Effect of Keystone Mine Effluent on Colonization of Stream Benthos[1]

BARBARA L. PECKARSKY[2] AND KIMBERLY Z. COOK[3]

Rocky Mountain Biological Laboratory, Crested Butte, Colorado 81224

ABSTRACT

Environ. Entomol. 10: 864–871 (1981)

Colonization cages were filled with organism-free, standardized, stone substrate and placed in the stream bed above and below the effluent from an inactive lead and zinc mine in western Colorado. A significantly higher proportion of the total individuals colonizing cages from an upstream direction were dead below the effluent compared with the controls above the effluent. The percent "mortality" of the mayfly, *Baetis bicaudatus*, the dominant species in Coal Creek, was also consistently higher below the effluent. Total numbers of live insects colonizing cages were generally higher above the effluent; but results were not as consistent as "mortality" data. A diversity index (H′), species richness, and equitability (J′) of the samplers were not reliable indices of responses to stress by the benthic community. Given cages with contaminated substrate in uncontaminated water, the community recovered remarkably quickly. Colonizing populations were indistinguishable from those of control cages with uncontaminated substrate within 9 days. We conclude that the substrate habitat below the mine effluent is unsuitable for most benthic invertebrates and that the colonization technique that allows determination of percent mortality is more consistent and reliable than conventional measures of diversity for assessing the response of benthic invertebrates to stress. If water quality can be restored to a pristine state, the benthos may rapidly recover from the effects of previous acid mine drainage stress.

Mineral exploration and hard-rock mining have recently experienced a major boom in Gunnison County, Colo. The Keystone Mine, located on Mt. Emmons, approximately 3 km west of Crested Butte, has been intermittently active since July 1880. The property has changed ownership numerous times, as various individuals and companies have attempted to extract lead, zinc, copper, silver, or gold from the mine. From 1951 to 1976 the mine was relatively active; a mill and tailing dams were constructed, and operation primarily included extraction of Pb and Zn. American Metals Climax, Inc. (AMAX) leased some of the land for exploratory purposes in 1974, purchased the mine in early 1977 after discovery of "high grade" molybdenite, and assumed management of the property in 1978.

Since 1966 the water quality in Coal Creek, adjacent to the Keystone Mine, has been steadily deteriorating (Woodling 1977). In 1975 the lower of two tailings pond dams failed, allowing tailings runoff to enter the stream directly. No pollution abatement program was developed until 1977, when AMAX restabilized the tailings pond. However, effluent continues to pour into Coal Creek at a site 37 m below Crested Butte's municipal water intake (Fig. 1).

The most obvious visible effect of the effluent is the deposition and accumulation of "yellow-boy," a heavy-metal precipitate composed principally of $Fe(OH)_3$, on and in the substrate of Coal Creek. The mechanisms by which yellow-boy is formed are described by Koryak et al. (1972). The acute and chronic effects of acid mine drainage (AMD) have been investigated by numerous authors (Herricks and Cairns 1972). Most studies have employed bottom sampling programs to show that AMD reduces benthic species diversity and abundance and increases the populations of pollution-tolerant species.

Godfrey (1978) and Hilsenhoff (1977) have pointed out many inadequacies of the use of diversity indices or indicator species for evaluating water quality, the most important of which is that changes in diversity or low diversity may result from many variables other than a disturbance factor. Also, appropriate statistical comparison of most indices requires knowledge of the number of species in the sampling universe, a value that is generally unknown and, therefore, reduces ecological application of such tests (Peet 1974). Hilsenhoff (1977) developed a biotic index that incorporates both diversity and indicator species concepts as a more effective measure of the quality of the benthic community. This index retains some of the statistical problems of diversity indices, however, and introduces additional problems of qualitative ranking of taxa and cumbersome species identification. Its use is practical only where experts have carefully worked out the taxonomy of the insects, such as in Wisconsin.

Because of the problems stated above, and since not all bottom sampling techniques tend to be methodologically standardized across investigators, we developed a colonization technique that makes possible a simple, short-term analysis of benthic community response to a source of stress. Further, this methodology allows the statistical comparison of responses among migrating invertebrate populations between an experimental and a control sample. To our knowledge, this type of study is unprecedented. The purpose of this study was to quantify the present difference between substrate-habitat suitability above and below the Keystone mine discharge by measuring the relative mortality (calculated as percent dead) of benthos colonizing the substrate. The results represent preliminary data obtained before the

[1] Received for publication 7 July 1980.

