INADEQUACY OF DIVERSITY INDICES IN DISCERNING METAL MINE DRAINAGE EFFECTS ON A STREAM INVERTEBRATE COMMUNITY

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Abstract. The benthic invertebrates of the Dolores River in southwest Colorado were sampled during three seasons in an area of historic mine drainage. Benthic density exhibited significantly lower values below the mine drainage. However, the number of species did not decrease significantly, indicating that the effect of the mine drainage was primarily non-selective (i.e. favoring no one taxon). This pattern was seasonal with the least effects evident in summer and the greatest effects found in spring. Diversity indices used to assess the effects of this stress on the invertebrate community were Margalef's, Simpson's, Shannon-Weaver's, Brillouin's, and the Biotic Condition Index. None of the indices tested adequately responded to a decreasing trend in the benthic density when number of species remained constant. The indices did respond to a combination of low density and number of species or to the predominant representation by one species. The Biotic Condition Index actually increased at the stations with the lowest density and number of species. Diversity indices appear to be inadequate in assessing a non-selective stress.

1. Introduction

Diversity indices have long been used to assess impacts on stream invertebrate communities. By providing a single value, they allow rapid comparisons between stations without long species lists, density estimates and other parameters that can confuse the non-biologist. The types of indices used fall roughly into two categories (Peet, 1974): Species Richness indices, which generally assume a relationship between the number of species and the sample size, and Heterogeneity or Dominance indices, which consider both the number of species and the distribution of the density among them. The species richness indices, such as those proposed by Margalef (1958) and Menhinick (1964), have been used often but are of limited usefulness due to their dependence on sample size (Hellawell, 1978; Peet, 1974; Wilhm, 1972). Dominance indices such as those proposed by Brillouin (1962), Simpson (1949), and Shannon and Weaver (1949) have been preferred since they are relatively independent of sample size.

Wilhm (1967) and Hellawell (1978) have shown that both types of indices work relatively well when assessing the impacts of organic pollution. However, these indices work on the assumption that the pollution source will reduce the number of intolerant species while favoring the tolerant species (Godfrey, 1978; Winget and Mangum, 1979). Pollution which is non-selective (i.e. reducing the density of most species without favoring any one taxon) will not necessarily result in lower index values. Studies of the effects of sedimentation on stream invertebrates have often shown no decrease in the Shannon Index below the sediment source (Gammon, 1970; Luedtke *et al.*, 1976). The Shannon index also exhibited no decrease below inputs of metal mine drainage in a

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Colorado stream (Peckarsky and Cook, 1981). In addition, many pristine mountain streams exhibit low diversity index values where there is no pollution source (Winget and Mangum, 1979). In this case, the index is measuring the environmental 'stress' inherent in mountain streams rather than pollution.

Diversity indices are derived mathematically and do not consider which particular species inhabit a stream or their relative tolerance to pollution. In response to this problem, researchers have derived biotic indices which evaluate the community structure in terms of the pollution tolerance of individual species (Chutter, 1972). This type of index compares favorably with the mathematical indices and in fact may provide more reliable estimates of community response to pollution (Hilsenhoff, 1977; Jones *et al.*, 1981; Jorgensen, 1978; Murphy, 1978). However, these indices have been developed for and work best in areas of organic pollution where species' tolerances are relatively well documented. Recently, Winget and Mangum (1979) devised a Biotic Condition Index which combines water quality and physical habitat parameters with the biological tolerances to assess stream invertebrate communities in western North American streams.

The present study evaluates the invertebrates in the upper Dolores River, Colorado, U.S.A., in an area of historic metal mine drainage using a variety of diversity indices and the Biotic Condition Index as well as basic density estimates and number of species.

