A Symposium on the Recovery and Restoration of Damaged Ecosystems, Co-sponsored by the Association of Southeastern Biologists and the Center for Environmental Studies, Virginia Polytechnic Institute. The idea of this symposium was conceived by John Carpenter of the University of Kentucky some three years ago, and was finally brought to fruition through the combined efforts of many people throughout the Southeast. The four papers comprising the symposium were presented, by invitation, at the 32nd Annual Meeting of the Association of Southeastern Biologists, hosted by the University of Richmond, in April, 1971.

The Recovery of Damaged Streams

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From the four case 'history studies' presented it appears that the biological recovery of damaged rivers is a function of the physical, chemical, and biological characteristics of the receiving stream, the severity and duration of the stress, and the availability of undamaged areas to serve as sources for recolonizing organisms.

Short- term acute stresses produced by the release of acidic or caustic materials into a receiving stream elicit a response pattern in the macroinvertebrate and fish communities typified by an immediate reduction in the number of specimens. When no residual toxicity is found and there are undamaged areas available to act as sources for recolonizing organisms a rapid recovery may be expected. Mill Creek had such a recovery when a small (100 foot) section of the creek was experimentally treated with acid immediately below an undamaged headwater area. By comparison the biological recovery of the Clinch River from the acute pH stresses has been somewhat slower due to the severity and the extent of the biological damage.

A long term acute stress and stresses from materials with residual toxicities produce a similar but slightly different response pattern. Just as in short term acute stress situations the general response pattern is an immediate reduction in both diversity (number of species) and density. However, with residual toxicities the macroinvertebrate organisms that survive the stress seem to be able to establish an interim type of community structure which lasts as long as the toxicity persists. For example, the Roanoke River had a residual toxicity from the ethyl benzene — cresote spill which was combined with a sedimentation problem and resulted in an atypical benthic community consisting of snails, midge larvae, mayflies, and stoneflies. This community did not have representatives from the caddis fly, riffle bettle, and crayfish families. The macroinvertebrate community found under continuous acid stress in the Indian Creek study was also atypical consisting primarily of caddis flies and hellgrammites.

The rate of recolonization of damaged areas seems to be dependent upon 1) the distance an area is located from the site of the original spill and 2) the existence of undamaged tributaries. Those areas immediately below the site of the Clinch River spills were the first to show recovery. Reaches of the river further downstream were slower to recover. The rate of recovery is also faster below healthy tributaries as shown in the Indian Creek study.

ASB Bulletin

Aquatic ecosystems have the ability to assimilate a certain amount of waste material and maintain near normal function. With the constant use and reuse of water from our natural aquatic systems by industries, agriculture, and municipalities the function may be altered or disrupted if the assimilative capacity is exceeded. The ability of a stream or river to assimilate wastes is governed by the capacity of the system to transform them before they reach deleterious levels. If an overload occurs, the system is disrupted, and the transforming capacity may be substantially reduced. Recovery may be rapid or slow depending upon a number of factors including: (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.).

Industrial spills typically involve an abrupt release of a waste into a river. The waste usually passes downstream in a slug which lengthens as it proceeds due to mixing characteristics of the river and channel water. Exposure to peak concentration is usually short and will vary depending on velocity and other factors. This usually produces an acute stress which may eliminate most of the least tolerant organisms, but has considerably less effect upon the populations of moderately tolerant and tolerant organisms. Once the stress is removed or reduced the community will become reestablished through processes such as downstream drift and other methods of recolonization, although many of the species may be different from those originally present.

The assessment of biological damage caused by spills is in the early stages of development, and has been little more than cursory. It is usually restricted to observations of fish mortality and rarely includes detailed observations of the effects upon lower organisms. Observations may not begin until hours or even days after the spill, and are often carried out by untrained people. Interpretation of this information is difficult for many reasons, primary among these is the lack of information about conditions which existed before the spill and the rather random and unplanned gathering of data by untrained observers after the spill.

To restore damaged ecosystems we must understand both the processes which lead to disruption of ecosystem function and processes which are involved in the restoration of structural and functional integrity. The purpose of this paper is to describe the response of complex aquatic communities to an acute stress and to describe the natural recovery processes which occur when the stress is reduced or removed. These processes must be understood before appropriate management practices can be developed for (1) gathering relevant and useful information when a spill occurs, and (2) restoring and rejuvenating damaged areas.

SHOCK ACIDIFICATION OF A HEALTHY STREAM

To simulate a short term stress which leaves no residual toxicity, an acute acid stress was produced in a portion of a small mountain stream. The effects of the acute stress and the subsequent recovery of the aquatic community were studied. Mill Creek, a tributary to the North Fork of the Roanoke River near Blacksburg, Virginia was used in this study. The total length of the stream is 2.5 miles, its average width is 3 to 8 feet, and its depth ranges from two feet in pools to 6 to 8 inches in the riffle areas. There are springs along most of its length which maintain a fairly constant discharge. The temperature varied between 15 and 17 degrees Celsius in the summer with a gradual decrease in the fall to a winter minimum of 7 degrees Celsius. The stream has a very diverse fauna including naturally reproducing brook trout. More than 100 macro-invertebrate taxa were identified during the course of the study.

Materials and Methods

To create two sites of comparable habitat, a 100-foot straight riffle section was divided in half along 60 feet of its length by imbedding in the stream bed corregated roofing material covered on the lower quarter with plastic sheeting. The average width of this stream section was 6 to 8 feet with a typical depth over the riffles of 8 inches. To allow recovery from the effects of installation of the divider, the site was left untouched for four weeks prior to commencement of experimental work. When the stress was applied, the flow was alternately reduced on both sides of the divider for fifteen minutes (this increased the flow on the other side), and concentrated technical grade sulfuric acid was poured along the length of the experimental side during the reduced flow period. The pH in the treated section was reduced to well below 4.0 and maintained at that level for fifteen minutes. As water left the experimental section it was neutralized to pH 7.0 with sodium hydroxide.

Macro-invertebrate samples were collected in both treated (experimental) and reference (control) sections four weeks before as well as immediately before acid addition. Samples were also collected immediately after acid addition (day 0) and on day 2, 6, 13, 19, 28, and 34, following with additional samples at 14 to 60 day intervals. Each sample represents a composite of five Surber square foot bottom samples from both treated and reference sections on each date. Samples were collected in an upstream direction starting at the furthest downstream portion of the test site so that no area was sampled twice or was downstream from an area where sampling had occurred. Each Surber sample on successive dates was collected from the vicinity of the prior collection ±4 feet but never in the same area. Density was calculated as the average number of organisms in five square feet of bottom, diversity was calculated utilizing a method developed by Wilhm and Dorris 1968. Water chemistry was carried out with a Hach engineers' kit each time invertebrate collections were made.

Results

Figures 1 and 2 show that both treated and reference sections were stressed as a result of the experimental procedure. Density declined over 30% in both the treated and reference sections after acid addition. Since flow was alternately reduced and increased in both sections, the decline in density in the reference section was due either to the detrimental effects of low flow, or to the increased flow when water was diverted from the other side. The acid treated area, however, shows a more dramatic alteration with marked changes in both diversity and density. Two days after treatment, the community structure diversity index ($\bar{d}$) in the treated section

