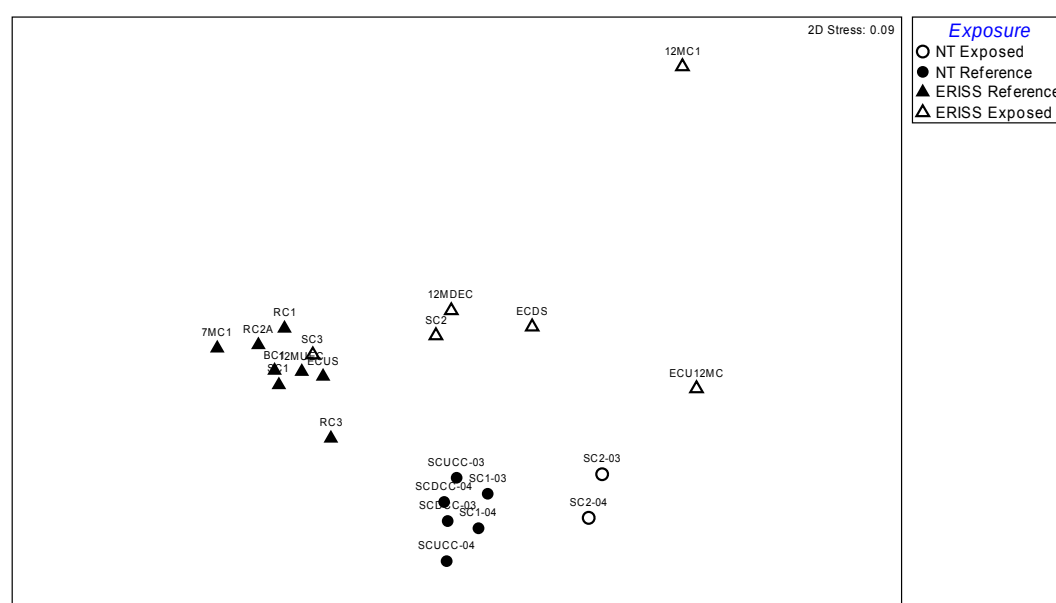


Figure 10 MDS ordination conducted on combined log (X+1) transformed taxa abundance data from the present *eriss* (2008) and previous NT DRDPIFR (2003 and 2004) studies. *eriss* site codes provided in Table 1. Suffix for NT site codes indicates year (03 or 04) while SCUCC and SCDCC refer to Settlement Creek upstream and downstream of Camp Creek confluence respectively.

Table 7 ANOSIM and SIMPER results for site group comparisons around Redbank mine using *eriss* 2008 and NT DRDPFR 2003 and 2004 data. Italicised taxon indicates higher abundance in the second of the comparative couplets compared with the first. (Microcrustacea taxa removed so that *eriss* data may be compared with NT data)

Comparison and Summary Statistics	Dominant taxa (top 10) in descending order contributing to separation of groups
ERISS Reference, ERISS Exposed ANOSIM R Statistic = 0.53, Significance level = 0.2%	Caenidae, Chironominae, Baetidae, Oligochaeta, Oribatida, Philopotamidae, Tanypodinae, Hydroptilidae, Planorbidae, Simuliidae
Average inter-group dissimilarity (%)	61.6
Cum. % of overall dissimilarity (top 10) contributed by dominant taxa	50.6
NT Reference, NT Exposed ANOSIM R Statistic = 1, Significance level = 3.6%	Chironominae, Caenidae, Corixidae, Baetidae, <i>Dytiscidae</i> , <i>Hydroptilidae</i> , Hydraenidae, <i>Pleidae</i> , <i>Ceratopogonidae</i> , <i>Hydrochidae</i>
Average inter-group dissimilarity (%)	50.1
Cum. % of overall dissimilarity (top 10) contributed by dominant taxa	56.9
NT Exposed, ERISS Exposed ANOSIM R Statistic = 0.073, Significance level = 35.7%	<i>Orthocladinae</i> , Hydrochidae, Pleidae, Tanypodinae, Hydroptilidae, Chironominae, Leptoceridae, Hydraenidae, Hydracarina, <i>Ceratopogonidae</i>
Average inter-group dissimilarity (%)	62.0
Cum. % of overall dissimilarity (top 10) contributed by dominant taxa	52.6
ERISS Reference, NT Reference ANOSIM R Statistic = 1, Significance level = 0.1%	Orthocladinae, Philopotamidae, Oribatida, Hydroptilidae, Simuliidae, Oligochaeta, Baetidae, Chironominae, Chironomidae, Tanypodinae
Average inter-group dissimilarity (%)	60.3
Cum. % of overall dissimilarity (top 10) contributed by dominant taxa	46.2

3.2.3 Relationship between environmental and community data (BIOENV)

The best 10 BIOENV results between environmental and community structure data are shown in Table 8. The top 10 results consistently included Zn in water, Cu in sediment and stream velocity at the riffle, as correlates of community data. The influence of Zn in water and Cu in sediment is indicated in Figure 11 by way of bubble plots where it is evident that community data are influenced on Axis 2 (Y axis) by these mine-derived contaminants (Figure 11B, C).

Table 8 Best 10 BIOENV results between environmental and macroinvertebrate community data from Redbank survey sites.

Spearman rank correlation (ρ)	Variable combinations
0.825	Zn in water, Cu in sediment, Zn in sediment, Stream velocity at riffle, Bed compaction
0.823	Zn in water - Cu in sediment, Stream velocity at riffle, Bed compaction
0.821	Zn in water, Cu in sediment, Stream velocity at riffle, Stream width across pool, Particle size graphic mean
0.820	Zn in water, Cu in sediment, Stream velocity at riffle, Stream width across pool, Bed compaction
0.820	Water temperature, Zn in water, Cu in sediment, Stream velocity at riffle, Stream width across pool
0.819	Latitude, Zn in water, Cu in sediment, Stream velocity at riffle, Stream width across pool
0.819	Zn in water, Cu in sediment, Zn in sediment, Stream velocity at riffle, Stream width across pool
0.819	Zn in water, Cu in sediment, Stream velocity at riffle, Stream width across pool
0.819	Latitude, Zn in water, Cu in sediment, Stream velocity at riffle, Bed compaction
0.818	Longitude, Zn in water, Cu in sediment, Stream velocity at riffle, Bed compaction

