STREAM FAUNAL RECOVERY AFTER MANGANESE STRIP MINE RECLAMATION

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by

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INTRODUCTION

In recent years an upsurge of activity in the mining, road building, and other industries has greatly increased the quantities of silt and heavy metals entering aquatic environments. The U. S. Department of the Interior report "Surface mining and our environment" (1968) states that in eight Appalachian states 832,605 acres of land have been disturbed by surface mining. This disturbance affects more than 5,000 miles of streams, and over 13,800 acres of impoundments. Current fossil fuel demands coupled with increases in the efficiency of strip mining operations serve to magnify the problem. Stricter legislation and increasing awareness of the problem is resulting in better mining practices and increased reclamation efforts, but little is known of the effectiveness of various reclamation efforts or the rates at which aquatic biological communities recover once effective reclamation has been accomplished.

Manganese strip mining operations in southeastern Smyth County, Virginia, during the mid 1950's have left several spoil areas that continue to contribute silt and manganese ions to the South Fork Holston River. In that area (Fig. 1), 295 acres have been disturbed. The U. S. Forest Service has purchased portions of this and adjoining lands and in 1959 began reclamation efforts on Brushy Mountain, the watershed in which Slemp Creek originates. This work was completed in 1960 and in 1966 reclamation was completed on spoils areas of Bishop Branch owned by the Forest Service. Because of a policy of the

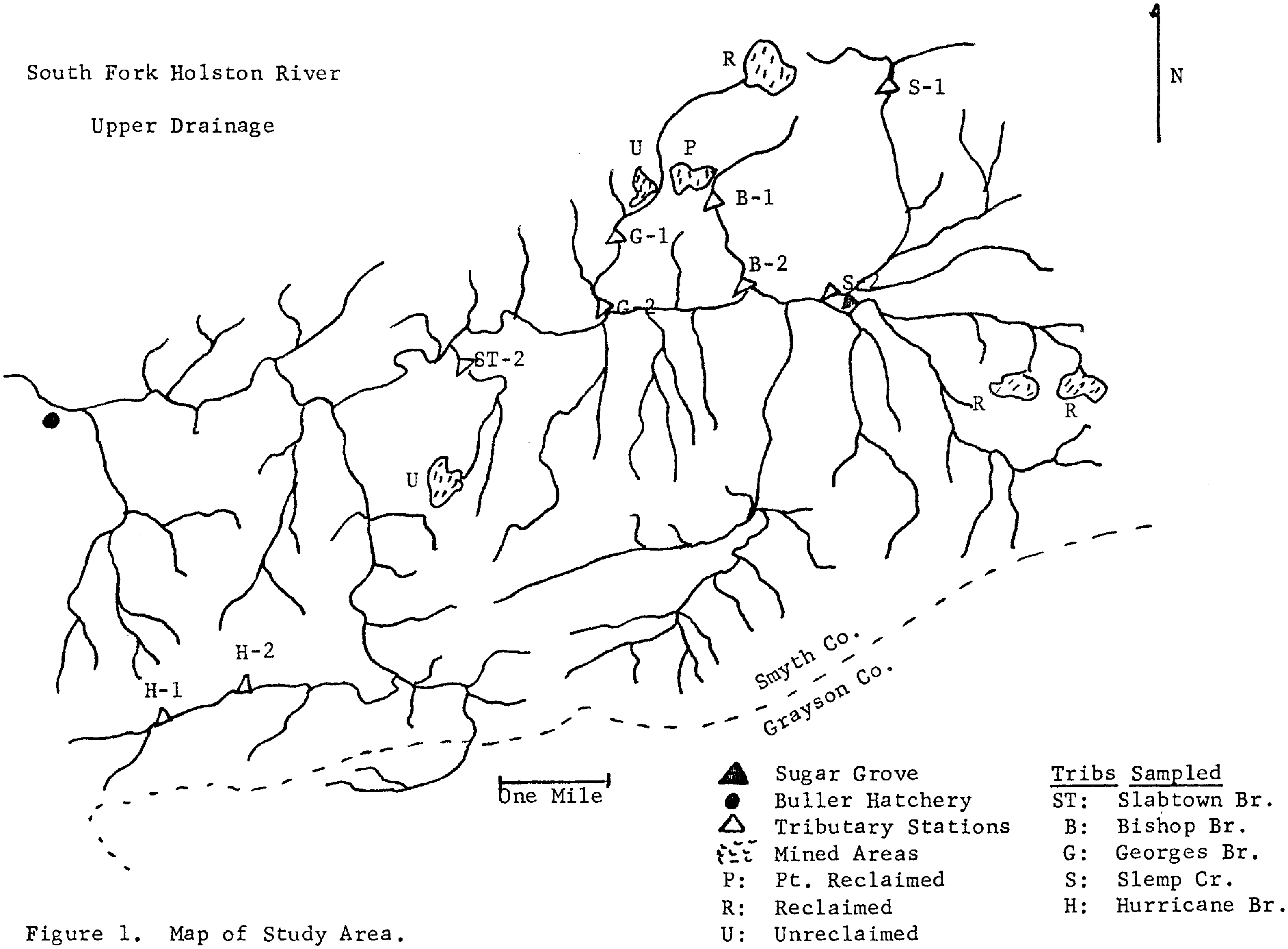

Figure 1. Map of Study Area.

Forest Service, their reclamation efforts are limited to land which they own. Consequently, in 1966 when the Forest Service completed reclamation efforts on the Slemp Creek and Bishop Branch watersheds, 40 acres of spoil areas had been reclaimed. This included all of the spoil areas on Slemp Creek, and part of the disturbed area on the Bishop Branch watershed. Because of private ownership of the spoil areas on Georges Branch and Slabtown Branch at that time, no reclamation was attempted on those areas, resulting in a series of reclaimed, partially reclaimed, and unreclaimed tributaries of the South Fork Holston. Following a recent purchase of Slabtown Branch, reclamation is planned for the Spring of 1971.

Prior to the reclamation efforts of the Forest Service, extensive damage to the property of local landowners as a result of flooding, deposition of silt and rock debris, and the fouling of water supplies along the tributaries was documented. Because of the extreme turbidity of the South Fork Holston, Buller Fish Hatchery was rendered "90% unusable." Previously clear waters of these tributaries and the South Fork Holston River were described by personnel of the Forest Service as "extremely turbid and heavily silted." These conditions persist in the partially reclaimed and unreclaimed tributaries of the South Fork. Turbidity values in the unreclaimed streams commonly are between 40 and 200 Jackson Turbidity Units and readings of 32,000 Jackson Turbidity Units (unpublished Forest Service stream survey report) have been recorded. Manganese ions have been measured in concentrations as high as 2.4 ppm.

The purpose of this research was to evaluate the effect of manganese strip mine reclamation on stream faunal recovery. This evaluation proceeded along the lines of chemical, physical, and biological monitoring activities designed to assess stream faunal population differences through time and under varying environmental conditions. Acute and chronic toxicity studies designed to determine whether the silt and manganese levels in the affected streams were high enough to limit survival of two local fish species were a corollary aspect of the research.

LITERATURE REVIEW

Although the effects of surface mining on the environment are many and varied, any surface mining activity will probably result in increased siltation and turbidity in streams draining affected areas. Other effects vary according to the mineral being mined and often involve changes in the acidity of receiving waters and increases in the concentration of certain heavy metals. Comprehensive accounts of the extent of surface mining throughout the United States, and some of the associated problems are given in three publications of the United States Department of the Interior: "Surface Mining and Our Environment" (1967), "Effects of Surface Mining on Fish and Wildlife in Appalachia" (1968), and "Restoring Surface-Mined Land" (1968).

Turbidity and Siltation

The effects of turbidity and siltation on aquatic life can be either direct or indirect, depending upon the organisms affected and the severity of their exposure. Cairns (1968) lists six ecological effects of suspended solids. In an excellent review of the literature on the influences of inorganic sediment on the aquatic life of streams, Cordone and Kelly (1961) cite evidence that the effects of inorganic sediments on fish are usually indirect, through reductions in their reproductive potential, available food supply and shelter, and changes in water quality.

Trautman (1957) presented well documented accounts of changes in the degree of siltation and turbidity of some Ohio streams over a long period of time and the consequent changes in fish populations. Gammon (1968) reported a reduction of about 50 percent in the biomass of fish in pools affected by quarry sediment as opposed to pools above the influence of the quarry discharge. Tebo (1955) in a study of the effects of siltation on the bottom organisms of a small North Carolina trout stream related limited production of rainbow trout in affected portions of the stream to a low standing crop of macrobenthic organisms. Smith (1940) concluded that erosion silt from hydraulic mines as well as from other sources limits the food supply of trout and may limit or entirely prevent successful reproduction, the amount of harm depending upon the quantity of silt in a stream and its persistence. Saunders and Smith (1965) correlated low standing crops of brook trout in a small stream with heavy siltation which destroyed hiding places and prevented spawning.

