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PAPERS

CHIRONOMIDS ABOUND IN THE ACID MINE DRAINAGE OF THE DEE RIVER, MT MORGAN

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ABSTRACT

The Dee River has been polluted by acid mine drainage (AMD) from the Mt Morgan gold mine for over 100 years. This study investigated downstream impacts of the Mt Morgan mine on macroinvertebrates in the highly impacted section of the Dee River, extending 18 km from the mine to the junction of Fletcher Creek. Specifically, macroinvertebrate and chironomid abundance and number of taxa were determined and tested for correlation with pH, conductivity and filtered metal concentrations. *In situ* pH ranged from 2.6 to 3.9 and conductivity ranged from 1.7 to 8.5 mS/cm during the sampling period from October 1999 to June 2001. The data obtained indicated a significant positive correlation between chironomid abundance and conductivity ($r_s = 0.76$, $n = 11$, $p \leq 0.01$) and between total number of taxa and pH ($r_s = 0.66$, $n = 11$, $p \leq 0.025$). Additionally there were significant positive correlations between chironomid abundance and filtered metal concentrations including Cd, Cu and Mn ($r_s = 0.94$, $n = 6$, $p \leq 0.025$).

Key words: chironomid abundance; macroinvertebrates; metals; pH; acid mine drainage.

INTRODUCTION

The water quality along the Dee River for 18 km downstream of the mine site to its junction with Fletcher Creek (Figure 1) is characterised by low pH, typically 2.7 to 4.0, and high conductivity, typically 2.8 to 6.6 mS/cm (Mackey 1988). This 'highly impacted section' of the river includes a number of pools unconnected by surface flows except following rain events. The emergent macrophyte *Eleocharis equisetina* (spike rush) was by far the most dominant macrophyte (> 80%) in the pools. In a water sample taken in the river adjacent to the mine, at Kenbula, in September 2000 the dissolved concentration of Al was 371 mg/L and Cu was 26.2 mg/L (Taylor 2004). The Al concentration exceeds the fresh water low reliability trigger value of 0.8 μg/L derived for aluminium at pH<6.5 using an Assessment Factor (AF) of 20 on the low pH trout LC50 figure (ANZECC & ARMCANZ 2000).

Previous studies had been undertaken in the Dee River investigating the extent and severity of biological and chemical impacts in the river (Mackey 1988; Duivenvoorden 1995, 1997). Mackey (1988) sampled biota at one site upstream of the mine and at seven sites along the length of the river downstream of the mine, on four separate occasions chosen to represent dry and wet season conditions. He concluded that the macroinvertebrate fauna was clearly depauperate at the two sites most impacted by the AMD, but gradually recovered as water quality improved downstream. In 1981/82 impacts were detectable 50 km downstream of the mine and, although the effect of pollution was not so marked in 1985/86, the impacts were easily discernible 18 km downstream (Mackey 1988). Duivenvoorden (1995, 1997) confirmed that the river was still adversely affected by AMD in studies undertaken in March 1995 and June to July 1997. This study describes the relationship between chironomid abundance and water quality which had not been correlated in prior studies of the Dee River.

MATERIALS AND METHODS

Four sampling sites were selected within the 'highly impacted section' of the Dee River (Figure 1). Kenbula was adjacent to the mine and at the upstream extent, Site 3a and Site 3b midway and Site 4 at the downstream extent of the 'highly impacted section' (Figure 1). A detailed description of sites and rationale for site selection and sampling frequency is provided in Howse (2003).

Macroinvertebrate sampling was conducted using pond nets as used in previous Dee River studies (Duivenvoorden 1995, 1997). Whereas these previous studies used 1 mm mesh size, in this study it was decided to use a 250 μm mesh net as adopted for the AusRivAS program throughout Australia (Queensland Department of Natural Resources and Mines 2001). The sampling and analysis protocol utilised varied substantially from the AusRivAS program which provides a rapid prediction system to assess the biological health of Australian rivers. Sampling duration and area were defined, six replicates were collected and sorted and taxa abundance was determined in this study.

