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Ecological Effects of Mine Effluents on the South Esk River, North-eastern Tasmania
III.* Benthic Macroinvertebrates

R. H. Norris,[A] *P. S. Lake*[B] *and R. Swain*[C]

[A] Canberra College of Advanced Education, P.O. Box 1, Belconnen, A.C.T. 2616.
[B] Department of Zoology, Monash University, Clayton, Vic. 3168.
[C] Department of Zoology, University of Tasmania, P.O. Box 252C, Hobart, Tas. 7001.

Abstract

The ecological effects of mine effluents on the South Esk River were investigated over 2 years on a 170-km section of the river. Quantitative samples of benthic macroinvertebrates were collected at eight sites (three above the trace metal inflow and five below) using an air-lift sampler. Drifting fauna were also collected in the river adjacent to the point of trace metal inflow and in a tributary entering the contaminated section. As far as 80 km downstream from the source of trace metals, the numbers of individuals and the numbers of taxa were reduced in relation to upstream sites. From the 29 most commonly occurring taxa, three groups have been defined by clustering strategies:

- (*a*) taxa that were abundant at both contaminated and uncontaminated sites (a leptocerid caddisfly and a baetid mayfly);
- (*b*) taxa that were most abundant at sites upstream of the contaminated section of river (two mollusc species, four species of leptophlebiid mayfly and five species of caddisfly);
- (*c*) taxa whose numbers were highest at sites below the source of contamination (six dipteran species, four species of caddisfly, one mollusc species, one amphipod species and one species of water mite).

Factors likely to be important in determining the harmful effects of trace metal contamination in the field include the particular metals under consideration, flow rate and stability of the substrata. There is little agreement between the acute lethal concentrations of metals determined by other workers in laboratory studies and the concentrations found to produce harmful effects in the South Esk River. The multivariate approach proved to be a sensitive means for the detection of trace metal contamination. The composition of the drifting fauna was also altered by the trace metal contamination. The numbers of rhyacophilid caddisflies were higher in the contaminated section of river and those of the baetid mayflies and helminthid beetles were lower.

Introduction

The environmental impact that contaminants may have on an aquatic ecosystem should be assessed by an interpretative study of the physicochemical characteristics in relation to the biota. Studies relating the effects of trace metals on the biota in Australia are limited, covering only five rivers (Bayly and Lake 1979; Jeffree and Williams 1980): the Molonglo River near Canberra (zinc), the South Esk (cadmium, copper, zinc and lead) and King (copper and lead) Rivers in Tasmania, the Murray River (zinc) in New South Wales downstream of Albury–Wodonga, and the Finniss River (copper, zinc and manganese) in the Northern Territory (Jeffree and Williams 1980).

This is the third paper on the ecological effects of mine effluents on the South Esk River in Tasmania. The first aim of the study reported in this paper was to determine whether the patterns of distribution and abundance of the individual taxa that make up

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the benthic macroinvertebrate communities of the South Esk River are affected by the trace metals contaminating the river (Norris *et al.* 1980, 1981). In past work, trace metals have been regarded as a force decreasing both the distribution and abundance of all the taxa that comprise the benthic macroinvertebrate community (e.g. Hynes 1960; Connell 1981). A further aim of this study was to determine, using multivariate statistical techniques, whether all taxa are responding in a similar way to the putative pollution or whether, as suggested by some in earlier studies (e.g. Weatherley *et al.* 1967, 1980; Thorp and Lake 1973), taxa may respond to trace pollution in different ways with some taxa being adversely affected and other tolerant taxa benefiting from the effects of the pollution. The animals in a stream may respond in an identical fashion to trace metal contamination, but it is our contention that the animals do not respond in this way and that the response at the community level is heterogeneous, bringing together the dissimilar responses of the species in the system.

Materials and Methods

Eight sampling sites were chosen along the South Esk River (Norris *et al.* 1980). Three were upstream of the inflow of trace metals (sites 1–3) and five were downstream (sites 4–8). There were 10 sampling occasions over 2 years, initially at intervals of 2 months, then at 4-month intervals. The criteria on which sites were chosen and a description of the study area are given in Norris *et al.* (1980). All samples were collected with an air-lift sampler (Norris 1980) at a depth of 0·8–1·0 m to minimize errors due to possible changes in sampling efficiency and animal distribution with depth. The catching net of the sampler was 967-μm mesh, the area sampled was 200 cm^2 and three 10-s blasts of air were used to take each sample. Thirty benthic samples were taken at each of the sites on the 10 sampling occasions and this number was found to exceed the number required to give a constant arithmetic mean using the method described by Elliott (1971).

In September 1975 and February 1976, samples of drifting fauna were collected in the South Esk River at Avoca and upstream of Storys Creek, in the St Pauls Rivulet and in Storys Creek. A further collection of the drifting fauna was made in February 1977 in the South Esk River immediately upstream and downstream of the inflow of Storys Creek. The area of the opening of the drift net was 1000 cm^2 and the mesh size was 967 μm. Flow velocities at each drift sampling site at the time of collection were measured with an Ott A5 current meter. Samples were collected every 2 h over a 24-h period.

All samples were preserved immediately after collection in 10% neutralized formalin with Rose Bengal stain added, as used by Dills and Rogers (1974). The stain assisted subsequent sorting, which was carried out with the aid of a stereomicroscope. The animals were identified to species or to discrete taxa, counted, transferred to alcohol and stored.

Two indices of diversity were calculated—the index of Margalef (1958) and the Shannon–Weaver index (Shannon and Weaver 1963). Principal Component Analysis (P.C.A.) was used to group animals in terms of their distribution and abundance in relation to the metal contamination. In this study, P.C.A. was used with varimax rotation, which allows the combination of different vectors to provide more meaningful axes of interpretation of the data matrix (Marriott 1974). Two different types of mathematical classification procedures were used: hierarchical and non-hierarchical. The hierarchical clustering method was agglomerative and polythetic and was available in the Genstat (Anon. 1977) statistical package with Average Linkage Sorting [Option CM = 4 of Genstat (Anon. 1977)] being the clustering method. The non-hierarchical method used was the REMUL classificatory program of the Taxon Package of the Division of Computing Research, CSIRO (Dale *et al.* 1980). This program was divisive, polythetic and used a re-allocation procedure; the Canberra metric coefficient was used (Lance and Williams 1975).

Results

Distribution and Abundance

In all, 2400 samples were collected and from these, approximately 44000 animals belonging to 75 benthic macroinvertebrate taxa were extracted and identified. Entries in the list of taxa (Table 1) are augmented by taxa collected from the drifting fauna and by the separation of juvenile and adult forms of those species in which all life-history stages are fully aquatic (e.g. helminthid beetles).