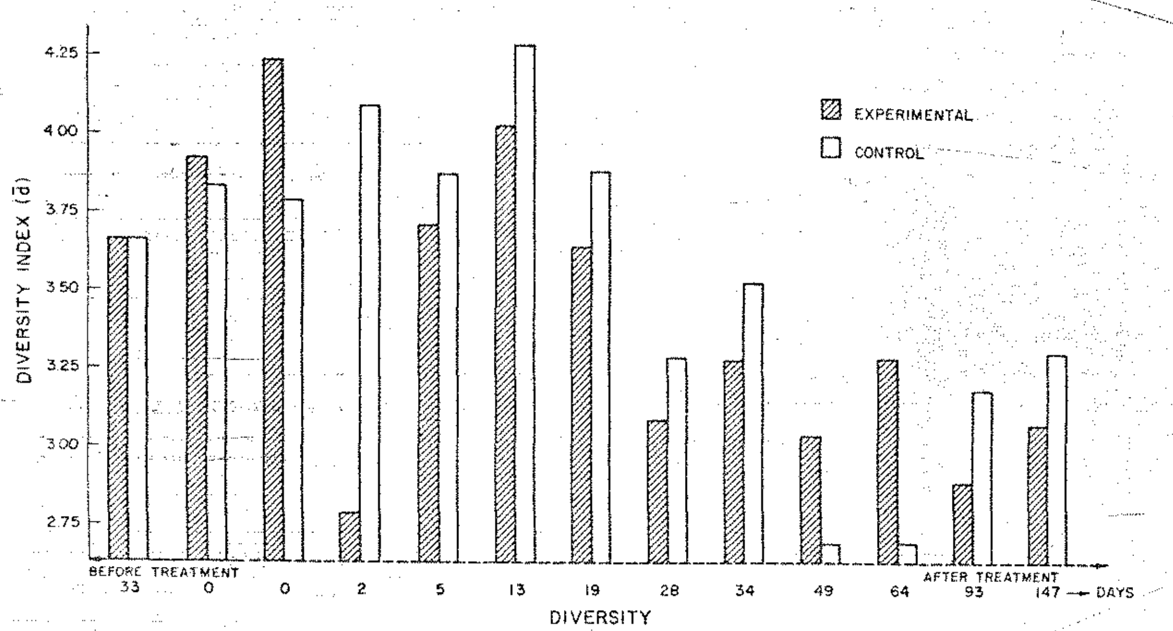


Figure 1. Diversity values obtained for the experimental and reference sections of Mill Creek.

was below 3.0 (Whilm and Dorris, 1968), indicating a stressed situation, while the $\bar{d}$ value for the reference section showed a health situation, above 4.0 (Figure 1). Density at this time in the treated section remained near 40 organisms/ft², while the reference section showed a large increase to over 200 organisms/ft². Recovery continued in the experimental section through day 19 when $\bar{d}$ and density values reached or exceeded the values recorded 33 days before the acid treatment. Restoration to a dynamic equilibrium occurred after day 19, with an average $\bar{d}$ value for days 28 — 147, of 3.0 and an average density of 130 organisms/ft².

Recovery in the reference section from the stress of low and high flow was very rapid. Two days after the experimental procedure was carried out the $\bar{d}$ value was greater than 4.0, and the density value was greater than 200 organisms/ft². The reference area was recolonized at a higher average density than the treated section, and diversity indices remained well above 3.0 through day 49. On day 49 the $\bar{d}$ value obtained, 2.69, indicated a stressed community. This decrease in $\bar{d}$ was accompanied by a decrease in density. The reference section showed a recovery pattern of increasing diversity and density through day 147 when the experiment was terminated.

Discussion

Immediately after treatment the diversity index in the treated section showed a temporary rise while density remained low (Figure 1). This was probably due to a non-selective reduction of organisms in the treated community due to the low pH shock combined with an increase in downstream drift due to changes in flow (Minshall and Winger, 1968). Two days after treatment the $\bar{d}$ value was very low, 2.79, as was the density, 43 organisms/ft². The reference area showed little alteration in diversity and had a very high density, 205 organisms/ft² at this time. This difference was probably due to the destruction of food organisms and temporary changes in the habitat which made immediate recolonization of the treated section unsuitable. Some of the surviving species had striking increases in numbers of individuals on day 2, becoming dominant in the community. This dominance was reflected in the low diversity value obtained for this day. Five days after treatment the community structure had regained some of its original complexity. The $\bar{d}$ value for day 5 was above

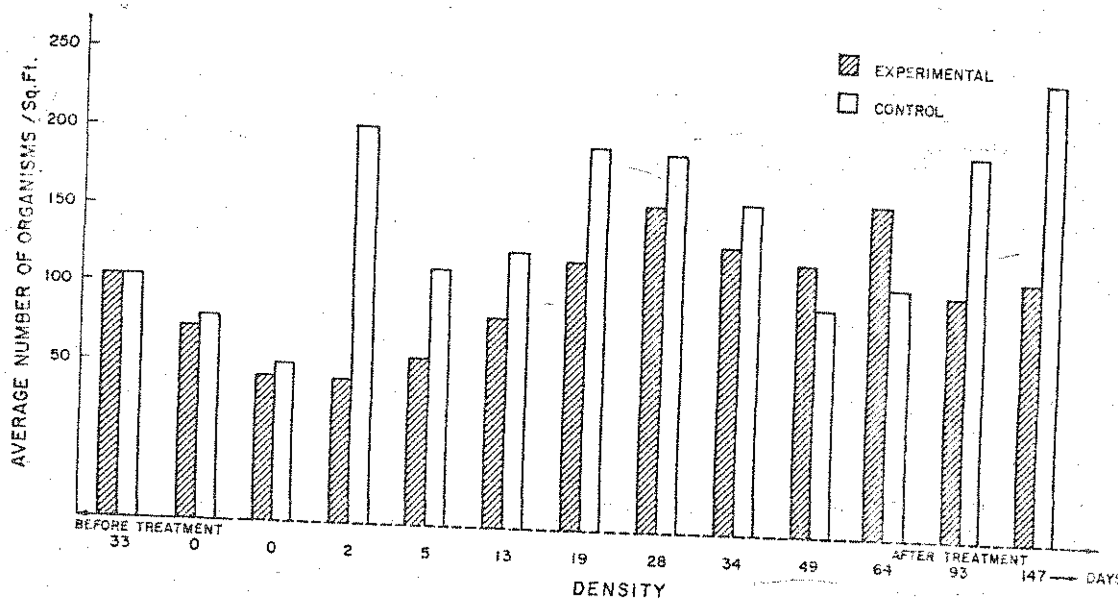


Figure 2. Density values obtained for the experimental and reference sections of Mill Creek

3.0, and density rose to 53 organisms/ft^2. During days 13 through 28 the community completely recovered, reestablishing its former level of complexity as evidenced by high diversity and density values. Decreases in $\bar{d}$ and density during the late stages of the experiment was undoubtedly due to a number of factors. The most important probably were fall emergence of adult insects and a low grade stress produced by high suspended solids loading (Cairns, 1967).

The effect of higher than normal sediment loading was noted in the reference section. Rainfall shortly before sampling on days 49 and 64 produced runoff with high suspended solids. Runoff from adjacent fields and a dirt road was channeled along the reference section by the divider. This load added to the light sediment load the stream carried during normal runoff situations produced a stress situation in the reference section (the two sides were otherwise similar). On day 49 the reference section had low values (Figure 2) and both $\bar{d}$ (2.69 reduced from 3.52) and density (95 organisms/ft^2 reduced from 166 organisms/ft^2) when compared with the previous sample. Recovery from this stress was slow due to the residual effect of deposited sediment on the substrate.

Conclusions

The results of the experimental acidification of Mill Creek provided information on the response of a stream fauna to an acute stress which left no residual toxicity. Community structure analyses ($\bar{d}$) and density values decreased after the pH shock and rose to pre-shock levels by day 28. The instability of the aquatic community after the pH shock was evidenced by a large difference in values of the reference and experimental sections after treatment. This difference decreased through time and after day 28 the values for $\bar{d}$ and density oscillated around a mean value. The mechanism of restoration in the experimental section was probably the downstream drift of invertebrate species which recolonized the damaged area.