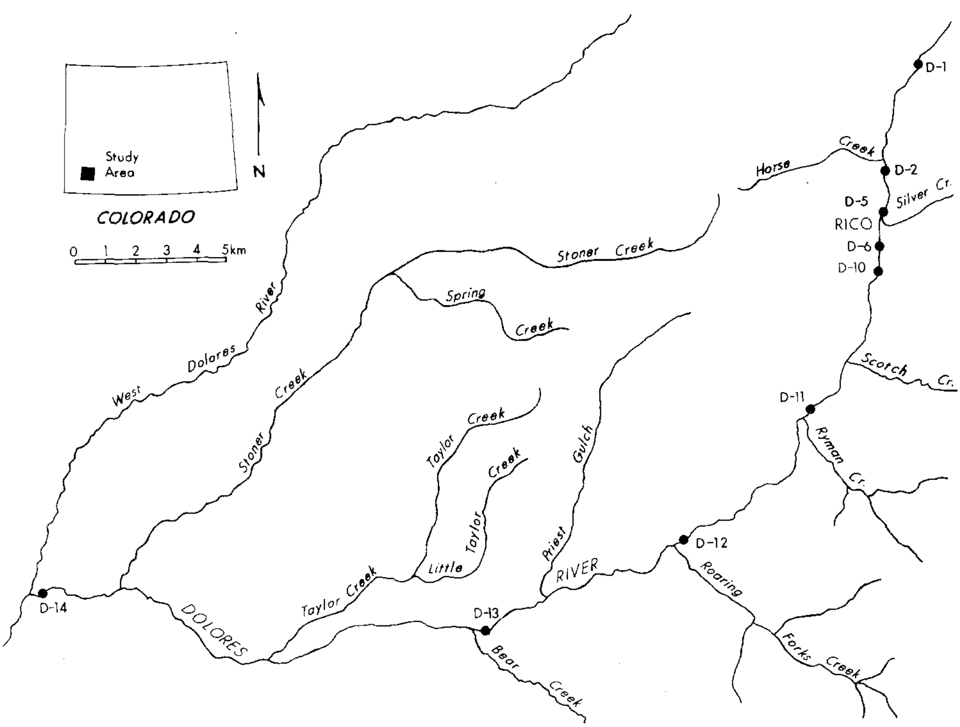

Fig. 1. Sampling station locations on the Dolores River, Colorado, U.S.A.

2. Methods

2.1. Study area

The Dolores River is in the upper Colorado River Basin in southwest Colordo, U.S.A. The study area encompasses a 46 km section of upper Dolores River which flows through an historic metal mining district at the southern end of the Colorado mineral belt (Figure 1). Metal mine drainage enters the stream near Rico, Colorado, from three main sources: (1) settling ponds and seepage between Stations 2 and 5; (2) abandoned tailing ponds on Silver Creek, which enters the Dolores River between Stations 5 and 6 and (3) abandoned mine adits between Stations 6 and 10. Although not acidic, this drainage has been shown to adversely affect the benthic invertebrates of the Dolores River (Anaconda, 1981; Bingham, 1968; Mars, 1979; Wentz, 1974); probably a result of the input of metals such as Zn, Fe, and Cd.

The effects of this drainage on the stream invertebrate community should depend on the discharge in the Dolores River and the dilution it would provide. The Dolores River exhibits a seasonal flow pattern typical of Rocky Mountain streams. During the study, peak flows of approximately 12 $m^3 s^{-1}$ (400 cfs) occurred during the late spring-early summer snowmelt runoff (Anaconda, 1981). Stream flows gradually decreased through summer and fall to winter base flows of approximately 0.8 $m^3 s^{-1}$ (30 cfs). The mine drainage, derived primarily from groundwater sources, did not exhibit this seasonal variation. The largest source of mine drainage, discharge from the settling ponds, had flows ranging from only 0.06 $m^3 s^{-1}$ (2.1 cfs) to 0.07 $m^3 s^{-1}$ (1.1 cfs) during the study (Anaconda, 1981).

The Dolores River is a moderate sized stream, increasing in width from roughly 10 to 17 m through the study area with an average gradient of 1.2%. Riparian vegetation consists primarily of willows (*Salix* spp.) and alders (*Alnus tenuifolia*) at the upper stations with mature cottonwoods (*Populus deltoides*) common along the middle and lower reaches. Rubble-boulder substrate is present at all stations.