Table 1. Taxa and total number of animals collected from each site, including additional taxa collected only from the drift

C., class; O., order; S.O., sub-order; F., family; S.F., sub-family

Taxa	No. at site								Total No.
	1	2	3	4	5	6	7	8	
C. TURBELLARIA									
O. Tricladida									
F. Dugesiidae									
Cura pinguis	2	18	5	3	0	5	1	2	35
C. ANNELIDA									
O. Oligochaeta									
F. Phreodrilidae									
Phreodrilus nudus	3	12	1	1	2	22	9	24	75
F. Megascolecidae									
Megodrilus sp.	35	123	46	1	3	16	18	41	283
Telmatodrilus multiprostatus	17	11	17	0	0	4	4	17	70
F. Lumbriculidae									
Lumbriculus variegatus^A									
O. Hirudinea									
F. Glossiphoniidae									
Glossiphonia tasmaniensis	0	4	0	0	0	0	0	0	4
C. GASTROPODA									
O. Basommatophora									
F. Planorbidae									
Isidorella hainesii	0	4	6	0	0	3	21	189	223
Gyraulus tasmanicus	0	7	2	0	0	0	0	0	9
O. Mesogastropoda									
F. Hydrobiidae									
Rivisessor gunnii	597	13 511	4491	0	0	0	0	0	18 599
Potomopyrgus niger^A									
F. Ancylidae									
Ferrissia tasmanica^A									
Ferrissia petterdi	0	10	4	0	0	0	0	0	14
C. BIVALVIA									
O. Heterodonta									
F. Sphaeriidae									
Sphaerium tasmanicum	7	643	107	0	0	1	0	1	759
C. CRUSTACEA									
O. Isopoda									
S.O. Phreatoicidea									
F. Phreatoicoidae									
Colubotelson sp.	0	4	7	0	0	0	0	0	11
O. Amphipoda									
F. Ceinidae									
Austrochiltonia australis	0	9	14	0	0	4	0	174	201
C. INSECTA									
O. Ephemeroptera									
F. Baetidae									
Baetis baddamsae	252	616	681	366	28	299	416	63	2721
Tasmanophlebia lacustris	0	1	0	0	0	0	0	1	2
F. Caenidae									
Tasmanocoenis sp.	4	27	99	0	0	0	0	1	131
F. Leptophlebiidae									
Atalophlebia australis	0	127	65	0	0	0	0	0	192
Atalophlebia nr *longicaudata*	5	3	5	0	0	0	0	0	13
Atalophlebioides sp. 1	773	342	205	28	2	0	0	0	1350

Table 1. (*contd*)

Taxa	No. at site 1	2	3	4	5	6	7	8	Total No.
Atalophlebioides sp. 2	75	724	480	25	1	0	12	0	1307
Atalonella sp.	356	485	337	27	2	1	2	0	1210
O. Odonata									
F. Gomphidae									
Austrogomphus guerini	1	0	6	1	0	2	31	31	72
F. Aeschnidae									
Aeschna longissima	0	0	0	0	0	8	3	17	37
O. Plecoptera									
F. Notonemouridae									
Tasmanocerca bifasciata	0	0	0	0	0	3	16	0	19
F. Gripopterygidae									
Leptoperla varia	0	4	4	2	0	1	1	0	12
Dinotoperla sericauda	0	2	8	0	0	0	0	15	25
Cardioperla nigrifons	6	56	25	2	0	1	0	1	91
Riekoperla sp.	0	3	1	0	1	2	0	3	10
O. Hemiptera									
F. Corixidae									
Micronecta sp.	0	1	37	0	0	0	0	0	38
O. Megaloptera									
F. Sialidae									
Austrosialis sp.	0	0	0	0	0	0	0	12	12
O. Coleoptera									
F. Helminthidae									
Austrolimnius sp. (adults)	27	70	40	15	8	3	2	1	166
Austrolimnius sp. (larvae)	314	285	148	20	2	1	6	0	776
Stetholus sp. (adults)	2	4	0	2	1	0	1	1	11
Stetholus sp. (larvae)[A]									
Unidentified genus sp. 1 (larvae)	1	1	1	1	1	0	1	0	6
Unidentified genus sp. 2 (larvae)	0	0	0	0	0	0	1	0	1
F. Dytiscidae									
Sternopriscus cervus	0	1	4	0	3	0	2	0	10
Antiporus femoralis	0	0	0	3	5	1	11	1	21
Platynectes reticulosus[A]									
Hydaticus sp.	0	2	0	0	1	0	1	0	4
Carabhydrus niger	0	9	1	3	1	2	0	1	17
Necterosoma penicillatus[A]									
F. Hydrophilidae									
Hydrobius macer[A]									
F. Psephenidae									
Unidentified genus sp.[A]									
F. Helodidae									
Unidentified genus sp.	12	52	0	2	0	0	1	0	67
O. Diptera									
F. Simulidae									
Austrosimulium sp. (larvae)	32	88	113	5	5	122	5	361	731
Austrosimulium sp. (pupae)	0	9	11	17	0	43	14	231	310
F. Muscidae									
Limnophora sp.	0	0	0	3	1	0	0	6	10
Unidentified genus sp. 1	48	3	4	15	47	3	1	0	121
Unidentified genus sp. 2	0	0	0	0	0	0	56	0	56
F. Chironomidae									
S.F. Orthocladiinae									
Cricotopus albitibia	12	36	46	65	36	35	809	74	1113
Eukiefferiella sp.	0	0	0	0	0	20	1063	0	1083

Table 1. (*contd*)

Taxa	No. at site								Total No.
	1	2	3	4	5	6	7	8	
Cardiocladius sp.	0	2	3	2	3	5	1	6	22
Unidentified genus sp. 1	104	3	3	8	4	0	12	1	135
F. Tanypodinae									
Coelopynia pruinosa	0	0	2	1	0	8	127	2	140
Ablabesmyia notabilis	0	18	18	0	2	6	54	0	98
F. Chironominae									
Stempellina sp.	0	1	2	1	0	0	43	1	48
Stenochironomus sp.	0	0	1	0	1	0	0	0	2
Rheotanytarsus sp.[A]									
Microspectra sp.[A]									
O. Trichoptera									
F. Helicopsychidae									
Helicopsyche murrumba	11	150	186	3	0	0	0	0	350
F. Rhyacophilidae									
Taschorema ferulum	65	100	56	65	14	35	13	5	353
Apsilochorema sp.	13	9	5	2	5	2	7	0	43
F. Leptoceridae									
Unidentified genus sp. 1	0	2	0	2	1	1	4	0	10
Oecetis sp. 1	75	2302	1404	1030	1681	672	203	2	7369
Oecetis sp. 2	0	0	0	0	0	1	2	0	3
Notalina sp.	0	7	2	0	11	0	4	0	24
F. Odontoceridae									
Atriplectides dubia	5	19	25	3	6	1	6	0	65
F. Ecmonidae									
Ecnomus sp.	5	18	18	46	21	59	293	3	463
F. Glossosomatidae									
Agapetus sp.	376	63	261	2	0	0	0	0	702
F. Hydropsychidae									
Cheumatopsyche sp.	1	13	4	6	0	5	23	162	214
Asmicridea sp.	504	23	24	231	1	127	1	33	944
F. Hydroptilidae									
Unidentified genus sp. 1	0	5	14	6	1	6	23	71	126
Unidentified genus sp. 2	0	0	0	0	0	0	15	3	18
F. Conoesucidae									
Unidentified genus sp. 1	21	23	81	10	8	3	0	1	147
Unidentified genus sp. 2	152	160	189	1	0	3	6	0	511
Unidentified genus sp. 3	5	32	17	1	0	0	1	0	56
Unidentified genus sp. 4	6	71	7	0	0	0	0	0	84
F. Calamoceratidae									
Anisocentropus latifascia	0	3	2	0	0	0	0	0	5
F. Philorheithridae									
Aphilorheithrus sp.	14	2	2	10	15	3	13	5	64
F. Tasimiidae									
Unidentified genus sp. 1	20	11	20	3	18	2	1	0	75
Unidentified genus sp. 2	3	3	4	2	0	0	0	0	12
Unidentified genus sp. 3	2	4	5	2	0	0	4	14	31
C. ARACHNIDA									
O. Acarina									
F. Hydracarina									
Unidentified genus sp. 1	2	25	23	2	31	2	35	40	159
Unidentified genus sp. 2	0	0	11	0	0	0	2	0	13
Unidentified genus sp. 3	0	0	2	0	0	0	1	0	3

[A] In drift only.