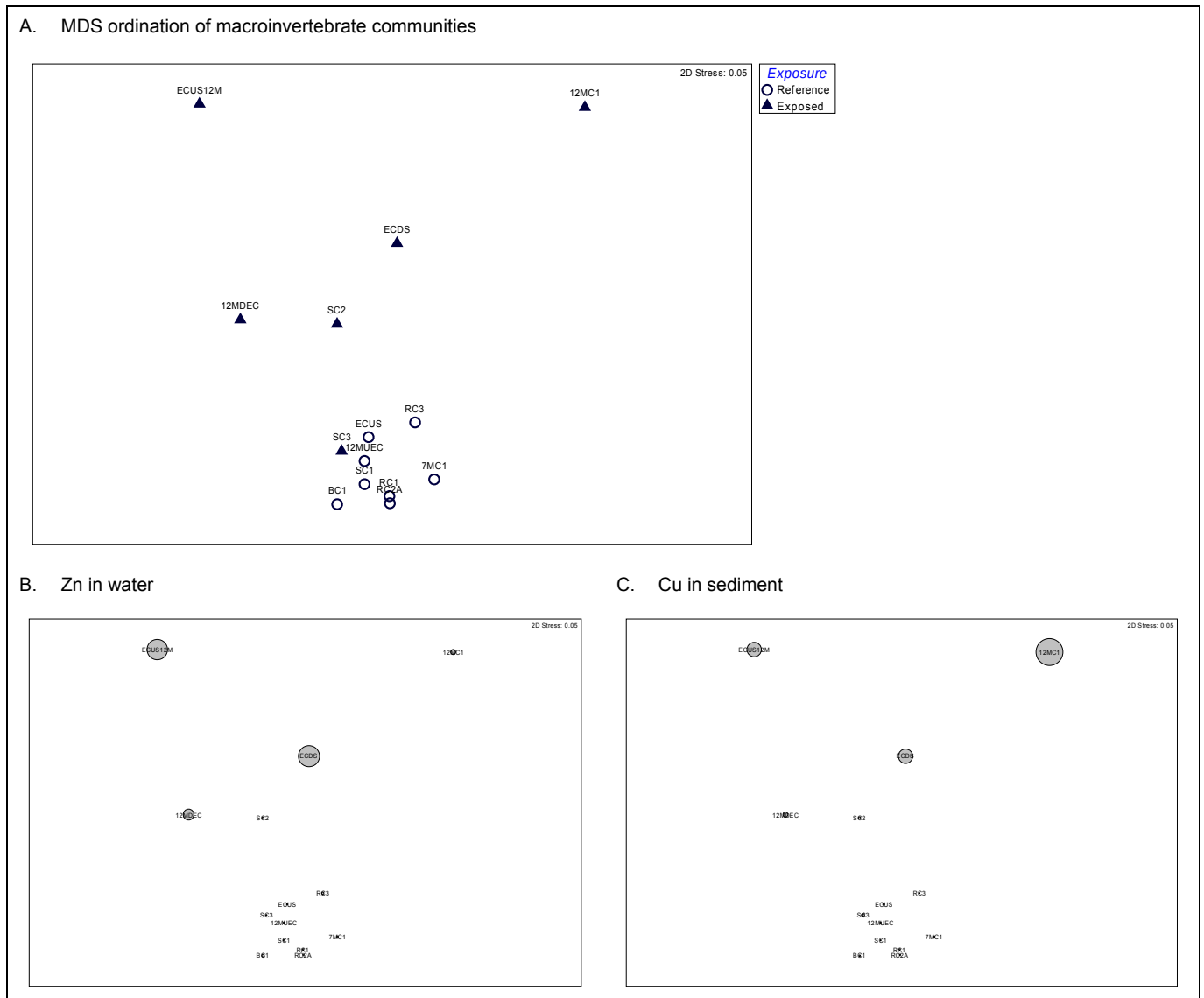


Figure 11 Bubble plots superimposed on the macroinvertebrate MDS ordination of influential environmental variables identified by BIOENV. Site codes are explained in Table 1.

3.3 Conservation value of macroinvertebrate communities of Redbank Creek

The possible presence of rare, restricted or endemic macroinvertebrate species of conservation significance that were collected from the three Redbank Creek sites was determined by cross-referencing taxa lists for each site with an established in-house database (*eriss*), the Commonwealth's Australian Biological Resources Study (ABRS) website (<http://www.environment.gov.au/biodiversity/abrs/online-resources/fauna/index.html>) and a specialist Chironomidae website maintained by a world specialist, Prof Peter Cranston (<http://entomology.ucdavis.edu/chiropage/index.html>). However, due to the general lack of data on distributions of Australian aquatic macroinvertebrates and taxonomic uncertainties, conclusions on the rarity or otherwise of many macroinvertebrate groups/species cannot be made with certainty.

The majority of macroinvertebrate species recorded from Redbank Creek sites during the current study are considered common throughout northern Australia, many with cosmopolitan distributions including Asia (see Appendix B, Table B2). A conservation category code pertaining to endemism was ascribed to each taxon (Appendix B, Table B2) and the percentage contribution of each category was recorded for the three sites (Figure 12). Twenty nine taxa (26.5%) were considered regionally endemic while 10 taxa (9.5%) were considered common with nation-wide distributions. Twenty taxa (19%) were considered cosmopolitan with distributions extending into the Oriental region. The endemism of the remaining 48 taxa (45%) was indeterminate owing either to poor taxonomic resolution or lack of published data on distributions. Site RC3 had the highest proportion of regionally endemic taxa (33%) and RC1 the lowest (25%).

It is likely that this study represents the first to acquire species-level macroinvertebrate data for this Gulf of Carpentaria region of the NT. As such, the study expands the knowledge of distributions of macroinvertebrate taxa for northern Australia generally and provides useful contextual information for future conservation assessments for the region.

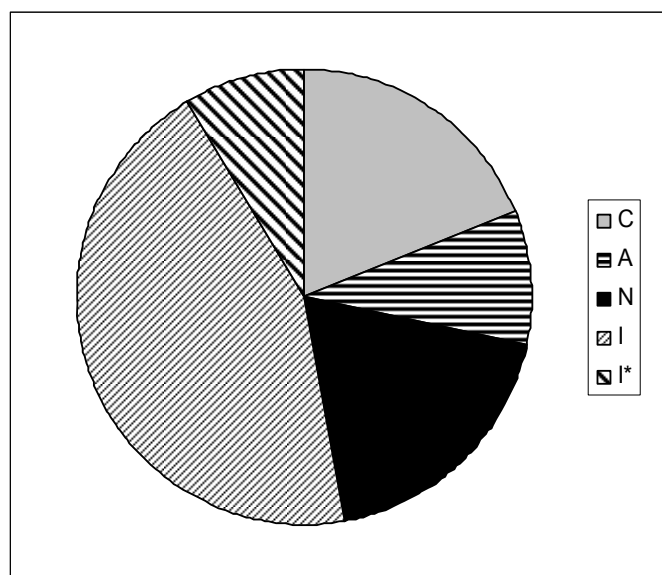


Figure 12 Proportional occurrence of conservation categories of macroinvertebrate taxa collected during March 2008 from three Redbank Creek sites. Conservation category codes are as follows: C = Cosmopolitan (Australia and beyond - however not necessarily worldwide); A = Australia (not necessarily Australia-wide, but more than northern distribution); N = endemic to northern Australia; I = indeterminate; I* = indeterminate but probably northern Australian endemic.

4. SUMMARY AND RECOMMENDATIONS

4.1 Summary

1. In March 2008, macroinvertebrate samples and associated water and sediment samples were collected from 15 stream sites in the vicinity of Redbank mine. The sites comprised 6 'exposed' sites (impacted or potentially impacted): two on each of Echo, 12 Mile and Settlement Creeks; and 9 reference sites: four on Redbank Creek, one each on Echo, 12 Mile and Settlement Creeks, as well as one each on 7 Mile and Branch Creeks, additional tributaries of Settlement Creek.

Water and sediment quality

2. Ordination of the water and sediment quality data by Principal Components Analysis showed that the dominant influence upon receiving waters and sediments (38% of the variation, PC Axis 1) was a mine disturbance gradient associated with elevated acidity, Cu, Mn, Al, Co, Zn, Ni and sulphate in waters, and elevated Cu, Co, Ni, S, Zn and Al in sediments. The next dominant water quality influence upon receiving waters (30% of the variation, PC Axis 2), related to catchment geology: the influences of the Masterton sandstone in close contact with upland streams in the immediate vicinity of the mine site (soft, low solute concentration waters), and the mainly shale and volcanic geology associated with lowland streams (harder, higher solute concentration waters).
3. Water and sediment chemistry values from key sampling sites exceeded recommended ANZECC & ARMCANZ (2000) toxicant triggers for ecosystem health for a number of metals – from numerous exceedances across a range of parameters just downstream of the minesite to much reduced contamination (by Cu only) 36 km downstream in lower Settlement Creek.
4. While surface waters followed a distinct gradient of decreasing concentrations of mine-derived contaminants with increasing distance downstream of the minesite, highest sediment concentrations for Cu, Ni and Zn were observed at an intermediate site, 18 km downstream of the minesite (on 12 MileCreek), and just upstream of the confluence of 12 Mile Creek with Settlement Creek. The formation of backed-up, slack waters at this site during high flow events, from the greater flows in Settlement Creek immediately downstream, most likely contributes to the deposition of finer (silt/clay), contaminant-laden sediment particles at this site.