RECOVERY FROM ACID MINE DRAINAGE

Long term stresses produce effects which may severely alter the aquatic environment. Acid drainage from mining operations may persist for many years. Acid discharges have been noted since the late 1600's when they were observed in association with the first productive coal beds in the United States (Eavenson, 1942). A more complete description of the "sulphur water" was given by T. M. Harris in 1803: "Spring water issuing through fissures in the hills which are only masses of clay, is so impregnated with bituminous and sulphurous particles as to be frequently nauseous to the taste, and prejudicial to the health" (Eavenson, 1942). A 1962 report prepared for the Committee on Public Works of the House of Representatives on Acid Mine Drainage notes that there are 48,000 miles of streams and 29,000 surface acres of impoundments affected by acid discharges. A more recent appraisal of the mine drainage problem in Appalachia, made by the Appalachian Regional Commission (1967), noted there were 10,500 miles of streams in Appalachia which received a total of 6,000 tons of acidity per day. Total acid loads for all streams in the U.S. is estimated at 3.5 million tons/year. These acid discharges often result from mining operations when sulfuric minerals are oxidized in water producing acids and heavy metal hydroxides. Acid may be produced from the mining of lead, zinc, barite, manganese, gold, anthracite, and bituminous coal.

The acid drainage problem is localized in areas of moderate rainfall where solution and oxidation of the minerals pyritic, marcastics and pyrites (FeS) can take place and acid formation can occur.

$$\underset{\text{(Pyrite)}}{2FeS_2} + 2H_2O + 7O_2 \rightarrow \underset{\text{(Ferrous sulfate)}}{2FeSO_4} + \underset{\text{(Sulfuric acid)}}{2H_2SO_4}$$

$$\underset{\text{(Ferrous sulfate)}}{4FeSO_4} + 2O_2 + 2H_2SO_4 \rightarrow \underset{\text{(Ferric sulfate)}}{2Fe_2(SO_4)_3} + 2H_2O$$

$$\underset{\text{(Ferric sulfate)}}{Fe_2(SO_4)_3} + 6H_2O \rightarrow \underset{\text{(Ferric hydroxide)}}{2Fe(OH)_3} + 3H_2SO_4$$

$$\underset{\text{(Ferric sulfate)}}{Fe_2(SO_4)_3} + 2H_2O \rightarrow \underset{\text{(Basic ferric sulfate)}}{2Fe(OH)(SO_4)} + H_2SO_4$$

The most intense area of acid drainage is in the Appalachian region coal fields in the eastern United States. The reaction is both chemical and biochemical in nature (Silverman, 1967). The dissolution of one mole of the pyritic material leads to the production of four equivalents of acidity. It is this acidity associated with heavy metals and other byproducts of mining operations which may produce the high stress situations in the aquatic environment.

Coal production in the Appalachian region began in the late 1800's and reached a peak between 1910 and 1940. Two major methods are used in the mining of coal. Subsurface operations include deep shaft and drift mines while surface mining includes strip and auger mining. The effects of each type of mining operation on the environment depend largely on the geological and hydrological nature of the area and the physical and chemical characteristics of the coal seam to be mined. Deep shaft mines normally lie below the water table and have a constant supply of water which put minerals into solution. When this water comes to the surface, or in contact with air in the mine, the pyritic materials are rapidly oxidized producing large amounts of acid. Active deep mining operations usually control the water level in the shaft, but abandoned mines soon fill up with water and can produce severe drainage problems. It is estimated that approximately 75% of the total acid production has its source in subsurface mining operations.

The effect of surface mining on the environment are much more noticeable. Of the total of 3.2 million acres disturbed by surface mining operations in the United States, 41% are due to coal mining operations, and 62% of these operations occur east of the Mississippi River (USDI 1967). Strip mining operations normally expose large areas of land to erosion, and great quantities of pyritic materials to oxidation. The pyritic materials are usually found in slag and gob piles, byproducts of surface coal mining, and are porous, allowing free circulation of water and air within the pile, thus both active and abandoned mines produce acid discharges. It is estimated that approximately 40% of the acid drainages are from active mines, and of the remaining 60%, 35% is attributed to abandoned shaft and drift mines, and 25% to abandoned surface mines.

Acid mine drainage is typified by low pH water, high hardness, suspended solids and dissolved solids such as Fe and SO_4. The criteria for determination of acid discharges are contained in Table 1. As previously described, the oxidation of pyritic materials produces large quantities of sulfates. Sulfates are usually present in low concentrations in nature (less than 20 ppm) and are found in high concentrations in acid mine discharges. Other elements of acid discharges tend to precipitate or plate out of solution while sulfate remains inert and detectable. This makes sulfate the best trace substance to identify mine discharges. The low pH conditions present in most mine discharges increase the solubility of heavy metals; mine discharges may also have high concentrations of zinc, copper, manganese, calcium, magnesium and arsenic. The increased solubilities of heavy metals in low pH situations may produce situations where synergistic or antagonistic reactions can occur which place further stress on the biological portion of the system.

TABLE 1. — Criteria for determining acid mine drainage

pH	less than 6.0
Acidity	greater than 3 mg/l
Alkalinity	normally 0
Alkalinity/Acidity	less than 1.0
Fe	greater than 0.5 mg/l
SO_4	greater than 250 mg/l
Total Suspended Solids	greater than 250 mg/l
Total Dissolved Solids	greater than 500 mg/l
Total Hardness	greater than 250 mg/l

Two streams were selected to determine the effects of acid mine drainage on the aquatic environment, and to study recovery of conmmunities which were affected by acid discharges. Indian Creek, a tributary to the Youghigheny River in S. Pennsylvania was selected because it had an isolated acid discharge and showed full recovery in a rather short distance. This stream was neutralized naturally by alkaline tributaries which diluted the mine discharges and neutralized the free acidity in the streams. A second site was selected which was artificially neutralized by a lime neutralization plant. Little Scrubgrass Creek in Venango County in northwestern Pennsylvania had approximately the same discharge as Indian Creek. In each case the regions had been fairly extensively studied by the Pennsylvania Department of Mines and Mineral Industries or the Fish Commission;

data from their reports were useful as background material.

Indian Creek

Indian Creek is located in Westmoreland and Fayette Counties in southwestern Pennsylvania (Figure 3). The stream flows southeast from its origin in Westmoreland County to its confluence with the Youghigheny River in Fayette County. The total drainage area of the stream is 124 square miles of which 28% is in Westmoreland County and 72% in Fayette County. The total length of the stream is 27 miles with an average discharge of 85 cfs. Maximum discharge during the water year of 1966 was 256 cfs., with 2 cfs. the minimum discharge. Indian Creek flows along the Ligonier-Barnesboro Syncline in a shallow valley ¼ to ½ mile wide. The surface rocks in the area are of Pennsylvania age made up of shales and weak sandstones, interbedded with coal beds. No major limestone formations exist in the Indian Creek Valley, but limestone exposures do occur in Laurel Hill to the east.

Five sampling stations were established on Indian Creek. Station 1 was located 200 feet above the confluence of Indian Creek with Champion Run. Station 2 was located in the mouth of Champion Run. Station 3 was located .25 miles downstream from Champion Run. Station 4 was located 2.5 miles, and Station 5 was 8.5 miles downstream from Champion Run. All stations were ecologically similar. A station was comprised of a shallow riffle area with rock or gravel substrate with wooded banks of rather gentle slope. Each station was sampled in a similar manner with the exception of Station 2. Five Surber square foot bottom samples were made in a transect across the stream, and qualitative samples were collected with a Turtox 8″ × 10″ × 18″ bottom net. Station 2 consisted of a shallow riffle covered heavily by a $Fe(OH)_3$ flock. It was impossible to obtain a quantitative sample from this area so only a qualitative bottom net sample was taken. Samples were preserved in 70% alcohol and returned to the laboratory for analysis.

All samples were treated in the same manner and bottom fauna were floated from the bottom substrate in a 1.12 s.g. sugar solution, a modification of the techniques by Anderson (1959). The organisms were then separated and identified to genus wherever possible. Species diversity was calculated by the technique developed by Wilhm and Dorris (1968). Density values were calculated as the average number of organisms per square foot, while the community diversity index included all organisms collected at a station.

