Excellence in your environment

niche Environment and Heritage

Berrima Colliery
Environmental Performance Monitoring
Aquatic Ecology

Prepared for Boral Cement Limited | 24 January 2019

Document control

Project number	Client	Project manager	LGA
4555	Boral cement Limited	Matthew Russell	Wollondilly

Version	Author	Review	Status	Date
D1	Matthew Russell	Lucy Porter and Simon Tweed	Draft	13 December 2018
Rev1	Matthew Russell	David Spears/Boral	Final	24 January 2018

Enquiries should be addressed to:

Sydney Head Office
Niche Environment and Heritage
02 9630 5658
info@niche-eh.com
PO Box 2443 North Parramatta
NSW 1750 Australia

niche Environment and Heritage

Executive summary

The Berrima Colliery is an underground coal mine located at Medway in the NSW Southern Highlands. The mine operated continually from 1926 until October 2013, when it was placed on care and maintenance, pending full closure. Boral Cement Limited (Boral) is preparing the mine for full closure and is responding to issues by regulators before a final closure plan can be approved. Specifically the Berrima Colliery was required to address mine water discharge into Wingecarribee River.

Special Condition 8 of Environmental Protection Licence (EPL) 608, requires Berrima Colliery to develop and implement an action plan to prevent, control, abate and mitigate pollution to the Wingecarribee. Condition E3.1 requires the colliery to prepare a Performance Monitoring Program to monitor the performance of the water treatment works implemented and specifies aquatic ecological monitoring as a component of the program. Consequently, Niche Environment and Heritage (Niche) were engaged by Boral to conduct aquatic monitoring at Berrima Colliery.

The purpose of this aquatic study is:

- To assess the gradient changes in composition and abundance of in-stream biota downstream of Berrima Colliery's adit discharge to the Wingecarribee River.
- To assess changes over time, following the installation of the water treatment system.

The survey used standard quantitative macroinvertebrate dip-net sampling in accordance with the License Conditions at five impact monitoring sites downstream and two reference sites upstream of the mine water discharge and at Medway Rivulet tributary. The indicators used for statistical analysis included macroinvertebrate Family Richness, EPT (Ephemeroptera, Plecoptera, Trichoptera) Richness, %EPT and macroinvertebrate community data.

The following conclusions were made:

In general, impacts from discharge were observed downstream at Site 3 (300m downstream) and Site 4 (1000m downstream) in all three survey periods (March, June and September 2018) with no obvious impacts at sites further downstream. Impacts included: reduction in abundance, taxonomic richness and EPT, and change in macroinvertebrate assemblage structure. There were some small improvements in EPT, taxonomic richness at Site 3 and 4 in September 2018 and became more similar to reference sites. However this is difficult to relate to any improvements due to water quality treatment. Improvements in water quality were offset by extensive low flows of the Wingecarribee River and associated water quality. Iron precipitate is the likely mechanism affecting macroinvertebrates, and was the most improved parameter observed within the mine after improvements in water treatment practices. With the longer term implementation of these measures it is likely that further improvements will be measurable in future monitoring.

Glossary and list of abbreviations

Term or abbreviation	Definition
ANZECC	Australian and New Zealand Environment and Conservation Council.
AUSRIVAS	Australian Rivers Assessment System.
Adit	A horizontal passage leading into a mine for the purposes of access or drainage.
Drift	The passive dispersal of the larvae of invertebrates living in rivers,
EPT Index	Ephemeroptera, Plecoptera, Trichoptera index – total count of the different taxa with in these orders
% EPT	Total EPT counts divided by the abundance of all individuals
Eco toxicity	Refers to the potential for biological, chemical or physical stressors to affect ecosystems.
Macroinvertebrates	Macroinvertebrates are animals without a backbone that can be seen with the naked eye.
SIGNAL	Stream Invertebrate Grade Number Average Level.

Table of Contents

List of Figures

List of Plates

List of Tables

1. Introduction

1.1 Background

The Berrima Colliery is an underground coal mine located at Medway in the NSW Southern Highlands. The mine operated continually from 1926 until October 2013, when it was placed on care and maintenance, pending full closure. Boral Cement Limited (Boral) is preparing the mine for full closure and is responding to issues by regulators before a final closure plan can be approved. Specifically the Berrima Colliery was required to address mine water discharge into Wingecarribee River.

Special Condition 8 of Environmental Protection Licence (EPL) 608, requires Berrima Colliery to develop and implement an action plan to prevent, control, abate and mitigate pollution to the Wingecarribee. Condition E3.1 requires the colliery to prepare a Performance Monitoring Program to monitor the performance of the water treatment works implemented and specifies aquatic ecological monitoring as a component of the program.

1.1.1 Purpose and objectives of this report

Niche Environment & Heritage (Niche) have been commissioned by Boral to conduct an aquatic ecological monitoring program to examine the stream health downstream of the mine water discharge in the Wingecarribee River and compare it to reference sites to assess the improvements to stream health after the implementation of water treatment measures.

The purpose of this aquatic study is:

- To assess the gradient changes in composition and abundance of in-stream biota downstream of Berrima Colliery's adit discharge to the Wingecarribee River.
- To assess changes over time following the installation of the water treatment system.

1.2 Environmental Protection License conditions

Licence conditions relating to aquatic ecological monitoring (Section E3.1 of Berrima Colliery's EPL) are listed in Table 1 below and addressed in this report. Water quality monitoring and analysis was undertaken by International Environmental Consultants. This report focusses primarily on aquatic ecology components of the program.

Table 1: E3.1 Performance Monitoring Program – aquatic ecology

Parameter	Requirement
Project objective	• To assess the gradient changes in composition and abundance of in-stream biota downstream of Berrima Colliery's adit discharge to the Wingecarribee River. • To assess changes over time following installation of the water treatment system.
Hypothesis	• That the abundance and composition of aquatic biota will become more similar to reference sites following commissioning of the required water treatment project. • A specific bio-indicator target is for % EPT at sites downstream of the discharge (Point 4, 5 and 6) to be statistically similar to reference sites. • The EPT index is used to calculate the relative abundance of pollution sensitive macroinvertebrates of the Ephemeroptera, Plecoptera and Trichoptera Orders. (Wright & Ryan 2016).
Quantitative macroinvertebrate sampling and analysis	• Representative macroinvertebrate monitoring should be carried out following the methods (taxon level, sampling method) used by the University of Western Sydney in the study area (Dr Ian Wright). Monitoring frequency:

	• Quarterly during 2018 or 3 samples with two in the first half of 2018 Autumn, Spring/Summer 2019. • Monitoring should reasonably coincide with water quality monitoring.
Sampling design	The sampling design consists of three treatment groups: • Discharge Monitoring Site (near) (5 sites - 1, 3, 4, 5, 7) which capture the gradient from the discharge water • Discharge Monitoring Site (far) (Site 8), this site is not directly associated with the discharge monitoring sites gradient but are used for comparison with ANZECC trigger values. • Reference (sites) — upstream (Site 2) and Medway Rivulet (Site 8) or as otherwise agreed
Statistical design	• Recognised statistical methods should be used to test for differences in abundance and richness between treatments and in gradient analysis.

1.3 Wingecarribee River and mine water discharge

The Wingecarribee River is a highly regulated system with three water supply structures and many farm dams which starve the river of natural water flow. The mine discharges into the Wingecarribee River approximately 1.8 km above the confluence with Medway Rivulet with mining operations ongoing for at least 88 years. Upstream, the river is regulated by Wingecarribee Reservoir which provides a limited base flow to the stream. As a result, the water flow upstream of the mine reduces substantially during low rainfall periods (IEC 2015).

A small but regular base flow is provided by the mine water discharge (average 2.7 ML/day) to which the downstream environment has adapted (IEC 2015). Further downstream the flow regime becomes progressively more natural as more tributaries feed the system (IEC 2015) before its confluence with the Wollondilly River which ultimately flows into Lake Burragorang (Warragamba Dam). Monitoring undertaken at various locations downstream of the adit (licenced discharge point) shows that there has been an increase in electrical conductivity and concentrations of metals such as iron, manganese, nickel and zinc since mid-2016 (IEC 2016). Despite some moderate reductions in metal concentrations since water treatment, levels have remained elevated compared to historical levels.

1.3.1 Summary of water treatment measures (from Boral 2018)

The underground treatment system seeks to emulate the original underground water management system within the confines of the non-flooded mine workings. When operating, underground water was collected at several points within the mine and either pumped or allowed to gravity flow into a large sump at the lowest point in the mine (400 Panel Main Sump). From here the water was pumped into the 4a/4b Sump, then K Mart Sump then finally the Pit Bottom Sump. From here the water overflowed into the old mine workings and discharged into the Wingecarribee River at the licensed discharge point via the drain adit.

The mine water would generally travel up to 4 km underground and passed through at least 3 separate aeration and settlement processes prior to discharge. Aeration was provided by pumping and gravity feeding the water along channels. This process also maintained the pH at or slightly above neutral while the large sumps provided time for settlement. This process was able to remove the majority of iron and a proportion of manganese and other minerals from the water prior to discharge.

As part of the closure process, the first three underground sumps were allowed to flood and are no longer accessible. Only the Pit Bottom Sump and the remaining dry mine workings can be utilised. The current underground treatment system involves pumping from the edge of the flooded workings along 400 Panel to 3 North Panel where it is passed through a limestone bed and weir arrangement to increase pH. The water then passes through old workings into the Pit Bottom Sump for settlement prior to discharge via the Drain

Adit. The use of limestone and active aeration is necessary given the much smaller available area underground compare to the original water management system. (Boral 2018).

1.3.2 Water quality monitoring - 2018

The underground treatment system commenced in late January 2018 and the following changes were observed from the treatment of mine water (Boral 2018):

- Increase of 0.5 pH units (i.e. towards pH neutral)
- Improved dissolved oxygen concentration
- Reduction in electrical conductivity
- Significant reduction in dissolved iron concentration
- Reduced concentrations of manganese, nickel and zinc.

The Wingecarribee River ambient monitoring showed a slight improvement in water quality, however it was concluded that any improvement to the river in mine water discharge may be diminished by poorer water quality associated with exceptionally dry conditions and low river flow concentrating the mine water discharge.

1.4 Aquatic ecology - 2017 monitoring

Ecological monitoring conducted by Dr Ian Wright in February 2017 (Wright et al. 2018) and by Niche in spring 2017made the following conclusions:

- Below the mixing zone (> 6km downstream: Site 8 Biloela) in the Wingecarribee River were in good health, and as indicated by AUSRIVAS assessment, consist of macroinvertebrate fauna which would be expected to occur in a natural stream (Niche 2018).
- There is a marked change in macroinvertebrate communities 100-200m downstream of the mine water discharge, with reduction of family richness, density, reduction in sensitive fauna (Niche 2018; Wright et al 2018) and an increase in site variability compared to the site sampled upstream of the discharge (Niche 2018).
- There was a reduction in EPT indices (Niche 2018; Wright et al 2018) at 100-200m downstream of the discharge. EPT richness increased at 500m downstream (Niche 2018).
- There was a modest recovery of stream fauna 500m downstream of the mine water discharge with an increase in density, richness and sensitive families (Niche 2018).
- The deposition of iron precipitate within the Wingecarribee River downstream of the mine water discharge is possibly the predominant factor affecting macroinvertebrates immediately downstream of the discharge (Niche 2018).

