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James H. Thorp

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J. Whitfield Gibbons
Savannah River Ecology Laboratory and University of Georgia

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THE STREAM ENVIRONMENT AND MACROINVERTEBRATE COMMUNITIES: CONTRASTING EFFECTS OF MINING IN COLORADO AND THE EASTERN UNITED STATES

JAMES V. WARD,* STEVEN P. CANTON,* and LAWRENCE J. GRAY†
*Department of Zoology and Entomology, Colorado State University, Fort Collins, Colorado, and †Department of Zoology, Arizona State University, Tempe, Arizona

ABSTRACT

Studies were conducted year-round on a Colorado stream that receives drainage from a coal mine to assess the potential response of macroinvertebrate communities to mining activities in the western United States. Species composition, diversity, and standing crop were examined, and results are compared with similar studies conducted in eastern states. Generally low values of sulfate and iron, highly-buffered waters, and low levels of toxic substances characterized the Colorado stream and applied, in general, to many streams in the western energy-development region. Moderate inputs of soluble salts increased abundance of macroinvertebrates without significant changes in community structure or other discernible indications of stressed conditions. This is attributed to the relatively soft waters above the mine and the protection afforded by a buffer strip between the mine spoils and the stream. Increased salinity, sedimentation, and water depletion are major problems, but, with proper environmental considerations, mining in the West may not have the severe impacts on stream biota which characterize many eastern mining regions.

The western United States has vast expanses of coal. Kauffman and Schaefer (1977) indicated that "70 percent of all known, high-grade, low-sulphur, strippable coal deposits are located in this area, as are all of the country's major high-grade oil shale reserves." They estimated that the next 10 to 25 years will be a developmental period for the energy resources of the western United States.

Coal-bearing strata underlie 28% of the state of Colorado (Landis, 1964). Coal deposits are of the Upper Cretaceous and early Tertiary periods, as are the majority of surface mineable coal reserves of the Rocky Mountains and the Northern Great Plains (McWhorter, Skogerboe, and Skogerboe, 1975).

The ecological impacts on aquatic ecosystems of mining and processing activities differ in many ways in the West from those in mining regions of the eastern states. Yet, although there is a plethora of literature documenting the effects of mining on aquatic biota in the eastern United States, there are relatively few data on problems associated with mining and resulting effects on aquatic organisms in the West.

A year-round study was conducted on a Colorado stream that receives drainage from a strip coal mine. The objectives were (1) to compare macroinvertebrate communities and environmental conditions at stream locations differentially affected by mining activities and (2) to contrast the results with those of studies of eastern streams receiving coal-mine drainage.

METHODS AND SITE DESCRIPTION

Trout Creek, in the Upper Colorado River Basin of northwestern Colorado (Fig. 1), receives groundwater and surface runoff from a strip coal mine (Edna Mine). The area of the watershed above and including the mine totals approximately 1.1×10^4 ha; the area of mine spoils (597 ha) is slightly more than 4% of the total watershed area upstream from the mine (McWhorter, Skogerboe, and Skogerboe, 1975). The upper portion of the basin, which lies in Routt National Forest, is well vegetated with aspen and conifers. The middle portion of the watershed is a mixture of forests and farmland. Lower reaches are more xeric, with sagebrush and other shrubs and grasses predominating. Agricultural practices (primarily grazing) variously affect middle and especially lower portions of the basin. At elevations ranging from 2160 to 2100 m, the stream is bordered on the east by the Edna Mine. Trout Creek progressively flows past spoils from mining about 30 years ago, spoils 20 to 30 years old, and an area of current mining activity.

Sampling stations on Trout Creek were located on rubble riffles above, adjacent to, and below the mine spoils at sites from which water chemistry data had been collected in a previous study (McWhorter, Skogerboe, and Skogerboe, 1975). An additional sampling station (TC-1) was established upstream from a mine shaft (see Fig. 1) even though the shaft is horizontal and there was no evidence of seepage entering the stream.