[2] Present address: Entomology Department, Cornell University, Ithaca, NY 14853.

[3] Present address: Institute for Environmental Studies, University of Wisconsin, Madison, WI 53706.

0046-225X/81/0608-6408$02.00/0

installation of a water treatment facility that began operation in May 1981. We plan to continue this study to monitor the recovery rate of the benthic stream community as a reflection of the change in suitability of the substrate habitat as water quality improves.

Materials and Methods

Study Area

Three Coal Creek stations were chosen in the vicinity of the Keystone Mine drainage. Station A (the control) was 57 m upstream of the effluent and 20 m above the intake for Crested Butte's municipal water supply. Station A was moved 9.4 m upstream after the first trial in summer 1980, due to disturbance problems described below. Station B was 40 m downstream from the drainage, where the effluent is mixed across the channel width of the stream. Station C was 11.5 m below the Crested Butte water intake, and 25.5 m above the effluent. Widths of stations A-1979, A-1980, B, and C were 8.0, 6.4, 8.2, and 10.6 m, respectively (Fig. 1). All stations were natural riffles, with similar temperature, current velocity, and depth regimes. The water temperatures ranged from 7 to 17° C, and were never more than 1° C different between stations. Occasional differences in current velocity and depth occurred (Fig. 2A and B, respectively) and will be explained later.

Experiments

(1) Three to five stainless-steel screen cages (40 by 30 by 10 cm, mesh 0.81 mm) were placed at stations A (control) and B (experimental) with a 1-cm-mesh baffle end facing upstream (Peckarsky 1979a). The number of cages at stations A and B was held constant within trials. Cage lids were flush with the surface of the stream substrate. Sites of cage placement within each station were selected to minimize current, depth, temperature, and substrate differences among the cage replicates. Organism-free Coal Creek substrate was placed in each cage; the rocks were standardized for size heterogeneity among cages by placing the same size distribution of substrate in each cage. One 4-day colonization period (20 to 24 July 1979) and five 3-day colonization periods (24 to 27 July 1979, 8 to 11, 14 to 17, 17 to 20, 20 to 23 July 1980) were allowed. These periods were shown to be sufficient for the purpose of collecting comparative data (Peckarsky 1979b). After each colonization period, cages were removed from the stream; colonizers were immediately sorted from the cages on site, and living were stored separately from dead in 70% ETOH upon cage retrieval. (2) Eight cages were buried at station C (Fig. 1) for three 3-day periods (25 to 28, 28 to 31 July, and 31 July to 3 August 1980). Half of the cages contained uncontaminated substrate from the station C location; the others contained substrate imported from below the effluent, contaminated with yellowboy precipitate. Size distributions of cage substrates were standardized, and the same substrates were used for all three trials (new contaminated substrate was not introduced for each trial).

The purpose of experiment 1 was to quantify differences in the fauna above and below an extreme habitat stress. Experiment 2 was designed to test the recovery of the benthic community given uncontaminated water flowing through contaminated substrate. Current velocity was measured at each cage with a Marsh-McBirney model 201 current meter. The depth from the top of each cage to the surface of the water, and the temperature at each station were also recorded. A Mann-Whitney U test was

