Effects of Pollutants at the Ecosystem Level
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CASE 7.3
Comparison of Gradient Studies in Heavy-Metal-Polluted Streams

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7.3.1 INTRODUCTION

The impact of heavy-metal pollution in streams on macroinvertebrates was reported several decades prior to the more recent concern over the potential hazards of synthetic organic compounds (e.g. Jones, 1940). However, there have been few critical evaluations of the specific changes in macroinvertebrate community structure which can be consistently attributed to heavy-metal stress.

The gradient approach, that is, the analysis of macroinvertebrate community response to a decline in pollutant concentrations common with downstream distance from a point-source input, has provided a means of assessing changes in structural indices in relation to pollutant levels. This approach has several notable advantages, provided that care is taken in the choice of appropriate sampling sites to assure environmental homogeneity in such factors as benthic substrate, discharge rate, temperature, turbidity and ionic concentrations. If this is done, general environmental conditions will in all probability be similar throughout the study sites with the exception of the variable of interest, pollutant concentrations. Comparisons of changes can then be made within the same system and can be evaluated in terms of a reference (upstream from the outfall), also within the system. Such factors as dilution, sedimentation and adsorption provide a gradient of exposures which can be related to community and ecosystem changes. Gradient studies are a form of 'natural bioassay' of concentration and effect, incorporating seasonal and other environmental factors.

This case study compares data from three stream-gradient studies in which copper was the principal contaminant. The purposes of this exercise are to examine which structural characteristics of the marcoinvertebrate community exhibit a predictable graded response to heavy-metal pollution and to elucidate how seasonal and other cyclic factors influence the recognition of pollution-induced changes in structural patterns.

Criteria for evaluating indices of response to the impact of heavy metals on a community include:

1. The strength (statistical significance) of the relationship between the index and the metal concentrations.
2. The sensitivity of the index to changes in concentration along the gradient.
3. The influence of spatial and temporal variability on the index.
4. The degree of difficulty in collecting and analysing data from which to estimate the response.
5. The ecological relevance of the index.

Changes in communities are generally assessed in terms of the presence or absence of species or the more basic parameters of population density and biomass. The latter indices are relatively easy to measure and require little taxonomic skill but they also provide the least ecological information. In comparing mieobenthos samples from a brackish pond, Heip (1980) noted that most of the natural variance in density and biomass was introduced by long-term biological periodicity, making these parameters potentially valuable in monitoring change. On the other hand, the problems of quantitatively estimating density and biomass in the heterogeneous habitat of a stream riffle are more difficult. Specifically, considerably more variability is expected in most estimates of stream macroinvertebrate density or biomass than in taxonomic parameters (see Chapter 3). Indeed, Heip (1980) found a much larger coefficient of variation for density than for diversity measures for the more homogeneous lentic benthos.

Although diversity and evenness indices are generally highly correlated, a number of researchers have shown a preference for using the number of species or Shannon's index (Heip and Engels, 1974; Rosenberg, 1975; Marshall and Mellinger, 1980) and have been inclined to avoid evenness indices in monitoring pollution effects (Heip, 1980). Both indices have desirable statistical properties, as their temporal behaviour responds primarily to events with long periodicities. Shannon's diversity index measures something different from the number of species. The loss or the addition of a species is a more dramatic ecological event than those subtle interactions which affect relative abundance and thereby influence the diversity index. The variability in all of the community characteristics discussed above is expected to be of much less magnitude than that of the numbers of individuals in various populations.

In order to evaluate the sensitivity and utility of the various structural indices applied in this study, analysis of variance techniques and Duncan's New Multiple Range Test (Steel and Torrie, 1980) were employed to facilitate multiple comparisons along specific heavy-metal concentration gradients.

7.3.2 THE STREAM ECOSYSTEMS

Shayler Run and Elam's Run are small, second-order Southwestern Ohio streams and Little Grizzly Creek is a second-order stream in the Sierra Nevada Mountains of Northern California. Although Little Grizzly Creek is located at nearly 1500 m greater elevation, the three streams are similar in size, substrate and macrobenthic fauna. The Ohio streams are subject to occasional flooding, and the Sierra stream to spring snow melt, events which increase their volumes substantially. Sampling stations were located in rock-rubble riffle habitats where aquatic insects were the predominant macroinvertebrates.