Macroinvertebrate community response

5. Macroinvertebrate (family-level) taxa number and total abundance were substantially and significantly lower at mine-exposed stream sites compared with reference sites. There was a general increase, and hence recovery, downstream in taxa number and total abundance such that the summary values at Settlement Creek 36 km downstream of Redbank (site SC3) were consistent with those recorded at reference sites.
6. Multi-Dimensional Scaling ordination of taxa abundance data showed clear separation of exposed and reference sites, confirmed by ANOSIM testing. However, exposed site SC3 on Settlement Creek plotted amongst reference sites, a pattern also observed in the corresponding water and sediment chemistry (PCA) ordination and consistent with taxa number and total abundance results reported in numbered point 5 above.
7. Macroinvertebrate taxa most influential in separating exposed and reference sites had greatly reduced abundances at the exposed sites. The dominant 10 taxa included two mayfly families (Caenidae, Baetidae), two chironomid subfamilies (Chironominae, Tanypodinae), two microcrustacean groups (Ostracoda, Cladocera), two caddisfly families (Philopotamidae, Hydropsychidae), oribatid mites and oligochaete worms.
8. Significant negative correlations were observed between community summaries and key metals in water and sediment, indicating the adverse impacts of mine waste water dispersion to receiving water health. The highest negative correlations were generally observed for Cu in water and sediment. Significant correlations were also found between community summaries and percent of substrate cover comprising filamentous algae or biofilm, and two riparian descriptors, proportion of the sampled stream length with overhanging riparian vegetation and proportion of the sampled stream length with

riparian vegetation draped in water. These habitat correlations also appeared to reflect adverse effects of mine water input on receiving waters. Two of the strongest environmental correlates of the macroinvertebrate ordination space (depicting community structure) as identified by BIOENV were Zn in water and Cu in sediment.

9. Species-level data were acquired from the three Redbank Creek sites. These data will provide important ecological baseline and conservation assessment information to assess future mining that is planned for the Redbank, Azurite and Bluff copper deposits. The data also expand the knowledge of distributions of macroinvertebrate taxa for northern Australia generally and provide useful contextual information for future conservation assessments for the region. None of the species present at the three Redbank sites appeared to be restricted in distribution and/or locally-endemic.

Interannual observations

10. NT DRDPIFR have assessed water quality and macroinvertebrate communities in receiving waters downstream of Redbank in past years. The general patterns in water quality (contaminant concentration gradients) observed in 2008 were also evident in NT DRDPIFR data from 2003 and 2006. Further and similarly, macroinvertebrate communities sampled in Settlement Creek in this 2008 study and by NT DRDPIFR in 2003 and 2004 displayed much lower taxa number and total abundance at the exposed site, SC2, compared with reference site values at SC1, just upstream. For both 2008 and 2003/2004 sampling periods, the two mayfly families, Caenidae and Baetidae, and non-biting midge subfamily, Chironominae, were observed to be influential in distinguishing reference sites from exposed sites (i.e. were dominant taxa in reference sites).
11. Given the general similarity in results of this study compared with those reported by NT DRDPIFR in past years, there is no evidence for any improvement in water quality and stream health in recent years.

4.2 Recommendations

1. Macroinvertebrate assemblages sampled in the March 2008 study clearly demonstrated mine-related impacts arising from the Redbank mine upon receiving waters. To this end, periodic (end-of-wet season) macroinvertebrate sampling should continue in future, using the general configuration of sites used in the current survey. Over time, paired site comparisons can be analysed to statistically infer mine-related disturbance (viz exposed versus reference site statistical testing) and hence monitor system recovery.
2. Improvements to the design of future sampling at Redbank receiving water sites could include the relocation of sites immediately below reference-exposed creek confluences – such as ECDS, 12MDEC and SC2 – to locations further and sufficiently downstream so as to avoid mixing zones and artefacts arising from drift of organisms from the reference stream immediately upstream giving the appearance of better-than-expected macroinvertebrate diversity and stream health.
3. A zone of recovery in stream health was evident in this study for Settlement Creek between 18 km (SC2) and 36 km (SC3) downstream of the Redbank minesite. Should significant remedial works be undertaken at the minesite in future, further downstream recovery would presumably be first detected in Settlement Creek. To this end, future surveys should focus on Settlement Creek; better definition of the extent and degree of impact between sites SC2 and SC3 would provide an improved basis for detecting and assessing system recovery.

4. ANZECC & ARMCANZ (2000) recommend that ecological baseline data be gathered for stream sites for a minimum of three years prior to planned developments. It is recommended, therefore, that annual sampling continue in Redbank Creek, a receiving water potentially exposed to any mine wastes arising from future development of the Redbank, Azurite and Bluff copper deposits.
5. Redbank receiving waters offer a variety of different habitats from which to sample macroinvertebrate communities for monitoring. A dedicated study should be conducted in future at selected stream sites, sampling different habitats at each site and examining results from samples processed separately from the different habitats. This comparison would identify the most appropriate habitat(s) to sample and monitor in future.
6. Sediment samples collected from sites RC2, ECU12MC, 12MUEC, 7MC1 and BC1 were not analysed. These archived samples should be chemically analysed in the near future and PCA and BIOENV statistical analyses re-run to more accurately characterise the impact of sediment contamination arising from inputs of water from the the Redbank mine.

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APPENDIX A

Environmental data

Table A1 Habitat variables for all sites sampled in the vicinity of Redbank Mine

A. Locational variables

Site		WGS 84		Latitude				Longitude				Distance d'stream of mine		Date	Time
Code	Description	MGA Zone	East	North	Deg	min	sec	decimal	Deg	min	sec	decimal	km		
RBS	Redbank Spring	53K	792316	8099668	17	10	8.74	17.1691	137	44	52.15	137.7478	N/A	17/03/2008	8:45
RC1	Redbank Ck Site 1	53K	794226	8099937	17	9	59.112	17.1664	137	45	56.592	137.7657	N/A	15/03/2008	16:25
RC2	Redbank Ck Site 2	53K	795301	8100214	17	9	49.608	17.1638	137	46	32.808	137.7758	N/A	15/03/2008	15:20
RC2A	Redbank Ck site 2A. Track crossing	53K	796530	8100240	17	9	48.204	17.1634	137	47	14.352	137.7873	N/A	17/03/2008	18:00
RC3	Redbank Ck Site 3	53K	797667	8100877	17	9	26.964	17.1575	137	47	52.476	137.7979	N/A	15/03/2008	14:00
ECUS	Echo Ck upstream of Hanrahans Ck confluence	53K	789874	8095975	17	12	9.9	17.2028	137	43	31.332	137.7254	N/A	16/03/2008	14:22
ECDS	Echo Ck downstream of Hanrahans Ck confluence	53K	789814	8095914	17	12	11.916	17.2033	137	43	29.352	137.7248	2.2	16/03/2008	15:15
ECU12MC	Echo Ck upstream of 12 Mile Ck confluence	53K	788558	8093294	17	13	37.632	17.2271	137	42	48.096	137.7134	5.9	18/03/2008	9:28
12MUEC	12 Mile Ck upstream Echo Ck confluence	53K	788520	8093294	17	13	37.668	17.2271	137	42	46.836	137.713	N/A	18/03/2008	9:17
12MDEC	12 Mile Ck downstream of Echo Ck confluence	53K	788585	8093243	17	13	39.288	17.2276	137	42	49.032	137.7136	6	18/03/2008	9:22
12MC1	12 Mile Ck site 1, upstream of Settlement Ck confluence	53K	797379	8087456	17	16	43.32	17.2787	137	47	49.308	137.797	18.3	17/03/2008	12:35
SC1	Settlement Creek site 1, upstream of 12 Mile Ck confluence	53K	797475	8087360	17	16	46.38	17.2796	137	47	52.62	137.798	N/A	17/03/2008	14:28
SC2	Settlement Creek site 2, downstream of 12 Mile Ck confluence	53K	797492	8087425	17	16	44.256	17.279	137	47	53.16	137.7981	18.5	17/03/2008	13:24
SC3	Settlement Creek site 3, Wollogorang Road crossing	53K	811786	8094051	17	13	2.028	17.2172	137	55	53.292	137.9315	36.2	16/03/2008	9:48
7MC1	Seven Mile Creek, Wollogorang Road crossing	53K	798569	8094238	17	13	2.316	17.2173	137	48	26.244	137.8073	N/A	16/03/2008	11:18
BC1	Branch Creek (QLD), Wollogorang Road crossing	54K	183032	8094607	17	12	41.364	17.2115	138	1	11.784	138.0199	N/A	16/03/2008	8:07

Table A1. (Contin.)