Taxa whose numbers were at least 0·5% (arbitrary minimum) of the total numbers of animals collected, excluding the snail *Rivisessor gunnii*, were used for statistical analyses. *R. gunnii* was omitted as it was only present at sites 1–3, but was so numerous there as to overshadow the other taxa, thus obscuring other relationships. On this basis, there were 29 commonly occurring taxa.

Differences between total numbers of animals, with and without *R. gunnii*, collected at sites 1–3, upstream of the inflow of trace metals to the South Esk River, and sites 4–6, which were immediately downstream, were very highly significant ($t = 6\cdot65$ with *R. gunnii*, and $t = 4\cdot25$ without *R. gunnii*). The number of taxa collected on each sampling occasion, both the commonly occurring taxa and the total number of taxa, also exhibited a very highly significant difference, being greater at sites 1–3 than at sites 4–6 ($t = 7\cdot55$ for the common taxa and $t = 5\cdot21$ for the total number of taxa).

There were several significant spatial and temporal variations in the total numbers of animals (with and without *R. gunnii*), the total number of commonly occurring taxa and the total number of all taxa (Table 2). In view of the temporal variations that occurred in the physicochemical variables (Norris *et al.* 1980, 1981), significant differences between the numbers of animals and taxa have also been examined for corresponding months in 1975 and 1976 (Table 3).

Table 2. Spatial and temporal variations in the numbers of animals and the numbers of taxa

Results of analysis of variance, *F*-factors and levels of significance are given. n.s., not significant, $0\cdot05 < P$; * significant, $0\cdot05 > P$; ** highly significant, $0\cdot01 > P$; *** very highly significant, $0\cdot001 > P$

	Spatial variation		Temporal variation	
	Sites 1–3	Sites 4–8	Sites 1–3	Sites 4–8
Total Nos with *R. gunnii*	6·040**	—	2·266, n.s.	—
Total Nos without *R. gunnii*	1·192, n.s.	0·913, n.s.	5·294***	2·937**
Common taxa	8·638**	5·726***	3·298**	3·070*
Total taxa	9·350***	7·269***	5·030***	1·789, n.s.

Grouping of Taxa

Four different methods have been used to classify the commonly occurring taxa into different categories on the basis of their distribution and numerical responses to the trace metal input from Storys Creek.

The total numbers classification subjectively placed 29 commonly occurring taxa in three different groups (Table 4*a*). Group 1 of this total numbers classification represents species that were relatively abundant at both clean and contaminated sites in the South Esk River. The second group represents species that were abundant only at sites above Storys Creek, and in the third group are taxa whose numbers were highest at sites in the contaminated section downstream of Storys Creek.

Using an arbitrary level of significance of the principal component factors of 0·5 (Ratkowsky and Martin 1974), three groups were formed from the first four axes of the P.C.A. (Table 4*b*). The first axis identified taxa forming a group coinciding with groups 1 and 2 of the total numbers classification. The second axis grouped two taxa that were most abundant at site 7. The third axis did not yield a grouping of taxa, however, the fourth axis showed a group of four taxa that were all most abundant at site 8. The ungrouped taxa (Table 4*b*) may be subjectively placed in groups on the basis of their distributions, as done in the total numbers classification. Such allocations would only repeat procedures already used, and do not form part of the P.C.A. procedure.

A line was drawn at the 78% similarity level of the hierarchical classification to define three groups (Fig. 1). Group 1 of this classification consists of two species, which were present in relatively high numbers at all sampling sites. Group 2 contains eight taxa that were all present in relatively high numbers in the South Esk River upstream of Storys Creek but that were found in much lower numbers, or not at all, at downstream sites. Group 3 largely contains taxa whose abundances were greatest at sites in the contaminated section. This group also includes a number of taxa (identified as subgroup 2A, Fig. 1) that were all more abundant at sites 2 and 3 than at site 1 and that were all very rare, or absent, at sites downstream of the trace metal inflow from Storys Creek.

Table 3. Differences between 1975 and 1976 in the numbers of animals and the numbers of taxa

Results of *t*-tests and the levels of significance for all sites considered together are given. n.s., not significant, $0 \cdot 05 < P$; * significant, $0 \cdot 05 > P$; ** highly significant, $0 \cdot 01 > P$; *** very highly significant, $0 \cdot 001 > P$

Period	Total numbers: with *R. gunnii*	Total numbers: without *R. gunnii*	Numbers of taxa: Common	Numbers of taxa: Total
Full year	1·428, n.s.	1·985, n.s.	1·247, n.s.	2·248*
February	1·050, n.s.	1·870, n.s.	0·445, n.s.	0·414, n.s.
April	0·400, n.s.	0·520, n.s.	0·620, n.s.	0·256, n.s.
August	2·584*	2·098, n.s.	2·898*	2·586*
December	0·022, n.s.	1·050, n.s.	0·612, n.s.	1·384, n.s.

Three groups were also created by the REMUL non-hierarchical classification (Table 4*c*). Group 1 consists of taxa that were abundant both upstream and downstream of the trace metal inflow; group 2, those most abundant upstream; and group 3, those most abundant downstream.

By interpretation of the groups formed by each method, the 29 commonly occurring taxa were classified finally to the three groups shown in Table 4*d*. These three groups have been adopted for use in further presentation of results and discussion and will be referred to as the operating classification.

Diversity Indices

The Margalef and the Shannon–Weaver diversity indices for each sampling occasion were calculated and tested for spatial and temporal variations (Table 5). A better understanding of how well each index represented the benthic communities in the South Esk River was obtained by correlating the indices calculated for each sampling occasion with the environmental factors (Norris *et al.* 1980, 1981). Only significant correlations are shown in Table 6.

Drift Sampling

Animals drifting in the South Esk River above Storys Creek and at Avoca and in Storys Creek and St Pauls Rivulet (for location of sites see Norris *et al.* 1980) in September 1975 and February 1976, were sampled to determine the effects of the trace metals on stream drift and the possible availability of fauna for recolonization