2.2. Sampling and analysis

Benthic invertebrates were collected October 1980, and March and August, 1981, from nine stations in the study area. Three samples were taken from each station using a modified Hess sampler enclosing 0.1 m^2 with a net mesh size of 710 μm. Samples were preserved in the field with 90% ethanol and returned to the laboratory where organisms were picked from the debris, identified and counted. Identifications were made to the lowest practical taxonomic level using available keys. Of the 66 taxa collected during the study, 60% were identified to the species level; the rest to the generic level. This analysis yielded density estimates and species counts.

In addition, 5 different diversity indices were calculated (Table I). The species richness index used was Magalef's index. In addition, three dominance indices were calculated: Simpson's index using Pielou's (1969) modification, the Shannon-Weaver Index and Brillouin's index.

TABLE I

Diversity indices used in this study

Margalef:	$S - 1/\ln N$
Modified Simpson:	$1 - \Sigma\, n_i(n_i - 1)/N(N - 1)$
Shannon-Weaver:	$-\Sigma\,(n_i/N)\log_2 n_i/N$
Brillouin:	$(1/N!)\ln N!/(n_1!\, n_2! \ldots n_i!)$

S = number of species, n_i = density of species i, N = total density.

To represent biotic indices, the Biotic Condition Index (Winget and Mangum, 1979) was calculated using the formula $(CTQ_p/CTQ_a)100$. CTQ_p = the predicted community tolerance quotient derived from a key in the paper combining the stream's gradient, substrate, total alkalinity and sulfate. CTQ_a = the actual community tolerance quotient derived by averaging the designated tolerance quotients for the species present (winget and Mangum, 1979). Total alkalinity and sulfate values were obtained from Anaconda (1981).

3. Results and Discussion

The general effect of mine drainage, evident at Stations 5 through 10 (Figure 2), was primarily decreased density without greatly reduced species richness when compared to the upper stations. This decrease in density was statistically significant (ANOVA $p < 0.05$) in the fall and spring seasons. This trend is typical for a non-selective pollutant, which does not favor any one particular taxon (Gammon, 1970). The cumulative effect of mine drainage from all sources was evident further downstream where both density and species richness are low. Upstream-downstream differences were very seasonal. Little difference in either density or species richness was evident in summer, with increasing differences through fall to maximum difference in spring. The key trend of interest here was the decreased density without reduced number of species at the stations just below the mining district. This is the trend that the diversity indices should be able to detect if they are to be useful indicators of the adverse effects of this moderate metal mine drainage.

The species richness index used was Margalef's index. This index exhibited a downstream trend basically identical to the species count (Figure 2). Lowest values were far downstream of mine drainage and this index did not exhibit a significant response to the notable changes in density from Stations 2 to 6 observed in fall and especially spring.

The dominance indices also did not respond to the trend (Figure 2). Values for Simpson's, Shannon's, and Brillouin's indices did not decrease from Stations 2–6 in fall, but did exhibit lower values further downstream. This appeared to be due to the predominance of the heptageniid mayfly, *Rhithrogena hageni.* There was little difference between stations in spring with these indices except for the low values at Station 2 which occurred despite high numbers of species and density. Again, the predominance of one