B. General variables. 'NR' = Not recorded.

Site	Stream velocity at riffle	Stream velocity at riffle (average from X-section profile)	Discharge estimate	Stream width - pool	Stream width - riffle	Avg depth at riffle	Max depth in pool	Bank angle (shelving-undercut)	Dist. overhang riparian veg	Cover riparian veg	Coarse organics omitted from sample
	m/sec	m/sec	L/sec	m	m	m	m	1-4	%	%	
RBS	0.03	NR	1.3	2.5			0.5	2	0	80	2 pans
RC1	0.1	NR	2.2	6	2	0.2	0.5	2	50	20	1/2 pan
RC2	0.25	NR	1	4	2	0.3	2	2	50	20	3/4 pan
RC2A	0.17	NR	1.25	20	2	0.07	2	2	30	20	1/2 pan
RC3	0.25	NR	2.5	4	0.5	0.1	0.5	1	30	60	1/2 pan
ECUS	0.25	0.047	22.91	5	4.5	0.15	0.3	2	70	60	1/2 pan
ECDS	0.1	0.07	56.88	40	4.5	0.15	1.5	2	10	40	1/5 pan
ECU12MC	0.14	0.14	22	7	1.5	0.14	0.6	2	10	20	1 pan
12MUEC	0.25	0.07	65	6.5	3	0.1	0.3	2	15	20	1/3 pan
12MDEC	0.25	0.05	81	6.8	4	0.1	0.4	2	20	15	1/3 pan
12MC1	0.33	0.126	97	7	7.5	0.15	0.3	2	2	30	1/3 pan
SC1	0.2	0.17	395	20	14.5	0.2	0.5	2	20	40	1/3 pan
SC2	3	0.189	547	25	15.5	0.25	0.4	2	15	20	1/4 pan
SC3	0.17	0.14	108	20	6.5	0.15	0.5	1	20	60	1/3 pan
7MC1	0.25	0.25	8	20	1	0.15	0.5	2	40	60	1/3 pan
BC1	0.14	0.12	100 ^A	45	13	0.1	2	2	50	50	1/2 pan

A: Subjective assessment based upon photographs.

C. Mineral substrate (%) and compaction

Site	Bedrock	boulders	cobbles	pebbles	gravel	sand	silt	clay	Particle size graphic mean (PSGM)	Bed compaction (high-low)
		>256 mm	64-256 mm	16-64 mm	4-16 mm	1-4 mm	< 1 mm		mm	1-5
RBS	70	10	10	5	5	0	0	0		2
RC1	0	5	15	20	20	40	0	0	28.6	4
RC2	60	10	10	0	10	10	0	0	129.3	1
RC2A	20	20	30	20	20	10	0	0	109.3	3
RC3	20	30	30	20	15	5	0	0	146.7	2
ECUS	20	30	20	20	5	5	0	0	179.2	2
ECDS	30	15	20	20	10	5	0	0	120.3	2
ECU12MC	0	15	50	20	12	3	0	0	123.5	2
12MUEC	0	10	50	20	15	5	0	0	73.4	2
12MDEC	0	20	40	30	10	0	0	0	126.9	2
12MC1	0	1	29	30	20	20	0	0	37.3	5
SC1	0	30	30	20	15	5	0	0	146.7	2
SC2	0	25	30	20	15	10	0	0	128	3
SC3	0	20	40	20	15	5	0	0	123.2	3
7MC1	0	10	50	20	15	5	0	0	109.1	2
BC1	0	10	50	20	10	9	1	0	109.1	3

Table A1. (Contin.)

D. Site habitat area (%) and macrophyte species composition

Site	Mineral substrate	Emergent macrophyte	Submerged Macrophyte	Floating Macrophyte	Filamentous Algal Cover	Detritus	Riparian veg. draped in water	Root mats	Large Woody Debris	Other
RBS	40	0	0	0	0	60		0	0	0
RC1	60	10	0	0	5	15	10	0	0	0
RC2	48	0	2	0	10	20	0	0	20	0
RC2A	30	5	0	0	20	15	30	0	0	0
RC3	90	5	5	0	0	0	0	0	0	0
ECUS	45	5	5	0	30	15	0	0	0	0
ECDS	85	0	0	0	0	10	5	0	0	0
ECU12MC	35	0	0	0	50	10	5	0	0	0
12MUEC	58	5	0	5	5	10	15	0	2	0
12MDEC	54	0	0	2	30	10	3	0	5	0
12MC1	58	0	0	0	20	15	2	0	5	0
SC1	76	0	0	0	3	15	1	5	0	0
SC2	34	0	0	0	60	5	1	0	0	0
SC3	40	0	0	0	0	10	0	50	0	0
7MC1	85	0	0	0	0	15	5	0	0	0
BC1	75	5	0	5	0	10	5	0	0	0

E. Vegetation records

Site	Algae notes	Riparian notes	Macrophyte species comp'n (%)
RBS			
RC1		50% of edge, grasses	Grasses 80%, Sedges 20%
RC2		0	<i>Eriocaulon</i> 100%
RC2A		0	<i>Dysophylla</i> 70%, <i>Myriophyllum</i> 30%
RC3		0	<i>Myriophyllum</i> 50%, <i>Dysophylla</i> 50%
ECUS		0	<i>Eriocaulon</i> 100%
ECDS	Fine slimy floc on rocks	0	Nil
ECU12MC		0	Nil
12MUEC	70% on rocks	0	<i>Nymphaea</i> (floating) 30%, <i>Limnophila</i> like plant (emergent) 30%, <i>Utricularia</i> like plant (feathery) 40%
12MDEC	70% on rocks (floccy)	20% grasses	<i>Nymphaea</i> 100%
12MC1	60% on rocks	0	Nil
SC1		5	Nil
SC2		0	Nil
SC3		50	Nil
7MC1		Grasses	<i>Dysophylla</i> on exposed shingle beds
BC1		50% of edge	<i>Nymphaea</i> 60%, <i>Nymphoides</i> 39%, <i>Potamogeton tricaratus</i> 1%

Table A1. (Contin.)

F. Site condition and disturbance

Site	List of fish species observed	Cane toad presence	General condition (erosion, weeds, cattle)
RBS	Spangled grunter, eeltail catfish		Very good condition. <i>Hyptus</i> at gorge entrance but not in gorge
RC1			Good condition. One cattle entry point. Presence of <i>Hyptus</i>
RC2		Tadpoles in abundance	Good condition. One cattle entry point. Presence of <i>Hyptus</i>
RC2A	Rainbowfish, small Ambassis-like fish		Good condition. Mussel shells about on banks
RC3	Banded and spangled grunters, rainbowfish	Tadpoles and toadlets	Generally good condition, riparian zone intact, evidence of cattle
ECUS	Spangled grunters	Tadpoles	Good condition. Riparian zone intact
ECDS	No fish		Riparian zone intact. Water apparently polluted. Two-tone colour on rocks indicates mixing zone, grey vs red/brown
ECU12MC	Banded grunter (1 live, 2 dead)		Looks sterile. Some dead trees. High water clarity. Site 30 m upstream of confluence
12MUEC	Schools of banded grunter, spangled grunter and rainbow fish	Tadpoles	Intact, good condition
12MDEC	Banded grunter (1 live, 2 dead)		Superficially looks in good condition. No green but abundant grey filamentous algae. Site is 130 m downstream of confluence
12MC1	Banded grunters, rainbowfish		Cattle with many entry points. Site in fair condition. Unconsolidated substrate
SC1	Rainbowfish, archerfish, banded grunter	Tadpoles	Riffle healthier - otherwise as for SC2
SC2	Banded grunter, rainbowfish, spangled grunter, archerfish	Tadpoles	Likely overnight stream rise. 8 cm ("tide mark"). Seems cattle disturbed
SC3	Mouth almighty, one specimen	Tadpoles	Quite good condition. Water slightly discoloured. Site accessed upstream of crossing on QLD side. Castor oil plants quite common
7MC1	No evidence of fish		Very good. High water clarity. Dead crabs in pool. Pigs bathing on arrival
BC1	Banded and spangled grunters, rainbowfish, flathead goby	Tadpoles	Good condition. Road crossing. Sample a composite of muddy/macrophyte pool edge and cobble riffle