Mackay and Kalff (1969) in a study of the standing crop and species diversity of insect communities in a small Quebec stream found that the species diversity of bottom insect communities varies seasonally and is proportional to the number of potential microhabitats in the environment and to the stability of the substrate.

The relationship of substrate composition to the production of macrobenthic organisms is well documented. Most studies have shown that insect production is higher in rubble and decreases as the substrate becomes composed of finer materials. An exception is organic silt, which often contains large numbers of organisms, although usually not of types readily available as fish foods. Tarzwell (1937) rated substrates according to their production of bottom organisms. Giving sand a rating of 1, the relative productivity of fine gravel was 9, rubble was 29, and rubble and gravel was 53. Ellis (1936) showed that a layer of silt one-fourth of an inch to one inch deep on the surface of otherwise satisfactory bottom habitats was lethal to most common fresh-water mussels.

Wallen (1951) conducted controlled aquarium investigations on the direct effect of turbidity on 16 species of warmwater fishes and found that most individuals of all species used endured exposures to more than 100,000 ppm of turbidity for a week or longer. He further states that the same fishes finally died at turbidities of 175,000 to 225,000 ppm and that the fishes that succumbed had opercular cavities and gill filaments clogged with silty clay particles from the water. Ellis (1937) gave a similar description of the gills of fishes killed by exposure to high levels of turbidity.

Although nothing comparable to Wallen's work with warmwater fishes has been done with coldwater species, some work has been published. Griffin (1938) reported tests of 3 to 4 weeks duration in which salmon and trout fingerlings withstood silt concentrations of 300-750 ppm which were increased each day for a while when the tanks were stirred by hand to concentrations of 2300-6500 ppm. In chronic (approximately 7 months) studies of rainbow trout Herbert and Merkens (1961) observed mortalities "usually in excess of 50 percent" at turbidities of 270 ppm and higher as compared with negligible mortalities in the control groups. In these same experiments they reported that there was no statistically significant difference between either the lengths or the weights of fish exposed to different turbidity levels.

Faunal Recovery

Concomitant with the current emphasis on pollution abatement is interest in the recovery of the fauna of affected streams following abatement. Cairns et al. (in press) state that among other factors, recovery rates depend upon: "(1) severity and duration of the stress; (2) number and kinds of associated stresses; (3) recolonization of the area by useful aquatic organisms; and (4) residual effects upon non-biological units (e.g., substrate, etc.)."

In cases where the stress is of short duration following abatement, recovery is often remarkably fast. Tebo (1955) in his study of the effects of siltation on a small trout stream found that the number of bottom organisms in a heavily silted area of the stream was comparable to unaffected portions of the stream less than three months after a flood which flushed the sediments out and exposed the original rubble and gravel bottom. Larimore et al. (1959) found that two weeks after flow resumed in a small warmwater stream following a long drought 21 of the 29 regularly occurring species had moved into most of the stream course. They attributed rapid recolonization by bottom insects to the "colonization cycle" in which adult insects migrate upstream to deposit eggs and the resulting benthic forms drift downstream recolonizing previously barren areas.

Bishop and Hynes (1969) determined that upstream movements of benthic invertebrates in the Speed River, Ontario, counteracted 6.5 percent of downstream drift by numbers and 4 percent by weight and that upstream movement was of sufficient quantity and species diversity to account for recolonization of dried-out or erosion-denuded areas.

Manganese Toxicity

Compared with various others of the heavy metals, information on the toxicity of different forms of manganese is relatively scarce, and in many cases, seemingly contradictory. Much of the variation in results can be attributed to the variety of procedures used in determining tolerance limits. "Standard Methods" (1965) presents detailed procedures for determining acute toxicity of a given toxicant to fish. Some of the more theoretical aspects of bioassays and the analysis of results are considered by Bliss (1957).

Doudoroff and Katz (1953) made a critical review of literature on the toxicity of metals as salts to fish and pointed out the discrepancy of some of the experimental results concerning manganese toxicity and the need for further investigation. They cited the work of Thomas (1924) who reported that manganese chloride can be fatal to fish at concentrations as low as 6 ppm and the results of Japanese researchers who found the toxicity of $Mn\ Cl_2$ and $Mn\ So_4$ to fish to be relatively slight.

McKee and Wolf (1963) summarized the findings of different investigators of manganese toxicity and proposed permissible concentrations for various domestic, industrial, and agricultural uses and for fish and aquatic life.

METHODS AND MATERIALS

The Study Streams

Slemp Creek

Slemp Creek originates on Brushy Mountain in the Jefferson National Forest. The upper reaches of Slemp Creek drain National Forest land, part of which is a reclaimed strip mine area, while the lower portion drains private farm land. Slemp Creek is seldom turbid, and although heavy deposits of sand and gravel occur in areas of low velocity, siltation is negligible. Slemp Creek and two others form the headwaters of the South Fork Holston River.

Bishop Branch

Bishop Branch originates on Brushy Mountain and joins the South Fork about 2 miles downstream from the mouth of Slemp Creek. The upper portion of Bishop Branch flows through a partially reclaimed manganese strip mine area, while the lower portion flows through private farm land. Bishop Branch is a narrow (seldom exceeding 4 feet in width), fast flowing stream with few pools. In the slower portions, the bottom is largely sand and silt, while in the faster portions, small boulders and sand predominate. During low flow, about a 150-meter stretch of the stream flows underground 0.25 mile above its mouth. Above the underground section, the entire substratum is covered with a fine layer of silt.

Georges Branch

Georges Branch also originates on Brushy Mountain, with a ridge of land forming a divide between the spoils of Bishop Branch and Georges Branch. No reclamation has been undertaken on the spoils of Georges Branch. The stream is always turbid and the entire substratum is covered with a fine layer of silt.

Slabtown Branch

Slabtown Branch flows into the South Fork about two miles downstream from Georges Branch and on the opposite side of the valley. One fork of the upper portion drains on unreclaimed strip mine area; and although that fork is intermittent, during periods when it flows it deposits enough silt in the other portions of the stream to maintain a constantly high turbidity.

Hurricane Branch

Hurricane Branch which originates in the Iron Mountains about 8 miles northeast of Sugar Grove serves as one of the control streams in the study. It is predominantly long series of rapids with small pools. The water is not turbid even at high flow, and the substrate is composed largely of gravel, rubble, and small boulders. Bedrock is encountered more frequently in this stream than in the others of this study.

Selection of a Control Stream

Control areas could not be established on the other streams described here because as tributary streams they originate on or near the strip mined areas, thus ruling out the possibility of using a portion of the stream above the pollution source as a control area. The two remaining alternatives were to compare the reclaimed stream with the unreclaimed and partially reclaimed ones, or to compare the reclaimed, unreclaimed, and partially reclaimed streams with a stream unaffected by strip mining activity. Hurricane Branch is unaffected by strip mining, but its waters are very soft (5-10 ppm) and have a low biological productivity. It was, therefore, not directly comparable to the other streams. With these facts in mind, it was decided that Slemp Creek should serve as the "control" stream and that Hurricane Branch should serve to represent the physical properties of a stream unaffected by strip mining.

Station Selections

With the exception of Slabtown Branch, two stations were selected on each of the study streams for sampling all parameters except substrate composition. Only one station was established on Slabtown Branch. The stations were established on the upper and lower sections of the streams and were chosen on the basis of how well they represented other sections of the streams. Each sampling area contained a riffle and a pool area. For the substrate analysis, an additional station was established in the mid-section of the stream.

Monitoring Activities

In order to document the continuing damage to the ecology of the study streams resulting from the influence of the unreclaimed strip mine areas and to evaluate the degree of recovery of streams draining reclaimed strip mine areas, the following parameters were sampled at approximately the intervals indicated: Water chemistry (dissolved oxygen, pH, alkalinity, total hardness, iron, and manganese) at 2-month intervals; temperature and volume of flow at 2-month intervals and coinciding with the measurements of water chemistry; fish and bottom fauna density and diversity quarterly; and substrate composition yearly.

Alkalinity, total hardness, pH, and dissolved oxygen were measured using the Hach Chemical Company's model AL-59 kit. The low-range tests of the kit were used for alkalinity and total hardness. Samples were taken at midstream and were analyzed on the site. The Hach Chemical Company's 1, 10 phenanthroline method for iron and the cold periodate method for manganese were employed, using that Company's AL-59 kit. After July, 1969, the same reagents for iron and manganese were used, but the determinations were made with a Bausch and Lomb Spectronic 20 colorimeter.