Table 4. Classification of groups of species

Group 1	Group 2	Group 3
	(a) **Total numbers classification**	
Baetis baddamsae	*Rivisessor gunnii*	*Isidorella hainesii*
Austrolimnius sp. (adult)	*Sphaerium tasmanicum*	*Austrochiltonia australis*
Austrolimnius sp. (larvae)	*Atalophlebia australis*	*Austrosimulium* sp. (larvae)
Taschorema ferulum	*Tasmanocoenis* sp.	*Austrosimulium* sp. (pupae)
Oecetis sp. 1	*Atalophlebioides* sp. 1	*Cricotopus albitibia*
Asmicridea sp.	*Atalophlebioides* sp. 2	*Eukiefferiella* sp.
	Atalonella sp.	*Coelopynia pruinosa*
	Orthocladiinae sp. 1	*Ecnomus* sp. 1
	Helicopsyche murrumba	*Cheumatopsyche* sp. 1
	Agapetus sp.	Hydroptilidae sp. 1
	Conoesucidae sp. 1	Hydracarina sp. 1
	Conoesucidae sp. 2	
	(b) **Principal component analysis**[A]	
Rivisessor gunnii[B]	*Eukiefferiella* sp.[C]	*Isidorella hainesii*[D]
Sphaerium tasmanicum	*Ecnomus* sp. 1	*Austrochiltonia australis*
Atalophlebia australis		*Cheumatopsyche* sp. 1
Tasmanocoenis sp.		Hydroptilidae sp. 1
Atalophlebioides sp. 2		
Atalonella sp.		
Austrolimnius sp. (adult)		
Austrolimnius sp. (larvae)		
Helicopsyche murrumba		
Taschorema ferulum		
Oecetis sp. 1		
Agapetus sp.		
Conoesucidae sp. 1		
Conoesucidae sp. 2		
	(c) **Non-hierarchical classification**	
Baetis baddamsae	*Rivisessor gunnii*	*Isidorella hainesii*
Cricotopus albitibia	*Sphaerium tasmanicum*	*Austrochiltonia australis*
Taschorema ferulum	*Atalophlebioides* sp. 1	*Tasmanocoenis* sp.
Oecetis sp. 1	*Atalophlebioides* sp. 2	*Atalophlebia australis*
	Atalonella sp. 1	*Austrosimulium* sp. (pupae)
	Austrolimnius sp. (adult)	*Coelopynia pruinosa*
	Austrolimnius sp. (larvae)	*Eukiefferiella* sp.
	Austrosimulium sp. (larvae)	Orthocladiinae sp. 1
	Helicopsyche murrumba	*Ecnomus* sp. 1
	Agapetus sp.	*Cheumatopsyche* sp.
	Conoesucidae sp. 1	*Asmicridea* sp.
	Conoesucidae sp. 2	Hydroptilidae sp. 1
		Hydracarina sp. 1
	(d) **Operating classification**	
Baetis baddamsae	*Rivisessor gunnii*	*Isidorella hainesii*
Oecetis sp. 1	*Sphaerium tasmanicum*	*Austrochiltonia australis*
	Tasmanocoenis sp.	*Austrosimulium* sp. (larvae)
	Atalophlebia australis	*Austrosimulium* sp. (pupae)
	Atalophlebioides sp. 1	*Cricotopus albitibia*
	Atalophlebioides sp. 2	*Eukiefferiella* sp.
	Atalonella sp.	*Coelopynia pruinosa*
	Austrolimnius sp. (adult)	Orthocladiinae sp. 1

Table 4. (*contd*)

Group 1	Group 2	Group 3
	Austrolimnius sp. (larvae)	*Ecnomus* sp. 1
	Helicopsyche murrumba	*Cheumatopsyche* sp. 1
	Tashorema ferulum	*Asmicridea* sp.
	Agapetus sp. 1	Hydroptilidae sp. 1
	Conoesucidae sp. 1	Hydracarina sp. 1
	Conoesucidae sp. 2	

^{A} Ungrouped species: *Baetis baddamsae*, *Atalophelbioides* sp. 1, *Austrosimulium* sp. (larvae), *Austrosimulium* (pupae), *Cricotopus albitibia*, *Coelopynia pruinosa*, Orthocladiinae sp. 1, *Asmiciidea* sp., Hydracarina sp. 1. ^{B}Axis 1. ^{C}Axis 2. ^{D}Axis 4.

(Table 7). In February 1977, the drifting fauna directly above and below Storys Creek were sampled: similar numbers of animals were drifting in a 24-h period at each site (Table 7). The relative numbers of selected taxa collected from the drift at the two sites upstream and downstream of Storys Creek, expressed as the number of animals collected per 24 h at a flow rate of $1\ \mathrm{m}^3\ \mathrm{s}^{-1}$ (Fig. 2), have been compared to indicate differences in the composition. There was a distinct nocturnal peak in the numbers of animals drifting at all sites.

Table 5. Spatial and temporal variation of the Margalef and the Shannon–Weaver diversity indices
F-values and levels of significance resulting from two-way analysis of variance are given. n.s., not significant, $0\cdot 5 < P$; * significant, $0\cdot 5 > P$; ** highly significant, $0\cdot 01 > P$; *** very highly significant, $0\cdot 001 > P$

Diversity index	Spatial variation			Temporal variation	
	Sites 1–3 *v.* Sites 4–8	Sites 1–3	Sites 4–8	Sites 1–3	Sites 4–8
Margalef	39·890***	1·551, n.s.	5·327**	2·853*	1·44, n.s.
Shannon–Weaver	5·580*	1·645, n.s.	4·615**	1·835, n.s.	0·596, n.s.

