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EFFECTS OF STRIP MINING ON SMALL-STREAM FISHES IN EAST-CENTRAL KENTUCKY[1]

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Prior to World War II, most of the coal mined in Kentucky was secured from shaft mines which could be (although many were not) sealed following the cessation of operations. Following 1940, with the advent of higher wages for miners and increases in severance taxes, shaft mining became much reduced and strip mining increased. In Kentucky, nearly 70 percent of the mine operators conduct stripping exposure of very poor-grade bituminous coal deposits (grades 4 to 9). In exposing the coal deposits, the mining machines cut an L-shaped notch in a mountain, thus producing a highwall 50 to 60 feet tall and massive spoil banks below it. Often, the miners auger into the veins which cannot be mined otherwise.

In 1964, there were over 580 square miles of U. S. lands that were deleteriously affected by acid mine pollution (Kinney, 1964), and from most of this devastated area little data on physical and biological effects are available. One of the main problems resulting from this type of mining operation is the exposure of substances responsible for the formation of acid-mine water, mainly three forms of iron sulfide: pyrites, marcasites, and black amorphous pyrite (Parsons, 1957). These substances react with water and air to produce ferrous sulfate ($FeSO_4$) and hydrosulfuric acid (H_2SO_4) which, during rains, flush into streams, sometimes reducing the pH to readings as low as 2.3 (Harrison, 1958). When an acid produces a pH of

[1] This study is being conducted in cooperation with the Northeastern Forest Experiment Station, Forest Service, U. S. Department of Agriculture, Berea, Kentucky.

4.0 or less, it is toxic to fishes, regardless of the acid or acid-salt combination (Ellis, 1937).

Although some workers (Jewell, 1922; Jewell and Brown, 1924; and others) have reported prolonged survival of various fishes at pH values below 5, a host of others (Frost and Streeter, 1924; Carpenter and Herndon, 1933; Trax, 1933; Lackey, 1939; Tarzwell and Gaufin, 1953; Turner, 1958; Musser, 1963; Collier et al., 1964; Sheridan, 1966; and many others) have reported the extermination of fishes when the pH remained below 4.0 for any length of time.

Some studies (Riley, 1960; Ruhr, 1952; Maupin, Wells, and Leist, 1954) have demonstrated the feasibility of reclaiming strip-mined areas, but of course this does nothing for local endemics and endangered species which might have been exterminated during the mining operation. Moreover, Harrison (op. cit.) reported acid drainage to drastically affect the benthos. A few highly resistant forms persist and there develops a specialized biota.

While acid drainage from stripped areas has received considerable attention, the importance of stream siltation has been neglected. Bell (1956) indicated that erosion of spoil banks carried calcium, magnesium, sodium phosphate, and other ions into surrounding waters, but he did not measure siltation. It has been demonstrated (Shaw and Magna, 1943) that silt originating from mine tailings smothers incubating salmon and trout eggs and eliminates benthic food organisms (Henderson, 1949). Our data (cited by Stevens, 1969) indicates that such siltation may be increased by 15 to 30 times that present in non-affected streams in east-central Kentucky, and that such siltation decreases benthic organisms, particularly Ephemeroptera and decapod crustaceans, by 90 percent in 1 year.

Extensive areas of eastern and western Kentucky are afflicted with strip-mining operations. In general, the unaffected streams of Kentucky are of excellent quality but are extremely susceptible to the effects of acid-water pollution because of the low bicarbonate content of the water. This is particularly true in the Lee formation, which is very low in bicarbonates (Shoup, 1943). For example, Branson and Batch (1970) reported bicarbonate values of 9.7 to 25.0 ppm for order I, II, and III