Streambed Composition

With the aim of quantifying differences in the physical characteristics of the various stream classes being studied, an analysis of the particle sizes of the streambeds was undertaken. Of particular interest was the percentage of the total substrate composed of finer particles such as sand and silt which would be indicative of continuing erosional activities. All the techniques proposed elsewhere for extracting samples of the streambed were inappropriate for the streams in this study because of the preponderance of large rocks and boulders, so a different sampling device, consisting of a saw-toothed, metal cylinder with handles, was designed and constructed. Operation of the sampler required two men who rotated it clockwise and counterclockwise about 30° in each direction, thus drilling the saw-toothed edge of the apparatus down into the streambed. After drilling the metal cylinder into the substrate, approximately 4 liters of the bottom material were scooped out and placed in a plastic bucket prior to separation into different particle size classes. Water containing silt particles in suspension was then dipped out and set aside in plastic buckets. Water was dipped from the scooped-out area until "dry," or in cases where penetration of the sampling device was inadequate to prevent seepage of water, until the water began to clear inside the sampling area.

After collection of the sample, the bottom materials and the scooped-out water were washed through a series of nine sieves (19, 12.7, 6.35, 3.36, 1.68, 0.841, 0.420, 0.210, and 0.105 mm openings) and their volume was measured by a method of displacement (McNeil and Ahnell, 1964). Water containing silt particles which passed through the finest sieve was placed in a large settling funnel and allowed to stand for 30 minutes, after which water containing most of the settleable solids was drawn off the bottom into a bucket, and was then stored in a plastic one gallon jug at least 24 hours prior to final measurement. At that time, the upper one half of the plastic jug was carefully removed, the water was poured off and the volume of settled solids was measured. About 28 to 32 hours are required for the analysis of a series of 30 samples which is the number required for single samples taken from pool and riffle areas on the upper, middle, and lower portions of the study streams.

Temperature

Air and water temperatures were taken after the method of Lagler (1956) with a centigrade thermometer at all stations whenever chemical data and fish and bottom fauna were collected.

Turbidity

For all samples after July, 1969, the procedure of the Hach Chemical Company was used to determine turbidity in standard Jackson Units. Using the Spectronic 20 colorimeter, percent transmittance was converted to turbidity in standard Jackson Units by referring to a table made from standard formazin solutions using a Jackson Candle Tirbidimeter. Prior to July, 1969, turbidity measurements utilized the Hach Chemical Company's model AL-59 kit.

Fish Collections

Fish collections were made utilizing the model BP-IC backpack shocker obtained from Coffelt Electronics Company, Denver, Colorado. A six foot whip electrode mounted on a single wooden pole was used.

A switch on the pole controlled the current. About 1.5 amps were produced on AC current at an output of 325 volts.

At the time of each collection, a 150-foot section of stream at each station was shocked and the fish were collected with a long handled nylon dip net. The operation required a minimum of two men. In the case of soft water, such as in Hurricane Branch, it was necessary to throw crushed salt into the water upstream prior to shocking. The fish were released after identification to avoid overexploitation of existing stocks in the small streams.

Bottom Fauna Collections

Bottom fauna collections were made at approximately 3-month intervals throughout the study. An unmodified Surber square foot sampler was the sampling device. Three samples were taken at every station each sampling period. The samples were transferred from the Surber sampler to a white enamel pan and separated from the accompanying debris at the sampling site. The sorted organisms were then preserved in vials of 70 percent ethanol. Identification was to genus.

Acute Toxicity Studies

The Test Fish

The rainbow trout sac-fry were obtained from the new Wytheville National Fish Hatchery (Wytheville #2) as eyed eggs and were hatched in aluminum hatching troughs at the old Wytheville National Fish Hatchery (Wytheville #1) where the toxicity studies were held.

Rainbow trout fingerlings also were obtained from Wytheville #2.

The white sucker fry were obtained from Wisconsin's Department of Natural Resources fish hatchery at Woodruff, Wisconsin, via air freight. The fish were shipped in a sealed and oxygenated plastic bag containing about 20 liters of water. Transit time was about 13 hours. After transporting the fry to the fisheries laboratory on campus, the fry were transferred to plastic swimming pools filled with dechlorinated tap water. Total hardness and pH (total hardness 45 ppm, pH 7.2) was nearly identical to that of the Wisconsin hatchery.

The white sucker fingerlings were reared by transporting some of Wisconsin fry to a cement pond at Virginia's Buller Fish Hatchery in late June, 1969. They were held there until the white sucker fingerling experiment, August, 1970, at which time they weighed an average of 1.6 grams.

When an attempt to hatch blacknose dace fry and a subsequent attempt to capture them in local streams failed, it was decided that juveniles and adults would be the life history stages of this species used in the toxicity experiments. The juveniles were captured in the headwaters of Big Stony Creek in Giles County and were held in a plastic swimming pool filled with dechlorinated tap water until they were used in the manganese toxicity study of July, 1970. The blacknose dace adults were seined from Meadowbrook Branch near Buller Hatchery in Smyth County.

The Bioassay Apparatus

The test containers for all the experiments were of a series of one gallon glass jars filled with either two or three liters of water, depending upon the weight of the fish and other experimental conditions. Fourteen-foot aluminum hatching troughs filled with running water served to maintain a relatively constant temperature. In all tests except the one with blacknose dace juveniles, each jar was supplied with one of a series of air stones connected to a small air compressor.

Water Quality

Three water qualities have been used in the toxicity experiments reported here. They are Slemp Creek (total hardness 35-45 ppm, pH 7.2), Wytheville #2 spring water (total hardness 120 ppm, pH 7.5), and V.P.I. tap water (total hardness 45 ppm, pH 7.6). Slemp Creek water was used in the rainbow trout sac-fry experiments and the rainbow trout fingerling study in which suspended silt was the toxicant. Wytheville #2 spring water was used to determine the tolerance of rainbow trout fingerlings to Mn^{+2} ions. V.P.I. tap water was used for all the white sucker and blacknose dace experiments.

Toxicants

The three toxicants which have been used in these experiments are $Mn(NO_3)_2$, MnO_2, and suspended silt. The $Mn(NO_3)_2$ was obtained as a 10,000 ppm atomic absorption standard solution from the Fisher Scientific Company, and as a 51.2 percent reagent grade solution from the same company. The atomic absorption standard solution was used for the rainbow trout sac-fry experiment and the 51.2 percent solution was used for the other experiments.

A 10,000 ppm solution of $Mn(NO_3)_2$ was always the strength of the solution pipetted into the diluent water. After pipetting, the solutions were stirred vigorously with a glass rod to insure thorough mixing before introducing the fish into the test containers.

The silt used in this series of experiments was obtained from the bed of a conical shaped depression located on the unreclaimed portion of the Bishop Branch strip mine. It was air dried and ground in a mortar and pestle prior to putting it into suspension. The silt was kept in suspension by moderately violent aeration.

The MnO_2 was in a powder form and was obtained from the Fisher Scientific Company.

Measurements to determine actual quantities of the various toxicants in solution or suspension were usually taken 48 hours after beginning the experiment. Materials in suspension were measured in terms of turbidity units, and manganese was measured colorimetrically using Hach Chemical Company's cold periodate oxidation method and a Spectronic 20 colorimeter.

Chronic Effects of Silt in Suspension

Facilities of the Buller Fish Hatchery near Marion, Virginia, were used to compare the growth of rainbow trout and white sucker fingerlings in clear versus turbid water. Two cement ponds 100 feet long, 8 feet wide, and 3 feet deep were each divided into six compartments by 1/4-inch mesh screens. In the study conducted during the fall of 1969, water was delivered to the two ponds from an adjacent earthen pond in an attempt to avoid the occasional high turbidities of water coming directly from the South Fork Holston. Turbidity was induced in one pond by having the incoming water flow across a basket of semi-dried clay silt. Each of the ponds was stocked with three groups of fifty white sucker and rainbow trout fingerlings. Individual lengths and mean weights were taken at the beginning and end of the experiment.

Because of difficulties in maintaining a high turbidity in the turbid pond and in an attempt to attain a better statistical design, a second experiment was initiated in the fall of 1970. This time a circulating pump maintained a stirring action inside a 55-gallon drum to which clay silt was added daily. The amount of turbid water leaving the drum and entering the test pond was controlled by the amount of influent water. Since the suspected significant differences in length and weight changes could not be validated statistically in the first experiment, fish were tagged internally with a numbered, plastic tag in the second experiment in an attempt to improve the experimental analysis through measurement of individual lengths and weights. In this experiment three groups of twenty-five rainbow trout and white suckers were stocked in each of the ponds and fed daily for thirty days. To allow for mortality and tag loss, twenty fish from each compartment were selected at random for the statistical analysis.