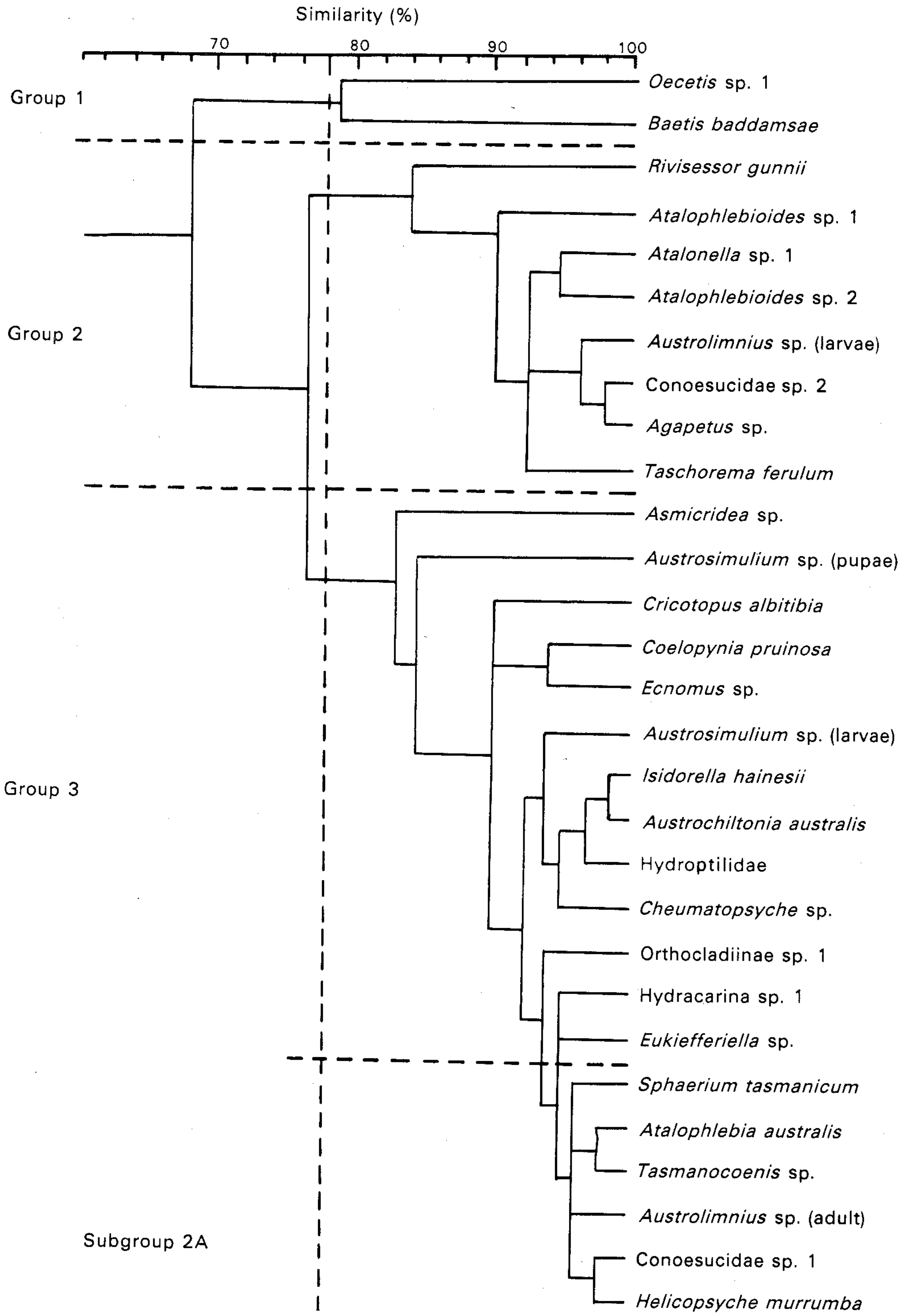
Discussion

Distribution and Abundance

The numbers of individuals and of taxa below the point of input of trace metals to the South Esk River were both much reduced (Table 1). Similar findings have been observed in numerous early studies of metal-polluted rivers in England and Wales, reviewed by Hynes (1960) and Whitton and Say (1975). In other studies from Australia, Lake (1963) and Weatherley *et al.* (1967) also reported a reduction in the numbers of taxa and individuals due to zinc contamination in the Molonglo River, as did Lake *et al.* (1977) in a study of a western Tasmanian river contaminated by copper, lead and zinc, and Thorp (1973) and Thorp and Lake (1973) in their study of the South Esk River.

In the South Esk River, with the exception of the baetid mayflies and the leptocerid caddisflies, the taxa that were numerically dominant at the uncontaminated sites 1–3 were intolerant of the metal contamination (Table 1). These three upstream control sites provide the best comparison as the water characteristics, geography and land use (Norris *et al.* 1980, 1981) are more relevant than they would be for an unpolluted

Fig. 1


Similarity (%)
70
80
90
100
Group 1
Group 2
Group 3
Subgroup 2A
Oecetis sp. 1
Baetis baddamsae
Rivisessor gunnii
Atalophlebioides sp. 1
Atalonella sp. 1
Atalophlebioides sp. 2
Austrolimnius sp. (larvae)
Conoesucidae sp. 2
Agapetus sp.
Taschorema ferulum
Asmicridea sp.
Austrosimulium sp. (pupae)
Cricotopus albitibia
Coelopynia pruinosa
Ecnomus sp.
Austrosimulium sp. (larvae)
Isidorella hainesii
Austrochiltonia australis
Hydroptilidae
Cheumatopsyche sp.
Orthocladiinae sp. 1
Hydracarina sp. 1
Eukiefferiella sp.
Sphaerium tasmanicum
Atalophlebia australis
Tasmanocoenis sp.
Austrolimnius sp. (adult)
Conoesucidae sp. 1
Helicopsyche murrumba

tributary or nearby river. Perhaps the most notable member of the group is the snail *Rivisessor gunnii*, which comprised almost half the total animals collected from all sites, although it was only present at sites above Storys Creek (Table 1). There were no significant differences between the total numbers of animals collected from sites within the contaminated sections of the river (Table 2). This, along with some animal taxa downstream, suggests that there is no significant recovery from the trace metal contamination for up to 80 km downstream of Storys Creek. However, this suggestion should be treated with caution as lack of recovery can be proven only by field toxicity tests.

Table 6. Correlations between the Margalef and the Shannon–Weaver diversity indices and the environmental factors

Values given are the Pearson product–moment correlation coefficients and their levels of significance. Only significant correlations are shown. *Significant, 0·05 > *P*; **highly significant, 0·01 > *P*; ***very highly significant, 0·001 > *P*

Factor	Correlation with: Margalef index	Correlation with: Shannon–Weaver index
Shannon–Weaver index	0·603***	
Metal in sediments		
Cd	−0·226*	
Zn		
Cu		
Pb	−0·247*	
Mn		
Fe		
Metal in non-filterable residue		
Cd	−0·318**	
Zn	−0·235*	
Cu		
Pb		
Mn		
Fe		
Dissolved metal		
Cd	−0·301**	
Zn	−0·347***	−0·256*
Cu		
Pb		
Total metal		
Cd	−0·318**	
Zn	−0·366***	−0·260*
Cu		
Pb		

The spatial differences between the numbers of taxa collected from sites 1–3 (Table 2) were probably due to differences in substrata and water chemistry between

Fig. 1. Dendrogram resulting from the hierarchical classification using the quantitative Pythagorean similarity definition. The line at the 78% similarity level defines three groups of species. A further subgroup (2A) has also been included (see text).

site 1 and sites 2 and 3. Site 1 was above the tributary of the Break O'Day River, which alters the chemical composition of the water of the South Esk River by increasing ionic concentrations (Norris *et al.* 1980). Also, site 1 had a sandier substratum than sites 2 and 3, which may offer fewer microhabitats (Hynes 1970).

The paucity of taxa at site 5 (Table 1) caused the spatial differences found in the numbers of taxa collected from the sites contaminated by trace metal (Table 2). Site 5 had very unstable substrata and the molar action of the bed is likely to have been more detrimental to some taxa than the toxicity of the metals. Jones (1940), Thorp and Lake (1973) and Weatherley *et al.* (1967, 1980) have all suggested that substratum instability is important in limiting the number of species and individuals of lotic species present in metal-polluted rivers. The metal concentrations in the South Esk River at site 5 were lowest in the sediments and highest in the dissolved state (Norris *et al.* 1981) and this might also have played an important role in determining the taxa present.

Table 7. Percentage composition of the drift fauna on each sampling occasion
Winter sampling was conducted in September 1975, and summer sampling in February 1976

	St Pauls Rivulet		South Esk R., Avoca		Storys Creek		South Esk R., above Storys Ck		South Esk R., Feb. 1977	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Above Storys Ck	Below Storys Ck
Trichoptera	10·0	57·9	38·5	76·1	10·4	4·9	24·4	88·0	46·4	65·4
Ephemeroptera	42·7	28·1	16·6	1·6	5·2	—	45·0	9·4	38·7	22·6
Amphipoda	34·4	2·1	9·5	—	5·2	—	3·5	—	—	—
Plecoptera	5·7	0·9	5·9	0·5	20·9	—	17·4	0·4	5·8	7·7
Coleoptera	1·5	1·5	6·0	14·2	46·1	36·5	1·9	0·2	8·2	1·5
Hemiptera	0·2	1·5	—	1·3	—	51·7	0·1	0·2	—	—
Diptera	3·3	7·1	4·8	7·9	10·5	—	7·0	0·2	0·1	2·0
Actual No. of individuals caught	1036 (100%)	432	89 (100%)	302	19 (100%)	265	653 (100%)	349	1580 (100%)	1954
No. of individuals caught at flow rate of 1 $m^3 s^{-1}$									3511	3908

The low number of taxa collected at sites in the South Esk River farthest from the inflow of Storys Creek (Table 1) was surprising as there was evidence of less metal contamination in the sediments and the water (Norris *et al.* 1981). It appears that the environment at site 8 was so affected by trace metal contamination that it was unable to support a more diverse fauna.