7.3.3 HEAVY-METAL INPUTS

The studies chosen for comparison, Winner *et al.* (1975, 1980) and Sheehan (1980), present some interesting contrasts in terms of the source, delivery and concentration of heavy metals. Shayler Run was experimentally dosed with copper as part of a United States Environmental Protection Agency study (Geckler *et al.*, 1976). It had been exposed to a low level of copper stress (Table 7.3.1) for 2.5 years prior to evaluation of biotic changes (Winner *et al.*, 1975). The copper was input at a level which allowed metal concentrations to decrease sufficiently downstream to a point where the biota were virtually unaffected by the chemical stress. This study represents one of the few in which the effects of a toxic effluent were tested in a natural ecosystem.

The other Ohio stream, Elam's Run, had been subjected to much higher and more highly variable concentrations of three metals (Cu, Cr and Zn) from the effluent of a metal-plating industry (Table 7.3.2) for 8 years prior to the assessment of impacts (Winner *et al.*, 1980). Concentrations of each metal fluctuated widely and were frequently in the $mg\,l^{-1}$ range, and slugs of cyanide were occasionally detected in the effluent and along the stream. However, there were also periods when the plant was not operational (nights and weekends), and during these periods there was virtually no introduction of pollutants into Elam's

Table 7.3.1 Copper concentrations and structural characteristics of macroinvertebrate communities in Shayler Run, 1972

Station	Cu($\mu g l^{-1}$)	Insects m^{-2}	% Chironomids/ sample	% Caddis-flies/ sample	% Mayflies/ sample
1	9a	2448	5e	11fg	42.0h
2	120	462c	75	6f	2.0 j
3	66	876cd	58	11f	0.3 j
4	52 b	805cd	41	22 g	10.0 j
5	38 b	1056cd	8e	40	12.0 j
6	23a	1652 d	3e	21 g	36.0h

Means followed by a common letter are not significantly different ($p \leq 0.05$).

Run. This stream merged with a much larger stream about 3.5 km below the effluent outfall and at this point the fauna still exhibited signs of being significantly stressed. Due to adverse publicity during the course of the Winner *et al.* (1980) study, the metal-plating industry initiated improvements in its waste-water treatment facility which resulted in a 4- to 25-fold decrease in average concentrations of the three metals in its effluent between 1978 and 1981 (Table 7.3.2).

Because of the periodic release of highly concentrated chemical slugs into Elam's Run, variability within water samples was so high that mean concentrations did not differ significantly between stations for any of the three metals. There was, however, a difference in the frequency with which the stations received these high concentrations as shown for Cu in Figure 7.3.1. Metal concentrations were also measured in the sediments from soft-bottomed pools adjacent to the riffle stations in Elam's Run. Metal concentrations were more stable in the sediments and were significantly different for each of the three metals among each of the five stations (Table 7.3.3). Sediment metal concentrations confirmed that there was a significant decrease in metal pollution between 1978 and 1981. These data also reflect the relationship between metal concentrations

Table 7.3.2 Metal concentrations ($\mu g l^{-1}$) in water of Elam's Run

	Cu		Cr		Zn	
Station	1978	1981	1978	1981	1978	1981
Effluent	1250	191	910	36	508	126
1	336	–[1]	70	–[1]	101	–[1]
2	237	–[1]	54	–[1]	55	–[1]
3	221	58	58	11	51	25
4	87	–[1]	15	–[1]	24	–[1]
5	74	13	2	4	24	5

[1] Samples not collected.

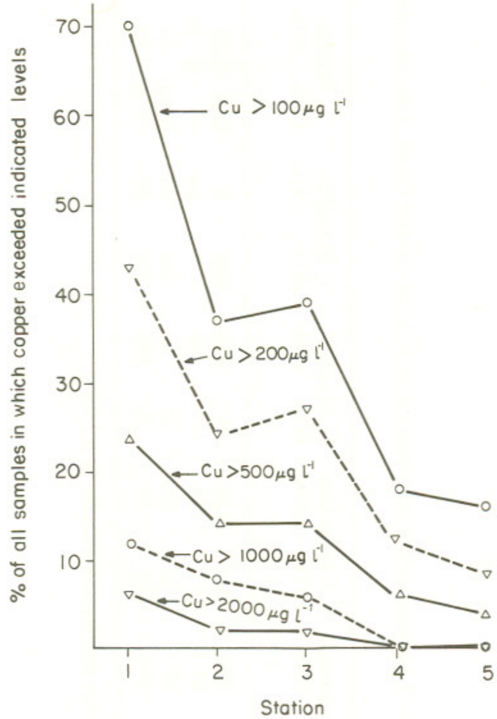

Figure 7.3.1 Percentage of samples containing selected copper concentrations at five stations on Elam's Run, 1978. (From Winner *et al.*, 1980. Reproduced by permission of the *Canadian Journal of Fisheries and Aquatic Sciences*)