Macroinvertebrates were sampled monthly from July 1975 through June 1976. High water or inclement weather precluded

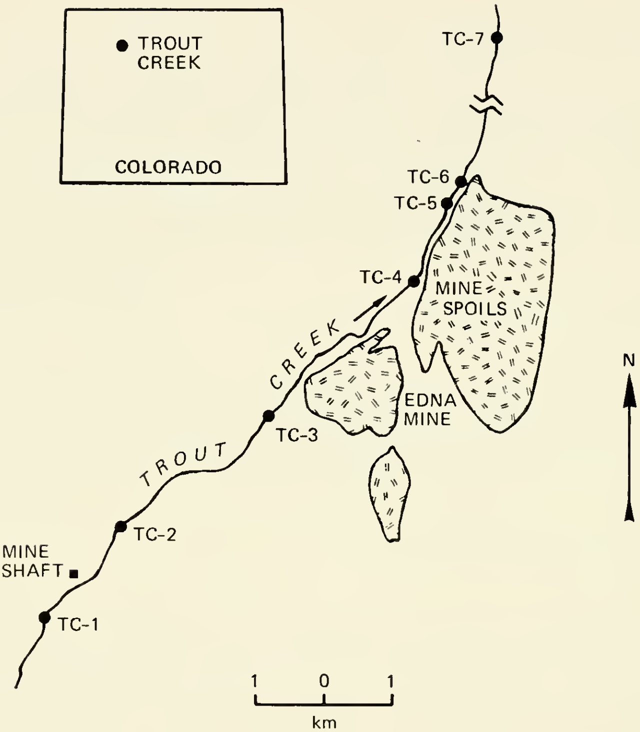

Fig. 1 Map of Trout Creek showing sampling stations and mine spoils. Station TC-7 is about 3 km downstream from TC-6.

sampling at one or two sites on three occasions. A 929-cm^2 Surber sampler with net mesh apertures of ~700 μm was used to take five or more replicate samples at each site. The organisms in each sample were enumerated separately, and numbers were pooled for diversity index calculations. The Shannon—Weaver index with logarithms to base 2 (bits per individual) was used to calculate macroinvertebrate diversity. Analysis of variance (f-distribution) was calculated on log transformations of raw density data to allow use of parametric tests (Elliott, 1973).

RESULTS

A total of 88 macroinvertebrate taxa were identified from the seven sampling stations on Trout Creek. A list of taxa, detailed methods, and site descriptions are given in Canton and Ward (1978).

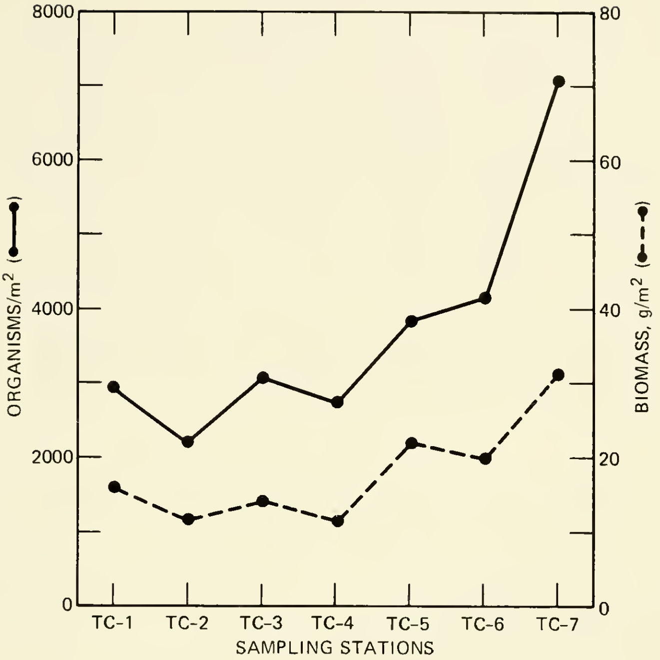

Fig. 2 Downstream changes in macroinvertebrate annual mean density and biomass values on Trout Creek.

Rather than decreasing, as expected, density and biomass exhibited a general increase downstream (Fig. 2). Differences between stations were significant ($P < 0.01$) for total numbers of organisms collected during the study but were not significant on certain collecting dates (June, July, and January). Significant differences ($P < 0.01$) between dates reflect periods of emergence and recruitment, effects of spring runoff, and onset of winter conditions.

Although density increased downstream, similar numbers of taxa occurred at all stations (Fig. 3). Shannon—Weaver index values also indicated no longitudinal pattern. Median values at all stations were between 3.0 and 4.0, the "normal" range defined by Wilhm (1970).