The numbers of taxa and of individuals collected were greatest during the summer (Table 2). It is probable that some species not caught during the winter were present but rare, and of course, as pointed out by Hynes (1970), some species may well be represented in the environment but in a form that would not have been collected by the sampling method or the pore size of the sampling net used, such as in the egg stage or as early instar stages, which may be deep in the substrata.

The physical and chemical differences in the river between the two years did not affect the total numbers of animals when each year is considered separately (Table 3). Specifically, the difference in the flow rate, which was much higher in 1975 (Norris *et al.* 1980), did not seem to have caused enough change in the metal contamination to alter the community composition between sites 4 and 8.

In 1976, the total numbers of taxa collected, but not the number of commonly occurring taxa, were higher than in 1975 (Table 3). The differences in total numbers of taxa suggest that the lower flow rates in 1976, and possibly the corresponding lower levels of dissolved metals (Norris *et al.* 1980, 1981), produced conditions more favourable for the survival of the less common taxa. These differences were particularly marked for the samples obtained in August (Table 3), which in 1975 was preceded by the period of highest flow rates and in 1976 was preceded by the period of lowest rainfall and lowest levels of dissolved metals (Norris *et al.* 1980, 1981).

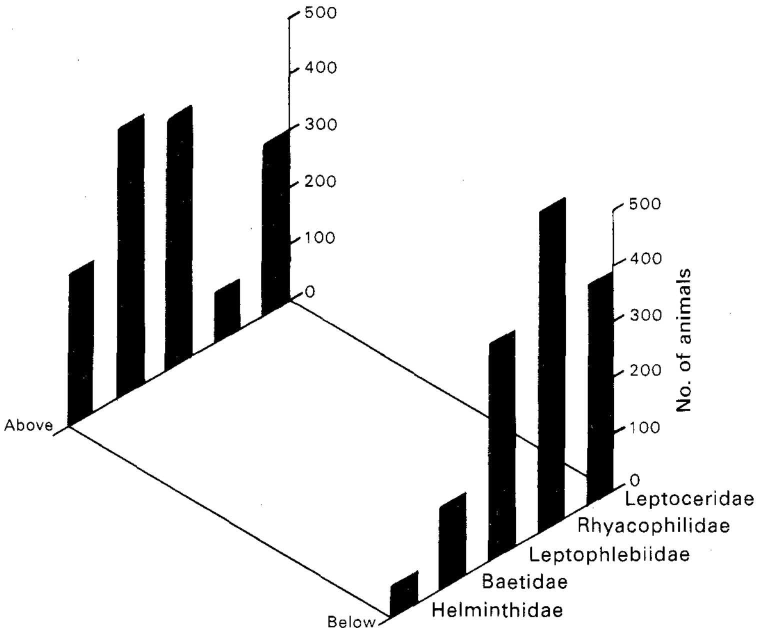


Fig. 2. Relative composition of the fauna drifting in the South Esk River above and below Storys Creek. There were two species of Leptoceridae: *Oecetis* sp. 1 and *Notalina* sp. (0·2 of total); one of Rhyacophilidae: *Taschorema ferulum*; five of Leptophlebiidae: *Atalophlebia australis*, *Atalophlebia* nr *longicaudata*, *Atalophlebioides* sp. 1, *Atalophlebioides* sp. 2 and *Atalonella* sp. (0·5 of total); one of Baetidae: *Baetis baddamsae*; and one of Helminthidae: *Austrolimnius* sp. (adults). Relative number of animals is expressed as number collected per 24 h at a flow rate of 1 $m^3 s^{-1}$.

Grouping of Taxa

The relative advantages and disadvantages of the clustering methods may be summarized as follows: the total numbers classification (Table 4*a*) was the simplest to conduct but was laborious; the P.C.A. classification (Table 4*b*) was the only one to define different groups within the contaminated zone but left many taxa ungrouped; the hierarchical classification (Fig. 1) is subject to errors resulting from following a hierarchy; the non-hierarchical method (Table 4*c*) yielded the most acceptable groups requiring only minor changes. The four methods have been used to create the three groups of the final operating classification (Table 7); each of these will be discussed in order.

Group 1

The taxa in this group are both shown to be tolerant of the metal contamination. *Oecetis* sp. 1 comprised a large part of the total populations at all sites downstream of the entry of Storys Creek, except at site 8 (Table 1). At the heavily contaminated site 5 (Norris *et al.* 1981), it comprised over 80% of the animals collected, although its actual numbers were not always greater than those found in the uncontaminated sites 1–3. *Oecetis* sp. 1 was clearly highly tolerant of the trace metal contamination and was unaffected by the unstable substratum at site 5.

Thorp and Lake (1974) found a 96-h LC_{50} for cadmium of >2000 mg l^{-1} for an unidentified leptocerid from the South Esk River (probably the same species). Weatherley *et al.* (1967, 1980) concluded that the relatively high numbers of a species of leptocerid in the zinc-contaminated reaches of the Molonglo River reflected the insect's metal tolerance, the availability of detritus for case building and the absence of metal-sensitive predators. The detritus levels may be higher in the contaminated zones due to the greatly reduced numbers of detritivores, such as the mayflies (Table 1).

The other member of group 1, *Baetis baddamsae*, was the only species of mayfly found to be tolerant of the metal contamination and of the conditions created by it. It formed a fairly large part of the collection at all sites except site 5 where *Oecetis* sp. 1 was abundant (Table 1). The numbers of *B. baddamsae* (Table 1) were lower at sites downstream of Storys Creek, especially at site 5 where the dissolved concentrations of zinc and cadmium in solution were often greatest (Norris *et al.* 1981). Insects of this species may be slightly sensitive to the trace metals in the dissolved state.

Group 2

The snail *R. gunnii* was the most abundant species at sites 1–3 but it was completely absent from all the sites in the South Esk River contaminated by trace metals (Table 1). Thorp (1973) in her study of the South Esk River did not find similar large numbers of gastropods at sites above Storys Creek and she reported snails identified as the genus *Physa* [synonomous with *Isidorella hainesii* (Smith and Kershaw 1979)] from sites in the contaminated section of the river. The collections of Thorp (1973) were taken with a hand net from the slower flowing regions of the river. This would almost certainly have resulted in her recording lower numbers of *R. gunnii* from sites above Storys Creek as it seems to be more commonly found in regions of faster flow (Smith and Kershaw 1979). In the present study, the gastropod *Isidorella hainesii* was collected at sites downstream of Storys Creek, its greatest abundance being recorded at site 8 (Table 1). Thorp (1973) also recorded the same species from the South Esk River downstream of the inflow of Storys Creek.

Wurtz (1962), working on the North-west Miramichi River in Canada, found that five species of gastropod were highly sensitive to zinc, copper and lead contamination. One year after mine water had ceased being pumped into the river, there were still no gastropods collected up to 19 km below the infall. The Ystwyth River in Wales, contaminated by lead and zinc, was still devoid of gastropods 35 years after mining ceased (Jones 1958). Copper pollution in the River Churnet, a tributary of the River Dove in England, also resulted in the loss of molluscs for 19 km below the infall to its confluence with the River Dove (Pentelow and Butcher 1938). Molluscs were also found to be absent from the River Rheidol in Wales polluted by lead and zinc but they were found to have returned 10 years after mining activities ceased (Jones and Howells 1975). Weatherley *et al.* (1967) observed that molluscs were absent from the zinc-polluted sections of the Molonglo River. In the present study, no molluscs were collected within 31·5 km of the inflow of trace metals. It would be expected that they would remain absent long after the trace metal contamination had abated.