Table A2 Water and sediment physico-chemistry results for sample sites in the vicinity of Redbank Mine

A. Water physico-chemistry

SAMPLING SITES AND TIMES		GENERAL FIELD PARAMETERS					LABORATORY WATER CHEMISTRY PARAMETERS														
		Water temperature	Dissolved Oxygen	Turbidity	pH	Electrical conductivity															
Site	Code						Alkalinity	Al_F	Ca_F	Co_F	Cu_F	Fe_F	K_F	Mg_F	Mn_F	Na_F	Ni_F	Pb_F	SO4_F	U_F	Zn_F
	Description	°C	mg/L	NTU		µS/cm	mg/L	µg/L	mg/L	µg/L	µg/L	µg/L	mg/L	mg/L	µg/L	mg/L	µg/L	µg/L	mg/L	µg/L	µg/L
RBS	Redbank Spring	26.1	4.86	0.3	3.88	7.8	<1	61.4	<0.1	0.18	0.2	260	0.6	0.4	2.47	2.3	0.14	0.01	<0.1	0.005	0.9
RC1	Redbank Ck Site 1	34.5	5.83	7.5	6.2	20.5	18	2.2	1.6	0.33	1.33	20	0.8	1.5	47.1	4.2	0.36	<0.01	0.1	0.009	0.7
RC2	Redbank Ck Site 2	32.5	6.28	4.9	6.4	39.9	27	142	2.8	0.09	2.47	380	1.9	2.4	12.4	3.9	0.24	0.07	0.1	0.02	0.6
RC2A	Redbank Ck site 2A. Track crossing	32.4	5.4	4.5	6.62	64.9															
RC3	Redbank Ck Site 3	34.7	6.13	3.1	7.07	44.5	31	110	2.2	0.11	3.16	180	3.8	3.2	10.7	3.2	0.32	0.03	<0.1	0.011	1.4
ECUS	Echo Ck upstream of Hanrahans Ck confluence	34.7	5.85	2.5	6.06	12.9	10	31.9	0.4	0.11	1.89	100	0.6	0.8	3.28	3.8	0.23	0.01	<0.1	0.015	0.4
ECDS	Echo Ck downstream of Hanrahans Ck confluence	35	4.4	2.6	4.7	183.0	5	617	4.5	169	6010	<20	1.8	9.6	667	5.3	70.2	0.04	67.6	0.646	116
ECU12MC	Echo Ck upstream of 12 Mile Ck confluence	31.6	5.5	0	5.09	192.0	7	109	6	156	5180	<20	2.6	11.5	568	5.5	74.8	0.05	77.6	0.145	109
12MUEC	12 Mile Ck upstream Echo Ck confluence	30.5	6.18	0.5	6.12	13.4	13	11.7	0.8	0.08	0.24	140	0.7	1	7.71	3.2	0.08	<0.01	<0.1	0.006	0.5
12MDEC	12 Mile Ck downstream of Echo Ck confluence	30.9	5.84	0.4	5.86	88.2	14	31.6	2.3	44.1	1400	100	1.3	4.1	165	3.7	21.3	<0.01	21.9	0.043	30.6
12MC1	12 Mile Ck site 1, upstream of Settlement Ck confluence	33.9	6.5	4.5	7.74	143.5	46	6.1	8.4	10.3	152	<20	2.5	9.3	84.4	4.8	8.76	0.01	31	0.04	6.3
SC1	Settlement Creek site 1, upstream of 12 Mile Ck confluence	31.8	4.31	21.7	7.35	158.4	89	11	12.8	0.14	0.9	<20	3.3	10	39.9	5.6	0.48	0.02	0.8	0.11	0.7
SC2	Settlement Creek site 2, downstream of 12 Mile Ck confluence	32.5	5.2	12.9	7.44	155.7	79	10.9	12.1	1.01	23.4	<20	3.1	10	22	5.5	1.61	0.01	5.6	0.099	1
SC3	Settlement Creek site 3, Wollogorang Road crossing	31.7	5	26.4	7.46	148.5	70	20.1	10.5	0.09	9.6	40	2.6	9.3	17.9	5.3	0.49	0.02	8.4	0.104	0.4
7MC1	Seven Mile Creek, Wollogorang Road crossing	30.8	4.54	1.3	7.43	191.7	106	7.55	14.8	0.16	0.785	20	5.6	12.45	26.95	4.05	0.155	0.0125	0.2	0.0635	0.65
BC1	Branch Creek (QLD), Wollogorang Road crossing	30.7	4.7	4	7.15	110.0	66	101	6.2	0.08	0.86	160	1.5	8.9	8.45	4.8	0.44	0.03	0.4	0.034	1.8

Table A2. Contin.

B. Sediment chemistry. Italicised values interpolated or extrapolated from the values from other sites, as indicated.

SAMPLING SITES		SEDIMENT QUALITY							
Site Code	Notes	Al mg/kg	Cu mg/kg	Fe mg/kg	Mg mg/kg	S mg/kg	Zn mg/kg	Pb mg/kg	Approx % <63 µm
RBS									
RC1		1570	59	7530	772	30	14	5.95	6.4
RC2	Sediment values for this site are averages of sites RC1 and RC3	<i>1645</i>	<i>46.3</i>	<i>7665</i>	<i>1091</i>	<i>25</i>	<i>14.5</i>	<i>5.75</i>	<i>7.5</i>
RC2A	Sediment values for this site are averages of sites RC1 and RC3	<i>1645</i>	<i>46.3</i>	<i>7665</i>	<i>1091</i>	<i>25</i>	<i>14.5</i>	<i>5.75</i>	<i>7.5</i>
RC3		1720	33.6	7800	1410	20	15	5.55	8.5
ECUS		1840	76.4	20600	1050	50	6.5	5.6	7.3
ECDS		4850	5440	12700	858	2910	30	5.75	1.8
ECU12MC	Assumed similar to ECDS	<i>4850</i>	<i>5440</i>	<i>12700</i>	<i>858</i>	<i>2910</i>	<i>30</i>	<i>5.75</i>	<i>1.8</i>
12MUEC	Average of reference sites RC1, RC2 and ECUS	<i>1710</i>	<i>56.3</i>	<i>11976.7</i>	<i>1077.3</i>	<i>33.3</i>	<i>11.8</i>	<i>5.7</i>	<i>7.4</i>
12MDEC		1700	641	7100	1070	170	5	7.1	1.7
12MC1		2670	19000	5360	2840	35	41	11.3	20.7
SC1		1590	27.8	6300	1740	15	8.5	14.8	24.0
SC2		2560	135	7710	3000	20	26	8.75	30.2
SC3		1480	243	3480	2930	65	10	18	3.7
7MC1	Assumed similar to SC1	<i>1590</i>	<i>27.8</i>	<i>6300</i>	<i>1740</i>	<i>15</i>	<i>8.5</i>	<i>14.8</i>	<i>24.0</i>
BC1	Assumed similar to SC1	<i>1590</i>	<i>27.8</i>	<i>6300</i>	<i>1740</i>	<i>15</i>	<i>8.5</i>	<i>14.8</i>	<i>24.0</i>