At each site, a transect line was established, and six sampling positions were selected at one-metre intervals, excluding adjacent positions. Samples were collected within a 1-m^2 quadrat frame constructed of polypropylene tubing, which was placed upon the sediment for a period of one minute on each side of the transect line at each sampling position (six samples, each of two m^2 for two minutes).

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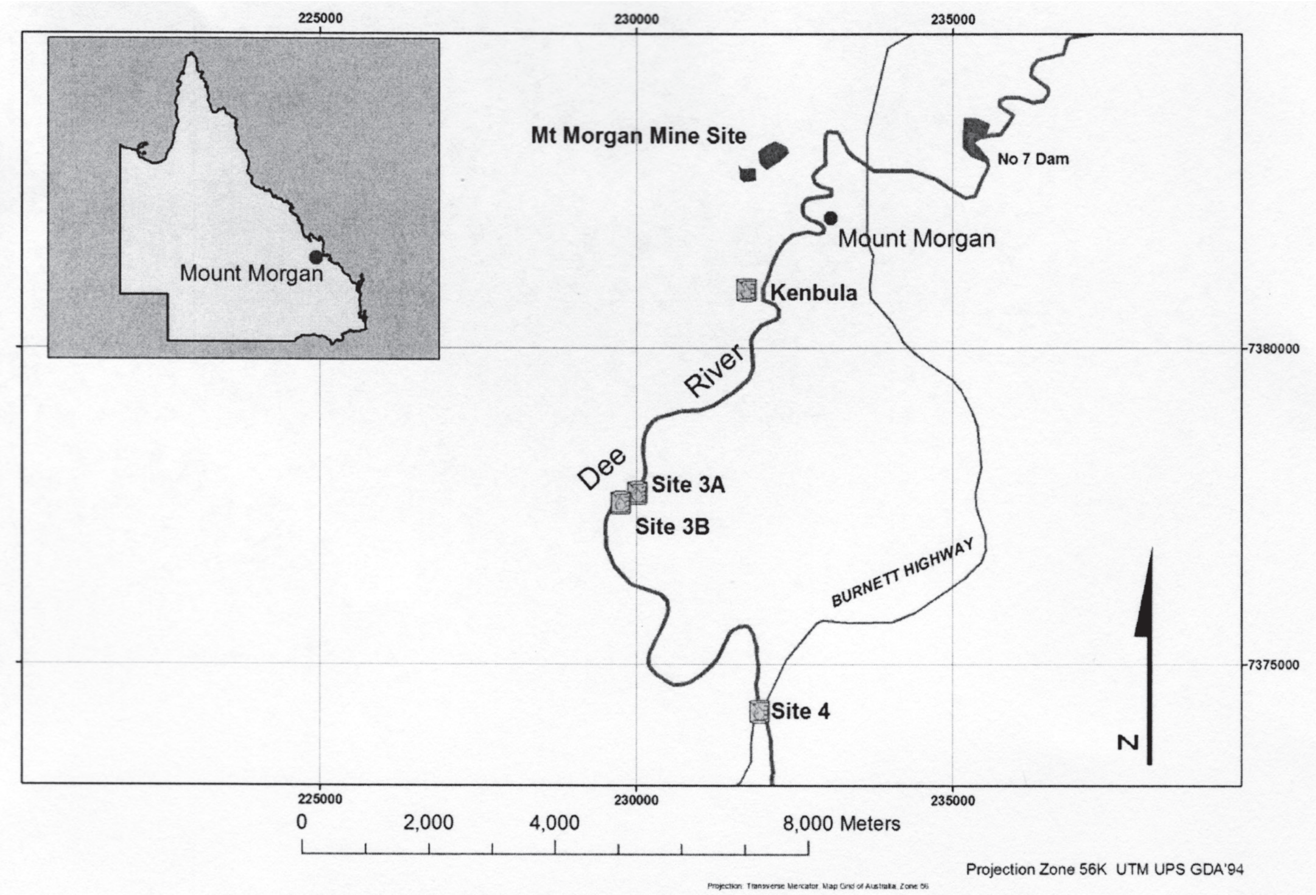

Figure 1. Map of the Dee River, Central Queensland, showing sampling sites Kenbula, Site 3a, Site 3b and Site 4.