The bivalve *Sphaerium tasmanicum*, also in group 2, is almost ubiquitous in Tasmania, occurring in a very wide range of habitats (Smith and Kershaw 1979). This distribution indicates that *S. tasmanicum* may be tolerant of wide ranges in the natural physical and chemical factors of its environment. The levels of man-made metal contamination present in the South Esk River may have resulted in its elimination from all sites below Storys Creek (Table 1).

The four species of leptophlebiid mayfly were collected in fairly high numbers at sites 1–3 and formed a large part of the populations at these sites (Table 1). Small numbers of these mayflies were recorded from site 4 below Storys Creek (Table 1), suggesting some resistance even in the most heavily contaminated conditions, but the specimens probably represented a continual inflow of mayflies from the clean area. Winner *et al.* (1975) showed that the lowest numbers of various species in a stream experimentally contaminated with copper, occurred at the second site downstream of the point of contamination.

The available toxicity information reveals acute concentrations of cadmium, zinc and copper lethal to mayflies that are all higher than the concentrations recorded from the South Esk River (Warnick and Bell 1969; Thorp and Lake 1974; Clubb *et al.* 1975; Nehring 1976). However, caution must be exercised when comparing acute toxicity values for different species. Thorp and Lake (1974) reported a 96-h LC_{50} for cadmium of $0 \cdot 84$ mg l^{-1} for *Atalophlebia australis* (collected from the South Esk River). This value is lower than those reported by the workers just referred to for other species of Ephemeroptera and it may indicate that the Leptophlebiidae are more sensitive than other families of mayfly. Thorp and Lake (1973) also reported elimination of mayflies at sites directly below Storys Creek. However, they also showed that they reappeared at Evandale (near site 8, Norris *et al.* 1980). The species of mayfly reported from Evandale by Thorp (1973) was *Atalophlebia australis*, which is better suited to the regions of slower flow sampled in her study.

Tasmanocoenis sp. is a burrowing form, typically at home in slow flowing water. In an uncontaminated stream, it would be expected to have been collected from site 7, which had a low flow rate (Norris *et al.* 1980). However, *Tasmanocoenis* sp. was absent from this site (Table 1). The concentrations of metals in the sediments were quite high at this site (Norris *et al.* 1981) and as *Tasmanocoenis* sp. is a burrowing nymph that feeds on detritus, the concentrations of metals it ingests may limit its distribution.

Lake (1963) also found that the larvae of several species of beetle did not occur in the zinc-polluted sections of the Molonglo River, although one species of Helminthidae was unaffected. He concluded that adult beetles in the Molonglo seemed to have a rather scattered distribution pattern relative to the metal contamination. Thorp (1973) showed that larvae of the Helodidae and Dytiscidae were absent from the trace-metal-polluted sections of the South Esk River, but two species of dytiscid adult occurred at contaminated sites.

The apparent intolerance of the eruciform caddisflies *Helicopsyche murrumba*, *Agapetus* sp. and *Conoesucidae* sp. 2 to trace metals contrasts with the findings of Brown (1977), Sprague *et al.* (1965) and Weatherley *et al.* (1967).

The campodeiform caddisfly *Taschorema ferulum* is only weakly located in group 2 as the total numbers and the non-hierarchical classifications placed it with the tolerant species in group 1 (Tables 4 and 6). Its distribution was similar to that of *Oecetis* sp. 1 and *B. baddamsae* (Table 1) and although its numbers were reduced in the contaminated sections of the river, this species was still relatively abundant there. *T. ferulum* was not numerically dominant at any site (Table 1); however, since it is a predator (Riek 1970), this is not surprising. This species formed an important component of the drifting fauna (Fig. 2) and so the downstream sites may have received continual recruitment.

Although the taxa in group 2 appear to be sensitive to trace metal contamination, the evidence for their relative insensitivity is only correlative and requires confirmation both by laboratory and field acute and theoretic toxicity tests.

Group 3

The species included in group 3 all reached their highest numbers in the South Esk River downstream of the inflow of the trace metals from Storys Creek.

The snail *Isidorella hainesii* and the amphipod *Austrochiltonia australis* both formed a moderate part of the total animals collected at site 8 (Table 1). Their presence at this site was somewhat surprising as both organisms belong to taxa that are known to be sensitive to metal contamination. As *I. hainesii* was collected intermittently in small numbers at sites 6 and 7 (Table 1), it is possible that the concentrations of metals at these sites (Norris *et al.* 1981) were near the limits prohibitive to the survival of the snail.

Several authors have shown that the Crustacea, as a group, is eliminated by metal contamination of rivers. Carpenter (1924) found them lacking in the River Ystwyth in Wales, which was contaminated by lead and zinc. Eighteen years later, Jones (1940) found that Crustacea were still absent from this river, and this was still true 35 years later (Jones 1958). Weatherley *et al.* (1967) reported them to be absent from the zinc-contaminated Molonglo River, and Wurtz (1962) recorded their absence from the zinc- and copper-contaminated North-west Miramichi River in Canada.

Few amphipods were collected from the uncontaminated sites of the South Esk River and they did not drift in large numbers at these sites (Table 7). They were present in very large numbers in the drift at St Pauls Rivulet (Table 7), which enters the South Esk River just downstream of site 5. These high numbers suggest that this and perhaps other tributaries may contribute large numbers of amphipods to the South Esk River; however, amphipods were not collected at sites close to St Pauls Rivulet, indicating that they are sensitive to, or avoid, the metal contamination. Thorp (1973) found amphipods to be abundant at uncontaminated upstream sites and also recorded much larger numbers at Evandale (near site 8). This pattern is similar to the one recorded in this study, although Thorp's absolute numbers were very much greater. Thorp (1973) and Thorp and Lake (1973) suggested that the presence of amphipods at Evandale indicated that they were tolerant of mild intermittent pollution.

Lake *et al.* (1979) have carried out extensive experiments on cadmium toxicity to *Austrochiltonia australis*. In acute toxicity tests, they determined a 96-h LC_{50} for cadmium of $0 \cdot 15$ mg l^{-1} for *A. australis*, which is well above the levels recorded in the South Esk River (Norris *et al.* 1981). These lethal concentrations determined from acute tests seem unlikely to be ecologically meaningful. Lake *et al.* (1979) also showed that concentrations of cadmium as low as $0 \cdot 5$ μg l^{-1} have a detrimental effect on the reproductive potential of *A. australis*. Several other aspects of cadmium toxicity to *A. australis* were also tested by these authors and they showed that cadmium stress reduced the life expectancy of laboratory populations, caused increased juvenile mortality and reduced growth rates of individuals. The concentrations of cadmium recorded in the South Esk River could have a direct effect on populations of *A. australis*.

Lake *et al.* (1979) also investigated the effect of increasing salinity on the toxicity of cadmium to *A. australis*. They obtained 96-h LC_{50}'s for cadmium ranging from $0 \cdot 039$

to 0·770 mg l^{-1} as the salinity of test water was raised from 38 to 1734 mg l^{-1}. These findings suggest that the increased ionic and alkalinity concentrations found progressively downstream in the South Esk River (Norris *et al.* 1980), in conjunction with the lower concentrations of dissolved metals (Norris *et al.* 1981), may ultimately create conditions allowing the survival of *A. australis*.