Data Analysis

Bottom Fauna Collections

Initially, the macrobenthic organisms were identified to genus, and numbers in each genus were tabulated according to date, sampling site, and sample number. This data was then used to calculate an index of community structure, the number of organisms per square foot, and the number of genera per square foot. The index of community structure was calculated according to the information theory model $\bar{d} = \sum_{i=1}^{s} \frac{ni}{n} \log_2 \frac{ni}{n}$ as proposed by Wilhm and Dorris (1968). Statistical comparisons among stations for each of these parameters were made utilizing Duncan's multiple range test following the methods of Steel and Torrie (1960).

Substrate Analysis

Data on the percentage composition by particle size of substrate in the study streams was first transformed from percentages using an arcsine transformation. Comparisons were made among the mean percentage compositions for all stations of particles less than 0.841 mm diameter and those less than 0.105 mm diameter using Duncan's multiple range comparison.

Chronic Effects of Silt in Suspension

Comparisons of mean length and weight increments for rainbow trout in clear versus turbid water were made using a one-way analysis of variance.

RESULTS

Water Chemistry

A summary of some of the water chemistry parameters sampled on ten occasions from July, 1968 to July, 1970, is presented in Table 1. Other parameters which were measured but not considered limiting to the biota on the basis of criteria developed by other investigators (McKee and Wolf, 1963) include dissolved oxygen and carbon dioxide.

Values for pH and iron showed the best variation between sampling dates. Changes in total hardness, turbidity, and manganese were associated with increased stream flow and probably resulted from high flow dilutions in the case of total hardness and increased erosional activities in the instance of turbidity and manganese. Manganese concentrations in all categories of streams studied are higher than usually occur in natural waters (Hem, 1959) and can probably be attributed to the geology of the region.

Streambed Percentage Composition Analysis

A statistical comparison of the percentage of the substratum of the study streams composed of two size classes of fine particles is presented in Table 2. The comparisons among stations is based upon the procedures of Duncan's multiple range test (Steel and Torrie, 1960). The mean values being compared were obtained by averaging the results

Table 1. Means and standard deviations of some water quality parameters measured during ten sampling periods between July, 1968 and July, 1970. Results for all parameters are expressed in parts per million with the exception of turbidity which is expressed in Jackson Turbidity Units, and pH.

Station	Total Hardness	Iron	Manganese	pH	Turbidity
S-1	30 ± 8	0.14 ± 0.09	0.74 ± 0.42	7.5 ± 0.40	12 ± 10
S-2	41 ± 13	0.10 ± 0.02	0.76 ± 0.49	7.7 ± 0.40	18 ± 15
B-1	10 ± 6	0.20 ± 0.18	0.96 ± 0.63	6.9 ± 0.60	49 ± 28
B-2	93 ± 20	0.20 ± 0.17	0.30 ± 0.24	7.7 ± 0.36	15 ± 8
H-1	15 ± 16	0.10 ± 0.03	0.40 ± 0.22	6.8 ± 0.23	5 ± 2
H-2	18 ± 7	0.10 ± 0.06	0.30 ± 0.34	6.8 ± 0.19	5 ± 2
G-1	10 ± 7	0.10 ± 0.03	0.50 ± 0.20	7.1 ± 0.40	43 ± 25
G-2	12 ± 7	0.17 ± 0.13	0.30 ± 0.15	7.2 ± 0.23	41 ± 21
ST-2	90 ± 25	0.10 ± 0.04	0.90 ± 0.79	7.7 ± 0.39	104 ± 69

Table 2. Multiple range comparison of the percentage of the substratum composed of particles less than 0.841 mm diameter and 0.105 mm diameter in the study streams. Abbreviations identify the respective streams, whether a riffle or pool was sampled, and the section of the stream sampled. For example, STPL represents a pool on the lower section of Slabtown Branch.

p[1]	% of particles less than 0.841 mm diameter			p	% of particles less than 0.105 mm diameter		
	Station sampled	Mean %	Least significant range		Station sampled	Mean %	Least significant range
	HPL	18.41			BRL	8.84	
2	BRL	19.99	22.31	2	HRL	9.27	10.06
3	HRL	20.55	23.51	3	HPL	10.58	10.60
4	SPL	25.25	24.31	4	SPL	11.02	10.96
5	HRU	26.51	24.86	5	SRM	11.82	11.21
6	HRM	26.81	25.34	6	HPM	12.37	11.43
7	STRL	26.98	25.66	7	GRU	12.57	11.57
8	HPM	27.30	25.98	8	SRL	14.51	11.72
9	STRU	27.60	26.22	9	STRU	14.99	11.82
10	GRU	29.15	26.46	10	HRU	15.17	11.93
11	SRM	29.26	26.58	11	SPM	15.21	11.98
12	SRL	30.21	26.78	12	HRM	16.29	12.08
13	HPU	31.54	26.89	13	HPU	16.78	12.15
14	SPM	34.20	27.09	14	SRU	17.77	12.22
15	BRU	34.29	27.11	15	BPM	18.28	12.26
16	GRM	34.97	27.25	16	STRL	18.51	12.29
17	STRM	36.56	27.39	17	SPU	19.36	12.34
18	SRU	37.81	27.49	18	BRU	19.80	12.40
19	BPM	38.12	27.57	19	BRM	20.92	12.43
20	BRM	38.72	27.65	20	GRM	21.26	12.47
21	GRL	41.27	27.65	21	GRL	21.52	12.47
22	STPU	46.87	27.65	22	BPL	22.51	12.47
23	GPM	47.18	27.65	23	STRM	24.25	12.47
24	GPU	50.40	27.65	24	GPM	24.25	12.47
25	BPL	52.16	27.65	25	GPU	29.62	12.47
26	BPU	56.48	27.65	26	BPU	31.87	12.47
27	SPU	58.95	27.65	27	STPU	31.95	12.47
28	STPL	62.05	27.65	28	GPL	33.77	12.47
29	GPL	67.89	27.65	29	STPM	42.58	12.47
30	STPM	78.58	27.65	30	STPL	43.76	12.47

[1]p = The number of means in a comparison.

obtained from single samples at each of the stations during three yearly sampling periods. The range of particles less than 0.841 mm diameter represents the categories of coarse sand, fine sand, and silt. Particles less than 0.105 mm are composed entirely of silt. Appendix Table 1 and 2 summarizes the results of each of the three yearly substrate analyses based upon separation of the substrate samples into 10 size classes.

If one compares ranges of means for stations that are statistically different, at least two pertinent observations can be made. First, for the "less than 0.841" size class, of the thirteen lowest means declared significantly different than the three highest values, nine of the stations are on Hurricane Branch and Slemp Creek (unaffected and fully reclaimed, respectively) whereas the three highest means represent stations on Georges Branch and Slabtown Branch. Comparisons based percentages of silt only suggest even more definitive results of reclamation efforts. Stations on Slemp Creek and Hurricane Branch represent ten of the thirteen lowest values, while the five high range values are comprised of stations unreclaimed or only partially reclaimed. The occurrence of reclaimed and partially reclaimed stations in the high range values is discussed elsewhere.

Macroinvertebrate Densities, Diversities, and Community Structure Relative to Degree of Reclamation

A comparison of the mean density of macroinvertebrates at different sampling stations on the study streams is presented in Table 3.

Table 3. Multiple range comparison of the mean densities of bottom organisms at each of the sampling stations.

p	Station	Mean No. per Square Foot	Least Significant Range
	H-2	12.00	
2	G-1	12.29	12.56
3	G-2	12.29	13.22
4	ST-2	12.29	13.67
5	H-1	12.50	13.93
6	B-1	12.67	14.20
7	S-1	22.00	14.38
8	B-2	34.71	14.55
9	S-2	48.86	14.69

The values compared are based upon the average of seven collections of three square foot samples per station. The two stations on Slemp Creek and the lower station on Bishop Branch produced significantly higher numbers of bottom organisms than did stations on the affected unreclaimed streams, stations on the unaffected stream, or the upper station on Bishop Branch. As mentioned elsewhere, the unexpected productivity of the lower station on Bishop Branch is related to the underground passage of the upper portion of the stream. The extremely low productivity of Hurricane Branch can be attributed to the low concentration of dissolved minerals.

The mean number of genera (Table 4) collected at both stations on the fully reclaimed stream and on the lower portion of Bishop Branch was significantly higher than for the other stations sampled. As in the density comparisons, the affected unreclaimed streams gave evidence of supporting the poorest population of bottom organisms.

Statistical comparison of the mean diversity values for the different stations (Table 5) indicates no significant difference among stations on the unaffected stream, the affected reclaimed stream, or the lower station on Bishop Branch. All of these stations had mean diversities near or above 3.0, indicating "clean water" areas (Wilhm and Dorris, 1968). Diversities for the other stations characterize them as being "moderately polluted." The lower $\bar{d}$ values for the affected unreclaimed and partially reclaimed stations are associated with the low diversities (number of genera) of bottom organism

Table 4. Multiple range comparison of the mean[1] number of genera of bottom organisms at each of the sampling stations.

p	Station	Mean No. per Square Foot	Least Significant Range
	ST-2	8.71	
2	G-2	9.29	3.31
3	G-1	9.43	3.51
4	H-1	10.00	3.63
5	B-1	10.50	3.70
6	H-2	12.00	3.77
7	B-2	15.86	3.82
8	S-1	16.14	3.87
9	S-2	16.14	3.90

[1]Mean number of genera for each station is based upon an average of seven collections.