2. Methods

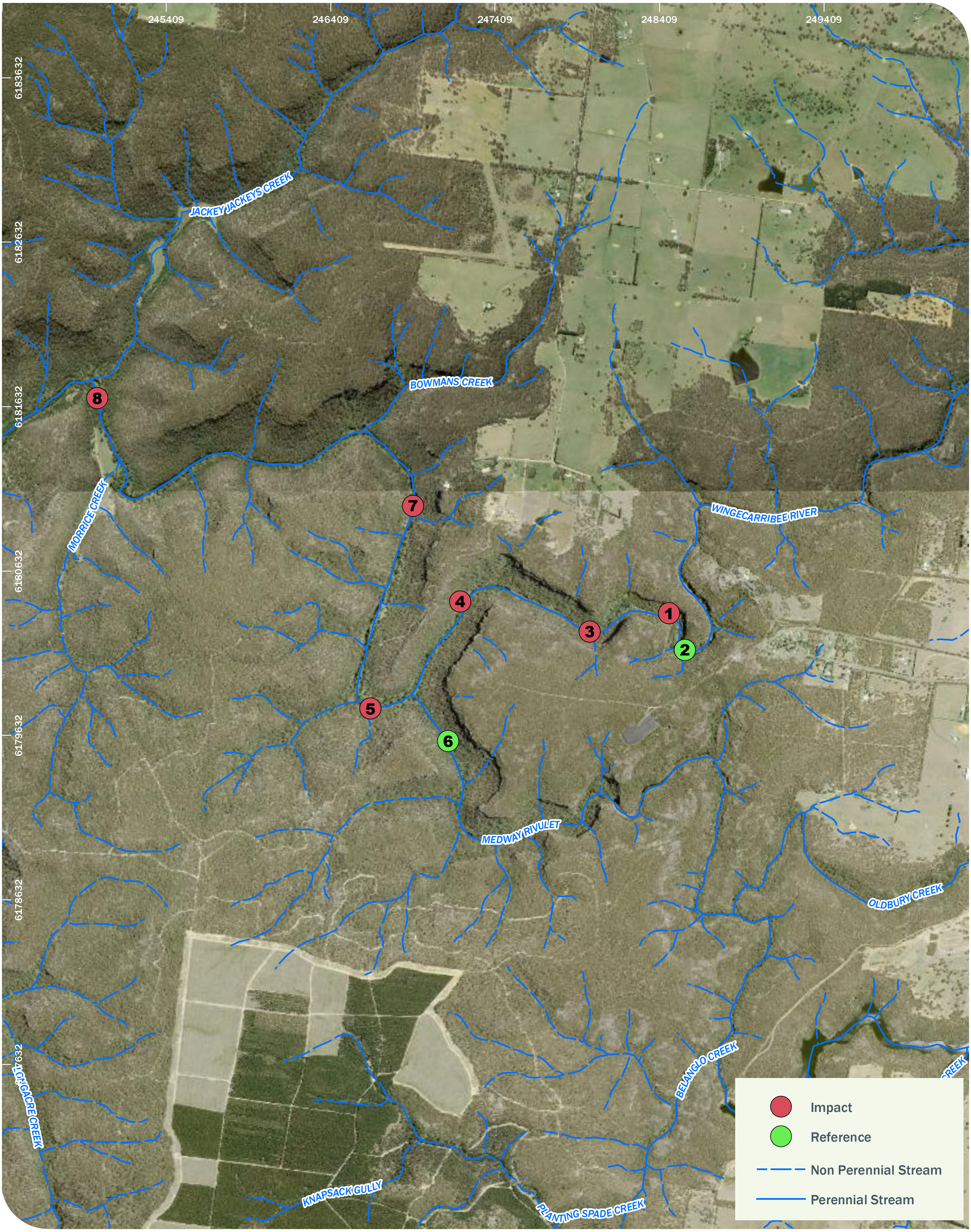
2.1 Sampling location and study design

Sites were sampled at the locations as specified in the EPL licence 608 (Table 1). With five impact monitoring sites located downstream of the mine adit, two reference sites upstream in Wingecarribee River and a third reference site in Medway Rivulet. The purpose of the Medway Rivulet site is to determine background ecological condition without the impacts of other activities upstream of the mine discharge such as effluent from the sewage treatment plants and runoff from agricultural land and urban areas.

Downstream quantitative samples were compared to the upstream sites and longitudinal changes downstream of the mine water discharge were assessed to determine any improvement in stream health. The sites were also compared through time.

Table 2: Location of macroinvertebrate sampling sites

Site Number	Location	Easting	Northing
1. Impact (no samples)	V-notch weir (discharge)	248467	6180374
2. Reference	100m upstream of LDP1 (adit) in the Wingecarribee River (WR - reference)	248562	6180151
3. Impact	~300m downstream of the confluence (WR)	247983	6180264
4. Impact	1 km downstream of the confluence (WR)	247197	6180447
5. Impact	2 km downstream but upstream of the confluence with Medway Creek (WR)	246650	6179795
6. Reference	Medway Creek	247123	6179596
7. Impact	3 km downstream of the confluence (WR)	246909	6181028
8. Impact	Biloela camping ground - 6km downstream of the confluence (WR)	244988	6181683



Drawn by: Matt Harris File: T:\spatial\projects\a4500\a4555_Berrima_Colliery_AQ\Maps\report\4555_Figure_1_SurveySites.mxd Last updated: 23-Jan-19 3:32:36 PM

niche Environment and Heritage

0 600
m
GDA 1994 MGA Zone 56

Niche PM: Matthew Russell
Niche Proj. #: 4555
Client: Boral Cement Limited

Berrima Colliery
Environmental Performance Monitoring
Aquatic Ecology

Figure 1

2.2 Survey methods

The project area was investigated by Niche Aquatic Ecologists in autumn 2018 on two occasions and spring 2018 on one occasion in accordance with the EPL conditions. The survey method used a quantitative dip net method as prescribed by the licence.

2.2.1 Quantitative dip net sampling

Quantitative sampling was undertaken using methods previous conducted in studies on mine water impacts in the Wingecarribee River and other mine water discharges in the southern coal fields (Wright et al. 2018; Wright and Burgin 2009). Quantitative sampling included a timed (1 minute) dip net sampling of flowing water/riffle habitat. This involved disturbing the substrate upstream of the dip net with the feet at a random locations within the riffle habitat. Five subsamples/replicates samples were taken at each site. Each sample was preserved in the field in a 500ml plastic jar and taken to the laboratory for processing.

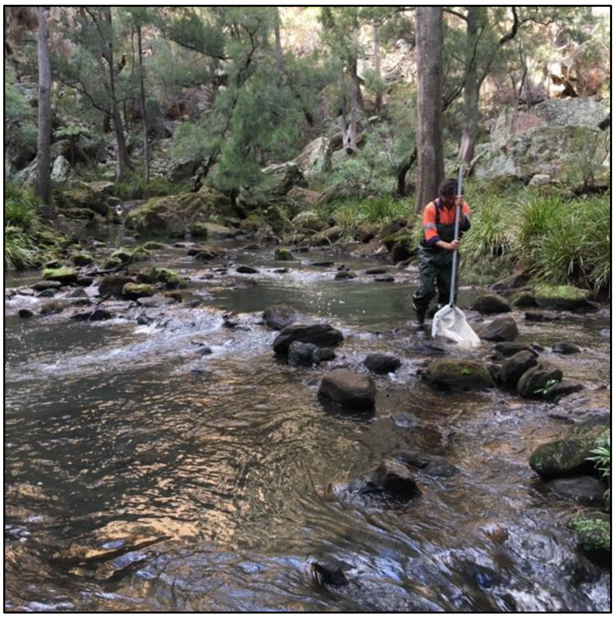


Plate 1: Field survey method – dip netting

2.2.2 Laboratory methods

Quantitative samples were processed in the laboratory. Samples were placed on to a sorting tray. All macroinvertebrates were picked under a magnifying lamp and placed into a labelled jar containing 70% ethanol.

Macroinvertebrate samples were identified to family level with the exception of Oligochaeta (to class), Polychaeta (to class), Ostracoda (to subclass), Nematoda (to phylum), Nemertea (to phylum), Acarina (to order) and Chironomidae (to subfamily). Identification keys used include:

- Dean, J., Rosalind, M., St Clair, M., and Cartwright, D. (2004) Identification keys to Australian families and genera of caddis-fly larvae (Trichoptera) Cooperative Research Centre for Freshwater Ecology.
- Gooderham, J. and Tsyrlin, E. (2002). The Waterbug Book: A guide to the Freshwater Macroinvertebrates of Temperate Australia, CSIRO Publishing.
- Hawking J. and Theischinger G. (1999). A guide to the identification of larvae of Australian families and to the identification of ecology of larvae from NSW.
- Madden, C. (2010) Key to genera of Australian Chironomidae. Museum Victoria Science Reports 12,1-31.

- Madden, C. (2011) Draft identification key to families of Diptera larvae of Australian inland waters La Trobe University.
- Smith, B. (1996) Identification keys to the families and genera of bivalve and gastropod molluscs found in Australian inland waters Murray Darling Freshwater Research Centre.
- Website - http://www.mdfrc.org.au/bugguide/.

2.3 Data analysis

Multivariate and univariate analysis of family level macroinvertebrate community data collected from the Wingecarribee River was conducted to investigate the ecological response to water quality mitigation measures implemented by the colliery.

2.3.1 Univariate Analysis

Univariate analysis was performed on the following assemblage indices:

- Taxonomic richness - the count of different families present in a region or ecological environment. A higher richness is indicative of good stream health.
- Abundance – number of individuals.
- % EPT - the number of EPT individuals divided by the total number of individuals in the sample.
- EPT index - Ephemeroptera, Plecoptera and Tricoptera (EPT) index is based on the insect orders that contain a majority of pollution sensitive taxa (Lenat 1988). All family of Ephemeroptera, Plecoptera and Tricoptera will be identified and then the number of distinct taxa counted as an indicator of ecosystem health - the higher the number the healthier the aquatic ecosystem.

The analysis was conducted to determine if sites downstream of the discharge are statistically similar to reference sites. The PERMANOVA (Permutational Analysis of Variance) procedure in PERMANOVA+ for Primer statistical software package (Anderson et al 2008) was used. A two factor (Survey and Site) fixed design was used to explore differences between sites and surveys using the Euclidean distance matrix. For pairwise comparisons where unique permutations were less than 100, a permutational P value was adopted by applying the Monte Carlo boot strapping procedure to increase possible permutations (Anderson et al 2008).

Regression analysis was used to determine the strength and significance of any linear relationships of taxonomic diversity, abundance, and EPT with distance from the discharge point. The data analysis was performed using the data analysis add-in in the Microsoft Excel Software package. Regression analysis was run separately for each survey and trends were compared graphically to the reference sites.

2.3.2 Multivariate Analysis

Multivariate analysis was performed on the macroinvertebrate assemblage data using the PERMANOVA+ for Primer statistical software package (Anderson et al 2008). The analysis was based on Bray-Curtis similarities computed from (transformed) species abundance values. The data was transformed using the fourth-root function to normalise the distribution of the data. A two factor (Survey and Site) crossed ANOSIM (Analysis of Similarity) routine was used to test the significance of dissimilarity between groups, and to explore if sites downstream of the discharge are statistically similar to reference sites. The ANOSIM procedure is a non-parametric statistical procedure using Bray-Curtis dissimilarities and a test statistic (R) based on the difference between the average of all the rank dissimilarities between objects (Quinn and Keough 2002). The R statistic provides a comparative measure of the degree of separation of sites, with values closer to 1 indicating sites are most dissimilar, while those closer to zero indicate sites are similar (Clarke and Warwick 2001). This procedure tests the null hypothesis that the similarity between groups is greater than or equal to the similarity within the groups. Where the null hypothesis is rejected

(Significance level <0.05), the ANOSIM routine can then be used to explore the strength of dissimilarity (R Statistic) between the reference and impact sites (downstream sites) and identify the reference site with most similarity to the impact sites for benchmarking. A two-way crossed Simper analysis was performed to determine the fauna contributing to significant differences identified within the ANOSIM.

Non-metric MDS (Multi-Dimensional Scaling) was also performed using the Bray-Curtis dissimilarities on both the entirety of the assemblage data and the centroids calculated from this data (Anderson et al 2008). This procedure was used to visualise dispersion and changes amongst sites and between the different surveys, visualise similarity between assemblages, and identify if decreasing separation between the reference and downstream sites was evident. For MDS plots using the full data set vector overlays based on Spearman correlations with coefficients greater than 0.6 were added to the graphical display to identify taxa most responsible for the differences in the assemblage.