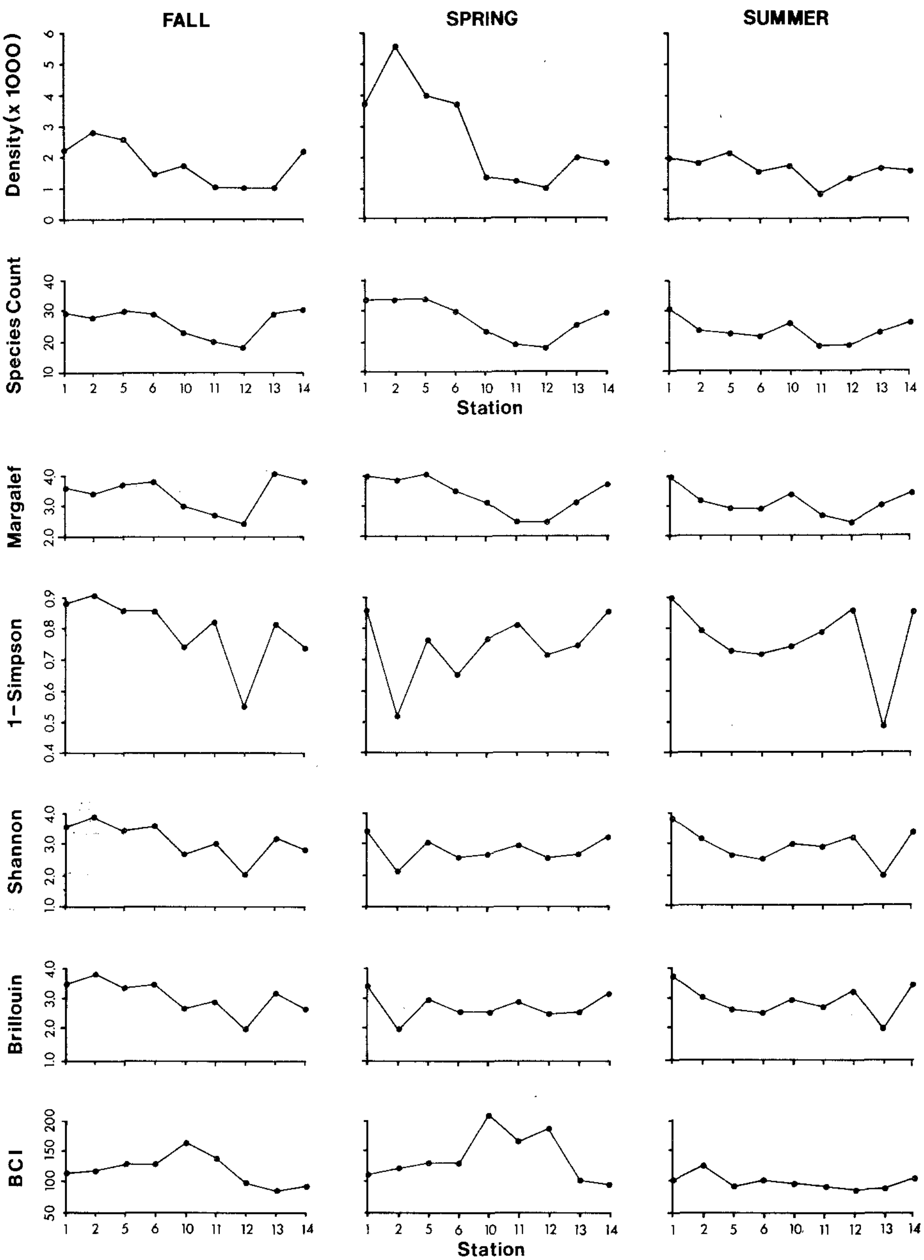

Fig. 2. Downstream trends in invertebrate density, number of species and diversity indices over three seasons at stations on the Dolores River, Colorado, U.S.A.

species, in this case the winter stonefly *Prostoia besametsa*, was reponse for the low values. In neither case would the dominant invertebrate be considered a pollution tolerant form although index values would indicate moderate pollution (Wilhm, 1970). Summer values indicated similarity between stations as did density and number of species. The dip in values at Station 13 again was due to the density of *R. hageni*. Notably, Shannon Index values and Brillouin values were nearly identical over all three seasons at all stations indicating that the theoretical differences between the indices were negligible in this case.

The Biotic Condition Index did not respond as expected (Figure 2). The lowest values were at the stations with greatest density and number of species. But the stations with low density and richness exhibited relatively high values. This is not the response predicted by Winget and Mangum (1979) and points to the problems of assigning tolerance levels to organisms.