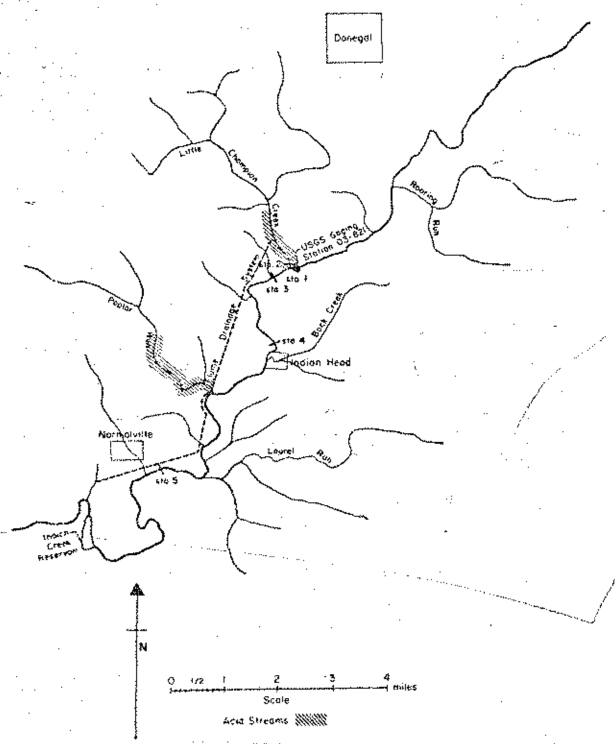


Figure 3. Indian Creek, Fayette County, Pa.

Results and Discussion

Water chemistry results from Indian Creek (Table 2) shows that Indian Creek normally has a high pH and alkalinity. After entrance of Champion Run (pH 3.9 and total acidity 94 ppm) the pH of Indian Creek is depressed one pH unit, and the alkalinity is severely reduced. At Station 3 the alkalinity/acidity relationship is 1, a marginally acid stream. Alkalinity is further reduced at Stations 4 and 5, but the alkalinity-acidity ratio is well above 1, indicating a healthy chemical situation.

The effect of the acid tributary on Indian Creek was very severe. The upstream reference station showed a community structured ($\bar{d}$) value slightly below 3.0, and a low density (Figure 4). When values are compared with a healthy mountain stream, i.e. Mill Creek (Figure 2), the density is very low. Station 2 showed an extremely low $\bar{d}$ value. Stations 3 and 4 showed diversity values below 2.0 and very low density values. Station 5 showed a diversity near 3.0 with density values greater than the reference station.

Station 1 was located behind a group of houses with several suspected sewage outfalls observed in the bank. The $\bar{d}$ values at this station, below 3.0 are typical of a moderately stressed situation, and are probably due to the influence of sewage on the bottom community. Two genera of caddisflies made up over 50% of the number of organisms at this station with organisms intolerant to high organic enrichment found in moderate numbers. This indicates an enriched situation with pollution loads of moderate intensity. Station 2 was a combined organic enrichment and low pH stress situation. A total of 186 organisms were collected at this station, 185 *Tendepes* sp. and 1 caddisfly larva. Stations 3 and 4 both further downstream of the acid discharge, showed $\bar{d}$ values below 2.0, indicating a highly stressed situation (Figure 5). Density was low at both stations, below 10 organisms/square foot.

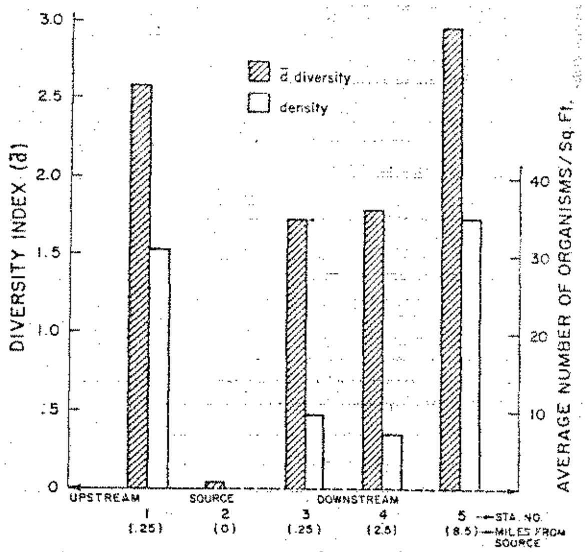


Figure 4. Density and diversity values obtained for stations on Indian Creek.

TABLE 2. — Representative water chemistry from Indian Creek.

Station Number:		1	2	3-LB	3-RB	4	5	I	II
Date		10/16/70	10/16/70	10/16/70	10/16/70	10/16/70	10/16/70	10/10/70	10/10/70
Free Acidity	(Hot)	0	0	0	0	0	0	0	0
ppm as $CaCO_3$	(Cold)	0	18	0	0	0	0	0	8
Total Acidity	(Hot)	10	94	10	4	4	4	6	40
ppm as $CaCO_3$	(Cold)	6	64	8	4	4	4	6	42
Total Hardness gpg as $CaCO_3$		3.96	11.31	6.06	4.78	6.17	4.31	4.66	6.29
Calcium gpg as $CaCO_3$		2.91	6.64	3.96	3.14	3.73	2.91	3.14	3.84
Fe ppm		0	1	0.66	0.45	0	0	NR	1.0
pH		7.8	3.9	6.4	6.8	6.8	RB-6.5, LB-6.7	7.6	below 3.7
Specific Conductance (in millimhos)		.155	4.1	.21	.17	.195	RB-.15, LB-.15 M-.155		
CO_2 ppm		1.76	61.6	7.04	1.76	1.76	1.76	3.52	33.44
Phenolphthalein Alkalinity ppm as $CaCO_3$		0	0	0	0	0	0	0	0
Methyl Purple Alkalinity ppm as $CaCO_3$		40	0	10	24	16	18	12	0

Since no major tributaries enter Indian Creek between Champion Run and Station 4, the acid discharge may effectively reduce downstream drift if not block it completely. This section of the stream showed improved water quality, but is evidently dependent on airborne sources for recolonization. Because there are no tributaries to dilute the effects of the acid discharge, residual conditions in this region may make it unsuitable for recolonization of any type, or periodic increases in discharge from Champion Run may keep development of a healthy community in this region restricted. Station 5 had a $\bar{d}$ value near 3.0 (a healthy situation) with a density value greater than found at the reference station. Two major tributaries, Back Creek and Laurel Run enter Indian Creek between Station 4 and Station 5. These tributaries have the dual effect of further diluting the acid discharge, and acting as a source for recolonization in the downstream sections. Caddisfly larva still predominate at Station 5, but comprise less than 50% of the total number of organisms at the station. A large number of organisms intolerant to stress are present at this station including stoneflies and mayflies.

Little Scrubgrass Creek

Little Scrubgrass Creek is located in Venango County in northwestern Pennsylvania (Figure 5). The stream flows northeast to the Allegheny River. The total drainage area of the stream is approximately 15 square miles, and the total length of the stream is 8 miles. The stream lies in the Allegheny formation of Pennsylvania age. The stream flows through two rock types. The upstream portion is in the Conemaugh Formation consisting of soft sandy shales, a strong sandstone at the base, and interbedded with thin coals and limestone. The downstream portion flows through the Pottsville Formation predominated by sandstone with large shale lenses and thin seams of coal (Shaw and Munn, 1911). The upper portions of the stream have a low gradient, with the lower portions having a high gradient. The stream from Suttonmill drops more than 300 feet in approximately 2 miles to the confluence with the Allegheny River. In the headwaters of Little Scrubgrass there are 11 deep mines, and 6 strip mining operations. The deep mines have been abandoned since 1950, and the strip mining operations have been sporadic since that time. The state of Pennsylvania has been active in reclamation of abandoned mines in the area. Most of the deep mines have been sealed, and backfilling operations have begun on many of the abandoned strip mines.