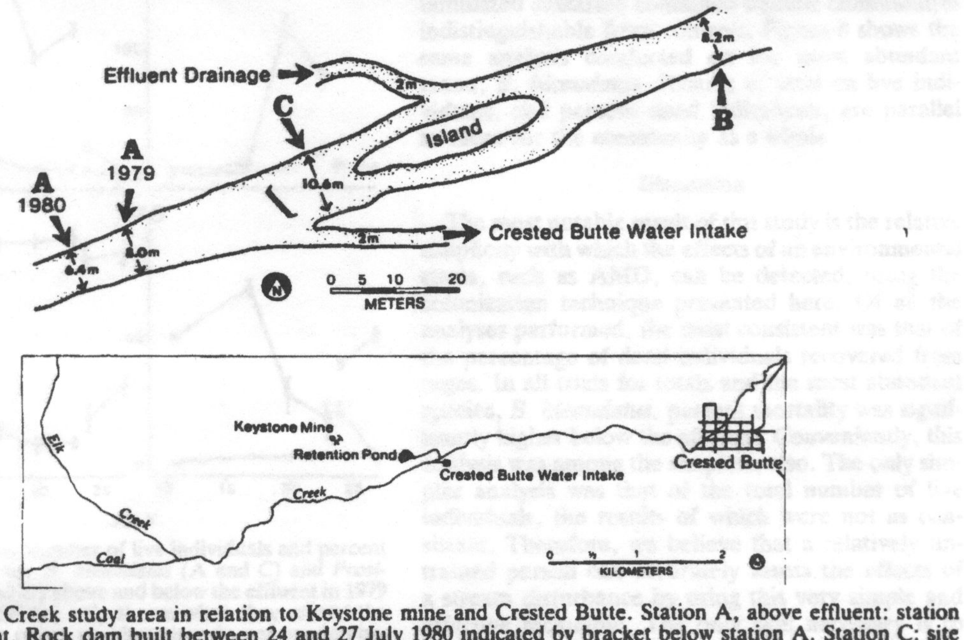

FIG. 1.—Coal Creek study area in relation to Keystone mine and Crested Butte. Station A, above effluent: station B, below effluent. Rock dam built between 24 and 27 July 1980 indicated by bracket below station A. Station C: site of experiment 2. Direction of current is from left to right. Detail not to scale.

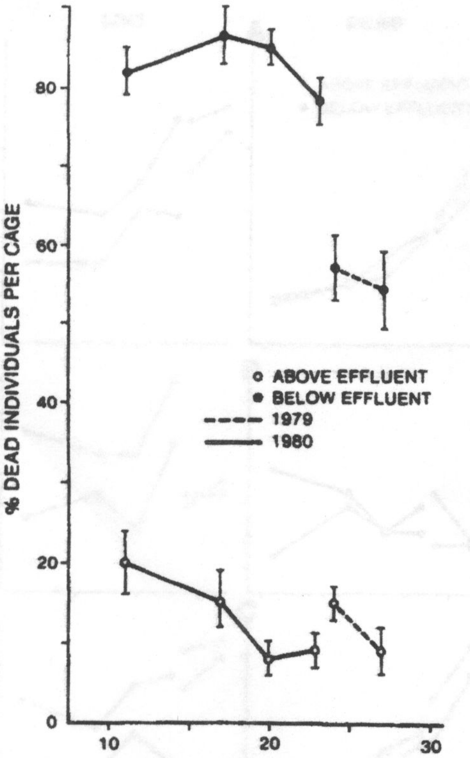

FIG. 4.—Percent total dead individuals per cage above and below the effluent in 1979 and 1980 trials ± 1 SE.

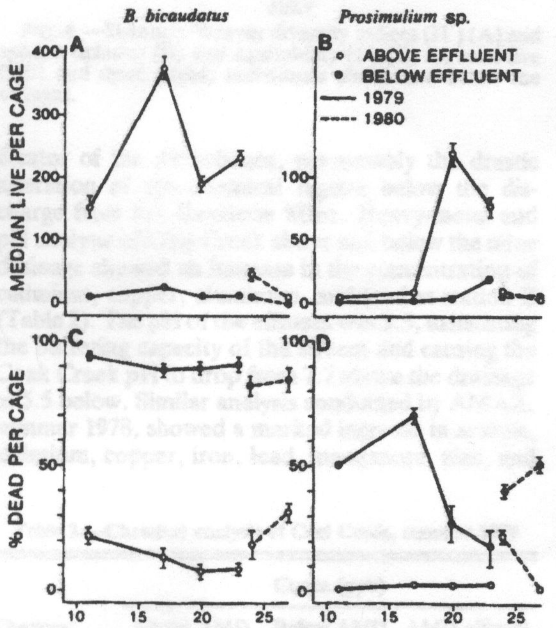

FIG. 5.—Median number of live individuals and percent dead individuals for *B. bicaudatus* (A and C) and *Prosimulium* sp. (B and D) above and below the effluent in 1979 and 1980 trials. SE are only shown when they exceed the magnitude of the point, or when they do not overlap between open and closed circles for each date.

values for dead individuals above and below the effluent, although these values generally increased later in the season. Statistical comparisons between H′ values cannot be made, as stated earlier, due to the nature of their distributions. Therefore, the components of the Index were analyzed separately. As shown in Fig. 6B, species richness (S = the number of species) was consistently higher for live individuals in control cages than for those below the effluent in 1980. These differences were not significant, however. Species richness was generally, though not consistently, higher for dead individuals below the effluent.