During the first 15 seconds of the sampling the pond net was quickly swept through the top surface of the pond to collect surface-dwelling macroinvertebrates. Subsequent sampling involved rapid movement of the pond net, with the handle held vertically, to dislodge and collect macroinvertebrates residing around the macrophytes, whilst ensuring the net remained within the water column. Although the macrophyte growth (*Eleocharis* sp.) was often dense this did not inhibit the net sampling. The length of each side of the triangular frame supporting the pond net was 0.3 m, net length was 0.4 m, mesh size 250 µm, and handle length 1.2 m. Samples were immediately transferred into plastic bags and preserved with 100% ethanol, so that the resulting concentration was approximately 70%. Subsequent to processing, macroinvertebrates were transferred to 70% ethanol with 2% glycerol.

Taxa were identified to Family level with the exception of Hydracarina (mites), Cladocera, Copepoda and Ostracoda. The last three taxa are micro-crustaceans and were not frequently collected in this study. Williams (1980) was used as a source for identification for all families except Trichoptera, which were identified according to Dean and Cartwright (1991). This enabled comparison with prior studies (Duivenvoorden 1995, 1997). A number of other references was utilised to assist with identification, including CSIRO (1999), Merritt and Cummins (1996) and Hawking and Smith (1997).

The replicates were found to be highly variable in the number of macroinvertebrates present and the time required for sorting entire samples, particularly those with very high chironomid abundance, would have been excessive. Thus the subsampling method described by Walsh (1997) was adopted. Walsh (1997) determined that subsampling to a fixed proportion was less efficient than subsampling to a fixed number of individuals. He also found that for urban stream communities, subsampling to 300 individuals was adequate for four out of six comparisons and was adequate for all comparisons when a minimum proportion of 10% was applied. Subsampling to 200 individuals was found to be adequate for a study of more than 200 sites from 1994-1996 of the Fraser River catchment, British Columbia (Reynoldson et al. 2001).

All of the six replicates collected were sorted. Replicate efficiency was demonstrated to be appropriate according to the rules described by Mackay et al. (1984) to determine whether a 'representative' number of taxa had been collected (Howse 2003). Replicate similarity was determined using the multivariate program SIMPER (PRIMER-E 2001) and was greater than 70% for 11 of the 14 samples sorted and greater than 55% for all samples sorted. Chironomids were the most significant contributor to replicate similarity for all samples (Howse 2003).

Table 1. Summary of pH and conductivity (average of at least 5 replicates, ± standard error) of sampling of four sites along the Dee River from October 1999 to June 2001.

Sampling Date	Kenbula	Site 3a	Site 3b	Site 4
pH				
Oct-99		3.62 ± 0.02	3.42 ± 0.06	
Dec-99	2.56 ± 0.01	3.39 ± 0.03	3.38 ± 0.02	3.40 ± 0.05
May-00	2.92 ± 0.01	3.34 ± 0.01	3.26 ± 0.01	3.69 ± 0.01
Sep-00	2.86 ± 0.01	3.50 ± 0.01	3.57 ± 0.004	3.88 ± 0.004
Nov-00	3.14 ± 0.004	3.35 ± 0.004	3.31 ± 0.004	3.48 ± 0.002
Dec-00	3.01 ± 0.01	3.53 ± 0.01	3.48 ± 0.002	3.80 ± 0.01
Jun-01	2.86 ± 0.004	3.77 ± 0.004	3.63 ± 0.003	3.69 ± 0.04
Range	2.56 – 3.14	3.34 – 3.77	3.31 – 3.63	3.40 – 3.88
Conductivity (mS/cm)				
Oct-99		3.41 ± 0.01	3.49 ± 0.03	
Dec-99	6.36 ± 0.03	3.42 ± 0.04	3.65 ± 0.02	2.36 ± 0.05
May-00	4.31 ± 0.01	4.55 ± 0.16	4.84 ± 0.02	3.18 ± 0.02
Sep-00	8.50 ± 0.01	4.44 ± 0.03	5.22 ± 0.02	2.92 ± 0.002
Nov-00	2.19 ± 0.02	1.68 ± 0.002	1.76 ± 0.01	1.68 ± 0.004
Dec-00	3.18 ± 0.02	2.13 ± 0.01	2.25 ± 0.01	2.01 ± 0.004
Jun-01	3.90 ± 0.01	3.04 ± 0.01	2.96 ± 0.01	2.10 ± 0.02
Range	2.19 – 8.50	1.68 – 4.55	1.76 – 5.22	1.68 – 3.18