Table 7.3.3 Mean metal concentrations ($\mu g g^{-1}$) in sediments of Elam's Run, 1978 and 1981

Station	% Organic content 1978	% Organic content 1981	Copper 1978		Copper 1981	Zinc 1978		Zinc 1981	Chromium 1978		Chromium 1981
1	2.8	–[1]	239		–[1]	259		–[1]	121		–[1]
2	5.5	3.6	669	*	29	515	*	17	508	*	17
3	4.5	4.8	431	*	60	488	*	37	213	*	43
4	3.6	3.2	157	*	17	195	*	10	63	*	12
5	2.5	2.8	24	*	6	70	*	4	3		4

Corresponding 1978, 1981 means marked with asterisks are significantly different ($p \leq 0.05$).
[1] Samples not collected.

Table 7.3.4 Copper concentrations and structural characteristics of macroinvertebrate communities in Little Grizzly Creek, July through October, 1975 and May through October, 1976.

Station	Cu($\mu g l^{-1}$) 1975 max	Cu 1975 min	Cu 1976 max	Cu 1976 min	Insects m^{-2} 1075	Insects m^{-2} 1976	% Chironomids 1975	% Chironomids 1976	% Caddis-flies 1975	% Caddis-flies 1976	% Mayflies 1975	% Mayflies 1976	% Stoneflies 1975	% Stoneflies 1976	% Beetles 1975	% Beetles 1976
7 Reference	< 4		< 4		7150	7815b	14	29e	19g	12h	28	24k	10m	9	22p	25
8	630	200	150	80	24a	1345 c	–[1]	95 f	–[1]	1h	–[1]	0k	–[1]	0n	–[1]	1r
9	390	130	120	30	118a	1830 c	65d	79 f	13g	6h	0j	7k	0m	0n	14pq	0r
12	320	50	60	20	463a	4562bc	54d	46ef	31g	7h	2j	38k	2m	2n	4 q	0r

For structural characteristics, means followed by a common letter are not significantly different ($p \leq 0.05$).

[1] Samples not collected.

and organic content of the sediment. In 1978, the highest organic content and metal concentrations were at station 2. In 1981 the highest organic content and metal concentrations had shifted to station 3.

Little Grizzly Creek has been exposed to heavy-metal drainage from tunnels of a nonoperational copper mine for nearly 40 years. Although the effluent has traces of several potentially toxic metals (see Sheehan, 1980), only the levels of copper are high enough to be toxic during most of the year (Table 7.3.4). The input of copper is greatly increased during the snow-melt period and is highly dependent on the amount of snow accumulated during the winter. In 1975, a normal snow-fall year, Cu levels as high as 1700 $\mu g\,l^{-1}$ were recorded entering Little Grizzly Creek during snow-melt. This elevated input was noticeable even in the site 12 levels (320 $\mu g\,l^{-1}$), at greater than 15 km downstream. At the entry site in 1976 (a drought year), only 830 $\mu g\,l^{-1}$ Cu were measured during the high-flow period (Sheehan, 1980). Copper levels throughout the summer period, accompanying minimal flow, were always significantly less than those measured during the high-flow spring season. The contrast between soluble copper levels in a normal year and a drought year in California can be seen in the range of values recorded from water samples taken from Little Grizzly Creek during the summers of 1975 and 1976, respectively (Table 7.3.4).

Other investigations at this creek have shown that Cu^{2+} made up a large portion of the soluble copper pool at all contaminated sites; however, the greatest portion of copper in the water column was adsorbed on suspended particulates (Sheehan, 1980). As reported for Elam's Run, metal concentrations in the sediments of Little Grizzly Creek were more stable than soluble levels, although there was still significant seasonal variation.