Table 5. Multiple range comparison of the mean diversity for bottom organisms at each of the sampling stations.

p	Station	Mean $\bar{d}$ [1]	Least Significant Range
	G-2	2.51	
2	ST-2	2.54	0.51
3	G-1	2.58	0.53
4	B-1	2.67	0.55
5	H-1	2.92	0.56
6	B-2	3.06	0.57
7	S-2	3.09	0.58
8	H-2	3.12	0.59
9	S-1	3.33	0.59

[1] Mean $\bar{d}$ = The average of $\bar{d}$ values for seven collections as calculated by the formula $\bar{d} = \sum_{i=1}^{s} \frac{ni}{n} \log_2 \frac{ni}{n}$ where s represents the number of genera in an area, n is the total number of individuals, and ni is the number of individuals per genus.

populations. That Slemp Creek stations have relatively high $\bar{d}$ values and low numbers of genera is indicative of less redundancy.

Fish Species Composition and Relative Abundance

The summarization of fish collections (Table 6) gives strong evidence of the recovery of fish populations in Slemp Creek and of the continuing stress being exerted on populations in affected unreclaimed and partially reclaimed streams, with the exception of the lower station on Bishop Branch.

In the stations having fish populations, blacknose dace (*Rhinichthys atratulus*) and sculpins (*Cottus sp.*) are the two most commonly occurring species, with rainbow trout (*Salmo gairdneri*) and stone rollers (*Compostoma anomalum*) following in that order. No fish were collected at the upper station on Bishop Branch, and only a single specimen (blacknose dace) was collected on Slabtown Branch. When a specimen was collected at one of the affected, unreclaimed stations it was usually a blacknose dace. Sculpins were conspicuous in their absence.

The Toxicity of Silt in Suspension and Manganese Ions to Blacknose Dace, Rainbow Trout, and White Suckers

Blacknose Dace

Tables 7 and 8 summarize the results of two experiments designed to determine the acute toxicity of Mn^{+2} ions to early juvenile and adult blacknose dace. The 96 hr. TLm values were 50 ppm for the juveniles, and 88 ppm for the adults. Of the three species tested,

Table 6. Numbers and species of fish collected on five sampling dates. The sample is based upon a 150 feet section of stream.

Station	Species	9/18	7/69	11/69	3/70	7/7/70
H-1	Salvelinus fontinalis	3	2	1	2	3
	Cottus sp.	0	0	3	0	2
	Rhinichthys atratulus	0	0	1	1	2
H-2	Cottus sp.	7	0	2	6	4
	Rhinichthys atratulus	5	6	3	4	6
	Salmo gairdneri	0	0	0	0	1
B-1		0	0	0	0	0
B-2	Salmo gairdneri	5	1	2	3	10
	Rhinichthys atratulus	2	0	3	6	2
	Compostoma anomalum	1	0	0	0	0
	Cottus sp.	30	6	47	34	30
S-1	Rhinichthys atratulus	14	42	11	5	31
	Cottus sp.	14	9	15	11	37
	Compostoma anomalum	0	0	1	0	0
	Salmo gairdneri	1	0	0	0	0
S-2	Compostoma anomalum	18	9	0	6	12
	Lampetra sp.	5	0	1	1	0
	Rhinichthys atratulus	125	34	17	9	36
	Cottus sp.	18	1	6	4	0
	Catostomus commersonii	0	0	0	1	0
	Salmo gairdneri	0	0	0	0	1
	Chrosomus oreas	0	0	0	0	8
	Labidesthes sicculus	0	0	0	0	1
G-1	Rhinichthys atratulus	2	2	1	1	0
	Salmo gairdneri	0	0	0	1	0
G-2	Rhinichthys atratulus	0	14	0	4	8
	Cottus sp.	0	0	0	1	0
	Chrosomus oreas	0	0	0	1	0
ST-2	Rhinichthys atratulus	0	0	0	1	0

Table 7. Survival of blacknose dace juveniles exposed to five concentrations of Mn^{+2} ions for 96 hrs.

Calculated Conc. (mg/l)	Measured Conc. (mg/l)	Percent Survival			Mean % Survival
		Rep I	Rep II	Rep III	
Control	.1	100	100	100	100
13.5	14.0	100	100	100	100
18.0	16.8	100	100	90	97
24.0	24.3	80	100	90	90
32.0	31.2	70	90	90	83
56.0	54.0	40	30	50	40

TLm = 50 mg/l

Table 8. Survival of blacknose dace adults exposed to five concentrations of Mn^{+2} ions for 96 hrs.

Calculated Conc. (mg/1)	Measured Conc. (mg/1)	Percent Survival		
		Rep I	Rep II	Rep III
Control	0.1	100	100	100
24.0	23.8	100	100	100
32.0	32.5	100	100	100
56.0	55.4	100	90	90
75.0	73.2	80	80	60
100.0	98.7	30	40	40

TLm = 88 mg/1

This species had the highest tolerance to Mn^{+2} ions. No tests with silt or silt and manganese in combination were run on this species.

Rainbow Trout

The results of a series of six experiments in which rainbow trout fry and fingerlings were exposed to varying concentrations of Mn^{+2} ions, silt in suspension, and combinations of silt and Mn^{+2} ions are summarized in Tables 9 through 14. The median tolerance limit of rainbow trout fry to Mn^{+2} ions was more than four times that of fingerlings. The higher tolerance of the fry may be partly due to having been reared in very hard water (350 ppm).

Data from two experiments conducted in an attempt to measure the tolerance of rainbow trout fry and fingerlings to silt in suspension are presented in Tables 11 and 12. Results for the fry are probably biased by the fact that all of the silt could not be kept in suspension, making resting fry susceptible to smothering. The same inadequacy of the test apparatus prevented more definitive measurements of the tolerance of fingerlings to silt.

An interesting result of the experiments designed to test the effects of combinations of silt and manganese upon rainbow trout fry and fingerlings (Tables 13 and 14) is the fact that fingerling trout can tolerate higher levels of manganese combined with suspended silt than of manganese alone. As is the case with trout fry and silt, results of the combination tests are probably biased by the sediments which accumulate in the bottoms of the test containers.

Table 9. Survival of rainbow trout sac fry to varying concentrations of Mn^{+2} ions after 96 hrs. exposure.

Calculated Mn^{+2} Conc. (mg/l)	Measured Mn^{+2} Conc. (mg/l)	Percent Survival		
		Rep I	Rep II	Rep III
Control	0.1	100	100	100
3.2	2.9	100	100	100
5.6	4.6	90	100	95
10.0	8.0	100	100	100
18.0	16.5	100	95	No Test
32.0	29.2	55	30	40
56.0	52.7	35	0	5

TLm = 30 mg/l

Table 10. Survival of rainbow trout fingerlings exposed to four concentrations of Mn^{+2} ions for 96 hrs.

Calculated Mn^{+2} Conc. (mg/l)	Measured Mn^{+2} Conc. (mg/l)	Percent Survival	
		Rep I	Rep II
Control	.1	100	95
2.9	2.5	100	100
5.1	4.8	90	90
6.9	6.5	50	55
9.2	8.7	20	15
	TLm = 7.0 mg/l		

Table 11. Survival of rainbow trout sac fry after 96 hrs. exposure to varying amounts of silt in suspension.

Dry Silt Added (g/1)	Initial Turbidity (JTU)	48 hr. Turbidity (JTU)	Mean % Survival
0	4	4	98
4	1,400	1,200	98
8	5,012	4,720	92
16	7,902	6,000	37
32	10,965	6,500	3
64	29,200	17,000	0
128	60,800	26,500	0

Table 12. Survival of rainbow trout fingerlings exposed to five levels of silt in suspension for 48 hrs.

Dry Silt Added (g/l)	Initial Turbidity (JTU)	48 hr. Turbidity (JTU)	Mean % Survival
Control	4	4	87
4	5,550	3,950	100
8	9,875	8,000	100
16	18,000	9,850	100
32	22,800	17,500	83
64	30,000	18,000	43

Table 13. Percent survival of rainbow trout fingerlings 96 hrs. after exposure to four concentrations of Mn^{+2} ions in combination with two levels of silt. Concentrations listed are quantities measured 48 hrs. after beginning the experiment.