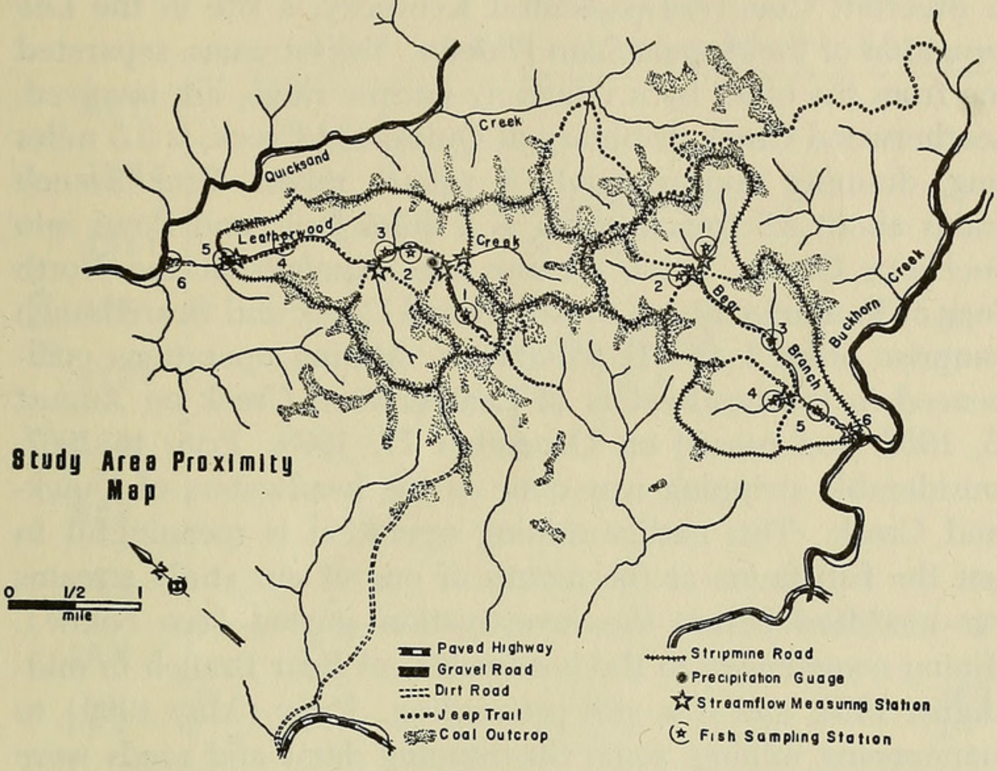

FIG. 1. Proximity map of the Study Area.

streams in east-central Kentucky. In streams tributary to the Big Sandy Drainage, Biesecker and George (op. cit.) reported an absence of bicarbonates, but indicated that in northern Kentucky free acidity from mining operations is not as severe as in other parts of the state. They suggest that among the various solutes in these streams sulfates are the best index to acid drainage from mines.

The purpose of the study was to observe the effects of siltation from strip mining on the fish populations of two streams. Such observations were feasible since acid drainage from the mines was very limited. The present report covers the first 17 months, May 1967 to September 1969, of a 5 year project.

The authors are greatly indebted to Mr. Willie Curtis and his assistants of the U. S. Forest Service for their assistance in conducting weekly chemical analyses and stream-flow determinations. Mr. Steve Stacy, graduate student, Eastern Kentucky University, conducted the food study on *Semotilus atromaculatus*.

Materials and Methods: The study area (Fig. 1) is located in Breathitt County, east-central Kentucky, a site in the Lee formation of the Appalachian Plateau. Two streams, separated one from the other by a relatively narrow ridge, are involved. Leatherwood Creek, tributary of Quicksand Creek, is 3.5 miles long, draining approximately 4 square miles. Bear Branch drains about 2.5 square miles, is 2 miles long, and flows into Buckhorn Creek. These streams are segments of the North Fork of Kentucky River. Leatherwood Creek and Bear Branch comprise order I and II tributaries. Mining operations commenced in the headwaters of Leatherwood Creek on August 15, 1967, and ceased on December 17, 1968. Prior to 1967, considerable stripping was done in the headwaters of Quicksand Creek. This earlier mining operation is meaningful in that the fish fauna at the mouth of one of our study streams was modified before the investigation started (see below). Mining commenced in the headwaters of Bear Branch in mid-August 1969, and it is still proceeding. Prior (May 1969) to commencing mining, some silt-trapping dams and roads were constructed on the latter stream, and the influence of this activity was reflected in an increased turbidity (Fig. 3).