7.3.4 COMMUNITY ANALYSIS

7.3.4.1 Density

The densities of insect communities were affected below the point of metal introduction in all streams, although there were some obvious differences in response. In Little Grizzly Creek, macroinvertebrate densities were most severely impacted during the 1975 increases in copper exposure. At the sampling site closest to the outfall, density was found to be only 1 percent of that measured for the reference community (station 7). Even at a distance greater than 15 km from the pollutant source, the density was only 10 per cent of the reference value. In both 1975 and 1976, significant reductions in densities at all contaminated sites were observed, with the exception of site 12 for the summer of 1976 (Table 7.3.4.).

A similar pattern is evident in the density data from Shayler Run, although the uncontaminated riffle in this stream contains only about one third as many macroinvertebrates as are found at the comparable station in Little Grizzly Creek (Tables 7.3.1 and 7.3.4). Mean density was reduced by 81 per cent just below the point of discharge, and although it had increased fourfold at a point 2.6 km downstream, it was still significantly lower than at station 1, upstream from the outfall. The numbers of individuals in both the Little Grizzly Creek and the Shayler Run samples were inversely correlated ($p < 0.01$) with soluble copper concentrations.

Although macroinvertebrate densities appeared to be depressed in Elam's Run below the point of metal introduction, the variablity in the numbers of individuals made it impossible to distinguish significant differences among the samples at varying distances from the outfall. Insect densities were generally higher in Elam's Run than in Shayler Run (Tables 7.3.1 and 7.3.5). It would seem that the situation should be reversed since the Elam's Run fauna were exposed to much higher concentrations of three metals. The difference may be related to the continuous versus intermittent nature of the stress in the two streams. In Shayler Run, the copper dosage was continuous throughout the diel period for each day of the week. In Elam's Run, the composition of the effluent was extremely variable from hour to hour and from day to day and was virtually zero between the hours of 21.30 and 07.30 and on holidays and weekends. There is evidence which suggests that some components of the fauna can avoid peak concentrations of toxic chemicals by burrowing into the stream bed. For example, at 10.45 on 15 September 1978, a slug of 4 mg Cu l^{-1} and 3.8 mg CN^{-} l^{-1} was detected at station 5 in Elam's Run. Concentrations of both chemicals remained in the mg l^{-1} range throughout the remainder of the day. On 16 September, two bottom samples were taken from the riffle at this station and *no* macroinvertebrates were found. However, another set of samples was taken on September 28 and the macroinvertebrate density was 880 m^{-2}, with 75 per cent of the total being late-instar caddis-flies. The only reasonable explanation for this apparent repopulation is that the animals had avoided the chemical slug by burrowing into the substrate. This is probably a manifestation of a more general avoidance response which has evolved in the fauna of small streams to promote survival during periods of drought. Such a strategy was not possible in Shayler Run because of the continuous addition of copper to the stream, or in Little Grizzly Creek, where shallow sediments in combination with the high influx of heavy metals during snow-melt and normal bottom scouring severely stress the macrobenthic community on a regular cyclic basis.

Macroinvertebrate density data from Shayler Run and Little Grizzly Creek showed a strong inverse correlation with Cu levels and the values were relatively easy to measure. However, there was a considerable degree of variability even among replicate samples, and any combination of samples representing a sampling period of several months will certainly have as much variability, if not more. This situation corroborates the assumption that estimates based on a small number of replicate stream samples (two in Shayler Run and three in Little Grizzly Creek) can provide only a crude approximation of the actual density. Biomass of macroinvertebrates in Little Grizzly Creek also fluctuated greatly. Because biomass and

Table 7.3.5 Structural characteristics of macroinvertebrate communities in Elam's Run, June 1977–1978 and 1981

Station	Insects m^{-2} 1978	Insects m^{-2} 1981	% Chironomids/sample 1978	% Chironomids/sample 1981	% Caddis-flies/sample 1978	% Caddis-flies/sample 1981	% Mayflies/sample 1978	% Mayflies/sample 1981
1	1299a	2787b	86c	99f	2h	<1	0j	0k
2	1526a	2953b	77cd	98f	2h	<1	0j	0k
3	1301a	593b	66cde	89f	14h	6	0j	1k
4	2498a	1667b	60 de	22 g	20h	61	0j	14 m
5	2101a	1880b	48 e	39 g	45	38	0.1j	16 m

Means followed by a common letter are not significantly different.

density measures illustrated a similar pattern of change along the gradient, Sheehan (1980) suggested that it is unnecessary to assess both indices, with biomass being the less useful if secondary productivity estimates are not being made.