Mn^{+2} + 1 g/1 Silt			Mn^{+2} + 10 g/1 Silt		
Mn^{+2}	JTU	Mean % Survival	Mn^{+2}	JTU	Mean % Survival
Control	4	100	Control	4	97
7.4	70	90	4.5	1550	93
25.0	10	77	18.2	1240	60
33.0	0	40	25.0	1080	16.7
59.0	0	0	53.0	875	0
TLm = 29 mg/1 Mn^{+2}			TLm = 20.6 mg/1 Mn^{+2}		

Table 14. Percent survival of rainbow trout sac fry 96 hrs. after exposure to four concentrations of Mn^{+2} ions in combination with two levels of silt. Concentrations listed are quantities measured 48 hrs. after beginning the experiment.

Mn^{+2} + 1 g/1 Silt			Mn^{+2} + 10 g/1 Silt		
Mn^{+2}	JTU	Mean % Survival	Mn^{+2}	JTU	Mean % Survival
Control	4	98	Control	4	98
7.2	80	97	3.8	1640	21.6
22.0	4	35	16.6	1470	3.3
37.0	0	6.6	32.0	880	0
66.7	0	0	51.0	970	0
TLm = 19.5 mg/1 of Mn^{+2}			TLm = 2.4 mg/1 of Mn^{+2}		

White Suckers

Contrary to the fry and fingerling studies involving rainbow trout, white sucker fry (Tables 15 and 16) had a considerably lower tolerance to manganese ions (TLm = 14 ppm) than did fingerling white suckers (TLm = 80 ppm). These results lend further weight to the possibility that the high tolerance of the rainbow trout fry was due to having been reared in the hard water of Wytheville #1.

Effects of Chronic Exposure of Rainbow Trout and White Sucker Fingerlings to High Levels of Turbidity

Although this experiment was originally designed to test the effect of chronically high turbidities on the growth of both rainbow trout and white suckers, an 80 percent tag loss among the white suckers combined with high and seemingly random mortalities made a meaningful analysis of the results impossible. Both the tag losses and the high mortalities can probably be attributed to the small size of these yearling fish (average length = 110 mm).

Water quality data for the experimental ponds are presented in Table 17. As compared with the white suckers, tag loss and mortality among the rainbow trout studied was very low, the two factors combined never exceeding 20 percent of a test group. Increments in both length and weight (Table 18) for rainbow trout reared in clear water are consistently higher than gains for trout reared in turbid water. Analysis of variance (Table 19) further confirms that the parameters measured were different in the two groups of fish.

Table 15. Survival of white sucker fry exposed to five concentrations of Mn^{+2} ions for 96 hrs.

Calculated Conc. (mg/l)	Measured Conc. (mg/l)	Percent Survival			Mean % Survival
		Rep I	Rep II	Rep III	
Control	.1	73	72	73	73
2.8	2.5	61	76	81	73
6.8	6.4	83	60	51	65
9.2	7.25	94	75	68	79
12.2	10.1	74	94	74	81
16.3	14.65	29	0	4	11

TLm = 14 mg/l

Table 16. Percent survival and the median tolerance limit at the end of 96 hrs. for white sucker fingerlings subjected to four concentrations of $Mn(NO_3)_2$.

Concentration (mg/1 $Mn(NO_3)_2$)	Percent Survival Rep I	Rep II	Rep III	Mean % Survival
Control	100	100	100	100
32	100	80	100	93
56	90	70	80	80
100	20	50	30	33
180	10	0	20	10

TLm = 80 mg/1

Table 17. Water quality in the clear and turbid ponds.

Date	Temperature (C^o)	D.O. (ppm)	pH	Mn (ppm)	Turbidity (JTU)
		CLEAR			
9-14-70	20.0	9.0	8.0	0.1	20
9-18-70	22.0	8.5	7.5	tr.	15
9-26-70	15.5	9.5	8.0	tr.	15
10-10-70	13.0	9.5	8.5	0.2	10

Date	Temperature (C^o)	D.O. (ppm)	pH	Mn (ppm)	Turbidity (JTU)
		TURBID			
9-14-70	21.0	9.0	8.0	tr.	875
9-18-70	22.0	9.0	7.5	0.2	680
9-26-70	16.0	9.5	8.5	0.1	1030
10-10-70	13.0	9.5	8.5	0.1	560

Table 18. Mean length and weight increments for rainbow trout reared in clear versus turbid water. Length of the experiment was 30 days, beginning Sept. 14, 1970 and ending Oct. 14, 1970. Mean values are based on 20 fish per compartment.

	Mean length increment (mm)			Mean weight increment (mm)	
	Clear	Turbid		Clear	Turbid
Rep. I	26.0	18.0	Rep. I	52.6	30.7
Rep. II	26.3	19.2	Rep. II	47.6	28.9
Rep. III	25.0	19.7	Rep. III	53.3	32.1
Exp. Mean	25.7	19.0	Exp. Mean	51.1	30.6

Table 19. Analysis of variance of mean length and weight increments for rainbow trout reared in clear versus turbid water.

	Length Increments			
Source of Variation	df	SS	MS	F
Between treatments	1	1,314.68	1,314.68	111.41
Among locations	4	47.20	11.80	
Within locations	120	3,671.05	30.59	
Total	125	5,032.93		

	Weight Increments			
Source of Variation	df	SS	MS	F
Between treatments	1	12,104.00	12,104.00	105.45
Among locations	4	459.17	114.79	
Within locations	120	12,368.00	103.07	
Total	125	24,932.00		

DISCUSSION

Effects of Manganese Strip Mine Reclamation on Some Physical and Chemical Parameters of Streams

Water Chemistry

The results of chemical analyses in this study show that the concentrations of the parameters sampled varied little between sampling dates, with the exception of values for turbidity and manganese (Table 1). Changes in these turbidity levels can be attributed to increased erosional activity during periods of heavy rainfall. The fact that the highest turbidity ranges for Hurricane Branch and Slemp Creek (unaffected and reclaimed respectively) are not much higher than low range values for the other streams attests to the effectiveness of reclamation efforts on the Slemp Creek drainage area.

Manganese is a common component of soils of the earth's crust, existing mainly as insoluble oxides and hydroxy-oxides. Fluctuations in manganese concentrations appear to be strongly correlated with the changes in turbidity, suggesting a higher loading of the insoluble forms of manganese as part of the suspended materials. Hem (1959) states that minerals containing the largest amounts of manganese occur in sedimentary and metamorphic rocks, and that in the former types, manganese oxides and hydroxides are concentrated through the removal of more soluble minerals, and are found in the oxidates (often associated with iron) and hydrolyzates (clay minerals). The consistently lower values obtained for the concentrations of iron in this study is probably due to the presence of clay minerals in the area.

Shawarbi (1952) has reported that soils in the United States commonly contain from 0.001 to somewhat over one percent manganese. Hem (1959) stated that water passing through soil will dissolve some manganese. The relatively high manganese concentrations in Hurricane Branch can probably be ascribed to the geology of the region. The somewhat higher concentrations in affected streams (including Slemp Creek) are probably related to increased loading of manganese in suspensoids, and to the fact that mined areas probably expose more ores to the solution action of water and microbes. Poon and Deluise (1967) related a lowering of pH and other factors to the increased solubility of manganese. It can be surmised from the higher manganese concentrations in reclaimed and unreclaimed streams as opposed to unaffected streams that the reclamation accomplished here would be much more ineffective in a more acid environment.

Of the other chemical properties measured, total hardness is probably the most pertinent because of its apparent influence on aquatic productivity. Commonly a function of the concentration of calcium and magnesium ions, total hardness values for a stream may be influenced by the presence of other cations (Hem, 1959), the nature of the stream substratum, and length of contact with the substratum. It is apparent from Table 1 that Slemp Creek, Slabtown Branch, and the lower portion of Bishop Branch have "harder" water than the other study areas, probably because of substrate differences, since all five streams were of about the same length. The higher total hardness of the lower portion of Bishop Branch can be attributed to the fact that somewhere in the middle section of its descent a portion of the stream during high flow and all of it during low flow goes underground, making possible the solution of more calcium and magnesium ions. Values for turbidity and temperature are also affected by this diversion. Effects of these changes on the biota are discussed below.

Substrate Analysis

The importance of substrate type to stream biota has been emphasized by a number of investigators of stream ecology (McNeil and Ahnell, 1964; Tarzwell, 1937; Cordone and Kelly, 1961; Tebo, 1955; Mackay and Kalff, 1968). The concensus is that the production of fish and macrobenthic organisms is inversely related to the percentage of sand and silt particles in the substratum. Adverse effects of heavy siltation can usually be attributed to reductions in substrate permeability and diversity of microhabitats, blanketing and scouring action against attached algae and other aquatic plants, and impairment of holdfast mechanisms necessary for the survival of many microbenthos.