Table A3 Results of Principal Component Analysis of Redbank water and sediment physicochemistry**Eigenvalues**

PC	Eigenvalues	%Variation	Cum.%Variation
1	7.66	38.3	38.3
2	6.05	30.2	68.5
3	2.12	10.6	79.1
4	1.34	6.7	85.8
5	1.06	5.3	91.1

Eigenvectors

(Coefficients in the linear combinations of variables making up PC's)

Variable	PC1	PC2	PC3	PC4	PC5
DO	0.010	0.246	-0.403	-0.428	0.042
Turbidity	0.203	-0.184	0.020	0.108	-0.458
pH	0.296	-0.189	-0.107	-0.230	-0.022
EC	-0.102	-0.370	0.084	-0.070	0.218
Alkalinity	0.278	-0.247	0.008	-0.078	0.045
Al_F	-0.216	0.012	0.478	-0.250	-0.036
Cu_F	-0.317	-0.099	-0.120	-0.077	0.236
Fe_F	0.129	0.253	0.329	-0.326	0.170
K_F	0.020	-0.318	0.106	-0.300	0.107
Na_F	-0.110	-0.328	-0.034	0.269	-0.227
Pb_F	-0.128	-0.138	0.475	-0.328	-0.261
U_F	-0.204	-0.303	0.114	0.212	0.034
Zn_F	-0.329	-0.058	-0.037	-0.052	0.288
Al-sed	-0.333	-0.089	-0.099	-0.053	-0.206
Cu-sed	-0.276	-0.104	-0.320	-0.147	0.096
Fe-sed	-0.183	0.257	0.064	0.171	-0.290
Mg-sed	0.178	-0.283	-0.170	-0.209	-0.004
S-sed	-0.347	-0.004	0.020	0.098	0.099
Zn-sed	-0.190	-0.133	-0.263	-0.346	-0.483
Pb-sed	0.181	-0.304	0.021	0.149	0.242

Principal Component Scores

	Score 1	Score 2	Score 3	Score 4	Score 5
SC1	2.13	-2.8	0.807	1.58	-0.416
SC2	0.781	-2.56	-1.29	8.72E-04	-1.15
SC3	2.08	-2.97	0.159	0.124	0.391
12MC1	-0.222	-2.18	-3.31	-1.62	-7.40E-02
12MDEC	-1.23	1.69	-0.449	0.34	2.87
12MUEC	1.13	4.24	-0.871	0.112	-2.07E-02
7MC1	2.32	-1.89	0.52	0.476	1.13
BC1	1.81	-0.829	1.89	1.94E-02	0.347
ECDS	-6.26	-1.15	1.13	0.857	-0.747
ECUS12M	-5.99	-0.459	-0.113	-0.365	0.231
ECUS	0.334	3.84	0.158	1.04	-0.799
RC1	1.29	2.4	-1.69	1.38	-0.806
RC2A	0.693	1.2	2.12	-1.56	-0.763
RC3	1.13	1.47	0.928	-2.38	-0.188

APPENDIX B

Macroinvertebrate data

Table B1 Total abundance of macroinvertebrate families at Redbank sites. Site codes are explained in Table 1 of the main report. Taxa abbreviations: Ph, Phylum; Cl, Class; Or, Order. Life stage codes are L, larvae; P, pupae; A, Adult, while U = Unidentified.

Taxa			Site													
Phylum-Class-Order	Family		RC1	RC2A	RC3	ECUS	ECDS	ECU12MC	12MUJEC	12MDEC	12MC1	SC1	SC2	SC3	7MC1	BC1
CNIDARIA																
	Hydrozoa	Hydridae	0	0	0	0	0	0	0	0	0	33.33	0	0	50	0
PLATYHELMINTHES																
	Turbellaria		0	0	0	0	0	0	0	0	0	0	0	0	25	0
NEMATODA			50	200	10	0	0	0	0	0	0	0	6.25	11.11	0	0
MOLLUSCA																
	Bivalvia	Hyriidae	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	Gastropoda	Lymnaeidae	0	2	10	0	0	0	0	0	0	0	0	0	0	0
		Ancylidae	1	200	0	0	0	0	0	0	0	0	0	0	0	0
		Planorbidae	0	5	50	0	0	0	60	0	0	66.67	0	0	875	166.67
ANNELIDA																
	Oligochaeta		3100	2850	50	0	0	0	40	0	0	33.33	0	0	200	0
CRUSTACEA																
	Cladocera		1750	5850	10	0	0	0	60	0	0	233.33	0	122.22	0	33.33
	Copepoda		1700	3000	40	200	16.67	0	40	0	5.88	33.33	31.25	66.67	50	0
	Ostracoda		7000	4200	40	260	11.11	0	300	0	5.88	1000	25	644.44	1050	566.67
	Decapoda	Parathelphusidae	0	0	0	0	0	0	0	0	0	0	0	0	2	0
		Palaemonidae	1	0	0	0	0	0	0	0	0	0	0	1	0	0
ARACHNIDA																
	Acarina	Oribatida	600	50	0	40	0	0	280	0	0	33.33	0	11.11	225	233.33
		Hydracarina	200	400	90	40	55.56	27.78	160	100	0	166.67	68.75	411.11	0	66.67

Taxa		Site													
Phylum-Class-Order	Family	RC1	RC2A	RC3	ECUS	ECDS	ECU12MC	12MUJEC	12MDEC	12MC1	SC1	SC2	SC3	7MC1	BC1
INSECTA															
Ephemeroptera	Baetidae	250	650	60	160	11.11	0	220	0	0	1300	0	600	1200	500
	Caenidae	900	1900	360	100	0	0	200	0	5.88	833.33	0	144.44	250	2500
Odonata	Leptophlebiidae	100	0	0	0	0	0	80	0	0	200	0	0	0	166.67
	Zygoptera (U)	50	0	0	0	0	0	0	0	0	0	0	33.33	0	0
	Coenagrionidae	2	5	0	20	0	0	20	0	0	0	1	11.11	0	0
	Isostictidae	0	0	0	2	0	0	0	0	0	0	0	0	13	0
	Anisoptera (U)	100	150	0	20	5.56	0	0	12.5	5.88	66.67	0	66.67	75	0
	Gomphidae	50	0	0	0	16.67	0	1	0	0	0	0	11.11	0	0
	Hemicorduliidae	2	0	0	0	0	0	0	0	0	0	0	0	0	0
	Libellulidae	50	50	0	0	0	0	8	0	0	5	1	33.33	50	3
Hemiptera	Gerridae	0	0	0	0	0	0	0	0	29.41	0	0	0	0	0
	Nepidae	0	0	0	0	0	0	0	0	0	0	0	0	1	0
	Corixidae	0	1	40	20	0	0	0	0	0	100	0	0	0	0
	Notonectidae	0	0	40	20	0	0	0	12.5	0	0	0	0	25	0
	Pleidae	0	0	0	0	0	0	0	0	0	0	0	22.22	0	0
	Dytiscidae (A)	2	2	0	1	5.56	5.56	0	0	0	0	12.5	100	0	33.33
Coleoptera	Dytiscidae (L)	100	50	0	120	16.67	5.56	40	12.5	0	33.33	12.5	33.33	50	1
	Gyrinidae	0	0	0	0	0	11.11	0	0	0	0	0	0	0	0
	Hydrophilidae (A)	0	50	0	0	0	0	0	0	0	0	0	0	0	0
	Hydrophilidae (L)	0	50	1	0	0	0	0	0	0	0	0	0	0	0
	Hydrochidae	0	0	10	0	0	16.67	20	0	0	0	0	0	0	0
	Hydraenidae	0	0	20	0	0	0	0	0	0	0	0	0	0	0
	Elmidae	0	0	0	0	0	0	0	0	0	0	6.25	22.22	0	166.67