3. Results

3.1 Hydrology

Hydrological data was sourced from the Wingecarribee River MacArthur's Crossing (upstream of adit) and the V-notch weir at the adit (Boral 2018). The hydrograph shows generally low flow (an average daily flow of 8.9 ML/day) with one minor flow event in February 2018 (Figure 2). It is clear that on occasions the mine water has provided the majority of daily flow to Wingecarribee River and overall contributed to approximately 30% of the annual daily flow in 2018.

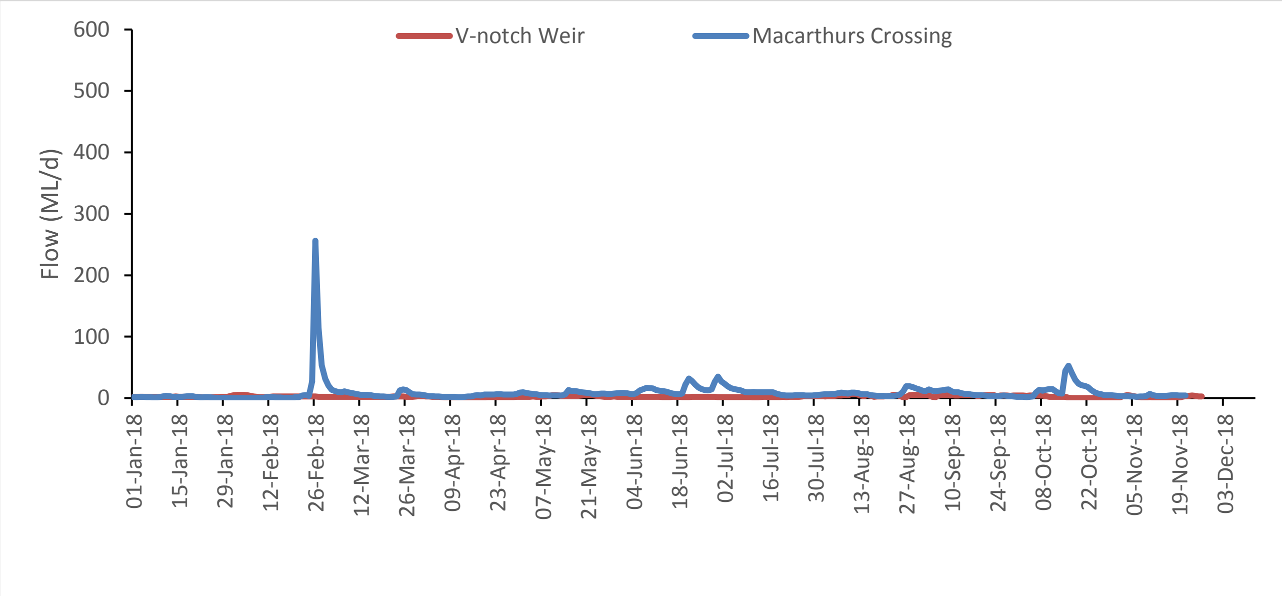


Figure 2: River flow at Wingecarribee River - Medway and V-notch weir (January 2018 - October 2018)

3.2 Macroinvertebrates

3.2.1 Taxonomic richness

Taxonomic richness was typically lower than reference sites at sites within 1000m of the discharge, with levels of taxonomic richness becoming more similar to the reference sites in the most recent (last) survey during September (Figure 3, Figure 4). Furthermore, sites downstream had similar or greater taxonomic richness than the reference tributary (Figure 4). A positive linear relationship (increasing) of moderate strength for taxonomic richness with distance was detected and found to be significant in June 2018. However these linear relationships were not significant during other surveys (Figure 4, Table 3). Comparisons between Sites, within Surveys, found Site 3 to have less taxa (average 8.6) compared to both reference sites (Site 2 (13.8) and Site 6 (18.6)) (Annex 1). Further analysis of differences between surveys and sites for taxonomic richness detected a significant interaction (Survey X Site) (Table 4, Figure 3). Pairwise tests showed significant differences between both upstream reference sites and Site 3 (300m downstream) for March and September; and the tributary reference site only in June. Other sites that showed significant difference to upstream reference sites include Site 8 Biloela (6000m downstream) in March and Site 4 (1000m downstream) in June (Annex 1).

Table 3: Regression results -Taxonomic richness

Group	R Square	Significance F
March	0.040	0.338
June	0.3925	**0.0008**

September	0.1075	0.1094

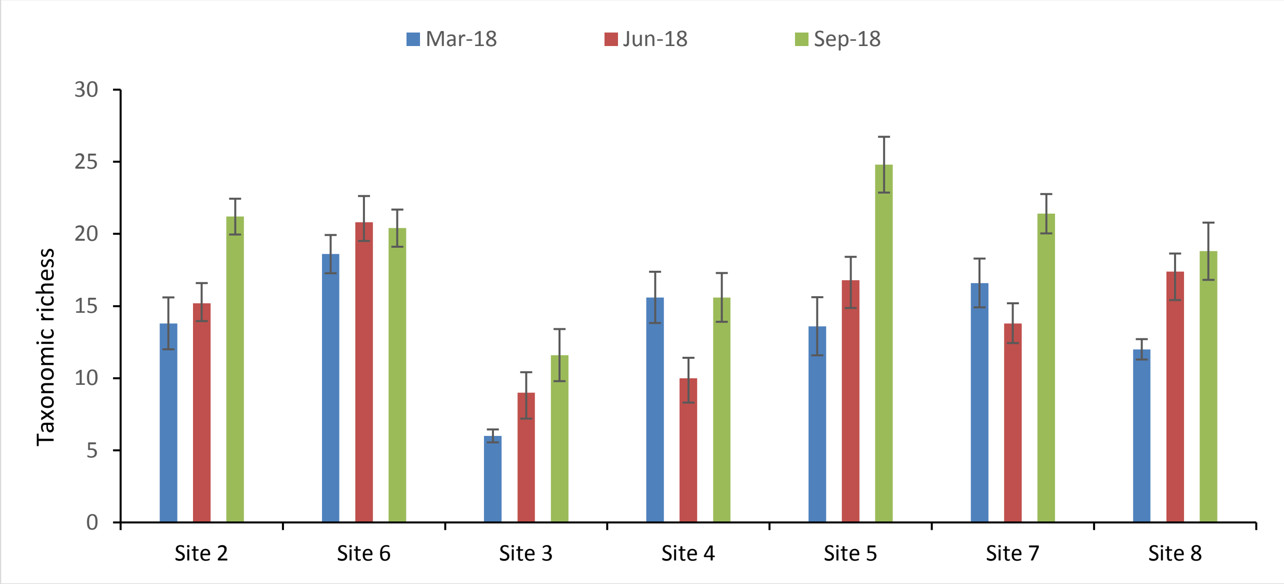


Figure 3 Mean (±SE) Taxa richness - Sites within season.

Table 4: PERMANOVA table of results -Taxonomic richness

Source	Degrees of Freedom	Sum of squares	Mean Square	Pseudo-F	P(perm)	Unique perms
Survey	2	573.49	286.74	24.498	**0.0001**	9944
Site	6	1188.9	198.14	16.928	**0.0001**	9958
Survey X Site	12	387.31	32.276	2.7575	**0.0032**	9930
Residual	84	983.2	11.705			
Total	104	3132.9				

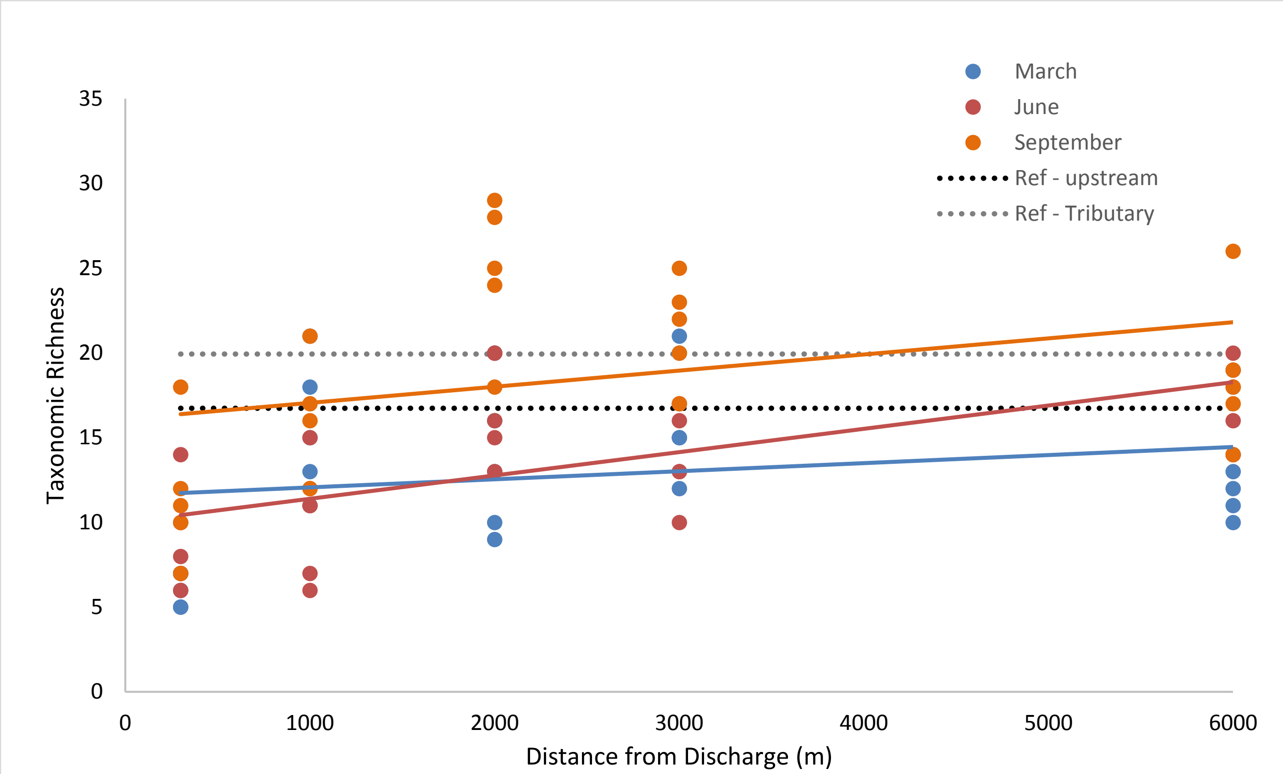


Figure 4: Scatter plot regression - taxonomic richness/distance from discharge

3.2.2 Abundance

Abundance downstream of the discharge typically increased with distance downstream and was lower than reference sites (Figure 5). There was an increase in overall abundance at impact sites in the September survey (Figure 6) compared with previous seasons. A positive linear relationship (increasing) of weak - moderate strength for abundance with distance was detected and found to be significant in all surveys (Table 5, Figure 7). Abundance was statistically significant for both the Survey and Site factors (Table 6). Pairwise tests showed significant difference between March, June and September sampling surveys, irrespective of site. Site pairwise tests showed significant differences between the upstream reference site (Site2) and Sites 3 and 4 (300 and 1000m); and between the tributary upstream reference site (Site 6) and sites to 3000m downstream (Sites 3,4,5 and 7) irrespective of survey (Annex 1). Reference sites had higher average abundances (Site 2: 229.20, Site 6: 330.93) which were significantly different from two downstream sites (Site 3: 300m -44.93, Site 4: 1000m-106.8).

Table 5: Regression results – Abundance.