Five orders of aquatic insects (Trichoptera, Diptera, Ephemeroptera, Plecoptera, and Coleoptera) comprised well over 90% of the mean annual density and biomass of macroinvertebrates at all sampling stations. Eight taxa at each station represented 55 to 83% of the density, and most of these taxa were among the most abundant at many stations. The mayfly *Baetis* was among the top eight at all stations. Others abundant at most stations included the

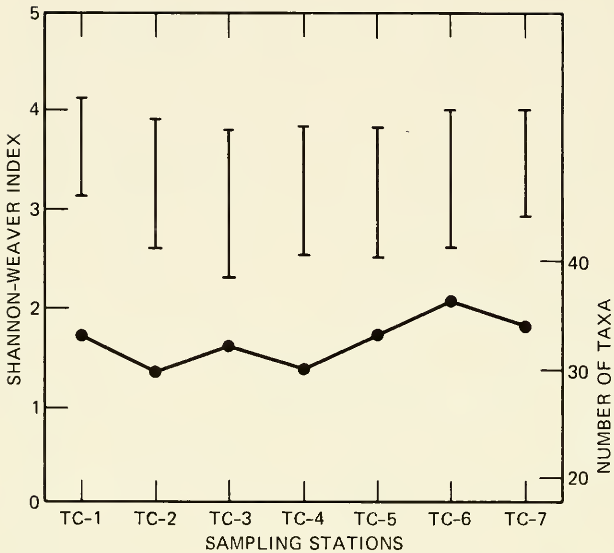

Fig. 3 Annual range of Shannon–Weaver index values (I) and the mean number of macroinvertebrate taxa per collection date (●—●) for sampling stations on Trout Creek.

caddisflies *Agapetus* and *Brachycentrus*, the mayfly *Rhithrogena*, and the elmid beetle *Optioservus*. Caddisflies were the most abundant order by density at all Trout Creek sampling stations (at TC-7 trichopterans and dipterans each comprised 33% of the mean density) and also comprised the largest biomass (at TC-2 trichopterans and ephemeropterans each comprised 28% of the mean biomass). Plecopterans comprised less than 10% of the macroinvertebrate numbers but were much more important gravimetrically. The reverse was true for coleopterans, which were primarily small riffle beetles. The relative importance of the five insect orders was similar at all stations and exhibited no longitudinal trend. Other orders of insects and noninsects were generally rare, and differences in their distribution patterns cannot be reliably relegated to anything except the sampling inadequacies inherent in studies of rocky streams (Hynes, 1970). Even at the generic and specific level, many of the common organisms were widely distributed.

DISCUSSION

Streams of the eastern United States which receive acid mine drainage are characterized by lowered diversity and density and greatly modified macroinvertebrate species composition (Appalachian Regional Commission, 1969; Roback and Richardson, 1969; Dills and Rogers, 1974; Herricks and Cairns, 1974).

Herricks and Cairns (1974) studied macroinvertebrate communities at locations above and below acid mine drainage in Pennsylvania streams (Table 1). Control stations were dominated by ephemeropterans, plecopterans, and odonates; dipterans (mainly chironomids) and *Hydropsyche* were the common organisms at a station receiving acid mine drainage.

In an Alabama stream an isopod *(Lirceus)* comprised 43% of the benthos at unpolluted stations, whereas acid stations were dominated by chironomids, ceratopogonids and megalopterans (Dills and Rogers, 1974). Reduced density and diversity were reported for polluted stations (Table 1).

These eastern studies contrast sharply with our study of Trout Creek. Despite the fact that coal strip mining began about 30 years ago and is presently being conducted along the creek, macroinvertebrate communities adjacent to and below the mine spoils indicated no discernible detrimental effect from mining activities. The number of taxa was similar above, adjacent to, and below the mine. Standing crop increased rather than decreased downstream, and taxonomic composition was remarkably similar throughout the stream section studied. Shannon—Weaver index values gave no indication of a stressed macroinvertebrate community at any of the sites on Trout Creek.

Chemical Conditions and Macroinvertebrates

Wentz (1974), referring to the effects of mine drainage on the water quality of streams in Colorado, indicated that "approximately 450 miles (724 kilometers) of streams in 25 different areas are adversely affected by metal-mine drainage. Coal-mine drainage is not a problem, apparently because of the low sulfur content of Colorado coal."