Due to the inherent variability in macroinvertebrate density data and the lack of ecological information transmitted by this parameter, density estimates by themselves do not provide a satisfactory description of quantitative changes. As pointed out in Chapter 3, their use should be encouraged only as a first approximation of the degree of impact or as part of a set of indices including taxonomic information.

7.3.4.2. Species Richness and Diversity

In both Shayler Run and Little Grizzly Creek species richness (number of species per sample) was more strongly and significantly correlated with copper level than

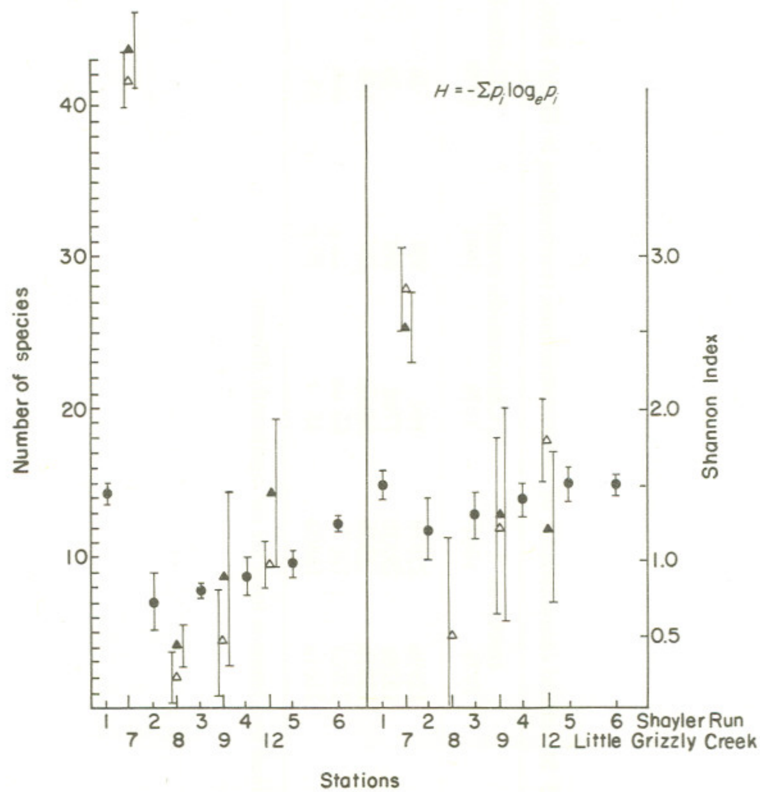

Figure 7.3.2 The numbers of species and Shannon diversity index values as means $\pm$ SDs of macroinvertebrate fauna along copper gradients in Shayler Run, 1972 (●), and in Little Grizzly Creek, 1975 (Δ), 1976 (▲)

was the Shannon diversity index. In fact, the 1976 macroinvertebrate diversity estimates for the Little Grizzly Creek stations were not significantly correlated with Cu levels ($p > 0.05$), while for the same period, the number of species (excluding chironomids) was significantly related to Cu in an inverse fashion ($p < 0.01$).

Although both taxonomic indices displayed reduced diversity with increased copper level (Figure 7.3.2), the number of species was the more sensitive parameter. In Shayler Run, using species richness as an index, stations 1 and 6 (the reference and the treated station having the lowest copper concentration, respectively) were significantly different from each other and from all the other stations; in addition, station 2 had significantly fewer species than station 5. Station 1 was significantly different from all other stations when evaluated with the Shannon index but there were no significant differences among any of the other stations.

Similar patterns emerged from the Little Grizzly Creek data although summer comparisons in 1976 showed less distinctive differences. In 1975, the numbers of species at stations 7 and 12 were significantly different from each other and from the more contaminated sites, while the Shannon index distinguished differences only between the reference and the stressed communities.

The ability of an index to distinguish significant differences within the intermediate range of pollutant concentrations is essential to a more fine-tuned appraisal of community response (Gray, 1976). The fact that the numbers of species provided greater resolution than the Shannon index in comparisons along the Cu gradient, in both Shayler Run and Little Grizzly Creek, is noteworthy because the latter index require considerable effort in calculation. This result also contradicts earlier assumptions that diversity indices based on information theory were superior to more direct indices, such as species richness, in detecting the severity of stress on macroinvertebrate communities (Wilhm and Dorris, 1968).