Survey	R Square	Significance F
March	0.315	**0.004**
June	0.5037	**0.000071**
September	0.2968	**0.0048**

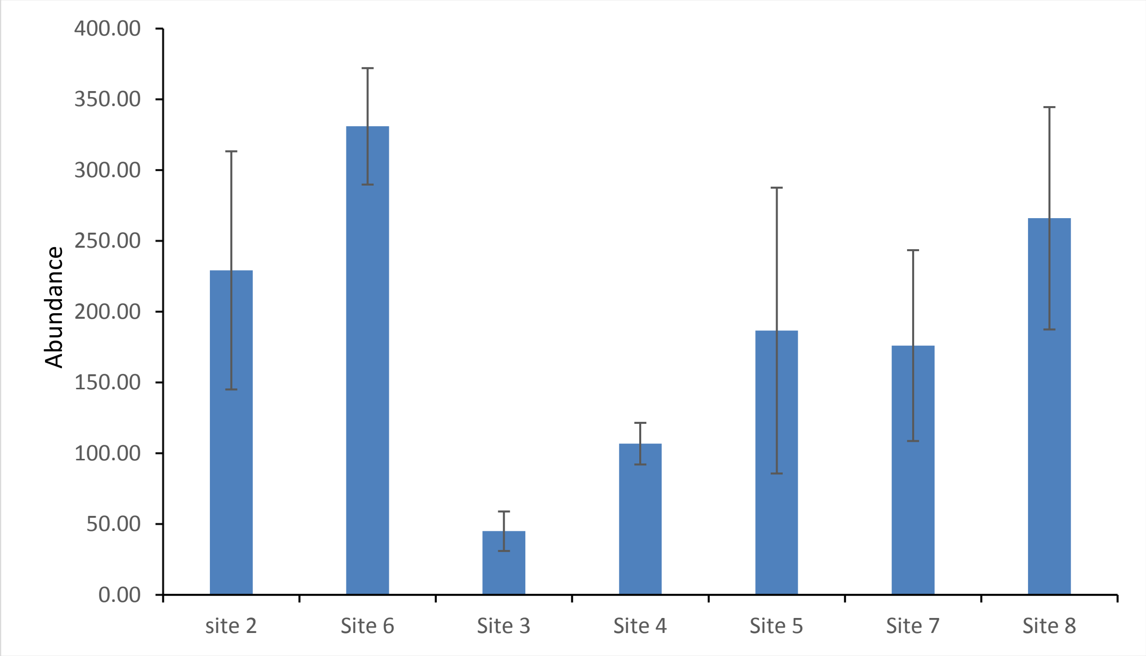


Figure 5 Mean (±SE) Abundance – Sites.

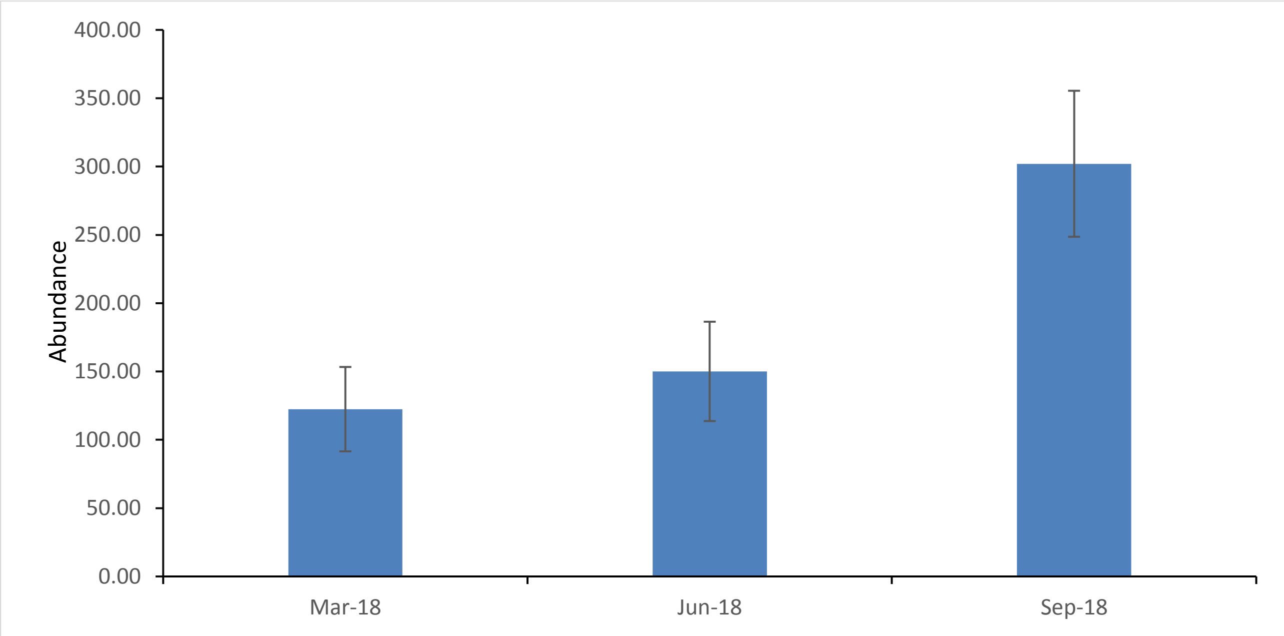


Figure 6 Mean (±SE) Abundance at all sites combined – Survey period

Table 6: PERMANOVA table of results -Abundance

Source	Degrees of Freedom	Sum of squares	Mean Square	Pseudo-F	P(perm)	Unique perms
Survey	2	6.5459E5	3.2729E5	20.537	**0.0001**	9952
Site	6	8.2996E5	1.3833E5	8.6795	**0.0001**	9926
Survey X Site	12	2.4778E5	20648	1.2956	0.2325	9946
Residual	84	1.3387E6	15937			
Total	104	3.071E6				

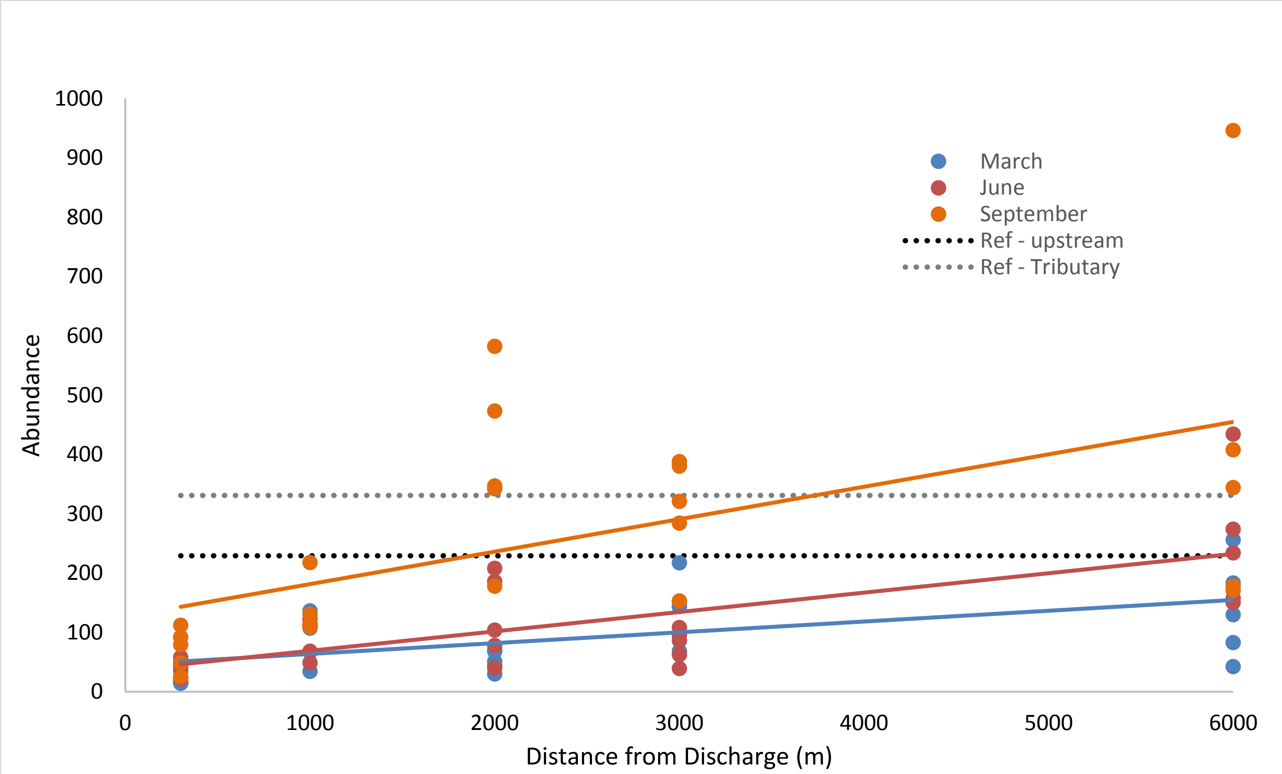


Figure 7 Scatter plot regression - abundance/distance from discharge.

3.2.3 %EPT

%EPT was typically higher than reference sites at sites within 1000m of the discharge in March and June Surveys (Figure 8). A negative linear relationship (decreasing) of moderate strength in March and June and weak strength for September for %EPT with distance was detected and found to be significant for all surveys (Figure 9, Table 7). Analysis of differences between surveys and sites for taxonomic richness detected a significant interaction (Survey X Site) (Table 8). The overall upstream average % EPT of the reference sites was lower (Site 2: 17. 43%, Site 6: 37.86 %) compared to average of 300m downstream (Site 3) 55.85% indicating that while there are significantly lower richness and abundance downstream at Site 3, EPT taxa make up a greater proportion of the invertebrate community. Site pairwise tests showed significant differences between at least one upstream reference site and Site 3 300m downstream in all seasons. Other sites which had significant differences to reference sites included: Site 4 and Site 5 (1000 and 2000m downstream respectively) in June and Site 7 (3000m downstream) in September (Annex 1).

Table 7: Regression results -%EPT

Survey	R Square	Significance F
March	0.479	**0.0001**

Survey	R Square	Significance F
June	0.537756437	**0.00003**
September	0.2134	**0.0201**

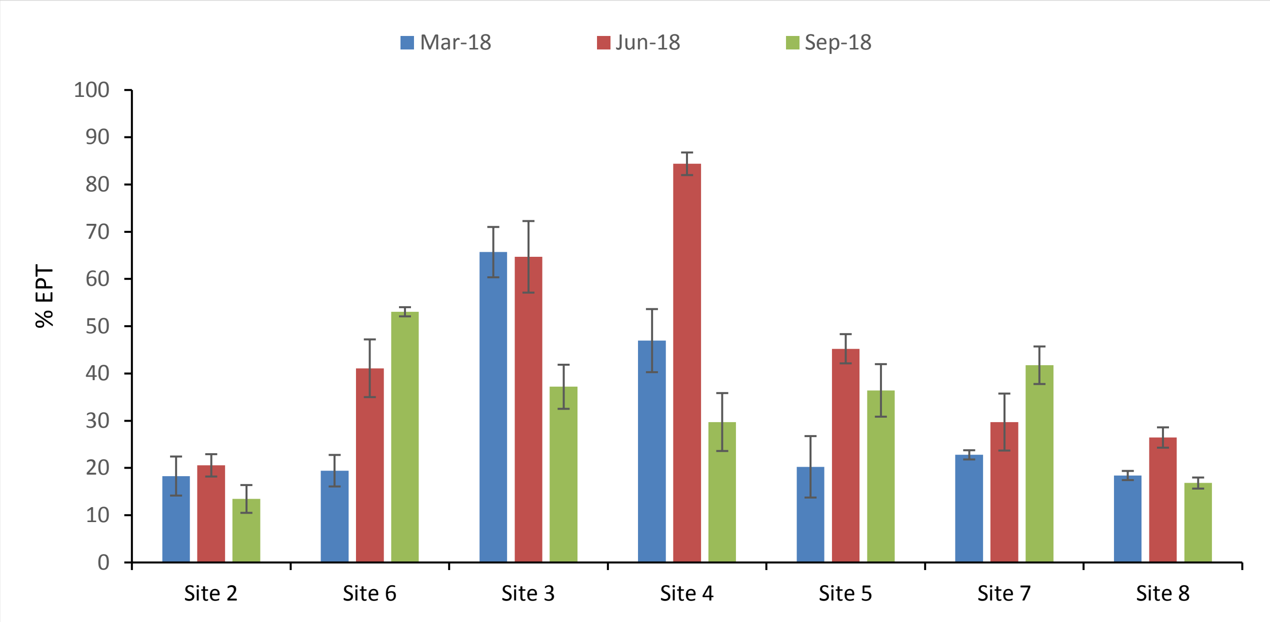


Figure 8 Mean (±SE) %EPT - Sites within season.