Table 2. Filtered metal concentration in water samples collected at Sites 3a and 3b along the Dee River from September 2000 to June 2001.

Sampling Date	Site	Filtered Metal Concentration (mg/L)					
		Al	Cd	Cu	Fe	Mn	Zn
05-09-00	Site 3a	171	0.049	10.4	2.40	32.6	5.63
	Site 3b	36.2	0.009	2.61	2.05	7.85	1.38
05-11-00	Site 3a	154	0.042	9.84	0.70	31.4	4.99
	Site 3b	35.9	0.009	2.62	1.81	8.10	1.36
21-12-00	Site 3b	41.7	0.014	3.85	2.93	10.7	1.80
01-06-01	Site 3b	57.5	0.017	4.50	2.31	13.5	2.11

Conductivity and pH measurements were conducted *in situ* using a TPS LC84 conductivity meter and a TPS LC80A pH meter respectively (Table 1). Water samples were collected for metal analysis from each site for each of the last four sampling events (5 September 2000 to 1 June 2001). Samples were collected in acid washed polyethylene bottles and were not acidified. However, as the pH of these samples *in situ* was < 3.5 there should not have been much difference between total and dissolved metals concentrations in these samples. Samples were transferred to an Esky containing ice prior to despatch by overnight courier to Australian Laboratory Services in Brisbane where they were filtered, prior to analysis, to determine (approximately) dissolved metals rather than total metals.

Correlation analysis was performed using Spearman rank correlation test (Sparks 2000), between chironomid abundance and conductivity, for example. The Spearman rank correlation test was used in preference to the Pearson product moment correlation as the former method downplays the effect of a few high values. Linearity in the ranks also indicates monotonicity in the original values (Sparks 2000).

RESULTS AND DISCUSSION

The water quality along the Dee River for 18 km downstream of the mine site continues to be impacted by AMD. The pH is low, typically 2.6 to 3.9, the conductivity is high, typically 1.7 to 8.5 mS/cm (Table 1), and metal concentrations are high (Table 2).

The observation of high abundance of Diptera (mostly chironomid larvae) at Kenbula and their rapid decline in abundance downstream towards Site 4, for sampling event conducted 11 May 2000 (Table 3), had not been anticipated from prior studies (Mackey 1988; Duivenvoorden 1995, 1997). The average total abundance of chironomids (for the

Table 3. Summary of macroinvertebrate data (including average abundance of six replicates, ± standard error) of sampling of four sites along the Dee River from October 1999 to June 2001.

Sampling Date	Site	Average abundance	% Chironomid abundance	Number of Taxa
27-10-99	Site 3b	9690 ± 2880	98.8	16
11-05-00	Kenbula	17360 ± 3160	96.8	12
	Site 3a	10690 ± 875	98.9	12
	Site 3b	7010 ± 643	96.8	9
	Site 4	847 ± 287	84.5	17
05-09-00	Site 3a	12700 ± 2620	96.5	22
	Site 3b	18960 ± 3780	98.7	17
05-11-00	Site 3a	643 ± 167	96.8	15
	Site 3b	787 ± 61	96.3	21
21-12-00	Site 3b	4805 ± 763	94.4	21
01-06-01	Site 3b	6977 ± 2024	97.8	23

Table 4. Summary of Spearman rank correlation analysis (2-tailed) for sites in the Dee River for pH and conductivity (Table 1), filtered metal concentration (mg/L) (Table 2) and macroinvertebrate data (Table 3).