The Little Grizzly Creek data, from the two summers (Figure 7.3.2), clearly

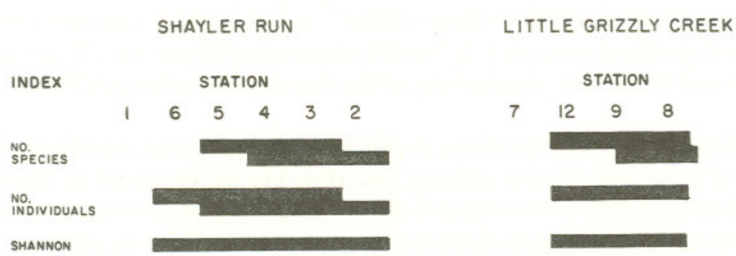

Figure 7.3.3 The effect of downstream location on measures of macroinvertebrate community response as determined by Duncan's New Multiple Range Test. Any two stations not underscored by the same bar are significantly different ($p < 0.05$)

indicate that the response of both taxonomic measures is most distinct under conditions of high copper stress. As taxonomic diversity increased in the stressed communities during the reduced effluent inputs of 1976, changes in the dominance component of the Shannon index masked any indication of the communities' recoveries despite an approximate doubling of the numbers of species found at polluted stations. This problem of a misleading interpretation, due to the influence of the evenness component when the Shannon index is applied within a community in which the total population density is low, evokes perhaps the most strenuous objection to its use (Godfrey, 1978; Gray, 1979). Equitability dramatically increases the importance of rare species in the index value under these conditions.

A comparison of density and diversity indices (Figure 7.3.3) showed that the two less complex measures were more useful than Shannon's index in distinguishing the degree of community response.

7.3.4.3 Community Composition

Although chironomids comprise a very small fraction of the macroinvertebrate riffle communities of unpolluted streams in North America and Europe (Hynes, 1961; Morgan and Egglishaw, 1965; Cummins *et al.*, 1966; Wynes, 1979), in all three heavy-metal contaminated streams chironomid larvae dominated the benthic communities at the most severely polluted riffles. In Shayler Run, chironomids comprised 40–75 per cent of the fauna collected at the most contaminated sites (Table 7.3.1), while in Elam's Run and Little Grizzly Creek this group made up 75–95 per cent of the organisms collected at stations near the outfall (Tables 7.3.4 and 7.3.5). There are some indications that this pattern may be common in heavy-metal contaminated streams. Butcher (1946) found that chironomid larvae were among the first macroinvertebrates to recolonize an English stream grossly polluted with industrial copper waste. Chironomid larvae, specifically *Cricotopus bicinctus*, have been shown to be particularly resistant to electroplating wastes containing high levels of chromium, cyanide and copper (Surber, 1959). In Elam's Run *C. bicinctus* and *C. infuscatus* were the dominant species at stations 1, 2, 3 and 4, comprising 92 per cent, 77 per cent, 77 per cent and 41 per cent, respectively, of the chironomids collected (Winner *et al.*, 1980).

While the numerical importance of chironomids, as a group, increased with the degree of pollution, species richness and diversity as measured by Shannon's index decreased with increasing pollution (Table 7.3.6). A downstream increase in the diversity of chironomid species generally results from an addition, not a substitution, of species (Winner *et al.*, 1980). Although the same number of species was collected from station 4 as from station 5 in Elam's Run, Shannon's index was somewhat higher at station 5 due to a more even distribution of individuals among species.

Table 7.3.6 Changes in the structure of chironomid communities along a heavy metal gradient in Elam's Run, 1977–1978

Station	Total species collected	Shannon's Index (H') Adults	Larvae
1	15	1.10	0.80
2	28	1.10	1.04
3	24	1.07	1.35
4	39	1.64	1.55
5	39	2.67	1.79

Although essentially eliminated from the most grossly polluted riffles, caddis-flies were co-dominant with chironomids at moderately polluted stations in all streams (Tables 7.3.1, 7.3.4 and 7.3.5). Elmid beetles also comprised a significant fraction of the fauna at moderately polluted sites in Little Grizzly Creek during the summer of 1975, following high copper inputs. Mayflies were a significant fraction of the community only at the unpolluted station and at the station farthest downstream from the point of copper introduction in both Shayler Run and Little Grizzly Creek. Prior to the improvement in wastewater treatment in Elam's Run, mayflies were virtually absent, even at the farthest downstream site. Subsequent to the improvement, mayfly nymphs appeared in samples from the two stations farthest downstream (Table 7.3.5). Concurrent with this appearance, there was a reduction in the chironomid fraction of the communities at these two stations. Stoneflies made up 10 per cent of the macroinvertebrate community at station 7 in Little Grizzly Creek but were not found at all in samples from stations 8 and 9. This order was not common in the Ohio streams (Winner *et al.*, 1980).