For the purpose of determining silt loads and water-level fluctuations, concrete wiers with spillways, and recording devices (housed in permanent, locked chambers) were installed at critical points in each stream (Fig. 1). Weekly water samples for chemical analyses were also taken at these sites. Each water sample was analyzed for: specific conductivity, suspended sediment, turbidity, Fe^{++}, total Fe, SO_4, Al, Mg, Mn, Ca, Zn, total alkalinity, bicarbonates, and pH. For the reasons given by Wang and Brabec (1969), turbidity was measured in and is presented here as Jackson units.

Six fish-sampling stations, selected to include as many habitats as possible, were established in each creek (Fig. 1). These were periodically visited in order to determine how the process of strip mining affected the benthos (subject of another paper) and fishes (Fig. 4). Fishes were primarily collected by intensive seining for 30 minutes at each site.

Finally, a food study was conducted on *Semotilus atromaculatus*, in order to determine if its diet was correlated with an observed resistance to mine pollution.

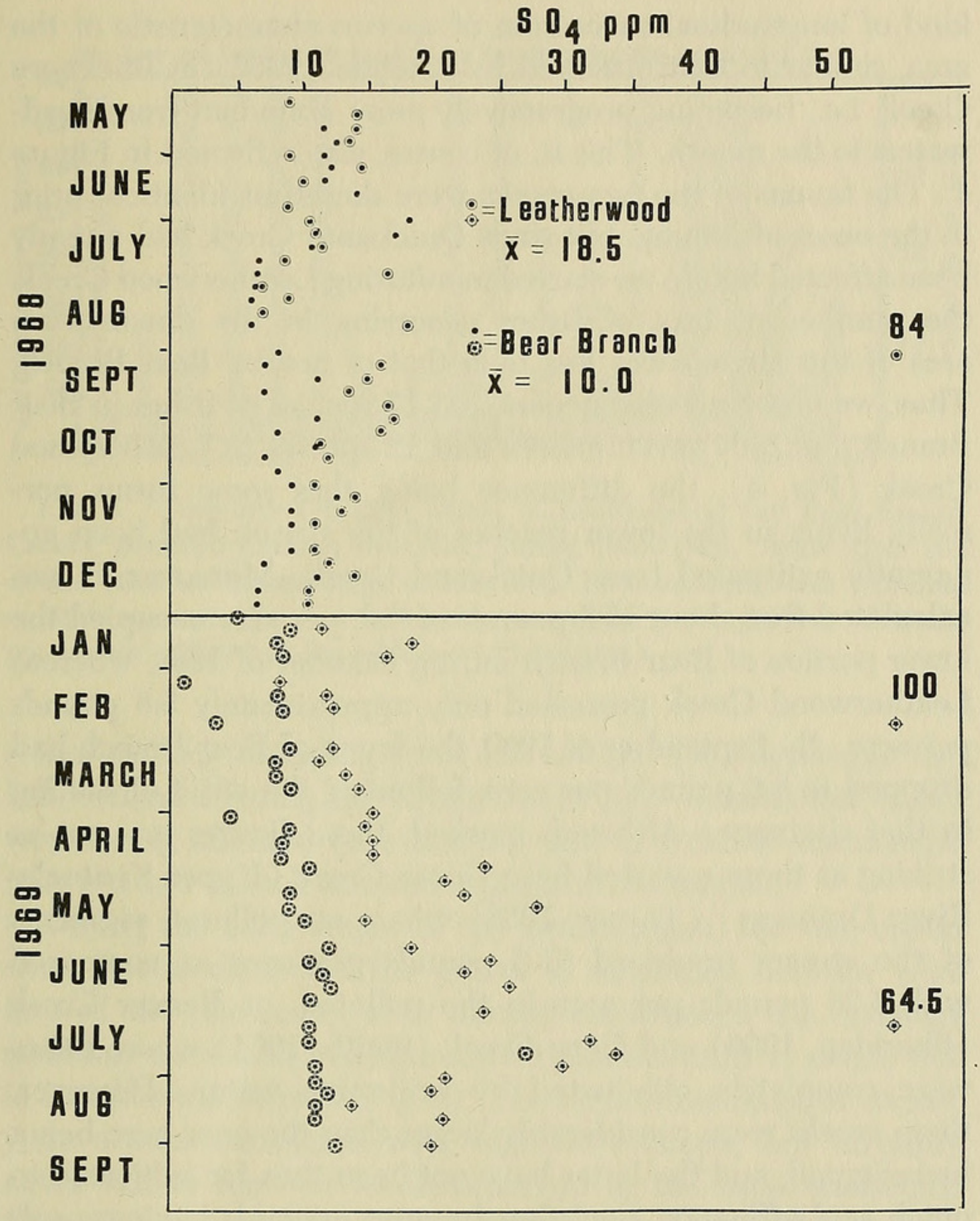

FIG. 2. Sulfate concentration in Leatherwood and Bear Branch Creeks, Breathitt County, Kentucky during 1968–1969.

The main objectives of the study were: (1) to determine the fishes present in a polluted versus an unpolluted stream (Leatherwood versus Bear Branch up to the time of mining in the latter); (2) to monitor the effects of strip mining on the fishes and bottom fauna; (3) to monitor recovery, if any.

Results: In general, our survey work demonstrated that the fishes of Leatherwood and Bear Branch creeks exhibited the kind of longitudinal succession of species characteristic of the area, similar to that observed by Kuehne (1962) in Buckhorn Creek, i.e., becoming progressively more abundant from headwaters to the mouth. This is, of course, also reflected in Figure 4. The faunas of the two creeks were doubtless identical prior to the onset