Calculation of equitability: J′ = H′ observed/H′ maximum. (Peet 1974), allows examination of the evenness of the distributions of colonizing insects, and facilitates interpretation of the H′ results. Figure 6C shows that below the effluent, a more even distribution of live individuals appeared. The high H′ values are an artifact of the high evenness combined with low species richness, producing an apparently more diverse community of insects in cages below the effluent. Dead insects showed similar equitability measures and species richness above and below the effluent, which explains the similar relative H′ values.

An analysis of the number of live individuals colonizing cages with contaminated vs. uncontaminated substrates is shown in Fig. 7A. There are no significant differences between treatments on any date. The percentage of dead individuals, however, shows an interesting trend from significantly higher mortality in cages with contaminated substrate on the first trial ($P < 0.005$), to a reduction in that difference to not significant on the second trial, to a total elimination of the difference on the third trial. In other words, after 9 days, cages with previously contaminated substrate contained benthic communities indistinguishable from controls. Figure 8 shows the same analysis conducted on the most abundant taxon, *B. bicaudatus*. Results of tests on live individuals, and percent dead individuals, are parallel to those for the community as a whole.

Discussion

The most notable result of this study is the relative simplicity with which the effects of an environmental stress, such as AMD, can be detected, using the colonization technique presented here. Of all the analyses performed, the most consistent was that of the percentage of dead individuals recovered from cages. In all trials for totals and the most abundant species, *B. bicaudatus*, percent mortality was significantly higher below the effluent. Conveniently, this analysis was among the simplest, also. The only simpler analysis was that of the total number of live individuals, the results of which were not as consistent. Therefore, we believe that a relatively untrained person can accurately assess the effects of a stream disturbance by using this very simple and effective technique. The only skill necessary is to sort live from dead individuals in colonization cages.

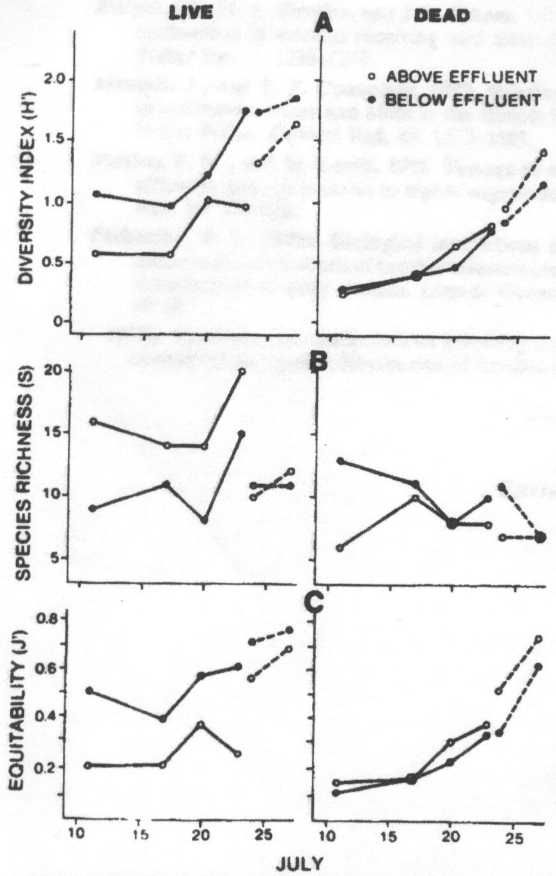

FIG. 6.—Shannon-Weaver diversity indices (H') (A) and species richness (B) and equitability (J') (C) for total live (left) and dead (right) individuals above and below the effluent.

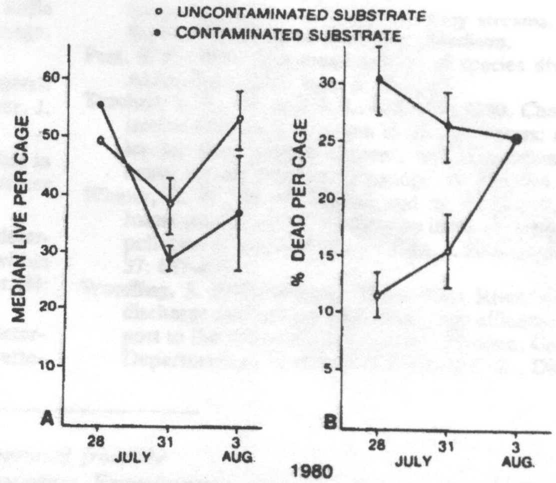

FIG. 7.—Median total live individuals (A) and percent dead (B) per cage with uncontaminated and contaminated substrates ± 1 SE (where there is no overlap).