Table 2 compares the water quality of Trout Creek with criteria for acid mine drainage. In streams in western energy-development areas, acidity is typically undetectable, and pH values generally range from 6.5 to 8.5, with over 85% of all pH values falling between 7.0 and 8.0 (Skogerboe, 1976). Stream waters are well buffered, and major inputs of acid or base would be required to shift the pH one or more units. The chemoautotrophic bacteria, which greatly speed the production of sulfuric acid and ferric hydroxide, are effective only at low pH, whereas bacteria that oxidize ferrous iron at higher pH are relatively unimportant in acid formation (Wentz, 1974).

TABLE 1

MACROINVERTEBRATE DIVERSITY, DENSITY, AND COMPOSITION AT STATIONS ABOVE AND BELOW MINE DRAINAGE ON TROUT CREEK AND IN STREAMS IN THE EASTERN UNITED STATES

Number of taxa*	Diversity index (median $\bar{d}$)	Organisms/m^2	Predominant groups†	Stream system	Reference‡
(33)	3.7	2930	T, E, D, P, C	Trout Creek (TC-1)	This study
(36)	3.5	4124	T, E, D, P, C	Trout Creek (TC-6)	
(37)	3.6	2518	E, P, O	Indian Creek, Penn. (Station 1, control)	Herricks and Cairns (1974)
(6)	2.2	low	T, D	Indian Creek, Penn. (Station 3)	
55	2.9	high	I (E, P, O)§	Cane Creek, Ala. (unpolluted stations)	Dills and Rogers (1974)
24	1.8	low	D, M	Cane Creek, Ala. (polluted stations)	

*Numbers in parentheses are mean numbers of taxa per collection date. Other values are total taxa.

†Abbreviations are T, Trichoptera; E, Ephemeroptera; D, Diptera; C, Coleoptera; P, Plecoptera; O, Odonata; I, Isopoda; and M, Megaloptera.

‡In some cases values were calculated from data of studies cited.

§Odonata, Plecoptera, and Ephemeroptera implied.

TABLE 2

CRITERIA FOR ACID MINE DRAINAGE COMPARED WITH WATER QUALITY OF TROUT CREEK

Water quality characteristic*	Acid mine drainage†	Trout Creek‡	
		TC-3	TC-6
Acidity	>3.0	0.0	0.0
Alkalinity	0	89.2 (41–166)	102.4 (24–205)
pH	<6.0	7.6 (6.5–8.2)	7.6 (6.8–8.3)
Iron	>0.5	0.17 (<0.02–1.10)	0.12 (0.04–0.54)
Sulfate	>250	10.6 (5–20)	80.6 (12–250)
Total hardness	>250	115.9 (43–270)	169.3 (67–418)
Suspended solids	>250	5.3 (0–24)	9.8 (0–62)
Dissolved solids	>500	110.4 (40–176)	223.0 (52–509)

*All values except pH are in milligrams per liter.

†Herricks and Cairns (1974).

‡Single values are annual means; ranges at sites above and below mine spoils are in parentheses.

Much of the stress on macroinvertebrates associated with acid mine drainage in eastern streams can be attributed to low pH, per se, although ferric hydroxide precipitation and heavy metals also have adverse effects. Napier and Hummon (1976) found that mayflies did not occur in streams which had otherwise recovered from acid mine drainage but which maintained low pH values. They concluded that low pH was primarily responsible for the elimination of mayflies.

From the results of a survey of Colorado sites receiving drainage from mines, Wentz (1974) tabulated the percentage of sample sites where concentrations of 15 heavy metals and pH exceeded stream criteria for fish and other aquatic organisms (criteria were drawn from various cited sources). Only one station associated with coal mining, the drain from an adit of an abandoned mine, exceeded these criteria and only for iron and manganese. Wentz found no macroinvertebrates in the drain, the bottom of which had a bright-orange coating.

Concentrations of most heavy metals are low in Trout Creek and in western energy-development areas generally (Skogerboe, 1976). The solubilities of many heavy metals associated with acid production processes in eastern mining areas are limited by hydroxide or carbonate precipitation processes. An examination of the solubility equilibria of metals showed that most are least soluble from pH 7.0 to 8.0, the range within which over 85% of all observed pH values in western energy areas lie (Skogerboe, 1976). The well-buffered nature

TABLE 3

IONIC COMPOSITION (mg/liter), SPECIFIC CONDUCTANCE, AND pH OF EDNA MINE SPOILS

Ion, mg/liter	Edna Mine spoils*
SO_4^{2-}	820
Na^+	41
Mg^{2+}	270
Ca^{2+}	52
Cl^-	15
HCO_3^-	280
K^+	24
Specific conductance, μmhos/cm	3967
pH	8.2

*Saturated paste analyses (McWhorter, Skogerboe, and Skogerboe, 1975).

of most western streams would require major inputs of acid or base to change the solubilities of most metals appreciably. In addition, Cairns (1976) stressed that hard, well-buffered waters reduce the adverse effects to biota of many toxic materials.