Taxa		Site													
Phylum-Class-Order	Family	RC1	RC2A	RC3	ECUS	ECDS	ECU12MC	12MUJEC	12MDEC	12MC1	SC1	SC2	SC3	7MC1	BC1
Diptera	Culicidae	1	0	0	0	5.56	0	40	0	0	0	0	22.22	0	0
	Chironomidae (L)	0	0	0	0	0	0	20	0	0	0	0	0	0	0
	Tanypodinae (L)	1200	1400	200	140	5.56	0	260	62.5	0	400	112.5	111.11	100	200
	Orthocladiinae (L)	250	350	90	680	11.11	5.56	360	87.5	5.88	566.67	37.5	211.11	200	133.33
	Chironominae (L)	2900	3200	400	520	16.67	0	1500	25	0	1433.33	37.5	100	1875	1266.67
	Chironomidae (P)	0	100	30	100	5.56	0	200	0	0	66.67	12.5	55.56	25	0
	Ceratopogonidae (L)	350	300	60	40	5.56	5.56	60	12.5	11.76	100	68.75	66.67	50	200
	Ceratopogonidae (P)	0	0	0	0	0	0	0	0	0	0	6.25	0	0	0
	Simuliidae (L)	50	150	0	300	0	0	40	50	0	33.33	0	233.33	75	200
	Simuliidae (P)	0	0	0	0	0	0	0	0	0	0	0	0	0	33.33
	Tabanidae	0	3	1	0	0	0	1	0	0	0	1	0	1	66.67
	Trichoptera	0	0	0	160	5.56	0	120	25	0	33.33	6.25	11.11	0	66.67
Trichoptera	Trichoptera (U)	0	0	0	160	5.56	0	120	25	0	33.33	6.25	11.11	0	66.67
	Ecnomidae	2	0	20	20	0	0	0	0	0	0	0	22.22	1	33.33
	Hydropsychidae	0	1	0	1	0	0	20	0	0	266.67	2	44.44	1	166.67
	Hydroptilidae (L)	900	850	110	380	0	5.56	340	62.5	0	333.33	250	11.11	0	33.33
	Hydroptilidae (P)	0	0	0	0	0	0	20	12.5	0	0	0	0	0	0
	Leptoceridae	1	0	0	80	0	0	100	0	0	66.67	18.75	144.44	0	133.33
Lepidoptera	Philapotamidae	0	300	10	1520	5.56	0	200	12.5	0	933.33	0	366.67	25	333.33
	Pyrilidae	1	0	0	20	0	0	2	0	5.88	0	12.5	0	0	0

Table B2 Total abundance of macroinvertebrate species at Redbank Creek sites. Site codes are explained in Table 1 of the main report. Life stage codes are L, larvae; P, pupae; A, Adult; imm., immature specimens. Distribution abbreviations: I = indeterminate; I* = indeterminate but probably northern Australian endemic; N = endemic to northern Australia; A = Australia (not necessarily Australia-wide, but more than northern distribution); C = Cosmopolitan (Australia and beyond - however not necessarily worldwide).

Phylum-Class-Order	Family	Species	Distribution	Sites		
				RC1	RC2A	RC3
NEMATODA		Nematoda spp.	I	50	200	10
MOLLUSCA						
	GASTROPODA					
	Lymnaeidae	<i>Austropeplea ?lessoni</i>	A	0	2	10
	Ancyclidae	<i>Ferrissia petterdi</i>	A	1	200	0
	Planorbidae	<i>Bayardella</i> sp.	A	0	0	4
		<i>Gyraulus</i> sp.	I*	0	5	50
ANNELIDA						
	OLIGOCHAETA	Oligochaeta spp.	I	3100	2850	40
ARTHROPODA						
	CRUSTACEA					
	CLADOCERA	Cladocera spp.	I	1750	5850	10
	COPEPODA	Cyclopoida spp.	I	1700	3000	40
	OSTRACODA	Ostracoda spp.	I	7000	4200	40
	DECAPODA	Palaemonidae	<i>Macrobrachium</i> sp. (imm./damaged)	C	1	0
	ARACHNIDA					
	ORIBATIDA	Oribatida spp.	C	600	50	0
	ACARINA	Acarina spp.	C	200	400	90
	INSECTA					
	EPHEMEROPTERA					
	Baetidae	<i>Cloeon</i> sp.	C	250	50	50
		<i>Baetidae</i> Genus 3 sp.1	N	0	50	0
		<i>Baetidae</i> Genus 4 sp.	N	0	50	10
		<i>Baetidae</i> spp. (imm.)	I*	0	500	0
	Caenidae	<i>Tasmanocoenis arcuata</i>	N	200	950	170
		<i>Tasmanocoenis</i> sp. J	N	200	0	0
		<i>Tasmanocoenis</i> sp. M	N	0	0	10
		<i>Tasmanocoenis</i> sp. (imm./damaged)	I*	500	950	180

				Sites				
Phylum-Class-Order	Family	Species	Distribution	RC1	RC2A	RC3		
EPHEMEROPTERA	Leptophlebiidae	<i>Thraululus</i> sp.	N	3	0	0		
		Leptophlebiidae spp. (imm.)	I*	100	0	0		
ODONATA								
Zygoptera		Zygoptera spp. (imm.)	I	50	0	0		
	Coenagrionidae	<i>Austroagrion watsoni</i>	C	1	0	0		
<i>Agriocnemis</i> sp. (imm.)		C	0	2	0			
<i>Argiocnemis rubescens</i>		C	0	2	0			
<i>Pseudoagrion ?microcephalum</i> (imm.)		C	0	1	0			
Coenagrionidae spp. (imm.)		I	1	0	0			
Anisoptera spp. (imm.)		I	100	150	0			
Gomphidae		Gomphidae spp. (imm.)	I	50	0	0		
Hemicorduliidae		<i>Hemicordulia intermedia</i>	N	2	0	0		
Anisoptera	Libellulidae	<i>Nannodiplax rubra</i>	C	1	0	0		
		<i>Diplacodes haematodes</i>	C	7	2	0		
		<i>Orthetrum caledonicum</i>	C	4	0	0		
		<i>Libellulidae</i> sp.A (imm.)	I	2	0	0		
		Libellulidae spp. (imm.)	I	50	50	0		
		HEMIPTERA	Corixidae	<i>Micronecta</i> sp.	I*	0	1	40
			Notonectidae	<i>Enithares</i> sp. (imm.)	I	0	0	30
				<i>Nychia sappho</i>	C	0	0	10
COLEOPTERA	Dytiscidae	<i>Hyphydrus decemmaculatus</i>	C	2	1	0		
		<i>Laccophilus sharpi</i>	C	0	1	0		
		<i>Allomatus</i> sp. (L)	I	0	2	0		
		<i>Hydrovatus</i> sp. (L)	I	100	0	0		
		<i>Hyphydrus</i> sp. (L)	I	2	2	0		
		<i>Laccophilus</i> sp. (L)	I	1	0	0		
		<i>Rhantus</i> sp. (L)	C	0	1	0		
		<i>Sternopriscus</i> sp. (L)	I	2	0	0		
		Tribe <i>Bidessini</i> sp. (L)	I	0	50	0		
		<i>Tiporus</i> sp. (L)	I	0	1	0		