7.3.4.4 Coefficient of Variation

The proportions of midges, caddis-flies and mayflies in samples collected from riffle communities, therefore, appear to constitute a useful index of the degree of heavy-metal stress to which the community has been subjected. Single samples, however, may produce misleading data. This is especially true for unpolluted habitats where samples may exhibit considerable spatial and temporal variability in the relative abundance of the three taxa. On the other hand, most of the temporal and spatial heterogeneity tends to be submerged in grossly polluted habitats and the taxonomic composition of samples is highly predictable. This situation is exemplified by the coefficients of variation for the percentage of chironomids in samples from the three streams (Figure 7.3.4). The CV is very low for samples from the most grossly polluted stations and increases in value for stations which are progressively less polluted. According to this index, the communities in Shayler Run at station 6 and Little Grizzly Creek at site 12 have

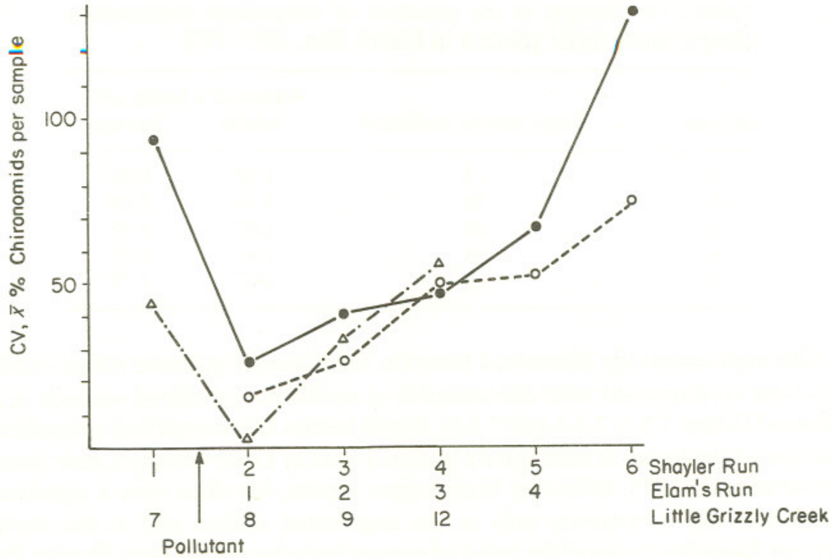

Figure 7.3.4 Changes in the coefficient of variation of mean percentage chironomids in benthic insect samples taken along heavy-metal concentration gradients in Shayler Run (●), Elam's Run (○) and Little Grizzly Creek (Δ)

recovered sufficiently to display variations in dominance similar to those of the assemblages at their respective unpolluted reference stations. However, these increases in natural variability are not dependent on a complete recovery of the communities; interpretations of the comparisons of macroinvertebrate densities and of numbers of species present in these streams do not indicate a corresponding total recovery.

7.3.5 NOTIONS OF ECOSYSTEM STABILITY RELATED TO POLLUTION STRESS

If greater stability can be associated with reduced variability in taxonomic composition, the depauperate macroinvertebrate communities under the most severe heavy-metal stress appear to be the most stable. This constancy in the chironomid-dominated composition of these communities can be interpreted as an indication of continuous, severe exposure to chemical stress swamping the spatial and temporal heterogeneity of other environmental factors. As the severity of the stress decreases, other factors such as substrate, seasonal and life-history influences begin to affect community composition. Haedrich (1975) argued that decreases in diversity would be accompanied by increases in taxonomic similarity from season to season. This relationship was exemplified by both coefficient of community and percentage similarity comparisons for Little Grizzly Creek sites 8, 9 and 12 (Sheehan, 1980).