Parameter	Number analysed	Average abundance	Chironomid abundance	Chironomid %	Number of Taxa
pH	n = 11	-0.06	-0.06	-0.13	**0.66** [b]
Conductivity	n = 11	**0.84** [a]	**0.76** [a]	0.53	-0.35
Al	n = 6	**0.89** [b]	**0.89** [b]	0.66	0.31
Cd	n = 6	**0.94** [b]	**0.94** [b]	0.54	0.49
Cu	n = 6	**0.94** [b]	**0.94** [b]	0.54	0.49
Fe	n = 6	-0.09	-0.09	-0.49	0.37
Mn	n = 6	**0.94** [b]	**0.94** [b]	0.54	0.49
Zn	n = 6	**0.89** [b]	**0.89** [b]	0.66	0.31

Significant correlations are shown in bold.
[a] Correlation is significant at the p = 0.01 level (2-tailed).
[b] Correlation is significant at the 0.025 level (2-tailed).

six replicates) was 17 357 and 818 at Kenbula and Site 4 respectively (Table 3). The high abundance of chironomids is readily explained, as prior studies had used a coarser 1000 µm mesh net, whereas this study utilised a 250 µm mesh net to be consistent with current protocols (AusRivAS, Queensland Department of Natural Resources and Mines 2001). It is likely that the majority of the chironomids were not retained by the 1000 µm mesh net in the prior studies. Storey (1985) investigated mesh-size and efficiency of sampling of larval chironomids by washing living and preserved larvae through a tier of sieves and plankton netting of decreasing mesh-size, ranging from 1000 µm to 50 µm. No chironomid larvae were retained by the 1000 µm aperture and almost 40% of the living larvae passed through the 125 µm sieve, whereas less than 6% of the preserved larvae did so (Storey 1985).

Spearman rank correlation analysis revealed a significant ($p \leq 0.01$) positive correlation between chironomid abundance and average abundance with conductivity ($r_s = 0.76$ and 0.84 respectively, n = 11) (Table 4). In addition there was a significant ($p \leq 0.025$) positive correlation between pH and number of taxa ($r_s = 0.66$, n = 11). Significant ($p \leq 0.025$) correlations were evident between chironomid abundance and average abundance for many metals (Al, $r_s = 0.89$; Cd, $r_s = 0.94$; Cu, $r_s = 0.94$; Mn, $r_s = 0.94$ and Zn, $r_s = 0.89$), however, this observation must be treated with caution due to limited sample numbers (n = 6) collected from only two sampling sites (Sites 3a and 3b).

Although chironomids were not identified as a potential indicator in past biological studies of the Dee River (Mackey 1988; Duivenvoorden 1995, 1997) they have been identified as indicators by studies in other areas.

Winner et al. (1980) investigated metal impact upon macroinvertebrates in two 2nd order, limestone streams in southwestern Ohio, USA. One stream was used as an experimental stream to evaluate the impact of a chronic Cu stress on stream fauna, whilst the other received effluent containing Cu, Cr and Zn from a small metal-plating industry. Data from both streams suggested that the macroinvertebrate community structure exhibited a predictable, graded response to heavy-metal pollution. In the more heavily-stressed sections of both streams, macroinvertebrates, other than tubificid worms and chironomids, were virtually eliminated from rock-rubble, riffle habitats. Midge (chironomid) larvae comprised 75 to 86% of all insects collected from the most grossly polluted stations and less than 10% of the insect communities at the least polluted stations. The correlation coefficient for percentage of chironomids in relation to copper concentration for the study by Winner et al. (1980) was +0.93 ($p \leq 0.01$) and this can be compared to this Dee River study where there was a significant positive correlation (r_s) of 0.94 ($p \leq 0.01$, Table 4).