The history of reclamation procedures in Little Scrubgrass extends prior to 1949. In March of 1949 the pH of the stream was recorded to vary between 3.2 in the upper portions to 6.7 approximately five miles downstream from the present neutralization site. No fish-food organisms were found above the confluence of Little Scrubgrass with the North Fork of Little Scrubgrass, and the stream was classified as chemically suited for stocking below the entrance of the South Fork, but because of low food production it was regarded only as a temporary holding stream (Penn-

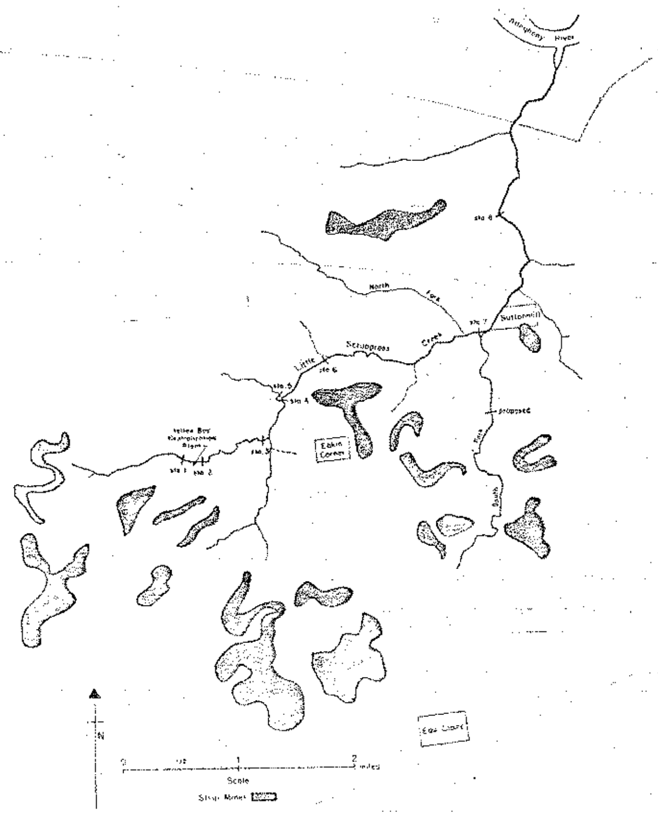


Figure 5. Map of Little Scrubgrass Creek, Venango County, Pa.

sylvania Fish Commission, unpublished). In 1966 the Department of Mines and Mineral Industries established an automatic lime neutralization plant in the headwaters of Little Scrubgrass (Maneval, 1968). The neutralization plant began operation in 1967 and other restoration procedures, including backfilling operations on the strip mine areas were undertaken at this time. The effect of this plant on the fish production of the stream was studied by the Pennsylvania Fish Commission, and several samples were made of fish populations and fish-food organisms (unpublished reports 1968, 1969). The initial effect of the plant was improvement of water quality; the pH above the plant was reported at 3.8 and that below the plant above 7.0 throughout the stream. The original liming operation produced a very thick $Al(OH)_3$ floc which covered the bottom of most of the stream, and made it unsuitable for the development of fish food organisms (Pennsylvania Fish Commission, unpublished). In 1969 the Department of Mines and Mineral Industries added a settling basin to the liming operation to remove the flocculent material. The effectiveness of this pond is noted in the present sampling. No floc was noted in the stream, and rich development of a macrobenthic community had occurred.

A total of 8 sampling stations were established on Little Scrubgrass. Stations were ecologically similar, with shallow riffle areas and good bank vegetation. Stations 1 and 2 were located above and below the liming plant respectively. The very low gradient in this region along with the high sedimentation due to upstream mining made quantitative sampling impossible. Bottom net samples were taken from diverse habitats to note the diversity in this region.

Sampling procedures were the same as described for Indian Creek. Because Little Scrubgrass is a small stream, the Surber samples were taken in an upstream direction rather than in a transect. Qualitative sampling involved sampling of both riffle and pool areas where they were adjoining.

Results and Discussion

The water quality in Little Scrubgrass is improved measurably by the lime neutralization plant. The upstream portions of the creek have a low pH and an alkalinity/acidity ratio of well below 1 indicating highly acid conditions. The lime neutralization process raises pH and improves the alkalinity/acidity ratio to well over 1 for the remainder of the stream. The pH of the stream

TABLE 3. — Representative water chemistry from Little Scrubgrass Creek.

Station Number:		1	2	3	4	5	6	7	8
Date		10/27/70	10/27/70	10/27/70	10/28/70	10/28/70	10/28/70	10/28/70	10/28/70
Free Acidity	(Hot)	0	0	0	0	0	0	0	0
ppm as $CaCO_3$	(Cold)	0	0	0	0	0	0	0	0
Total Acidity	(Hot)	26	0	4	4	4	2	2.5	4
ppm as $CaCO_3$	(Cold)	14	0	2	4	4	2	2	4
Total Hardness gpg as $CaCO_3$		17.4	19.82	15.39	12.94	6.64	9.67	9.56	9.21
Calcium gpg as $CaCO_3$		10.14	15.27	12.47	10.14	5.13	6.99	7.22	6.76
Fe ppm		0	0	0	0	0	0	.3-.4	0
pH		4.5	7.10	8.5	7.50	8.10	7.0	6.9	6.9
Specific Conductance (in millimhos)		4.15	4.05	2.8	3.1	.17	.27	.255	.255
CO_2		10.56	0	1.76	1.76	3.76	1.76	1.76	1.76
Phenolphthalein Alkalinity ppm as $CaCO_3$		0	24	0	0	0	0	0	0
Methyl Purple Alkalinity ppm as $CaCO_3$		4	42	34	38	50	34	34	36

remains near 7.0 and the alkalinity in downstream portions of the stream is very high (Table 2).

The effects of the limer on the aquatic organisms of the stream were also very beneficial. Station 1 upstream from the limer had a community structure diversity index ($\bar{d}$) value near 2.0 indicating a stressed situation (Figure 6). Station 2 immediately below the limer had an increased $\bar{d}$ value although the number of organisms at this station was very low (Figure 8). Station 3 showed a very high $\bar{d}$ value, well above 3.0, but density was still very low. Station 4, located immediately above a very healthy tributary, had a $\bar{d}$ value lower than Station 3, but the density value increased and the total number of organisms at the station was more than twice that found at Station 3. Station 5 was located in a healthy tributary free from the effects of mine drainage. The community structure index ($\bar{d}$) value was near 3, and the density value was similar to those found in a healthy mountain stream (Figure 2). Station 6 had a high $\bar{d}$ value with density almost double that of Station 4 with an increase in the total number of organisms at the station. Stations 7 and 8 both show decreased $\bar{d}$ values, and very low densities. The total number of organisms at Station 7 was greater than Station 8, but was approaching the values found at Station 3.

The effects of acid mine drainage on the organisms in Little Scrubgrass were not as severe as those found in Indian Creek. Station 1 was well vegetated, and the substrate was a loose silt deposited to a depth of 1.5 to 3.0 feet over the original substrate. The effects of vegetation and gentle water flow produced a community unlike other samples. The samples were dominated by the Neuropteran, *Sialis* sp. and the Dipteran *Tendepes* sp. These organisms are resistant to low pH (Katz, 1969). Station 2 had a very low number of organisms and a low diversity value. The installation of the settling pond created an artificial stream channel through a loose clay material. This artificial channel joined the original channel a short distance below the neutralization plant. It is suspected that this substrate was unsuitable for the development of a diverse bottom fauna. Station 3 was located in a short riffle immediately below a small pool area. The diversity value here was high although the density was very low. The