Phylum-Class-Order	Family	Species	Distribution	Sites		
				RC1	RC2A	RC3
COLEOPTERA	Hydrophilidae	<i>Amphiops sp. (damaged)</i>	I	0	50	0
		<i>Berosus macropunctatus</i>	N	0	1	0
		<i>Berosus sp. (L)</i>	I	0	3	1
		<i>Enochrus sp. (L)</i>	I	0	50	0
		<i>Hydrochus obsкуроaeneus</i>	N	0	0	10
DIPTERA	Hydraenidae	<i>Hydraena sp.</i>	I	0	0	20
	Culicidae	Culicinae spp. (L)	C	1	0	0
	Chironomidae					
	Tanypodinae	<i>Ablabesmyia sp. (L)</i>	I	2	0	0
		<i>Djalmabatista sp. (L)</i>	I	50	0	0
		<i>Larsia albiceps (L)</i>	C	550	650	20
		<i>Larsia albiceps (P)</i>	C	0	50	10
		<i>Paramerina parva (L)</i>	N	200	150	30
		<i>Procladius paludicola (L)</i>	A	400	600	150
		<i>Cricotopus brevicornis (L)</i>	A	0	0	10
	Orthocladiinae	<i>Corynoneura sp. (L)</i>	I	0	100	50
		<i>Nanocladius sp. 1 (L)</i>	I	50	100	10
		<i>Rheocricotopus sp. (L)</i>	I	200	0	0
		<i>Thienemanniella sp. (L)</i>	I	0	150	20
		<i>Chironomus februaryus (L)</i>	A	250	0	130
		<i>Cladopelma curtilvalva (L)</i>	C	0	0	50
		<i>Cladotanytarsus sp. (L)</i>	I	50	200	30
	Chironominae	<i>Conochironomus sp. (L)</i>	I	50	0	0
		<i>Cryptochironomus sp. (L)</i>	I	50	0	0
		<i>Dicrotendipes lindae (L)</i>	N	1	100	40
		<i>Dicrotendipes ? pelechloris (L)</i>	C	0	0	10
		<i>Microchironomus sp. (L)</i>	I	0	250	0
		<i>Parachironomus sp. (L)</i>	I	50	0	0
		<i>?Parachironomus sp. (L)</i>	I	150	0	0
		<i>Polypedilum leei (L)</i>	A	0	50	0
		<i>Polypedilum watsoni (L)</i>	A	100	100	0

Phylum-Class-Order	Family	Species	Distribution	Sites		
				RC1	RC2A	RC3
DIPTERA	Chironominae	<i>Polypedilum</i> sp. (L) imm./damaged	I	50	0	0
		<i>Rheotanytarsus</i> sp. (L)	I	700	700	10
		<i>Stenochironomus</i> sp. (L)	I	1	100	10
		<i>Tanytarsus dostinei</i> (L)	N	150	0	0
		<i>Tanytarsus ? manlyensis</i> (L)	A	100	250	10
		<i>Tanytarsus micksmithi</i> (L)	N	100	50	20
		<i>Tanytarsus richardsi</i> (L)	N	200	550	80
		<i>Tanytarsus richardsi</i> (P)	N	0	0	20
		<i>Tanytarsus</i> sp. (L) imm./damaged	I	650	150	10
		<i>Zavreliella marmorata</i> (L)	C	0	300	0
		Chironominae spp. (L) imm./damaged	I	250	400	0
		Chironominae spp. (P) imm./damaged	I	0	50	0
	Ceratopogonidae	Ceratopogoniinae spp.	I	350	300	60
	Simuliidae	Simuliidae spp. (L)	I	50	150	0
TRICHOPTERA	Tabanidae	Tabanidae spp.	I	0	3	1
	Ecnomidae	<i>Ecnomus</i> sp. RB1	I	1	0	10
		<i>Ecnomus</i> sp. RB2	I	1	0	10
	Hydropsychidae	<i>Cheumatopsyche ?suteri</i>	N	0	1	0
	Hydroptilidae	<i>Hellyethira cubitans</i>	N	1	50	30
		<i>Hellyethira vernoni</i>	N	50	50	10
		<i>Hellyethira</i> sp. (imm.)	I*	100	0	0
		<i>Orthotrichia velata</i>	I*	150	150	0
		<i>Orthotrichia</i> sp. (unid.)	N	0	0	30
		Hydroptilidae spp. (imm.)	I*	600	600	40
	Leptoceridae	<i>Oecetis</i> sp.	I	1	0	0
		Leptoceridae spp. (imm.)	I	0	0	0
	Philopotamidae	<i>Chimarra uranka</i>	N	0	100	0
		<i>Chimarra</i> sp.	I	0	0	10
		Philopotamidae spp. (imm.)	I*	0	200	0
LEPIDOPTERA	Pyalidae	<i>Nymphulinae</i> sp. 3	A	1	0	0
Total Taxa				67	65	49
Total Abundance				21690	26331	1746

APPENDIX C

Photographs of Redbank sampling sites

Plate 1. Redbank Creek sites

A. Redbank Ck (site RC1) – Pool-Riffle sequence



B. Redbank Ck (RC2)



C. Redbank Ck (RC2a)



D. Redbank Ck (RC3)



Plate 2. Echo Creek in the vicinity of Hanrahans Creek

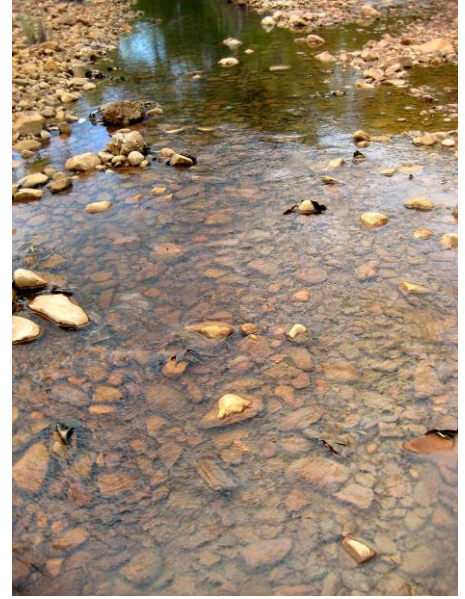
A. Echo Creek upstream Hanrahans confluence (ECUS) (riffle)



B. Echo Creek upstream Hanrahans confluence (ECUS) (pool)



C. Echo Creek-Hanrahans confluence looking upstream from a point 10 m downstream of confluence. See picture note below.



D. Echo Creek downstream of Hanrahans confluence (ECDS) (riffle)



E. Echo Creek downstream of Hanrahans confluence (ECDS) (pool). (Looking downstream of picture D.)



Observation for picture C: Note colour demarcation of substrates – normal dark coloured cobbles on the left (Echo Creek) arising from healthy epiphyte growth, versus denuded light coloured cobbles on the right, arising from polluted water from Hanrahans

Plate 3. Echo Creek and 12 Mile Creek confluence zone

A. Echo Creek upstream 12 Mile Creek confluence (ECU12MC) showing high clarity, turquoise (copper-laden) polluted waters)



B. Dead or sparse fringing vegetation along Echo Creek upstream of 12 Mile Creek confluence (ECU12MC)



C. 12 Mile Creek upstream Echo Creek confluence (12MUEC) (pool)



D. 12 Mile Creek downstream Echo Creek confluence (12MDEC)



E. 12 Mile Creek downstream Echo Creek confluence (12MDEC)



F. Filamentous algae ('streamers') in 12 Mile Creek downstream Echo Creek confluence (12MDEC)



Plate 4. 12 Mile Creek and Settlement Creek confluence zone

A. 12 Mile Creek upstream Settlement Ck confluence (12MC1)



B. 12 Mile Creek upstream Settlement Ck confluence (12MC1)



C. Settlement Creek downstream 12 Mile Creek confluence (SC2) (pool)



D. Settlement Creek downstream 12 Mile Creek confluence (SC2) (riffle)



E. Settlement Creek upstream 12 Mile Creek confluence (SC1) (riffle)



F. Settlement Creek upstream 12 Mile Creek confluence (SC1), looking downstream to confluence



Plate 5. 12 Mile Creek and Settlement Creek confluence zone, Settlement Creek near Wollongorang Station and reference streams, Branch Creek and 7 Mile Creek

A. 12 Mile Creek and Settlement Creek confluence zone, 12 Mile Creek entering from middle right of picture



B. Settlement Creek near Wollongorang Station (SC3) (pool)



C. Settlement Creek near Wollongorang Station (SC3) (riffle)



D. 7 Mile Ck upstream of Savannah Way road crossing (7MC1) (pool)



D. 7 Mile Ck upstream of Savannah Way road crossing (7MC1) (riffle)



E. Branch Creek (QLD) at Savannah Way road crossing looking downstream (BC1) (riffle)



F. Branch Creek (QLD) at Savannah Way road crossing looking upstream (BC1) (pool)