Although the statistical analysis of differences in percentage composition of particles less than 0.841 mm diameter and less than 0.105 mm diameter respectively among the different areas sampled (Table 2) does not permit allocation of a given percentage range according to degree of reclamation without exception, some patterns can be discerned. Of these trends, one of the most interesting is the fact that of the thirteen lower mean percentages of particles less than 0.841 mm diameter declared significantly different than the three highest mean percentages, nine of the values represented stations on Hurricane Branch and Slemp Creek. When comparisons among stations with respect to particles less than 0.105 mm diameter were made, of thirteen low range mean percentages for this particle size class, ten of the values represented stations on Hurricane Branch and Slemp Creek, suggesting the effectiveness of reclamation in reducing the percentage of finer sediments in the substrate.

The general trend of lower percentages of fine sediments in streams draining reclaimed or unaffected areas and higher percentages in streams draining partially reclaimed and unreclaimed areas is somewhat confused by two instances. One apparent contradiction is the designation of a pool in the upper section of Slemp Creek as an area having one of the highest percentages of particles less than 0.841 mm diameter. This is probably due to the fact that even after reclamation, considerably more erosion may occur in affected areas than in non-affected areas. Inspection of the percentages of particles less than 0.105 mm diameter, however, does not place Slemp Creek in the "high percentage" category since most of the particles in the range less than 0.841 mm diameter were sand rather than silt, suggesting that rather than a continuous deposition of silt such as seems to occur in the unreclaimed and partially reclaimed streams, deposition in Slemp Creek occurs mainly during high flow, consequently consists primarily of larger particles (sand and gravel).

A second apparent contradiction is the occurrence of a lower station of Bishop Branch among those stations having the lowest percentages of both of the above size classes. This can probably be attributed to the stream dropping a substantial part of its load during the underground passage of the stream discussed previously.

In summary, based on a comparison with affected unreclaimed streams it can be said that reclamation efforts have had a measurable influence in reducing the percentage of sand and silt in the substratum of Slemp Creek. Partial reclamation on the drainage area of Bishop Branch has been ineffective in bringing about such results.

The Role of Silt in Suspension and Manganese Ions in Solution as Factors Limiting to Rainbow Trout, Blacknose Dace, and White Suckers

Preliminary surveys of the streams in this study gave indications that affected streams on occasion had higher levels of manganese and suspended silt than unaffected streams, prompting hypotheses that one, both, or a combination of these two factors might be limiting to native fish species.

As reported by Doudoroff and Katy (1953), there are broad discrepancies in reports by different investigators of manganese toxicity. Most investigators however are in agreement that the toxicity of manganese and other heavy metals results from the precipitation of gill secretions and damage to the gill filaments, producing asphyxiation. Jones (1939) correlated the toxicity of heavy metals with their solution pressures and indicated that the relatively low toxicity of manganese was due to its high solution pressure and slow reaction rate with the gill secretions.

Of the three species investigated in this study, rainbow trout were most vulnerable to the toxic action of manganese ions, blacknose dace were next, and white suckers were least vulnerable. Although certainly other factors might be responsible, it is interesting to note that the degree of vulnerability to manganese toxicity closely parallels the relative susceptibility of these different species to hypoxic stress. The comparatively low resistance of white sucker fry to manganese may have resulted from stress due to transportation and handling as the other fry were more directly available.

Even though the toxicity of a compound varies among individuals of a species, among different species, and under different environmental and test conditions, it is significant that the results of all tests in this study (Tables 7-10 and 13-16) tend to substantiate the data of Jones (1939) and Thomas (1924) who reported toxic limits to fish of less than 100 ppm. When considered in relationship to ambient stream levels, however, one can only conclude that the concentrations of manganese in the study streams are not high enough to exert acutely toxic effects on the three species studied.

Since the response of fish to silt in suspension is not a graded one with respect to time, the data (Tables 11 and 12) should be interpreted simply in terms of tolerance rather than median tolerance limits as reported for manganese toxicity. Percentage of mortality could not be assessed except at the end of the experiments, but the condition of the dead fish indicated that mortality probably occurred early in the runs, suggesting an "all or none" response to the suspended silt. Although the limits established for rainbow trout and white sucker fry are much lower than for fingerling rainbow trout, the mortalities measured are probably in large part a response of the smothering action of silt which settled onto the bottoms of test containers, rather than to silt which remained in suspension.

From the experiments concerning the effects of combinations of suspended silt and manganese ions on rainbow trout fry and fingerlings (Tables 13 and 14) two conclusions may be drawn. First, the much lower TLm value for rainbow trout fry as opposed to fingerlings is probably not due to any additive or synergistic effect of the two substances, but to the fact that the precipitating action of the manganese ions on the silt particles creates a sludge on test container bottoms in which resting fry are more prone to suffocation. This supposition is borne out by the fact that the fingerling rainbow trout actually tolerated higher levels of manganese ions in the presence of silt than in its absence, leading to the second conclusion that of the measurable concentration of manganese, much of it is bound to silt particles and is not as available for contact with the test fish. This adds support to the hypothesis that ambient levels of manganese in the study streams affected by strip mining are not acutely toxic since of the manganese ions available to fish, many are probably bound with silt.

While these experiments have demonstrated that neither silt nor manganese singly or in combination is acutely limiting to the species studied, chronic effects are largely unknown. Contrary to the results of Herbert and Merkens (1961) the chronic exposure of trout to moderately high suspended silt loads (about 700 ppm) in this study (Tables 17 and 18) resulted in significantly lower increments in length and weight than occurred in non-turbid water. Mortalities in both groups of fish were negligible, whereas Herbert and Merkens always had some mortality in the turbid waters of their small tank experiments, and only measured the survivors. This suggests that the difference in results may be due to fewer mortalities of adversely affected fish in the larger, more natural raceways of this study.

In summary, it would appear that fish populations in unreclaimed affected streams of this study are probably limited both directly and indirectly by high levels of turbidity and siltation. One direct effect demonstrated was a reduction in growth rate resulting from chronic exposure to high turbidity levels. An effect to be supposed, based upon percentages of silt in the substrate, is a reduction in spawning success. Indirect effects center around reductions in populations of macrobenthos.

Fish and Macrobenthos Densities, Diversities, and Community Structure Relative to Degree of Reclamation

As was mentioned previously, reclamation work was completed on Brushy Mountain (Slemp Creek drainage area) in 1960 and on a portion of the Bishop Branch drainage area in 1966. The only recorded fish and bottom insect collections on these streams prior to the initiation of this study in 1968 were a series of collections made in 1966 with reference to food habits of the banded sculpin (Novak, 1968). Thus, recovery on Bishop Branch can be analyzed from the time of completion of reclamation, but recovery of the fauna in Slemp Creek must be analyzed on the basis of comparisons with unreclaimed affected streams in the same immediate geographic area.

The results of collections of macrobenthic organisms over a two-year period beginning July, 1968 suggest a striking parallel between numbers of organisms per square foot, number of genera, and diversity or complexity of community structure and degree of reclamation. Obvious exceptions to this generalization are the collections on Hurricane Branch and on the lower station of Slemp Creek. The paucity of organisms collected on Hurricane Branch can be related to the extremely soft water (5 ppm total hardness) and to the preponderance of bedrock and shale rubble in the substrate. The apparently tremendous recovery Bishop Branch makes between the upper and lower stations is a result of the stream passing underground for some distance about one-half mile above its mouth. During this underground passage, the stream drops a sizable portion of its silt load.

Although in keeping with the dynamic nature of streams there were significant variations in number of organisms per square foot, number of genera sampled, and diversity from one sampling date to another, a comparison among stations of the mean values for all collections (Tables 3-5) indicate statistically higher values of these parameters for Slemp Creek and the lower station of Bishop Branch. That these results are in close agreement with those of Novak (1968) attests to the static condition of the affected unreclaimed streams, and the advanced state of recovery of Slemp Creek. Close analysis of the parameters discussed above support the conclusions of Gammon (1968) that suspended inorganic sediments bring about an overall reduction in numbers per species. Changes in community structure are probably related to the destruction of populations of "rare" taxonomic groups.

Fish collections made during the course of this study (Table 6) further emphasize the degree of faunal recovery in Slemp Creek and the complete absence of recovery in the unreclaimed streams. It is important to note, however, that in the last two collections of this study four species not listed by Novak for Slemp Creek were collected. These species were the white sucker, rainbow trout, mountain redbelly dace, and the brook silverside. Sheldon (1968) reported that for headwater species succession takes the form of additions to the assemblage. While it is obvious that Slemp Creek is in an advanced state of faunal recovery, the collection of these new species suggests that recovery may not yet be complete, ten years after reclamation.

SUMMARY AND CONCLUSIONS

1. Comparisons of chemical, physical, and biological parameters of streams draining reclaimed as opposed to unreclaimed manganese strip mine areas indicate that the primary factors limiting to the fauna of unreclaimed streams is siltation and turbidity.

2. Reclamation of the spoil areas is effective in reducing turbidity and siltation in the receiving streams. Partial reclamation of spoil areas produced no measurable reduction in these parameters.