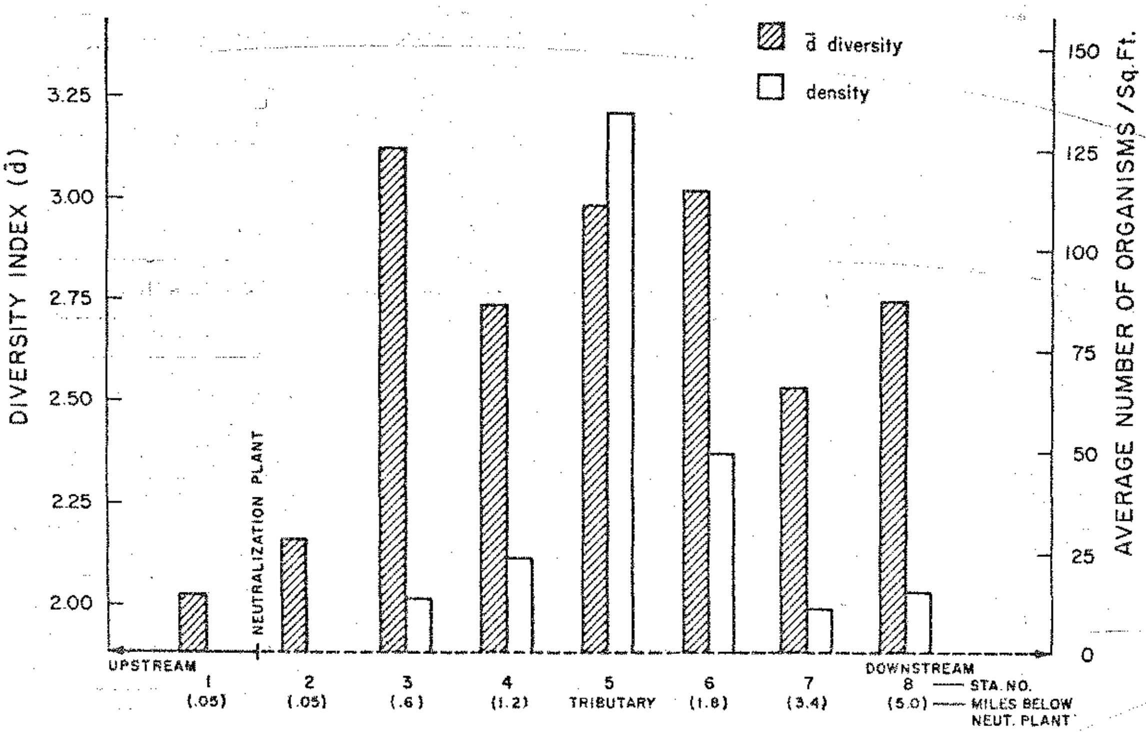


Figure 6. Density and diversity values obtained for stations on Little Scrubgrass Creek.

organisms which predominated were Dipterans, all typical of slow water habitats. Station 4 was located in a good riffle area immediately before the entrance of an unnamed tributary. The community structure evaluation at this station indicated a moderate stress, and the density value was low, but higher than Station 3. The tributary which entered Little Scrubgrass below Station 3 had little effect on the bottom fauna of the stream in this region. Station 5 was located on a very healthy stream. The community structure diversity index and density value were both very high, making this stream a good source for organisms which might recolonize downstream areas. Station 6 had a high $\bar{d}$ value and improved density over Station 4. This is probably due to the influence of the tributary at Station 5. There is a high correlation between the organisms which were dominate at Station 5 and those which were dominate at Station 6. This indicates that Station 5 did contribute large numbers of colonizing organisms which improved the bottom community of Station 6. Station 7 was located at the beginning of the high gradient area near a small community. The North Fork is dammed immediately above its confluence with Little Scrubgrass, and the South Fork shows evidence of acid discharges. The riffle area here was predominantly small boulders and rubble with some gravel. The combination of unsuitable substrate, possible sewage addition, and additional acid discharges may have contributed to the decrease in diversity and density at this station. Station 8 was located in the high gradient area with a substrate similar to Station 7 although there was more gravel. The low $\bar{d}$ value and density value here may be due to substrate conditions but biological indicators give evidence of improved water quality since the community was dominated by the mayfly *Ephemerella* sp. which is intolerant to high stress conditions.

BIOLOGICAL DAMAGE AND RECOVERY FROM AN ETHYL BENZENE — CREOSOTE SPILL

The effect of an abrupt release of acutely toxic material into a river is an immediate stress on the organisms in the river followed by dilution of the waste and eventual restoration of water quality. A spill of this nature occurred October 10, 1970 at Salem, Virginia on the Roanoke River. Ethyl benzene mixed with creosote was spilled into the Roanoke River from a primary storage tank of the Koppers Company. Approximately 2,000 gallons of solvent escaped and entered an open cooling water ditch (100 gal/min) which flowed into the Roanoke River. Approximately 400 to 600 gallons of the solvent entered the river in a period of 1 to 2 hours. River flow at the time of the spill was 19,000 gal/min resulting in an estimated concentration of solvent at the point of discharge of 1,000 ppm. The subsequent fish kill was reported by the Virginia Water Pollution Control Board and a total of 13,281 fish were killed consisting of 7,979 rough fish and 5,302 sport fish. Initial estimates by the water control board indicated that biological damage extended for a distance of 7 miles below the plant's outfall.

The exact toxicity of the ethyl benzene-creosote mixture is not known. However, using static bioassays, Cairns and Scheier (1959) found that the 96 hour TL_m for *Lepomis macrochirus* (bluegill sunfish) was 10.0 ppm for creosol. Pickering and Henderson (1966) established the 96-hour TL_m for the bluegill using ethyl benzene, at 29 ppm under static conditions. The synergistic or antagonistic actions of these compounds, or their action with other compounds in the river could have altered the acute toxicity of the spilled material in the Roanoke River.

Sampling stations were selected above and below the site of the spill and were sampled for both fish and aquatic macroinvertebrates. Sampling was done between 6 and 10 days after the spill for aquatic invertebrates, and 9 to 11 days after the spill for fish. A follow-up bottom fauna and cursory fish survey was conducted April 1 and 2, 1971 (six months later) to determine the extent of recovery. All sites were selected for their ecological similarity, having shallow riffles with rock and gravel beds with heavily wooded banks. The sampling stations were as follows:

Reference Station 1 — Located 50 yards above Virginia Rt. 612 Bridge and one-half mile upstream from the spill site.

Reference Station 2 — Located adjacent to Koppers Plant and .03 miles upstream from the spill site.

Station 3 — Located 0.5 miles below the site of the spill with access via Krogers Road.

Station 4 — Located approximately 2.0 miles below the site of the spill with access via Duguid Road.

Station 5 — Located 3.5 miles below Koppers with access via Mill Street.

Station 6 — Located approximately 4.5 miles below Koppers with access via Union Street.

Station 7 — Located approximately 6 miles below Koppers with access via Colorado Street.

Fish Survey

Fish were collected using a 10 foot × 4 foot seine of ¼ inch mesh. All ecologically distinct sections of the stream were searched for fish at each of the seven sampling stations.

Jordan published a list of fishes taken from several places in and near Salem, Virginia (1890: 120-124). Since then several collectors have sampled the river, including Raney and Ross. In 1952 they made a large and representative collection of the Roanoke River at the Route 11 crossing, on the Montgomery-Roanoke County line (V. P. I. & S. U. #506). There were 33 species in the collection, now preserved in the Cornell University Fish Collection at Ithaca, New York (Table 5). Jordan's results listed 28 species (Table 4). Four of the species obtained by Raney and Ross in 1952 were not recognized by Jordan, those marked with an asterisk. These collections are closely comparable and represented the former stream faunistic composition in the area under study.

Based on the survey of the Roanoke River conducted immediately after the spill the fish fauna appeared to be in a state of good health except for the portions of the river delimited by Stations 3 and 4 (Figure 7). A total of 26 species of fish were found at Station 1 with 20 species at Reference Station 2. Smallmouth bass, bluegills, and rock bass were present at the reference stations but were absent at Stations 3 and 4 downstream (Table 5). Six species of perches were present at Reference Station 1 but were absent at Reference Station 2. Their absence was probably due to the introduction of sediments from highway and construction projects located between the two stations. Stations 3 and 4 below the site of the spill had a paucity of fish with only four species of fish (all minnows) being found at Station 3 and eight at Station 4 (Table 5).

At Station 5 approximately three and one-half miles below the Koppers Plant, 23 different species of fish were found making it comparable to the diversities found at the reference stations. Stations 6 and 7 were highly productive with diversities similar to those found at the reference stations. They also supported a greater biomass of fish than noted at the other stations. This appeared to be due to nutrient enrichment which resulted in stimulated algal growth.