In a study of 17 sites in a stream receiving heavy metal inputs, Armitage and Blackburn (1985) showed that Chironomidae alone could be used to differentiate between sites with varying degrees of pollution in the same way as analyses using total benthos. Further identification only to Sub-Family level was adequate for this purpose.

The correlation of pH with number of taxa has been observed in another study. Kullberg (1992) conducted a study of Swedish streams where a total of 97 taxa was found in 20 streams. The number of taxa in each stream ranged from 4 to 33, and abundance from 416 to 54 000/m^2. Multiple regression analysis revealed a significant correlation ($r = 0.70$) between number of taxa and pH and colour ($p < 0.05$, F-test). pH was the major factor determining this correlation, with which the number of species was positively correlated (Kullberg 1992).

More recently, Reynoldson et al. (2001) investigated benthic invertebrate assemblages at more than 200 sites in the Fraser River catchment in British Columbia. In a comparison of 59 metrics, the second most useful metric was % Chironomidae. At the species level, the metric total taxa contributed most to the ordination, of all the metrics, and thus provided the greatest information; however Family level data were recommended for assessment purposes (Reynoldson et al. 2001).

Whilst chironomid abundance may be an effective indicator, the efficiency of their use is severely constrained by the time required for processing the samples. It is proposed that efficient subdivision of the samples may be achieved using for example a Marchant box (Marchant 1989), which enables a subdivision ratio of 100, although a number of units are usually then recombined to achieve representative subdivision.

Alternative techniques such as Surber sampling (Brooks 1994; Surber 1937) could be considered to reduce and/or optimise the collection of macroinvertebrates. However Mackey et al. (1984) found that pond net samples generally collected the most taxa in a given time, in comparison to samples collected using a Maitland corer and a Surber sampler. Whilst Edwards (2001) used a suction sampler, modified after Brooks (1994), in his studies of AMD impacts in the Finniss River, the equipment is bulky, takes longer to set up and the area sampled (in one replicate) is smaller and thus less representative of habitat sampled. Storey et al. (1991) concluded that kick sampling using a pond net, was more economical than Surber sampling, particularly for obtaining qualitative data. As flows in the Dee River are infrequent, pond netting is more suitable than kick netting, which relies upon water flow to carry the dislodged macroinvertebrates into the downstream net.

No attempt was made in this study to identify the species of chironomids present, however other studies (e.g. Cranston 1997) have reported variation in the pollution tolerance of different species of chironomids. Thus the species of chironomid present in the Dee River should be determined and investigated.

CONCLUSIONS

A change in the sampling technique, to a finer mesh for the dip net, is most likely to be the main reason for the collection of far more chironomids from the Dee River than in previous studies. The % chironomid abundance was higher in the samples at Kenbula, adjacent to the mine, and declined downstream. Percentage chironomid abundance appears to be an effective indicator, however, an efficient means of processing samples needs to be utilised (e.g. Marchant sampler).

Statistical analysis of the macroinvertebrate and water quality parameters (pH, conductivity and filtered metals) has demonstrated significant correlations which reinforce the value of combined biological and chemical monitoring. This study was focused on the highly impacted zone in the Dee River; it is in this region of the river where the greatest improvement in water quality and biological health would be anticipated in response to mine site remediation.

Why chironomids abound in the acid mine drainage of the Dee River warrants further investigation. The emergent macrophyte *Eleocharis* sp. is abundant in the highly impacted section of the Dee River and often completely covers Sites 3a and 3b, almost to the exclusion of all other macrophytes. In processing the replicates, chironomids were often extracted from inside the fragments of *Eleocharis* sp. It may be that the *Eleocharis* sp. offered refuge from predators for the chironomids.

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