4. Conclusions

The benthic invertebrate community of the Dolores River initially exhibited decreased density in response to metal mine drainage without significant changes in number of species. A variety of diversity indices applied to the data could not discern this trend, although the dominance indices did indicate relative changes in the invertebrate community that did not appear to be associated with mine drainage. And yet, these indices do respond in areas of organic pollution (Hellawell, 1978; Wilhm, 1967). It appears that many of the common indices used to assess benthic community response to pollution do not respond well to a non-selective stress, such as moderate metal mine drainage. Seasonal changes in the benthic community, which were more striking in terms of total density than numbers of species, were also less apparent in the indices. This points to the importance of a thorough analysis of the benthic invertebrate community, including species composition and density estimates along with diversity indices, rather than reliance on a single derived index when assessing the impacts of a pollutant.

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References

Anaconda Mineral Company: 1981, *Water Quality Study, Rico Project*, Anaconda Minerals Company, Denver, 156 pp.

Bingham, D. A.: 1968, *Rep. Fed. Aid Fish. Rest. Proj.* F–33–R–3: 31.

Brillouin, L.: 1962, *Science and Information Theory*, Academic Press, New York, 347 pp.

Chutter, F. M.: 1972, *Water Res.* **6**, 19.

Gammon, J. R.: 1970, *The Effect of Inorganic Sediment on Stream Biota*, U.S. Environmental Protection Agency, 18050DWC12/70, 141 pp.

Godfrey, P. J.: 1978, *Hydrobiologia* **57**, 111.

Hellawell, J. M.: 1978, *Biological Surveillance of Rivers: A Biological Monitoring Handbook*, Dorset Press, Dorchester, England, 331 pp.

Hilsenhoff, W. L. 1977, *Use of Anthropods to Evaluate Water Quality of Streams*, Wisconsin Department of Natural Resources, Madison, Tech. Bull. No. 100, 15 pp.

Jones, J. R., Tracy, B. H., Sebaugh, J. L., Hazelwood, D. H., and Smart, W. M.: 1981, *Trans. Amer. Fish. Soc.* **110**, 627.

Jorgensen, G. F.: 1978, *Verh. Internat. Verein. Limnol.* **20**, 1772.

Luedtke, R. J., Brusven, M. A., and Watts, F. J.: 1976, *Melanderia* **23**, 21.

Margalef, R.: 1958, *Gen. Syst.* **3**, 36.

Mars, J. P.: 1979, *Investigation of the Water Quality of the upper Dolores River, May 1978 through August 1978*, Colorado Department of Health, Water Quality Control Division, Denver, 49 pp.

Menhinick, E. F.: 1964, *Ecology* **45**, 859.

Murphy, P. M.: 1978, *Environ. Pollut.* **17**, 227.

Peckarsky, B. L. and Cook, K. Z.: 1981, *Environ. Entomol.* **10**, 864.

Peet, R. K.: 1974, *Ann. Rev. Ecol. Syst.* **5**, 285.

Shannon, C. E. and Weaver, W.: 1949, *The Mathematical Theory of Communication*, Univ. Ill. Press, Urbana, Illinois, 125 pp.

Simpson, E. H.: 1949, *Nature* **163**, 688.

Wentz, D. A.: 1974, *Effect of Mine Drainage on the Quality of Streams in Colorado, 1971–1972*, Colorado Water Conservation Board, Denver, Colo. Wat. Resour. Circ. No. 21, 117 pp.

Wilhm, J. L.: 1967, *J. Wat. Poll. Cont. Fed.* **39**, 1673.

Wilhm, J. L.: 1970, *J. Wat. Poll. Cont. Fed.* **42**, R221.

Wilhm, J. L.: 1972, *Ann. Rev. Entomol.* **17**, 223.

Winget, R. N. and Mangum, G. A.: 1979, *Biotic Condition Index: Integrated Biological, Physical, and Chemical Stream Parameters for Management*, U.S. Department of Agriculture-Forest Service, Intermountain Region, Provo, 51 pp.