Bottom Fauna Survey

Four Surber Square Foot Samples were taken in a transect across the Roanoke River at each sampling station to quantitatively determine the effects of the spill on the bottom fauna. A bottom net sample was also taken at each station for qualitative evaluation of species diversity. Bottom organisms were separated from the debris using a number 30 mesh sieve and preserved in 70% ethanol for enumeration and identification.

Based on the survey of the Roanoke River conducted October 19-21, 1970 the bottom fauna at Stations 3 and 4 were drastically reduced when compared to Reference Stations 1 and 2. Eighteen taxa of bottom fauna were found at Refer-

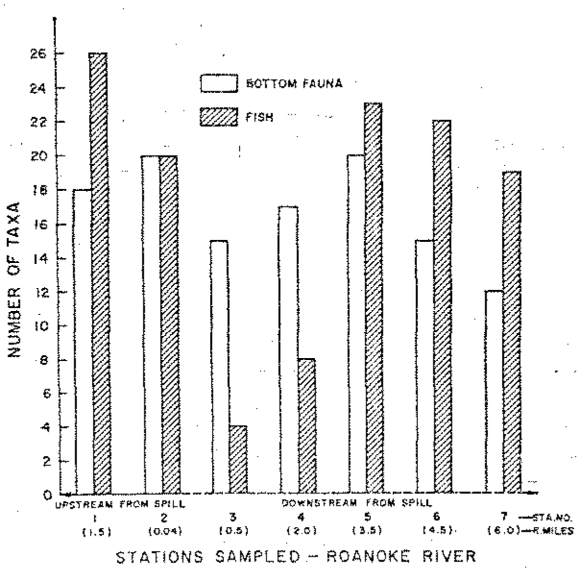


Figure 7. The number of bottom fauna and fish found at each sampling station.

TABLE 4. — Fishes taken by Jordan in 1888 and by Raney and Ross in 1952 from the upper Roanoke River in Montgomery and Roanoke Counties, Virginia.

	Jordan 1888	Raney & Ross 1952
Suckers, family Catostomidae.		
Hog sucker, *Hypentelium nigricans*	common	common
Roanoke hog sucker, *H. roanokense*		common*
Rustyside sucker, *Thoburnia rhothoeca*		several*
Common sucker, *Catostomus c. commersoni*	common	common
Black jumprock, *Moxostoma cervinum*	common	common
Bigeye jumprock, *M. ariommum*		common*
V-lip redhorse, *M. collapsum*		common
Suckermouth redhorse, *M. papillosum*	few	one
Minnows, family Cyprinidae.		
Rosyside dace, *Richardsonius funduloides*	scarce	
Bluehead chub, *Nocomis leptocephalus*	abundant	common
Nocomis sp.		several*
Blacknose dace, *Rhinichthys a. atratulus*	common	scarce
Cutlips minnow, *Exoglossum maxillingua*	common	common
Bluntnose minnow, *Pimephales notatus*		
Silvery minnow, *Hybognathus nuchalis regius*		one
Stoneroller minnow, *Campostoma anomalum michauxi*	common	several
Mountain redbelly dace, *Chrosomus oreas*	abundant	several
Mimic shiner, *Notropis volucellus*		common
Rosefin shiner, *Notropis a. ardens*	common	abundant
Cresent shiner, *Notropis cerasinus*	abundant	abundant
White shiner, *Notropis cornutus albeolus*	common	common
Satinfin minnow, *Notropis analostanus*	common	
Swallowtail shiner, *Notropis procne longiceps*	not rare	common
Spottail shiner, *Notropis hudsonius saludanus*		one
Catfishes, family Ictaluridae.		
Orangefin madtom, *Noturus gilberti*	present	several
Margined madtom, *Noturus insignis*	common	common
Sunfishes, family Centrarchidae.		
Smallmouth bass, *Micropterus d. dolomieui*	scarce	several
Redbreast sunfish, *Lepomis auritus*	common	common
Pumpkinseed, *Lepomis gibbosus*	scarce	
Roanoke rockbass, *Ambloplites rupestris cavifrons*	two	
Rockbass intergrades *A. r. rupestris* × *A. r. cavifrons*		several
Perches, family Percidae.		
Roanoke logperch, *Percina rex*	two	few
Piedmont darter, *Percina crassa roanoka*	common	common
Shield darter, *Percina peltata*	several	several
Fantail darter, *Etheostoma f. flabellare*	common	common
Riverweed darter, *Etheostoma podostemone*	common	common
Johnny darter, *Etheostoma nigrum nigrum*	one	several
Eels, family Anguillidae.		
Common eel, *Anguilla rostrata*	common	

* Species not recognized by Jordan.

ence Station 1 with 20 found at Reference Station 2 (Figure 7).

Construction of a sewer line introduced suspended solids between the two reference stations and may have been responsible for the decrease in density at Reference Station 2 (Figure 8). Mayflies, stoneflies, and caddisflies (pollution intolerant organisms) were present at the reference stations but were absent at Stations 3 and 4 (Table 6).

Stations 3 and 4 located below the site of the spill had a typical "pollution tolerant" community. Pollution tolerant snails and midge larvae made up the major part of the community. Fourteen taxa of bottom fauna were found at Station 3 with 17 found at Station 4. The average number of organisms/ft^2 was lower at these stations when compared to Reference Station 1, probably indicating an additive effect of sedimentation and toxicity from the spill.

TABLE 5.—The numbers of fishes collected at 7 stations (page 1) from the Roanoke River on October 19-21, 1970 in Roanoke County and Salem, Virginia.

Stations:	1	2	3	4	5	6	7
Suckers, family Catostomidae.							
Hog sucker, *Hypentelium nigricans*	3	20		2	7	11	14
Rustyside sucker, *Thoburnia hamiltoni*	12	10		2	1	14	7
Common sucker, *Catostomus c. commersoni*		1			1		
Black jumprock, *Moxostoma cervinum*	16	12		1		1	18
Bigeye jumprock, *Moxostoma ariommum*	2	8			2	6	6
V-lip redhorse, *Moxostoma collapsum*	4	4			6	1	2
Suckermouth redhorse, *Moxostoma papillosum*		1			1		
Minnows, family Cyprinidae.							
Bluntnose minnow, *Pimephales notatus*	36	15			3	4	
Bluehead chub, *Nocomis leptocephalus*	10	13	2	4	4	21	20
Nocomis sp.		8				10	35
Cutlips minnow, *Exoglossum maxillingua*	1						
Silvery minnow, *Hybognathus nuchalis regius*	1						
Stoneroller minnow, *Campostoma anomalum michauxi*	15	69			10	54	42
Rosefin shiner, *Notropis a. ardens*	86	151	3	15	8	144	142
Crescent shiner, *Notropis cerasinus*	126	77	19	47	15	64	29
White shiner, *Notropis cornutus albeolus*	125	8	4	46	109	50	76
Minnows, family Cyprinidae.							
Satinfin shiner, *Notropis analostanus*	1	1			1	7	1
Swallowtail shiner, *Notropis procne longiceps*						35	3
Spottail shiner, *Notropis hudsonius saludanus*		1			4		
Catfishes, family Ictaluridae.							
Orangefin madtom, *Noturus gilberti*	1						
Margined madtom, *Noturus insignis*	17	24		1	8	8	16
Sunfishes, family Centrarchidae.							
Smallmouth bass, *Micropterus d. dolomieui*	2					2	
Bluegill, *Lepomis m. macrochirus*		2			2		
Redbreast sunfish, *Lepomis auritus*	7	2			3	6	
Pumpkinseed, *Lepomis gibbosus*	1						
Rockbass intergrades, *Ambloplites r. rupestris* × *A. r. cavifrons*	1	2			1		1
Perches, family Percidae.							
Roanoke logperch, *Percina rex*	15				1	1	2
Piedmont darter, *Percina crassa*	58				35	88	61
Shield darter, *Percina peltata*	1						
Fantail darter, *Etheostoma j. flabellare*	7				1	66	12
Riverweed darter, *Etheostoma podostemone*	7				7	34	18
Johnny darter, *Etheostoma n. nigrum*	2					1	

Urbanization and the introduction of other industrial discharges into the Roanoke River influenced the character of the benthic communities at Stations 5, 6, and 7. *Cladophara*, a green algae was present at Stations 5, 6, and 7 indicating nutrient enrichment. Twenty taxa of bottom fauna were present at Station 5 with extremely numerous herbivorous caddisfly larvae and snails contributing to the high productivity of the area. Stations 6 and 7 supported a bottom fauna community typical of a nutrient enriched area.