Table 8: PERMANOVA table of results -%EPT

Source	Degrees of Freedom	Sum of squares	Mean Square	Pseudo-F	P(perm)	Unique perms
Survey	2	4134.4	2067.2	20.777	**0.0001**	9948
Site	6	19785	3297.5	33.143	**0.0001**	9948
Survey X Site	12	12127	1010.5	10.157	**0.0001**	9916
Residual	84	8357.5	99.494			
Total	104	44403				

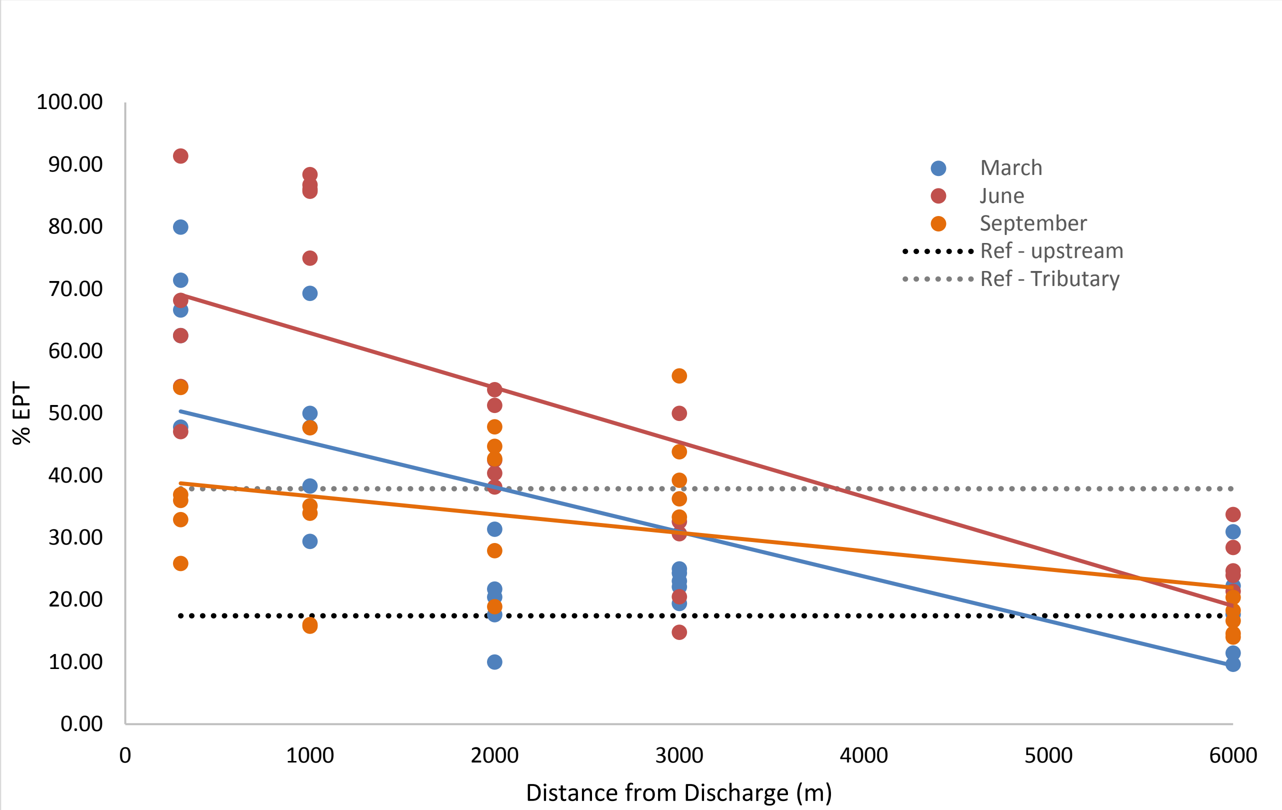


Figure 9: Scatter plot regression - %EPT/distance from discharge.

3.2.4 EPT

EPT was typically lower than reference sites at sites within 1000m of the discharge, with levels of EPT becoming more similar to the reference sites at sites downstream of this point (Figure 10). No linear relationship was observed from the surveys (Figure 12, Table 9). There was an overall slight increase in EPT from the March to September survey period. EPT was statistically significant for Survey and Site factors (Table 10). Pairwise tests showed significant differences between most survey periods with the exception of June vs September, irrespective of Site (Figure 11). Site pairwise tests showed significant difference irrespective of Survey between both upstream reference and Site 3 (300m) and Site 4 (1000m). The average EPT for reference sites (Site 2: 7.13 and Site 6:7.62) was higher compared to Site 3 (3.57) and Site 4 (5).

Table 9: Regression results -EPT

Group	R Square	Significance F
March	0.003	0.784
June	0.2055	0.0228
September	0.0587	0.2433

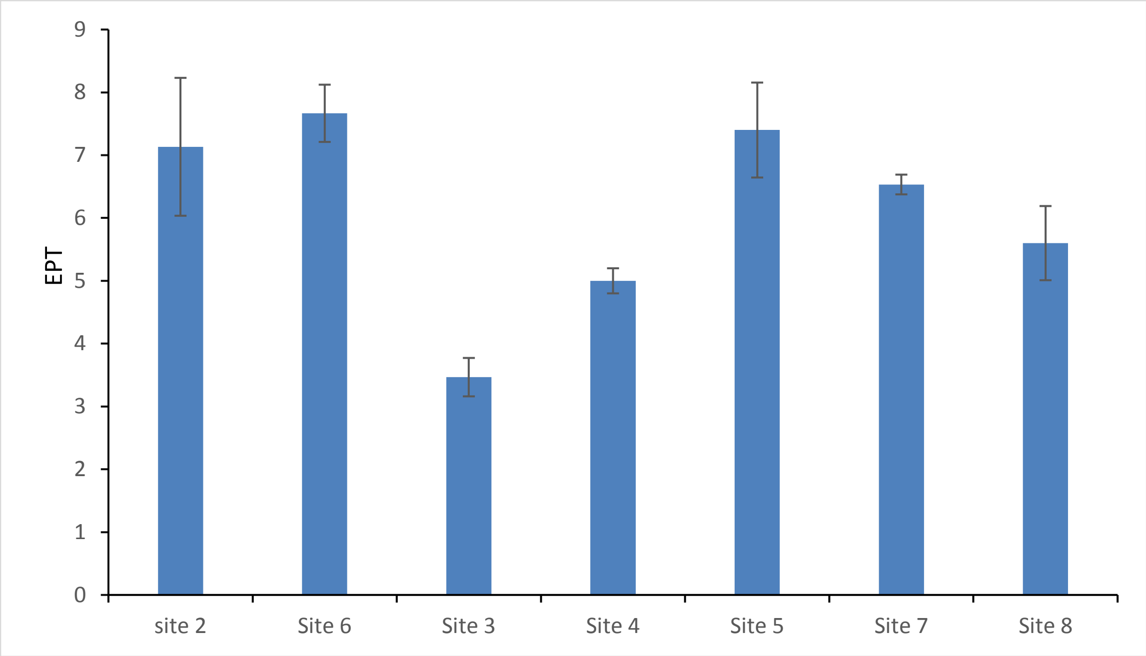


Figure 10 Mean (±SE) EPT – Sites.

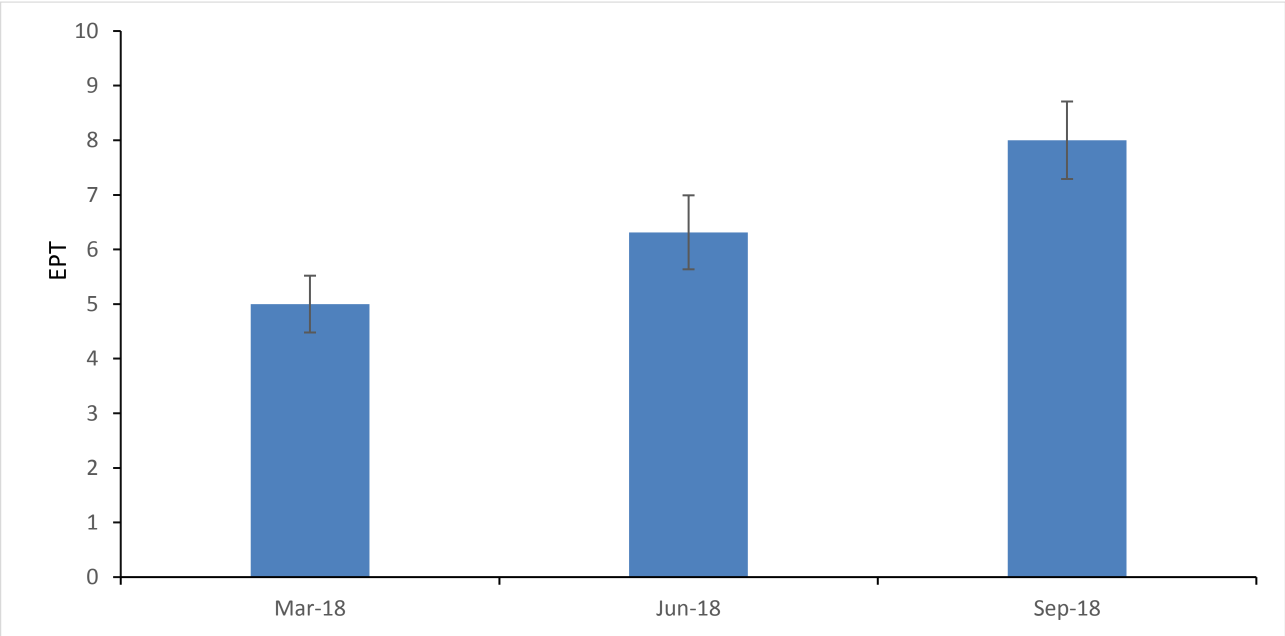


Figure 11 Mean (±SE) EPT – Survey.

Table 10: PERMANOVA table of results - EPT

Source	Degrees of Freedom	Sum of squares	Mean Square	Pseudo-F	P(perm)	Unique perms
Survey	2	74.114	37.057	13.798	**0.0001**	9957
Site	6	206.9	34.483	12.839	**0.0001**	9945
Survey X Site	12	52.019	4.3349	1.6141	0.1064	9933
Res	84	225.6	2.6857			
Total	104	558.63				

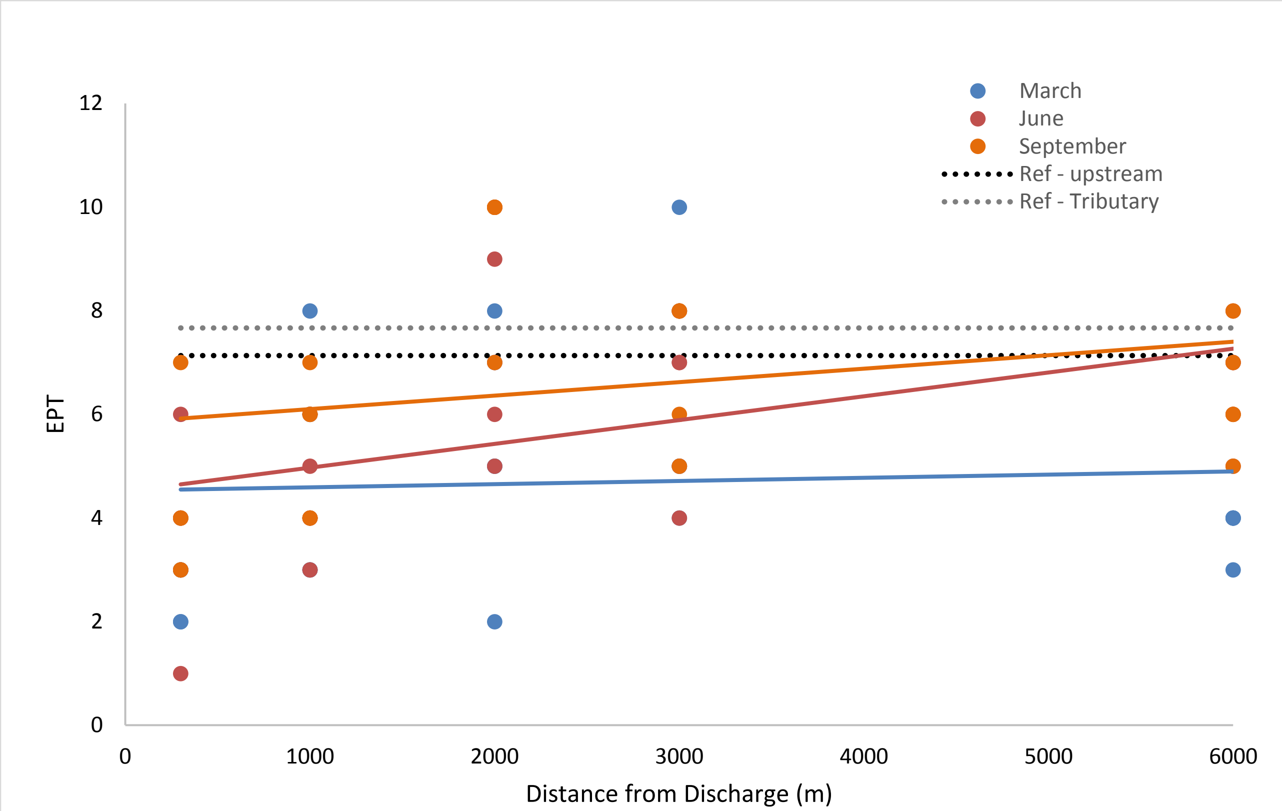


Figure 12: Scatter plot regression - EPT/distance from discharge.