of mining, but since Quicksand Creek had already been affected before we started monitoring Leatherwood Creek, the number of taxa of fishes occurring in the downstream area of this stream was less than that of nearby Bear Branch. Thus, we observed nine genera and 17 species of fishes in Bear Branch, but only seven genera and 12 species in Leatherwood Creek (Fig. 4), the difference being that some forms normally living in the lower reaches of the stream had been apparently extirpated from Quicksand Creek. Moreover, it was calculated that about 15.4 pounds of fish per acre occupied the lower portion of Bear Branch during October of 1968, whereas Leatherwood Creek possessed only approximately 5.8 pounds per acre. By September of 1969, the fauna of Bear Branch had dropped to 8.6 pounds per acre, following the onset of mining in that drainage. Although marked, these figures are not as striking as those reported from Goose Creek (Upper Kentucky River Drainage) (Turner, 1958) where nonpolluted segments of the stream produced 61.3 pounds per acre as compared with 5.38 pounds per acre in the polluted, or Beaver Creek (Sheridan, 1966) and Cane Creek (Smith, 1964) where fishes were completely eliminated by acid-mine water. However, these creeks were considerably larger than the ones here being investigated, and the latter have not been thus far subjected to much acid effluence, doubtless because minerals having a sulfur content are limited in the overburden.

A comparison (Fig. 2) of the sulfate profiles for the two streams shows the evidence of strip-mine pollution in Leatherwood Creek and the normal levels which were characteristic of Bear Branch prior to the onset of mining. The normal level of sulfates in waters of the region never rise above 100 ppm even during heavy rain washdown while contaminated waters may have concentrations of up to 832 ppm (Biesecker and George, 1966). During our period of study, pH values in the two streams varied between 5.6 and 7.8, with only an occa-