There is some evidence that many elements contained in the mine spoils do not reach Trout Creek in large quantities. Sediment from runoff channels in the mine contained higher concentrations of all heavy metals analyzed, except mercury, than did sediment from Trout Creek (Skogerboe, 1976); this "implies that those elements contained in the runoff are largely removed from solution, perhaps by precipitation, before the runoff reaches the creek." The presence of a strip of unmined land between the mine spoils and the creek may considerably reduce the input of potentially toxic substances to the stream.

Soluble salts from the overburden are considered by some to be the most significant potential pollutant of streams from strip mines in the West (McWhorter, Skogerboe, and Skogerboe, 1975). Edna Mine spoils contain large amounts of certain ions (Table 3). Precipitation in more mesic regions is sufficient to leach out soluble salts as they form, but, in the arid and semiarid regions of the western United States, only the top few centimeters of soil are adequately leached. Surface mining exposes fresh surfaces and increases leaching of soluble salts; this results in an approximate doubling of total dissolved solids in Trout Creek (Table 2). Increases in hardness and soluble salts may, within limits, result in increased productivity, especially in western streams, which often originate in mountainous regions of insoluble crystalline rock. Downstream increases in specific conductance in Trout Creek were correlated with increases in the density (r = 0.9) and biomass (r = 0.8) of macroinvertebrates.

Sedimentation and Macroinvertebrates

Coal-mine drainage often results in the production of ferric hydroxide, which is insoluble and forms a yellow—orange precipitate on the stream substrate (Wentz, 1974). This did not occur in Trout Creek, which had relatively low iron concentrations. Inorganic sediment from erosion of surfaces exposed by mining may also cover the substrate. Apart from any toxic effects, sedimentation decreases substrate heterogeneity, fills interstices with silt, may severely reduce algal populations, and directly affects the benthos (Ward, 1976). The presence of a strip of unmined land between the mine spoils and Trout Creek, in combination with the semiarid climate of the region, is apparently largely responsible for the maintenance of a heterogeneous and relatively silt-free substrate.

Climate, Groundwater, and Stream Flow

Climatic differences between western and eastern mining regions undoubtedly modify effects on stream ecosystems. Differences in leaching efficiency between xeric and mesic regions have already been referred to. Herricks and Cairns (1974) stressed the importance of relationships between stream flow and mine drainage. The apparent lack of adverse effects of Edna Mine drainage on Trout Creek macroinvertebrates may result in part from a hydrologic situation in which most substances enter the stream during a relatively short period associated with high stream flow. For example, over 80% of the total salt input from the mine occurs during April, May, and early June.

In summary, effects of mining on stream ecosystems in the western United States are different in many ways from those in eastern states. Acid mine drainage and ferric hydroxide precipitates are rarely associated with coal mines in western energy-development areas, partly because of the low sulfate content of western coal. Alkaline, highly buffered waters prevent the formation of acid conditions, even where sulfate values are high, and reduce the solubility of heavy metals. Water depletion, sedimentation, and increased salinity are the major potential problems associated with western mining.

The Trout Creek study shows that mining in the West need not be as seriously damaging to the stream ecosystem as mining in the eastern states. Although the Trout Creek basin had been mined for about 30 years, macroinvertebrates exhibited no definitive indications of stressed conditions in the stream section studied. Although Edna Mine spoils are extensive, we should emphasize that the headwaters of Trout Creek provide a source of organisms for recolonization of affected areas downstream. The mine spoils adjacent to Trout Creek are 30 to over 100 m from the stream channel. This buffer zone between the mine spoils and the stream apparently reduces sediment input and the quantities of other potentially harmful substances. It is postulated that physical, chemical, and biological processes occurring in the soil of the buffer zone reduce the toxicity of certain substances and retard the movement of potentially harmful substances into the stream channel. This is an area of research which merits further investigation.

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