3.2.5 Multivariate analysis of community data

Investigation of patterns in the assemblage using the centroid data shows three major groups. The downstream 300m site, the downstream 1000m site and the rest of the downstream sites along with the reference sites (Figure 13). The assemblage at the downstream 300m site appears to become more similar to the reference sites and other sites in the more recent surveys. There was an increase of 18% similarity to upstream reference site and 11% increase to tributary reference site similarity from March to September. The 1000m site increased by 12% similarity to upstream reference site but had comparable similarity to tributary reference site from March to September. At the remainder of the sites the major differences appear to be temporally driven. However, the assemblages at these sites appear to be changing temporally in a similar manner to the reference sites and potentially have become more similar in later surveys.

The ANOSIM routine detected that the differences between groups (Surveys and Sites) are more dissimilar then those within groups (Global R = 0.471, sig level = 0.01%). Further investigation of these differences using the pairwise tests showed that the sites 300m and 1000m downstream were most different to reference sites. The R values were highest immediately downstream (300m and 1000m) which decreased downstream (2000m and 3000m) and increased again at Site 8 (6000m) (Annex 1).

The SIMPER analysis showed that higher abundances of taxa Elmidae, Baetidae, Psphenidae, and Chironominae was driving these differences between Site 3 (300m) and Site 4 (1000m) downstream and the upstream reference sites. Higher abundances of Hyropsychidae and lower abundances of Orthocladinae at Site 4 also contributed to differences between Site 4 and Site 2 upstream reference.

The spearman correlations (Figure 14) indicate the assemblage differences overall is driven by EPT taxa including: mayflies – Baetidae (SIGNAL 5), Leptophlebiidae (SIGNAL 8), Caenidae; stonefly (SIGNAL 4) – Gripopterygidae (SIGNAL 8); and caddisflies – Hydropsychidae (SIGNAL 6), Philopotamidae (SIGNAL 8), Hydrobiosidae (SIGNAL 8); as well as riffle beetle Elmidae (SIGNAL 7). Pollution tolerant sub-family

Chironominae also contributed to differences. These families were also generally higher in reference sites than downstream site, particularly at Site 3 and Site 4.

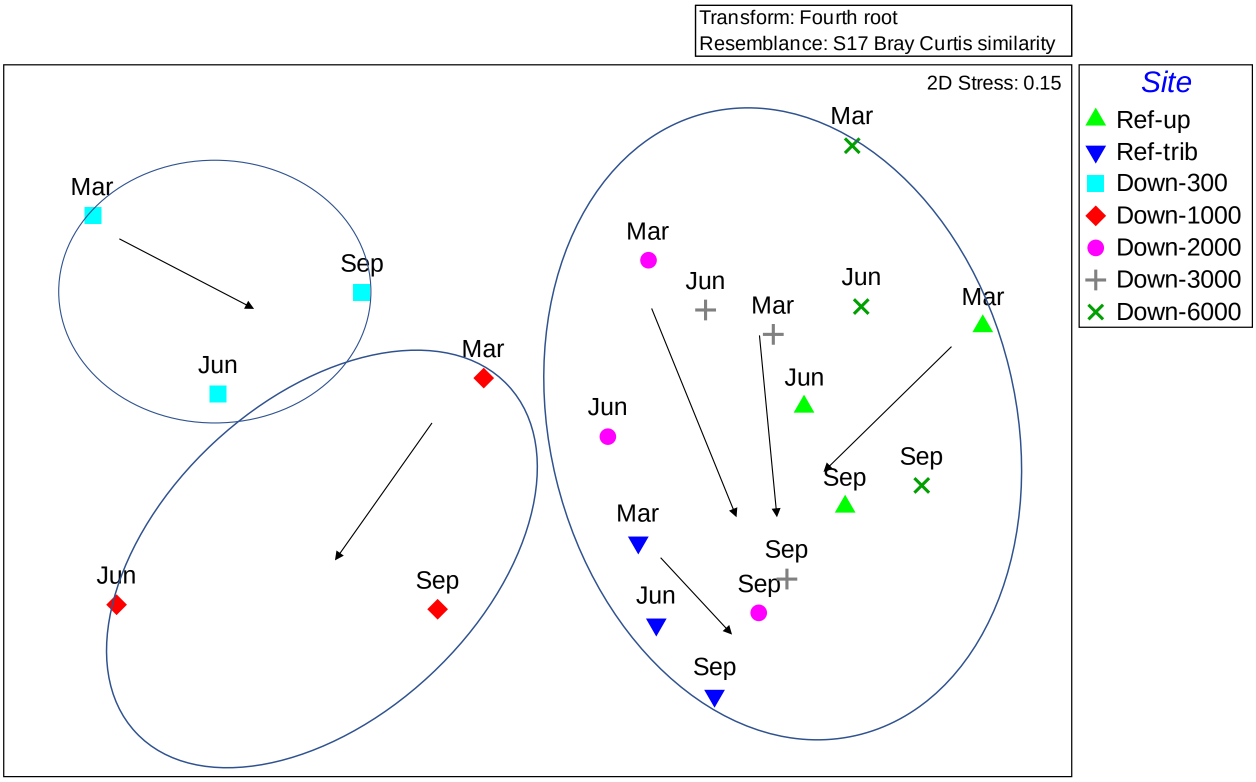


Figure 13 MDS plot of centroids. Black line denotes group, arrows denote general trajectory through Survey period.

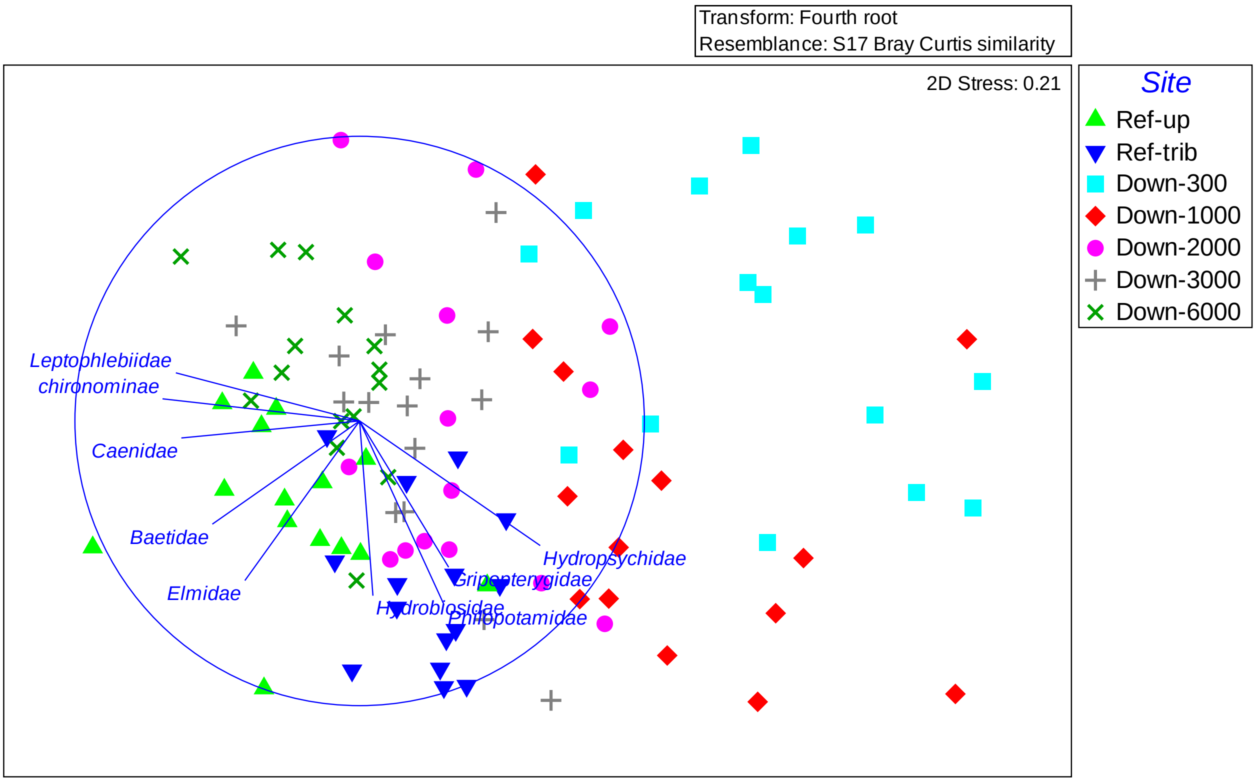


Figure 14: MDS plot of each sample for Site factor. Overlay - Spearman coefficient 0.6.

4. Discussion

The study found continued ecological impact downstream of the mine discharge with significant reductions in taxonomic richness, abundance, and EPT. However, in comparison to previous studies (Wright et al. 2018) where %EPT ranged 1-10%, against expectations, %EPT actually increased significantly at Site 3 300m downstream (range 25.1-91.38%). It seems that while other indicators decreased, the EPT taxa although in small numbers made up larger proportion of the assemblages. Hence this result is likely a mathematical artefact rather than an indication of improved stream health. This study found a 53% reduction in EPT taxa at 300m downstream and 32% 1000m downstream. Other studies conducted by Write (2018) found a reduction in EPT taxa (63%)at 200m downstream in February 2018 and sampling in spring 2017 by Niche (2018) found a 98% reduction 100m downstream and 38% reduction approximately 500m downstream (Niche 2018).

Multivariate analysis found similar patterns with the downstream sites (particularly Site 3 and 4) being impacted, however it showed differences between all sites and surveys. The invertebrates likely to drive these changes are shown to be predominately pollution sensitive taxa. Of these, mayflies Leptophlebiidae and Baetidae, were not observed immediately downstream. The lack of Ephemeroptera as well as sharp reductions in Elmidae were also identified within in 2017 study (Wright 2018, Niche 2018). Leptophlebiidae are known to be pollution sensitive and thought to be impacted by iron floc and precipitate (iron oxidizing bacteria) that was observed on all sampling occasions (Niche 2018, Plate 2). Elmidae are similarly sensitive species and are particularly susceptible to large flow events and pollution that can cause a reduction in dissolved oxygen e.g. soap and detergents (Elliot 2008).