Reduced variability in other structural parameters, under conditions of severe heavy-metal stress, has also been demonstrated. The density data for Little Grizzly Creek macroinvertebrates, from comparisons performed among samples from different summer months, showed significant differences between sampling dates within the station 7 and the station 12 measurements ($p \leq 0.005$), but no differences of significant magnitude within samples from the more polluted sites 8 and 9 ($p > 0.05$).

Community structure can be characterized, therefore, by fewer samples in polluted habitats than in those which exhibit comparable spatial and temporal heterogeneity but are unpolluted. This aspect of reduced variability is inconsistent with the idea that when comparing similar ecosystems, the one supporting the more diverse and interactive set of species should possess the greater stability.

One of the advantages of the pollutant-gradient approach is that it provides a means of assessing ecosystem vulnerability, a characteristic which is perhaps more relevant to the stability of stressed systems than are the ideas of balance or constancy. In the context of the vulnerability of polluted systems, properties which describe the degree, manner and pace of restoration to a reference-system-like structure are of primary interest and importance. Westman (1978) refers to these as the inertia and resilience of the system. Inertia is the ability of the system to resist change. It can be estimated by determining the concentration of a chemical which reduces species richness by 50 per cent. Sheehan (1980) found this concentration to be in the range of 6–18 $\mu g\, l^{-1}$ Cu during the summer months, reflecting a runoff high of 80–100 $\mu g\, l^{-1}$. This summer range is more than 5 times lower than the estimate from the Shayler Run data. Although this difference may infer some disparities in the buffering capacity of these ecosystems, it most certainly reflects the added severity of stress imposed on the Little Grizzly Creek fauna by high seasonal influxes of heavy-metal effluent. It is obvious that this seasonal pattern of copper exposure has overwhelmed the system's capacity to self-repair. Under current conditions, recovery to the reference structure cannot occur and, therefore, the system can be termed brittle (Westman, 1978) and is said to show a lack of resiliency (Cairns and Dickson, 1977). Although complete recovery of the Little Grizzly Creek system cannot be expected without pollution abatement, there were some short-term indications of recovery following the decreased copper fluxes in the spring of 1976. Comparisons of the composition of macroinvertebrate communities (excluding chironomid species), using Whittaker's coefficient of community (*CC*), showed that there was a substantial increase in similarity between moderately polluted stations and the uncontaminated reference during 1976. The *CC* index value between stations 7 and 12 improved from 0.34 in 1975 to 0.48 in 1976, and the *CC* for stations 7 and 9 increased from 0.21 to 0.33. There was no substantial improvement in similarity between sites 7 and 8 during this period. Samples from the reference station were relatively stable ($CC = 0.84$) between the high flow and drought years, while the moderately polluted sites demonstrated considerable variability in community make-up ($CC = 0.45$). Westman (1978) suggested that

85 per cent similarity would be an adequate measure of restoration. Using this criterion, it is clear that the heavy-metal exposed Little Grizzly Creek ecosystem remains substantially disturbed.

7.3.6 CONCLUSIONS

There are significant advantages in using the gradient approach to analyse pollutant-induced changes in community structure in stream ecosystems. An adequate reference site can normally be identified upstream of the outfall. Structural characteristics can be compared along the concentration gradient and correlations with the level of pollutant can be examined for significance.

There were surprising similarities in macroinvertebrate community response to heavy metals among the three streams examined even though metal effluent composition, concentration and loading were quite different, as was the duration of exposure. This observation is particularly significant in that ecosystems tests, such as those in Shayler Run, may adequately predict long-term changes in structure. However, the differences in taxonomic and density measures for the 1975 and 1976 Little Grizzly Creek samples indicate the need for a sampling period encompassing seasonal and other cyclic influences.

Not all structural indices respond equally in reflecting changes along the pollutant gradient. Species richness data provided resolution superior to density and Shannon's diversity measures, and can be used to estimate the ability of the system to absorb stress. The pattern of response provided by Shannon's index was not always consistent with other measures. Changes in the coefficient of variation of percentage chironomids per sample exhibited a consistent pattern and should provide a useful index of the severity of heavy-metal pollution.

Similarity indices provide an alternative means of evaluating taxonomic response and can be used to assess relative recovery and to estimate stability. The observation that severely stressed systems display significantly reduced taxonomic variability is important in that it shows stability, in this sense, to be inversely related to the diversity of the fauna and the well-being of the system.

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