3. Fish populations in unreclaimed streams are practically non-existent. After reclamation, the initial re-invaders are probably blacknose dace.

4. Turbidity and siltation in unreclaimed and partially reclaimed streams caused an over-all reduction in the numbers of bottom organisms, resulting in changes in density, diversity and community structure.

5. Faunal recovery in Slemp Creek appears to have been complete 6 years after completion of reclamation efforts.

6. Acute toxicity studies indicate that ambient levels of suspended silt and manganese ions in the study streams are not high enough to be acutely limiting to resident fish species.

7. Chronic exposure of rainbow trout to about 700 Jackson Turbidity Units of suspended inorganic silt resulted in significantly lower growth rates than for fish reared under the same conditions in non-turbid water.

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Appendix Table I. Streambed composition in designated riffle and pool areas of the affected streams for three sampling dates. Values are based on a single sample at each station. Symbols RU, RM, and RL represent riffles in the upper, middle, and lower section of the designated streams. The symbols PU, PM, and PL represent pools in the upper, middle, and lower sections of the designated streams.

Location		Boulders and Rubble 6.35 mm diameter			Gravel 1.68-3.36 mm			Coarse Sand .841-.420 mm			Fine Sand .105-.210 mm			Silt .105 mm		
		1968	1969	1970	1968	1969	1970	1968	1969	1970	1968	1969	1970	1968	1969	1970
Slemp Cr.	RU	61.0	42.2	47.7	13.9	15.0	17.4	20.3	29.3	22.1	4.9	3.2	5.3	10.7	8.5	8.8
	RM	72.1	55.4	63.9	13.0	16.2	12.2	12.7	21.6	18.9	2.1	2.0	1.9	5.3	4.2	3.2
	RL	70.4	64.1	64.6	11.3	11.2	9.2	13.5	17.6	15.5	4.3	2.6	3.6	5.6	5.9	7.4
	PU	19.8	8.4	31.3	10.8	10.0	8.5	57.8	65.9	44.3	9.8	4.2	6.7	12.4	11.6	9.1
	PM	66.2	33.0	54.2	16.5	21.8	17.4	14.2	31.1	18.2	3.0	3.6	4.3	3.9	11.9	5.9
	PL	75.1	66.3	64.2	12.8	11.3	18.5	9.2	16.7	11.1	2.7	2.3	1.8	3.8	3.0	4.2
Bishop Br.	RU	75.6	43.3	50.4	8.9	14.3	9.3	11.4	15.9	14.4	1.7	7.1	8.3	2.4	18.9	17.5
	RM	63.3	35.9	54.8	9.0	10.2	8.7	19.8	27.7	15.8	3.3	5.8	4.7	4.5	20.2	16.3
	RL	81.1	74.7	79.7	6.8	8.9	7.3	5.8	11.0	8.8	1.1	1.9	1.5	1.2	3.6	2.6
	PU	15.3	28.6	28.6	5.6	7.9	8.3	32.4	24.2	23.9	11.1	15.3	16.7	35.7	25.8	22.6
	PM	35.6	51.3	53.8	13.0	13.6	17.4	34.7	19.9	17.5	6.2	3.7	3.3	10.1	11.0	8.5
	PL	31.2	30.9	37.2	3.9	4.5	5.3	37.9	40.6	29.9	11.5	10.7	12.4	15.8	13.8	14.4
Slabtown Br.	RU	59.7	83.3	76.4	9.6	3.2	4.7	16.8	7.8	5.8	5.6	1.8	6.3	8.1	5.4	6.7
	RM	53.7	59.6	54.8	10.3	8.4	6.5	16.5	10.7	14.2	3.0	5.9	5.5	16.4	15.1	19.2
	RL	58.5	77.3	72.5	13.2	8.4	8.3	13.8	4.8	6.3	0.6	3.4	2.7	15.2	5.9	10.1
	PU	19.7	39.5	36.3	15.2	11.6	12.9	14.8	21.5	19.7	5.7	6.8	6.2	39.7	20.5	24.8
	PM	2.0	0.0	2.8	9.1	0.0	4.3	25.9	32.1	24.2	3.7	31.9	27.4	60.0	36.0	41.5
	PL	0.5	30.0	20.1	4.3	9.7	8.2	24.1	15.3	16.3	1.5	14.6	12.1	69.6	30.5	43.4
Georges Br.	RU	65.6	71.7	65.0	8.6	7.4	10.4	16.9	12.4	15.2	4.1	4.5	3.9	5.0	3.8	5.5
	RM	0.0	57.7	58.7	0.0	10.0	8.3	0.0	13.8	12.1	0.0	6.2	7.3	0.0	12.4	13.9
	RL	42.9	52.6	47.8	9.3	8.8	5.9	27.5	17.5	21.9	10.3	6.5	8.2	9.9	14.8	16.0
	PU	39.6	35.5	32.9	3.5	4.5	6.7	19.9	24.7	18.6	15.7	11.1	14.7	21.3	24.9	27.2
	PM	0.0	40.7	43.2	0.0	4.9	3.4	0.0	22.3	23.5	0.0	14.6	11.5	0.0	17.4	18.3
	PL	15.6	8.8	5.8	6.4	2.6	4.4	22.5	29.2	27.3	19.4	29.2	31.5	36.9	25.0	31.1

Appendix Table II. Streambed composition in designated riffle and pool areas of the control streams for three sampling dates. Values are based on a single sample at each station. Symbols RU, RM, and RL represent riffles in the upper, middle, and lower section of the designated streams. The symbols PU, PM, and PL represent pools in the upper, middle and lower sections of the designated streams.

Location		Boulders and Rubble 6.35 mm diameter			Gravel 1.68-3.36 mm			Coarse Sand .841-.420 mm			Fine Sand .105-.210 mm			Silt .105 mm		
		1968	1969	1970	1968	1969	1970	1968	1969	1970	1968	1969	1970	1968	1969	1970
Hurricane Br.	RU	82.0	69.0	71.3	10.1	6.1	5.3	6.6	13.7	14.2	1.2	2.4	1.8	4.9	8.6	7.3
	RM	71.6	57.8	59.3	12.5	13.0	22.5	7.4	15.7	6.4	1.4	3.0	4.2	7.0	10.2	6.6
	RL	78.4	74.9	67.1	7.4	13.3	18.7	10.9	7.8	6.5	0.5	1.5	2.0	2.7	3.4	1.8
	PU	66.9	59.0	67.5	7.3	7.4	9.6	13.5	15.6	14.2	4.8	4.8	3.7	7.5	13.0	5.3
	PM	71.4	53.8	59.7	13.8	19.5	21.7	12.3	14.5	12.4	2.5	4.1	2.4	4.8	5.1	3.9
	PL	85.9	66.7	72.1	7.4	18.2	19.3	3.6	6.6	5.4	0.6	3.1	0.9	2.6	5.5	2.4

VITA

The author of this paper was born in Letcher County, Kentucky, on September 30, 1940. He lived in Jenkins, Kentucky, and attended Jenkins High School until he graduated in 1958. He entered Morehead State University, Morehead, Kentucky, that same year and graduated with a B. S. degree in Chemistry and Biology, June, 1962.

He was employed as a high school science teacher by the Maysville, Kentucky, City School system for one year and by the Carter County school system for two years. In August, 1965, he received his M. A. degree in secondary education and was employed by Morehead State University as an instructor of biology. He maintained that position until July, 1968, when he took a leave of absence to return to graduate school at Virginia Polytechnic Institute.

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He married the former Miss Eunice Ison in Jenkins, Kentucky, July 1, 1962. Their daughter, Daphne Lea, is three years old.

Donley M. Hill

STREAM FAUNAL RECOVERY AFTER
MANGANESE STRIP MINE RECLAMATION

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ABSTRACT

In order to measure the effectiveness of manganese strip mine reclamation relative to stream faunal recovery, periodic stream monitoring activities and acute and chronic toxicity studies were conducted from July, 1968 through September, 1970. The streams studied drained areas representing four degrees of reclamation; reclaimed, partially reclaimed, unreclaimed, and unaffected.

Analysis of the physical, chemical, and biological parameters monitored indicates that the pollutant limiting to populations of fish and bottom organisms in the reclaimed and partially reclaimed streams is inorganic silt. "Complete" reclamation of spoil areas measurably reduces levels of siltation and turbidity, thus permitting recovery of the previously stressed faunal communities.

The acute toxicity studies indicated that ambient levels of suspended silt and manganese ions in the study streams are not high enough to be acutely limiting to resident fish species. However, chronic exposure of rainbow trout to about 700 Jackson Turbidity Units of suspended inorganic silt resulted in significantly lower growth rates than for fish reared under the same conditions in non-turbid water, suggesting adverse physiological effects of sublethal levels of silt in suspension.