The lowest numbers of the larvae and the pupae of the blackfly *Austrosimulium* sp. were recorded from sites 4 and 5, directly below the infall of trace metals from Storys Creek. This distribution suggests some appreciable sensitivity to these metals or the conditions created by them. Lake (1963) found simuliids at sites in the Molonglo River in areas highly contaminated with zinc. Simuliids are typical of running waters and they are selective in the type of substrata they will attach to (Colbo and Moorhouse 1979). Thus, it is possible that these animals are metal-tolerant [even though simuliids have been shown to accumulate zinc (Carter and Nicholas 1978)] but that their distribution is controlled by substrata and flow-rate characteristics. As the substrata were more unstable at sites 4 and 5 than at other sites, this might be sufficient to account for their low numbers at these sites.

The chironomids as a group have been shown to be highly tolerant of metal contamination. Wentsel *et al.* (1977) recorded *Chironomus tentans* from a lake with very high concentrations of both cadmium, up to 969 $\mu g\ g^{-1}$ dry weight, and zinc, 14032 $\mu g\ g^{-1}$ dry weight, in the sediments. Winner *et al.* (1975) found them to be most tolerant of copper contamination. Jones (1940) found certain chironomids to be particularly tolerant of lead and zinc contamination, and Lake (1963) concluded that, as a group, chironomids were tolerant of zinc contamination of the Molonglo River. The highest numbers of chironomids in the present study were recorded from site 7 (Table 1). This site generally had the highest concentrations of metals in the sediments (Norris *et al.* 1981) in which the chironomids live and feed, indicating that these species are tolerant of relatively high levels of metals in their immediate environment.

The campodeiform caddisfly *Ecnomus* sp. was also recorded in its highest numbers at site 7, showing that it also is tolerant of high concentrations of metals in the sediments, emphasizing the wide-ranging differences in the sensitivity to metal contamination that exist between different caddisfly species. The chironomids and *Ecnomus* sp. are more commonly found in the slower flowing sections of river. If the distribution and abundance of *Cricotopus albitibia* (Chironomidae) and *Ecnomus* sp. are considered after excluding site 7, their numbers are seen to be relatively constant at low levels at all sites (Table 1).

Diversity Indices

The Margalef and the Shannon–Weaver indices both showed the gross effect of the metal contamination as lower values were obtained at sites 4–8 than at sites above Storys Creek. The Shannon–Weaver index showed the contamination less clearly than the Margalef index (Table 5): Shannon–Weaver index values were between 1·0 and 2·5 for sites above Storys Creek and between 0·5 and 2·5 at sites in the contaminated section and the differences were not clear without a statistical test (Table 5). Neither index showed significant spatial differences at sites 1–3. As the numbers of both taxa and individuals, on which the indices are based, alter significantly (Table 2), it must be concluded that the indices are not as sensitive as analytical tests based directly on species richness and abundance.

The Margalef index showed significant temporal differences at sites 1–3 whereas the Shannon–Weaver index did not (Table 5). The numbers of species were shown to have significant spatial differences but the total numbers of animals exclusive of *R. gunnii* did not show such a difference (Table 2). Both the Margalef and the Shannon–Weaver indices showed significant spatial differences at sites in the contaminated section of the river (Table 5), reflecting the significant differences shown to exist in the numbers of species alone (Table 2). The spatial differences shown by these indices are due to the low diversities indicated at site 5 (Table 1).

The indices calculated by the Margalef method correlated significantly with zinc and cadmium concentrations in the water column and cadmium and lead in the sediments (Table 6), suggesting that this index may be useful for identifying factors important at the community level. The indices calculated by the Shannon–Weaver method correlated significantly only with the total and dissolved zinc concentrations in the water column and reliable conclusions could not be reached by examination of the value of this index as to the relative importance of these factors. The use of the Shannon–Weaver index for pollution assessment has also been criticized by Cook (1976), and in other studies, diversity indices have also been found to be wanting (e.g. Winner *et al.* 1975; Heck 1976).

Drift Sampling

The taxa comprising the major percentages of the drifting fauna at the uncontaminated sites were the caddisflies, mayflies and stoneflies (Table 7). Amphipods were numerically dominant in the summer sample from St Pauls Rivulet (Table 7) but they were notably absent from all other sampling sites and times. The numerically dominant components of the drifting fauna at the contaminated sites of Storys Creek and the South Esk River at Avoca were slightly different from those at the uncontaminated sites. The mayflies were reduced in importance and the beetles and water bugs were relatively more important (Table 7).

The absolute numbers of animals collected in the drift samples, standardized for flow rate, directly above and below Storys Creek were virtually the same (Table 7), but the compositions of the fauna at the two sites were quite different (Fig. 2). Some animals may be able to detect the trace metal contamination and react in some way to avoid its effects. This explanation was also proposed by Lake *et al.* (1977) in relation to the King River in Tasmania.

Assuming that some macroinvertebrate species are able to detect the contamination, they may be expected to behave in a manner appropriate to their morphological and physiological attributes. For example, the baetid mayflies are strong swimmers and, although they have been shown to be relatively tolerant of metals, they may be able to detect the contaminated areas and leave the drift and move back upstream (Fig. 2). The same reasoning may also be applied to the adult helminthid beetles. The numbers of rhyacophilid caddisflies collected from the drift were much greater below Storys Creek than above it (Fig. 2). This again may be interpreted as a behavioural response to the contaminated conditions but in this case, the animals are poor swimmers and would be unlikely to have the ability to move back upstream. The leptocerid caddisflies have been shown to be very tolerant of trace metal contamination in the South Esk River and, like the rhyacophilids, are also poor swimmers. Similar numbers of these species were collected from both above and below Storys Creek (Fig. 2). In this case, it may be concluded that the trace metal contamination had little effect on the drifting behaviour of this insect. The leptophlebiid mayflies were also collected in similar numbers from the drift above and below Storys Creek. It seems likely that they were unable to detect or escape the trace metal contamination. Although they are weak swimmers compared with the baetids, they probably have the ability to clamber along the bottom upstream. Reasonable numbers of them were collected at site 4 below Storys Creek, but at no other sites, suggesting an input due to drift and a short survival time.

In conclusion, the clustering strategies, based on the pattern of distribution and abundance of the 29 most commonly occurring taxa, allowed the discrimination of three groups of taxa, each of which reacted to the trace metal contamination in a very different way. It is unlikely that the distribution or abundance of each taxon is being determined solely by trace metal contamination. Some taxa may be very sensitive to trace metals whereas other taxa that are less abundant in the metal-contaminated section of the river may be being affected by indirect effects of trace metal contamination such as decreased substrata stability or elimination of a particular type of food. As we know very little about the factors controlling the distribution of Australian stream animals (Lake 1982) and the trace metal tolerances of Australian stream animals, the multivariate approach used in this paper appears from a pragmatic point of view to be a sensitive way to evaluate patterns of pollution. Furthermore, as suggested by Jeffree and Williams (1981), the multivariate approach detects pollution based on assemblages of taxa. This would not be possible if the tolerances of the taxa were combined, even if each tolerance were known.

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