Plate 2: Iron precipitate downstream of adit

Reasons for benthic invertebrate decline in streams affected by iron flocculants and iron precipitates may be related to several factors including: reduction in food quality, clogging of the hyporheic and interstitial spaces, and direct toxic effects of iron deposits adhering to an animal's body (Barnden 2008). They effectively act in a similar manner to sedimentation, and affect in-stream habitat by smothering substrate and clogging interstitial spaces that provide habitat for some species (Gray 1996).

It appears that longitudinally the further downstream the less impact is observed. While impact was observed at Site 3, Site 4 (although still impaired) shows upward recovery in EPT, taxonomic richness, abundance, and exhibit assemblages more similar to reference sites. Visual observation also indicate that iron precipitate is evident at Site 3 and black sediment at Site 4, which is the likely the mechanism for impact at these sites. Site 5 and Site 7 downstream, although having communities statistically different to reference sites, generally exhibit similar EPT, taxonomic richness, abundance and no obvious precipitate. Site 8 however is too far downstream (6000m) for any differences observed to be attributed to the mine water discharge. It is likely that the Wingecarribee River has near full recovery 1000-2000m downstream.

The aim of this monitoring program was to monitor the ecology of the stream in response to water treatment measures implemented under EPL 608, and while there were some small increases in EPT, taxonomic richness and a small increase in similarly to reference sites these are relatively minor and difficult to relate to changes in water management considering the natural variability of a river. Furthermore, while there have been improvement in some water quality parameters, the low flow which occurred for most of the year in the Wingecarribee River (Figure 2) limited any natural dilution of mine water (Boral 2018). In light of this, the results of this study are unsurprising, however the small changes observed could possibly be the start of a lagged recovery trajectory. Furthermore the dramatic improvement to iron concentration is encouraging, as high iron concentration is believed to be the main mechanism for impacts to macroinvertebrate communities downstream of the mine water discharge. It likely that there will be a lagged response (in improvement of macroinvertebrate community health) to the measured reduction in iron as there is a residual impact of precipitate that may require high flows to disperse it from the benthic substrate and interstitial spaces. Sufficient time is also required for recruitment of macroinvertebrates, particularly less mobile families such as Elmidae.

5. Conclusion

In general, impacts to macroinvertebrate communities were observed downstream at Site 3 (300m downstream) and Site 4 (1000m downstream) in all three survey periods in March, June and September 2018, with no obvious impacts at sites further downstream. These impacts include: reduction in abundances, taxonomic richness, EPT and change in assemblage structure. There was some small improvements in EPT, taxonomic richness, and assemblages at these locations in September, however this is difficult to relate to any improvements to water quality treatment which was complicated by extensive low flows of the Wingecarribee River. Iron precipitate is the likely mechanism affecting macroinvertebrates, and was the most improved parameter observed within the mine from the water treatment. With the longer term implementation of these measures it is likely that improvement will be measurable in future monitoring.

References

Anderson M.J., Gorley, R.N., and Clarke K.R. (2008). PERMANOVA+ for PRIMER – Guide to software and Statistical Methods. PRIMER-E: Plymouth, UK.

Barden, A. (2008). *Thesis: Ecology of streams affected by iron precipitates and iron flocculants*. University of Canterbury

Boral Cement. (2018). Berrima Colliery Performance Monitoring Program Summary Report - Environment Protection Licence 608 31 October 2018.

Clarke and Warwick 2001 *Change in Marine Communities: An Approach to Statistical Analysis and Interpretation.* Plymouth Marine Laboratory, UK.

Dean, J., Rosalind, M., St Clair, M., and Cartwright, D. (2004) Identification keys to Australian families and genera of caddis-fly larvae (Trichoptera) Cooperative Research Centre for Freshwater Ecology.

Elliot, M. (2008) The ecology of Riffle Beetles: Coleoptera Elmidae. *Freshwater Reviews.* 1, 189-203.

Gooderham, J. and Tsyrlin, E. (2002). The Waterbug Book: A guide to the Freshwater Macroinvertebrates of Temperate Australia, CSIRO Publishing.

Gray, N.F. (1996). A substrate classification index for the visual assessment of the impact of acid mine drainage in lotic systems. *Water Research*. Vol. 30: 1551-1554.

Hawking J. and Theischinger G. (1999). A guide to the identification of larvae of Australian families and to the identification of ecology of larvae from NSW.

International Environmental Consultants (2015) Rehabilitation and Final Closure Plan- Review of Environmental Factors prepared for Boral Cement Limited – Berrima Colliery.

Lenat, D.R. (1988) Water quality assessment using a qualitative collection method for benthic macroinvertebrates. *J.N. Am. Benthological Soc*. 7: 222-233.

Niche (2018) Berrima Colliery Aquatic Ecology Monitoring. Prepared for Boral Cement Limited.

Madden, C. (2010) Key to genera of Australian Chironomidae. Museum Victoria Science Reports 12,1-31.

Madden, C. (2011) Draft identification key to families of Diptera larvae of Australian inland waters La Trobe University.

Quinn, G. and Keough, M. (2002). *Experimental Design and Data Analysis for Biologists.* Cambridge University Press.

Smith, B. (1996) Identification keys to the families and genera of bivalve and gastropod molluscs found in Australian inland waters Murray Darling Freshwater Research Centre.

Website - http://www.mdfrc.org.au/bugguide/

Wright, I., Paciuszkiewicz, K., Belmer, N., (2018). Increased water pollution after closure of Australia's longest operating underground coal mine: a 13 month study of mine drainage, water chemistry and river ecology. *Water Air Soil Pollution*. 229:55

Wright, I. and Burgin, S. (2009) Comparison of Sewage and Coal-Mine Wastes on Stream Macroinvertebrates Within an Otherwise Clean Upland Catchment, Southeastern Australia

Wright, I. A., & Ryan, M. (2016). Impact of mining and industrial pollution on stream macroinvertebrates : importance of taxonomic resolution, water geochemistry and EPT indices for impact detection. *Hydrobiologia*, 772(1), 103-115.

Annex 1 – Pairwise tests

Pairwise tests – Taxonomic richness survey period survey X site

	Groups	t	P(perm)	Unique perms	P(MC)
March					
	Ref-up, Down-300	4.2055	**0.0072**	19	0.0028
	Ref-up, Down-1000	0.71151	0.5404	15	0.4928
	Ref-up, Down-2000	7.4023E-2	1	16	0.9469
	Ref-up, Down-3000	1.1337	0.2715	15	0.2819
	Ref-up, Down-6000	0.93076	0.4993	11	0.3826
	Ref-trib, Down-300	9	**0.0085**	24	0.0001
	Ref-trib, Down-1000	1.3525	0.2333	15	0.2096
	Ref-trib, Down-2000	2.0726	0.0937	18	0.0667
	Ref-trib, Down-3000	0.93048	0.4222	14	0.3797
	Ref-trib, Down-6000	4.3903	**0.0082**	17	0.0015
June	Ref-up, Down-300	3.1235	0.0306	18	0.0146
	Ref-up, Down-1000	2.4405	0.0666	17	0.0432
	Ref-up, Down-2000	0.81228	0.4839	14	0.4331
	Ref-up, Down-3000	0.75048	0.5282	12	0.4746
	Ref-up, Down-6000	1.2495	0.2884	12	0.2552
	Ref-trib, Down-300	5.1064	**0.0077**	26	0.001
	Ref-trib, Down-1000	4.4313	**0.0079**	24	0.0021
	Ref-trib, Down-2000	1.7408	0.124	14	0.1156
	Ref-trib, Down-3000	3.1688	**0.0071**	18	0.0126
	Ref-trib, Down-6000	1.6028	0.1953	11	0.1433
September	Ref-up, Down-300	4.3818	0.0166	22	**0.003**
	Ref-up, Down-1000	2.6697	0.0484	18	0.0275
	Ref-up, Down-2000	1.5667	0.1916	15	0.156
	Ref-up, Down-3000	0.10847	1	12	0.9148

	Ref-up, Down-6000	1.0252	0.3849	15	0.3238
	Ref-trib, Down-300	3.9673	0.0158	21	**0.0046**
	Ref-trib, Down-1000	2.2577	0.0963	15	0.0575
	Ref-trib, Down-2000	1.8935	0.1126	16	0.0885
	Ref-trib, Down-3000	0.533	0.7461	9	0.6062
	Ref-trib, Down-6000	0.67612	0.5644	14	0.521

Pairwise tests – Abundance -'Survey' factor

	Groups	t	P(perm)	Unique perms	P(MC)
	Mar, Jun	1.5277	0.1334	9838	0.1351
	Mar, Sep	5.1649	**0.0001**	9822	0.0001
	Jun, Sep	4.3951	**0.0001**	9848	0.0001
	Mar, Jun	1.5277	0.1334	9838	0.1351

Pairwise tests – Abundance -'Site' factor

	Groups	t	P(perm)	Unique perms	P(MC)
	Ref-up, Down-300	4.2449	**0.0001**	9879	0.0004
	Ref-up, Down-1000	2.7673	**0.0018**	9889	0.0112
	Ref-up, Down-2000	0.85355	0.4362	9862	0.4017
	Ref-up, Down-3000	1.1515	0.2965	9887	0.2533
	Ref-up, Down-6000	0.54626	0.5892	9830	0.5931
	Ref-trib, Down-300	6.6038	**0.0001**	9827	0.0001
	Ref-trib, Down-1000	5.0786	**0.0001**	9825	0.0002
	Ref-trib, Down-2000	2.9002	**0.0064**	9847	0.0083
	Ref-trib, Down-3000	3.3633	**0.0026**	9840	0.0022
	Ref-trib, Down-6000	0.9648	0.3492	9832	0.3418

Pairwise tests – %EPT -'Site X Survey' factor

	Groups	t	P(perm)	Unique perms	P(MC)
March	Ref-up, Down-300	7.0266	**0.0083**	126	0.0002
	Ref-up, Down-1000	3.6504	0.0153	126	0.0058
	Ref-up, Down-2000	0.36251	0.683	126	0.7202
	Ref-up, Down-3000	1.0567	0.3559	126	0.3278
	Ref-up, Down-6000	2.0146E-2	0.9765	126	0.9854
	Ref-trib, Down-300	7.358	**0.0083**	126	0.0003
	Ref-trib, Down-1000	3.6891	0.0148	126	0.0068
	Ref-trib, Down-2000	0.17066	0.8463	126	0.8755
	Ref-trib, Down-3000	0.96565	0.3968	126	0.3592
	Ref-trib, Down-6000	0.19978	0.8251	126	0.8453
June	Ref-up, Down-300	5.5636	**0.0077**	126	0.0005
	Ref-up, Down-1000	18.988	**0.0085**	126	0.0001
	Ref-up, Down-2000	6.3386	**0.008**	126	0.0002
	Ref-up, Down-3000	1.4149	0.1802	126	0.1971
	Ref-up, Down-6000	1.8425	0.1048	126	0.1013
	Ref-trib, Down-300	2.4245	0.0481	126	0.0391
	Ref-trib, Down-1000	6.6001	**0.0069**	126	0.0001
	Ref-trib, Down-2000	0.60321	0.5399	126	0.558
	Ref-trib, Down-3000	1.3268	0.219	126	0.2239
	Ref-trib, Down-6000	2.2649	0.0372	126	0.0501
September	Ref-up, Down-300	4.3039	**0.0087**	126	0.0031
	Ref-up, Down-1000	2.3946	0.0515	126	0.045
	Ref-up, Down-2000	3.652	0.0167	126	0.0066
	Ref-up, Down-3000	5.7237	**0.007**	126	0.0004
	Ref-up, Down-6000	1.0628	0.3142	126	0.3261
	Ref-trib, Down-300	2.5717	0.031	126	0.0329
	Ref-trib, Down-1000	3.1793	0.0233	126	0.013

	Ref-trib, Down-2000	2.4217	0.0401	126	0.041
	Ref-trib, Down-3000	1.9967	0.084	126	0.0771
	Ref-trib, Down-6000	8.6134	0.0088	126	0.0001

Pairwise tests – EPT -‘ Survey’ factor

Groups	t	P(perm)	Unique perms	P(MC)
Mar, Jun	3.2691	0.0019	9791	0.0016
Mar, Sep	5.1441	0.0001	9791	0.0001
Jun, Sep	1.8871	0.0662	9773	0.0635