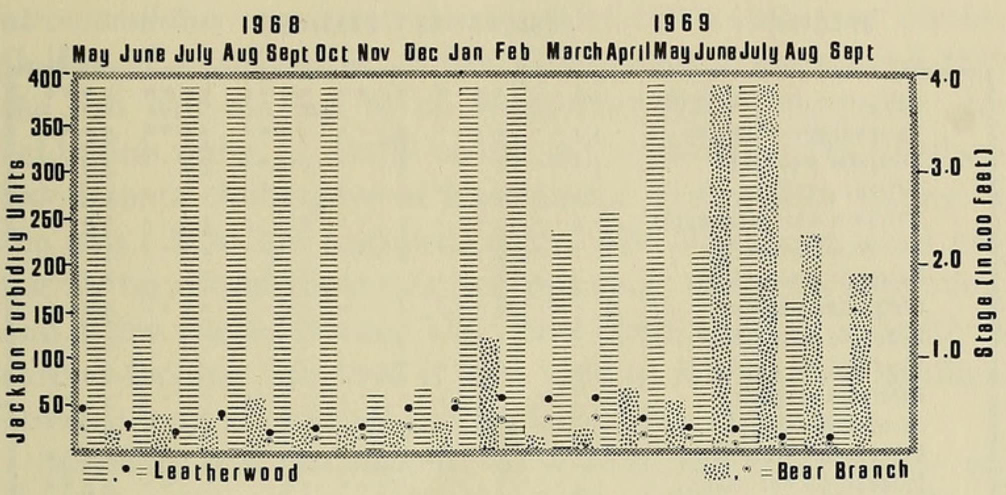

FIG. 3. Turbidity (Jackson units) in Leatherwood and Bear Branch Creeks, Breathitt County, Kentucky, during 1968–1969. Black spots and circled stars are stream stage distribution. Both measurements represent monthly averages for 4 or 5 samples, according to the number of weeks per month. (See text for additional discussion.)

sional reading dropping to as low as 4.0. No observable fish kills occurred during the advent of low pH. Nonetheless, fishes were being affected (see below), and in order to understand why we had to look at some aspects of the habitat.

During the early stages of the investigation, the two creeks were crystal clear and the gravel to sandstone bottoms were free of silt. However, after mining commenced the turbidity suddenly increased from around 30 Jackson units to nearly 400 in Leatherwood Creek (Fig. 3). The highest readings, of course, were always correlated with highwater stages, but turbidity never fell to the low levels observed in the then unaffected Bear Branch until June 1969 when some silt-catching dams and roads were constructed across the stream in an attempt to prevent down-stream siltation. During the highest turbidity in Leatherwood Creek, silt loads were measured at over 3,000 ppm. The bottom of the stream in some places was covered to a depth of 2 to 6 inches with clay, and nowhere was unaffected. The gravel and rocks were cemented to the bottom. The authors found salamanders (*Eurycea bislineata* and *Desmognathus*) entombed beneath rocks, and the bottom fauna and flora was virtually eliminated (mayflies and crayfish, for example, were reduced by 90%).