dicator of the disturbance, presumably the drastic alteration of the chemical regime below the discharge from the Keystone Mine. Heavy-metal and pH analysis of Coal Creek above and below the mine drainage showed an increase in the concentration of cadmium, copper, aluminum, and lead at station B (Table 2). The pH of the effluent was 3.5, exhausting the buffering capacity of the stream and causing the Coak Creek pH to drop from 7.7 above the drainage to 5.5 below. Similar analysis conducted by AMAX, summer 1978, showed a marked increase in arsenic, cadmium, copper, iron, lead, manganese, zinc, and fluoride below the AMD. The pH dropped from 6.3 above to 3.5 below the effluent (AMAX 1978).

Given similar substrate, current velocity, depth, and temperature regimes, we would expect similar survivorship of colonizers at both stations. We attribute the differences in mortality primarily to the chemical alterations in stream habitat below the effluent, and partially to the physical alteration above the effluent on the second trial date in 1979. Interestingly, given uncontaminated water flowing through contaminated substrate, as in experiment 2, the recovery of the benthos was extremely rapid (9 days). This may indicate that water treatment restoring water quality to a pristine state will be effective in renewing the populations of insects downstream of the effluent. Other factors, such as repeated handling of the substrate, might have facilitated the recovery.

The analysis of particular groups as tolerant or intolerant of AMD allows some interesting compar-

Table 2.—Chemical analysis of Coal Creek, summer 1979

	Concn (ppb)		
Chemical	Above AMD	Below AMD	AMD effluent
Cadmium	2	34	140
Copper	26	4,300	2,000
Aluminum	160	184	150,000
Lead	<6	60	200
pH	7.71	5.54	3.25

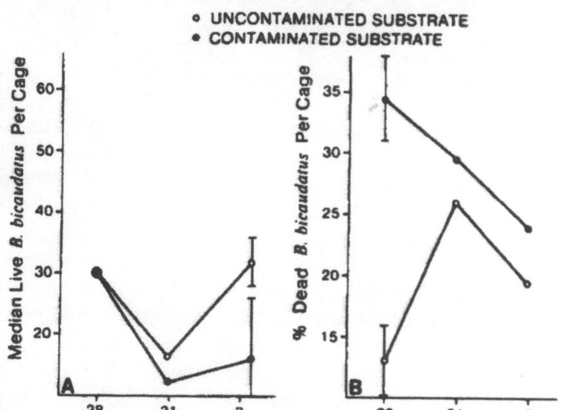

FIG. 8.—Median live (A) and percent dead (B) *B. bicaudatus* per cage with uncontaminated and contaminated substrates ± 1 SE (where there is no overlap).

Koryak, M., M. A. Shapiro, and J. L. Sykora. 1972. Riffle zoobenthos in streams receiving acid mine drainage. Water Res. 6: 1239–1247.

Manthis, J., and T. F. Cummings. 1973. Selected metals in sediments, water and biota in the Illinois River. J. Water Pollut. Control Fed. 45: 1573–1583.

Patrick, F. M., and M. Loutit. 1976. Passage of metals in effluents through bacteria to higher organisms. Water Res. 10: 333–335.

Peckarsky, B. L. 1979a. Biological interactions as determinants of distributions of benthic invertebrates within the substrate of stony streams. Limnol. Oceanogr. 24: 59–68.

1979b. Experimental manipulations involving the determinants of the spatial distribution of benthic invertebrates within the substrate of stony streams. Ph.D. thesis, University of Wisconsin, Madison.

Peet, R.K. 1974. The measurement of species diversity. Annu. Rev. Ecol. Syst. 5: 285–307.

Tuschall, J. R., Jr., and P. L. Brezonik. 1980. Characterization of organic nitrogen in natural waters: its molecular size, protein content, and interactions with heavy metals. Limnol. Oceanogr. 25: 495–504.

Winner, R. W., M. W. Boesel, and M. P. Farrell. 1980. Insect community structure as an index of heavy-metal pollution in lotic ecosystems. Can. J. Fish. Aquat. Sci. 37: 647–655.

Woodling, J. 1977. Pollution of the Slate River via mine discharge and sewage treatment plant effluents. A report to the Water Quality Control Division, Colorado Department of Health, F. J. Rozich, P. E., Director.

Reprinted from the
ENVIRONMENTAL ENTOMOLOGY