Pairwise tests – %EPT -‘Site’ factor

Groups	t	P(perm)	Unique perms	P(MC)
Ref-up, Down-300	6.2077	**0.0001**	9736	0.0001
Ref-up, Down-1000	3.4506	**0.0028**	9706	0.002
Ref-up, Down-2000	0.39223	0.7136	9528	0.6965
Ref-up, Down-3000	0.89113	0.3796	8892	0.3875
Ref-up, Down-6000	2.9448	**0.0062**	9707	0.0076
Ref-trib, Down-300	7.5299	**0.0001**	9370	0.0001
Ref-trib, Down-1000	4.5437	**0.0001**	9722	0.0001
Ref-trib, Down-2000	0.40932	0.6897	9640	0.6917
Ref-trib, Down-3000	1.7581	0.0899	9706	0.093
Ref-trib, Down-6000	4.2784	**0.0001**	9710	0.0005

Anosim pairwise tests – ‘Survey’ factor

Groups	R Statistic	Significance Level %
Mar, Jun	0.317	0.01
Mar, Sep	0.641	0.01

Anosim pairwise test ‘Site’ factor

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations
Ref-up, Ref-trib	0.748	0.01	2000376	9999
Ref-up, Down-300	0.891	0.01	2000376	9999
Ref-up, Down-1000	0.969	0.01	2000376	9999
Ref-up, Down-2000	0.515	0.01	2000376	9999
Ref-up, Down-3000	0.464	0.01	2000376	9999
Ref-up, Down-6000	0.739	0.01	2000376	9999
Ref-trib, Down-300	0.843	0.01	2000376	9999
Ref-trib, Down-1000	0.825	0.01	2000376	9999
Ref-trib, Down-2000	0.527	0.01	2000376	9999
Ref-trib, Down-3000	0.736	0.01	2000376	9999
Ref-trib, Down-6000	0.937	0.01	2000376	9999

Annex 2 –Simper

Groups Ref-up & Down-300
Average dissimilarity = 68.30

Species	Group Ref-up Av.Abund	Group Down-300 Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Elmidae	1.95	0.13	5.14	3.16	7.53	7.53
Orthocladinae	2.91	1.34	4.43	2.02	6.48	14.01
Baetidae	1.52	0.00	4.41	3.09	6.46	20.47
Chironominae	1.98	0.62	4.21	1.68	6.17	26.64
Caenidae	1.39	0.07	3.74	3.19	5.47	32.11
Sphaeriidae	1.31	0.07	3.59	1.75	5.25	37.36
Hydropsychidae	0.69	1.63	3.58	1.38	5.25	42.61
Hydroptilidae	1.07	0.39	3.17	1.34	4.64	47.26
Ecnomidae	1.31	0.60	2.96	1.22	4.33	51.58
Gripopterygidae	0.78	1.43	2.76	1.25	4.04	55.62
Leptophlebiidae	0.92	0.00	2.45	1.77	3.59	59.21
Nematoda	1.05	0.21	2.41	1.20	3.52	62.73
Lumbriculidae	1.70	1.00	2.40	1.25	3.51	66.24
Tanipodinae	0.94	0.63	2.19	1.02	3.21	69.45
Psephenidae	0.62	0.00	1.86	0.94	2.72	72.17
Gomphidae	0.21	0.65	1.81	0.98	2.65	74.82
Empididae	0.07	0.61	1.74	1.03	2.54	77.36
Tipulidae	0.52	0.37	1.70	0.91	2.49	79.85
Philopotamidae	0.66	0.07	1.43	1.00	2.10	81.95
Scirtidae	0.50	0.07	1.22	0.75	1.78	83.74
Calamoceratidae	0.43	0.28	1.22	0.88	1.78	85.52
Leptoceridae	0.49	0.08	1.11	0.78	1.63	87.14
Conoesucidae	0.18	0.35	1.06	0.74	1.56	88.70
Atyidae	0.07	0.23	0.81	0.54	1.19	89.89
Simuliidae	0.30	0.00	0.70	0.57	1.02	90.91

Groups Ref-trib & Down-300
Average dissimilarity = 63.09

Species	Group Ref-trib Av.Abund	Group Down-300 Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Elmidae	2.46	0.13	5.38	2.93	8.53	8.53
Baetidae	1.97	0.00	4.49	3.41	7.11	15.64
Psephenidae	1.96	0.00	4.42	3.69	7.00	22.64
Chironominae	2.35	0.62	4.08	1.84	6.47	29.11
Gomphidae	1.91	0.65	2.94	1.69	4.65	33.76
Philopotamidae	1.27	0.07	2.82	1.27	4.48	38.24
Corydalidae	1.24	0.07	2.76	1.93	4.37	42.60

Caenidae	1.20	0.07	2.56	1.71	4.05	46.66
Ecnomidae	1.16	0.60	2.25	1.50	3.57	50.23
Gripopterygidae	2.01	1.43	2.24	1.46	3.55	53.78
Hydrobiosidae	0.91	0.07	2.06	1.65	3.27	57.05
Lumbriculidae	1.69	1.00	1.81	1.28	2.87	59.91
Tanipodinae	1.32	0.63	1.76	1.20	2.79	62.70
Atyidae	0.71	0.23	1.69	0.90	2.68	65.38
Simuliidae	0.71	0.00	1.64	1.13	2.60	67.98
Orthocladinae	1.90	1.34	1.62	1.22	2.57	70.56
Leptophlebiidae	0.74	0.00	1.62	1.09	2.57	73.13
Hydropsychidae	1.76	1.63	1.37	1.22	2.17	75.30
Empididae	0.20	0.61	1.32	0.99	2.09	77.39
Tricladida	0.63	0.00	1.31	0.91	2.07	79.46
Calamoceratidae	0.66	0.28	1.22	0.83	1.94	81.40
Gyrinidae	0.66	0.07	1.20	0.59	1.90	83.30
Tipulidae	0.50	0.37	1.16	0.93	1.84	85.13
Leptoceridae	0.45	0.08	1.02	0.75	1.62	86.76
Sphaeriidae	0.39	0.07	0.94	0.72	1.48	88.24
Hydroptilidae	0.35	0.39	0.85	0.72	1.35	89.59
Conoesucidae	0.07	0.35	0.77	0.72	1.22	90.81

Groups Ref-up & Down-1000
Average dissimilarity = 60.62

	Group Ref-up	Group Down-1000				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Hydropsychidae	0.69	2.28	4.04	1.55	6.66	6.66
Orthocladinae	2.91	1.52	3.39	1.40	5.58	12.24
Baetidae	1.52	0.13	3.34	2.27	5.51	17.75
Elmidae	1.95	0.54	3.24	1.73	5.35	23.10
Caenidae	1.39	0.00	3.20	5.71	5.28	28.37
Chironominae	1.98	0.78	2.94	1.55	4.86	33.23
Ecnomidae	1.31	0.59	2.42	1.25	3.99	37.21
Hydroptilidae	1.07	0.13	2.36	1.52	3.89	41.10
Corydalidae	0.07	0.93	2.15	1.24	3.55	44.66
Tanipodinae	0.94	0.84	2.09	0.90	3.45	48.11
Lumbriculidae	1.70	1.40	2.02	1.01	3.33	51.44
Leptophlebiidae	0.92	0.15	1.98	1.53	3.27	54.71
Sphaeriidae	1.31	0.64	1.96	1.20	3.24	57.95
Philopotamidae	0.66	1.24	1.95	1.01	3.22	61.17
Nematoda	1.05	0.22	1.91	1.21	3.15	64.32
Gripopterygidae	0.78	1.37	1.83	1.22	3.02	67.34
Gomphidae	0.21	0.81	1.66	1.14	2.75	70.09
Empididae	0.07	0.77	1.60	1.23	2.65	72.74
Calamoceratidae	0.43	0.60	1.56	1.17	2.58	75.31
Tipulidae	0.52	0.53	1.42	1.06	2.34	77.65
Psephenidae	0.62	0.00	1.39	0.99	2.29	79.94

Atyidae	0.07	0.60	1.38	0.69	2.27	82.21
Leptoceridae	0.49	0.33	1.31	0.99	2.15	84.37
Scirtidae	0.50	0.07	1.19	0.81	1.97	86.33
Conoesucidae	0.18	0.44	1.12	0.80	1.84	88.18
Simuliidae	0.30	0.62	0.91	0.68	1.50	89.67
Tetrastemmatidae	0.29	0.20	0.68	0.66	1.13	90.80

Groups Ref-trib & Down-1000

Average dissimilarity = 53.26

	Group Ref-trib	Group Down-1000				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Psephenidae	1.96	0.00	3.77	3.39	7.08	7.08
Elmidae	2.46	0.54	3.74	2.31	7.02	14.10
Baetidae	1.97	0.13	3.55	2.97	6.66	20.76
Chironominae	2.35	0.78	3.06	1.87	5.74	26.50
Caenidae	1.20	0.00	2.36	1.73	4.43	30.93
Gomphidae	1.91	0.81	2.20	1.48	4.13	35.07
Philopotamidae	1.27	1.24	1.88	1.35	3.54	38.60
Tanipodinae	1.32	0.84	1.85	1.28	3.47	42.07
Gripopterygidae	2.01	1.37	1.84	1.49	3.46	45.53
Hydrobiosidae	0.91	0.16	1.62	1.47	3.04	48.57
Ecnomidae	1.16	0.59	1.57	1.18	2.95	51.52
Hydropsychidae	1.76	2.28	1.53	1.35	2.87	54.38
Simuliidae	0.71	0.62	1.48	1.31	2.78	57.17
Calamoceratidae	0.66	0.60	1.44	1.12	2.71	59.87
Leptoceridae	0.45	0.33	1.41	1.18	2.66	62.53
Corydalidae	1.24	0.93	1.41	1.09	2.65	65.18
Leptophlebiidae	0.74	0.15	1.41	1.04	2.64	67.82
Lumbriculidae	1.69	1.40	1.38	1.10	2.59	70.41
Orthocladinae	1.90	1.52	1.33	1.06	2.49	72.90
Sphaeriidae	0.39	0.64	1.28	1.06	2.41	75.31
Empididae	0.20	0.77	1.22	1.06	2.30	77.61
Tricladida	0.63	0.00	1.15	0.90	2.16	79.77
Tipulidae	0.50	0.53	1.15	1.13	2.15	81.92
Atyidae	0.71	0.60	1.05	0.76	1.97	83.89
Gyrinidae	0.66	0.21	0.92	0.61	1.73	85.61
Conoesucidae	0.07	0.44	0.88	0.82	1.65	87.26
Hydroptilidae	0.35	0.13	0.67	0.73	1.25	88.52
Nematoda	0.21	0.22	0.65	0.68	1.22	89.74
Tetrastemmatidae	0.13	0.20	0.60	0.69	1.13	90.87

Annex 3

niche
Environment and Heritage

niche-eh.com

Excellence in your environment

Contact Us

Niche Environment and Heritage
02 9630 5658
info@niche-eh.com

NSW Head Office – Sydney
PO Box 2443 North Parramatta
NSW 1750 Australia

QLD Head Office – Brisbane
PO Box 540 Sandgate
QLD 4017 Australia

Sydney
Illawarra
Central Coast
Newcastle
Mudgee
Port Macquarie
Brisbane
Cairns

Our services

Ecology and biodiversity
Terrestrial
Freshwater
Marine and coastal
Research and monitoring
Wildlife Schools and training

Heritage management
Aboriginal heritage
Historical heritage
Conservation management
Community consultation
Archaeological, built and landscape values

Environmental management and approvals
Impact assessments
Development and activity approvals
Rehabilitation
Stakeholder consultation and facilitation
Project management

Environmental offsetting
Offset strategy and assessment (NSW, QLD, Commonwealth)
Accredited BAM assessors (NSW)
Biodiversity Stewardship Site Agreements (NSW)
Offset site establishment and management
Offset brokerage
Advanced Offset establishment (QLD)