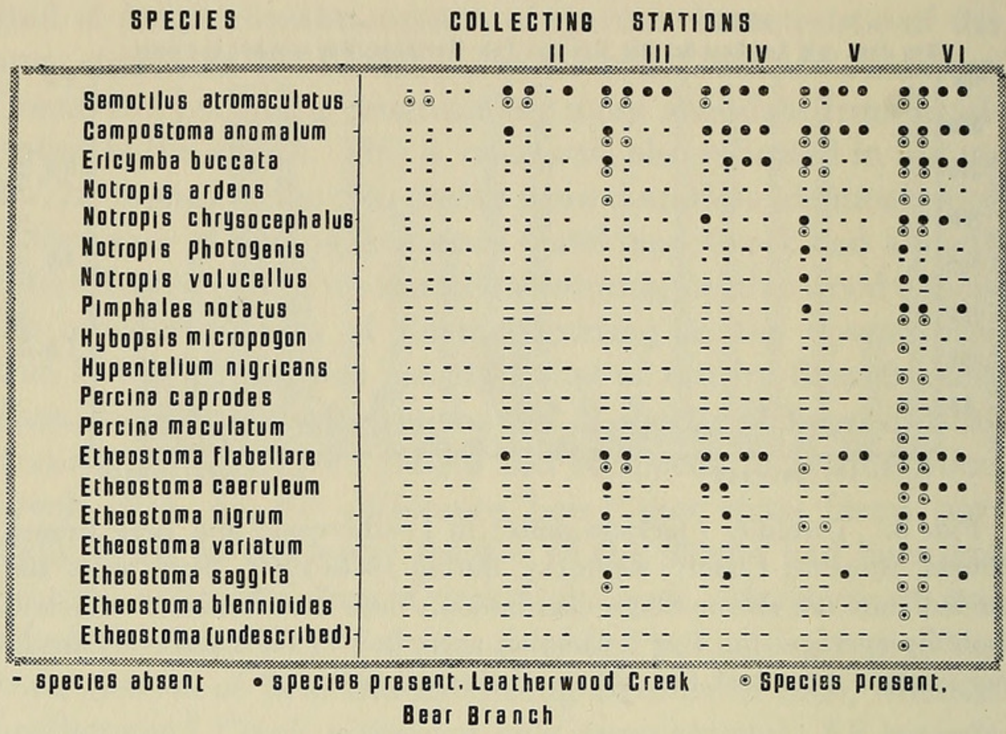

FIG. 4. Comparison of fish faunas at six stations in Leatherwood and Bear Branch Creeks, Breathitt County, Kentucky, affected by strip mining. Upper row of symbols, for each species, Leatherwood samples; lower row, Bear Branch. Visitation dates for Leatherwood Creek: 1 June 1968, 26 October 1968, 7 May 1969 and 1 October 1969; dates for Bear Branch: 21 March 1969 and 12 December 1969. (See text for additional discussion.)

Analyzing the results presented in Figure 4, two things become obvious. Declination of the ichthyofauna started upstream and progressed downstream in a kind of reverse succession; forms were either pushed downstream, or eliminated from the fauna altogether. We are of the opinion that this phenomenon resulted either directly or indirectly from siltation of the habitat. Since most of the fishes involved, i.e., *Campostoma* and *Etheostoma* and *Percina*, feed from the bottom, much of the adverse effects probably result from elimination of food supplies by siltation. Also, during later visits, although we secured numerous gravid females and ripe males, we did not observe young fishes from Leatherwood Creek. Either reproduction (mating?) had been curtailed, or the eggs and/or fry were smothered by the silt.

The second point made obvious by Figure 4 is that *Semotilus* *atromaculatus* appears to be considerably resistant to the influence of mine wastes. Smith (1964) also demonstrated that the fish was the last to be eliminated (but eliminated!) by acid-mine water. A study of the gut contents of 243 Leatherwood creek chubs gave at least partial explanation. Many of the guts (30 to 70%) proved empty. The others contained primarily terrestrial dipterans, coleopterans, adult trichopterans, and a few mayfly larvae. The creek chub, then, is primarily a surface-feeding fish, and is thus able to remain over ensilted bottoms long after other species have been eliminated.

Summary and conclusions: 1. A 17-month study of the effects of strip mining on the fish faunas of two small creeks in east-central Kentucky demonstrated a low-level of acid-mine water effluence but a high level of siltation and turbidity originating from intensive erosion of the spoil banks.

2. Fishes are progressively eliminated from headwaters downstream, or, are forced to emigrate downgrade.

3. Benthic food organisms were reduced in numbers and kinds by at least 90 per cent.

4. Reproduction in darters and minnows was curtailed by siltation, either by the prevention of mating or by kill-off of fry and eggs.

5. *Semotilus atromaculatus* is resistant to silt and turbidity pollution. This seems to be correlated with the fish's feeding habits, i.e., since the diet consists largely of terrestrial-type insects or aquatic ones taken from the surface, the fish is able to subsist following silting of the bottom.

Although silt-correlated removal of fish life, by smothering the benthos, by interfering with reproduction, or by direct effects, may not be as dramatic as that associated with acid-mine water kills, it is, nevertheless, an important disruptive force which is occuring on a large scale in Appalachia and elsewhere. Fishes are eliminated. When rare or endangered species are involved, as *Etheostoma saggita* is here, the results could and probably will be extirpation.

The authors intend to continue monitoring Leatherwood and Bear Branch Creeks in order to determine continued effects and whether or not recovery occurs. However, the situation in the entire upper Kentucky River appears bleak, since mining operations are being intensified.

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