A numerical diversity index evaluation ($\bar{d}$) (Wilhm and Dorris, 1968) indicated that Stations 1, 2, and 4 were healthy stations. All other stations qualified as mildly polluted (Figure 9). However, based on density, diversity, taxonomic information, and the diversity index evaluations, it appeared that the degradation of the Roanoke River due to the Koppers Company operations and/or spill was restricted to that area extending not more than three and one half miles below the plant.

Recovery Survey

A fish and bottom fauna survey was conducted in early April (approximately six months after the ethyl benzene-creosote spill) to document the extent of recovery of the damaged areas.

The results of the bottom fauna survey showed that riffle beetles which were present at Station 3, 6-10 days after the spill were absent six months later, possibly due to either a residual toxicity from the insoluble creosote or from continued introduction of suspended solids from construction (Table 6). Mayflies and stoneflies had recolonized the affected areas, indicating fairly good water quality since these organisms are generally considered "pollution intolerant" organisms.

A cursory fish survey (six months after the spill) of the upstream and downstream area around the Koppers Plant indicated that:

(1) The upstream area (Reference Station 1) still supported a healthy and diversified fish fauna. Approximately 28 species of fish were present including representatives from the sucker, minnow, catfish, sunfish, and perch families.

(2) The area immediately below the site of the spill supported a suppressed population of fish generally represented by the minnows. Apparently the minnows can reinvade more rapidly or are more resistant to any lingering toxicity or discharges from the Koppers Plant than are the other groups of fish.

Summary

(1) The effects of an acute stress from an industrial spill of ethyl benzene and creosote were

TABLE 6. — Number of bottom fauna genera in each family by stations.

Bottom Fauna	1 Upstream	2 Upstream	3 Downstream (Six Days After Spill)	4 Downstream (Six Days After Spill)	5 Downstream (Six Days After Spill)	6 Downstream (Six Days After Spill)	7 Downstream (Six Days After Spill)	1 Upstream (Six Months After Spill)	3 Downstream (Six Months After Spill)
Beetles	4*	3	3	2	4	2	2	2	0
Caddisflies	3	3	0	2	2	1	1	2	0
Damselflies	0	0	1	0	0	0	1	2	0
Dobsonflies	1	1	1	2	2	2	1	2	0
Mayflies	3	5	0	3	2	2	3	1	1
Stoneflies	1	1	0	1	1	0	0	5	5
Trueflies	4	3	2	3	4	2	1	2	2
Crayfish	1	1	1	1	1	0	1	1	2
Scuds	0	0	0	0	0	0	1	1	0
Sowbugs	0	0	0	1	0	0	0	0	0
Flatworms	0	0	1	0	0	0	0	0	0
Mussels	1	1	0	0	1	0	0	0	0
Snails	1	1	3	2	2	2	1	1	0
Worms	1	1	1	1	1	1	1	0	1
Total Number	20	20	13	18	20	12	13	15	11

* Number of Genera

to decrease the diversity and density of both the fish and bottom fauna for approximately 3 miles below the site of the spill.

(2) A differential response to the stress was apparent with all major groups of fish, except the minnows, being entirely eliminated in the stressed area. Perhaps the minnows avoided the stress by swimming into small isolated tributaries or perhaps they rapidly reinvaded the area, or they may be more tolerant to this type of stress.

(3) Mayflies, stoneflies, caddisflies, and mussels did not survive the stress and were eliminated. However, mayflies and stoneflies were present six months later indicating improved water quality.

(4) Riffle beetles, trueflies, crayfish, some snails, and segmented worms were apparently able to survive the short term exposure to the ethyl benzene and creosote stress.

BIOLOGICAL DAMAGE AND RECOVERY OF THE CLINCH RIVER FOLLOWING ACUTE pH STRESSES

The Clinch River has been subjected to two major industrial spills which have resulted in fish kills and elimination of other aquatic organisms. To evaluate the effects of these spills and to study the recovery processes benthic organisms and fish have been collected from the Clinch in southwestern Virginia and northeastern Tennessee for two years.

Description of the Clinch River

The Clinch River is a headwater tributary of the Tennessee River located in the ridge and valley region of southwestern Virginia and eastern Tennessee. As the main tributary of the Clinch River Basin, the Clinch drains 1,260 square miles of land in Virginia and extends for a distance of 148 river miles before it enters Tennessee (Tackett, 1963). The average discharge for the Clinch, at Speer's Ferry, Virginia, during the period of 1920 to 1960 was 1,578 c.f.s. with a maximum of 45,300 c.f.s. noted in January, 1957 and a minimum of 42 c.f.s. noted in September, 1939 (U.S. Geological Survey, 1960).

As the Clinch passes through the mountainous regions of Virginia it flows over exposed geologic formations of limestone and dolomite which range in age from early Cambrian to Pennsylvanian (Cooper, 1945). These formations contribute calcium bicarbonate to the water and raise the pH of the river to 8.0-8.5. Because of the high al-

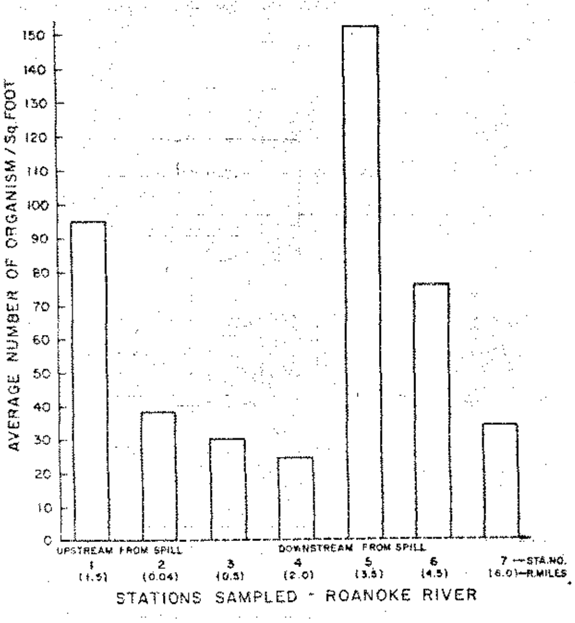


Figure 8. The average number of bottom fauna/square foot at each sampling station.

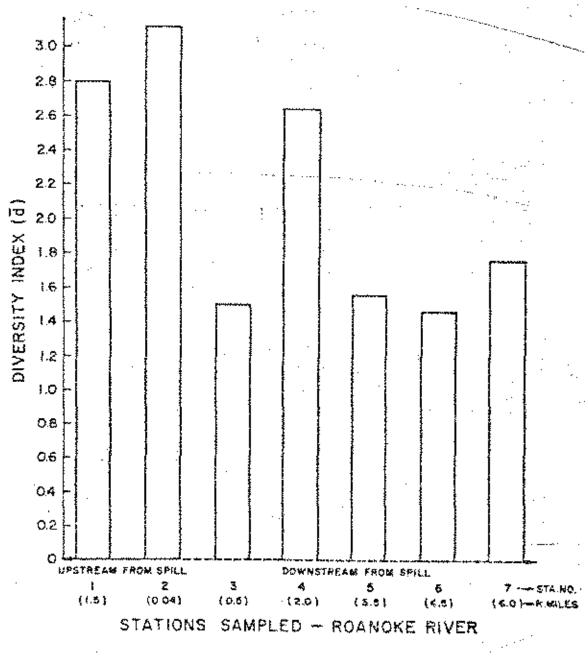


Figure 9. The diversity index $\bar{d}$ for bottom fauna at each sampling station.

kalinity, acid discharges from coal mines are readily neutralized. However, discharges from coal washing operations cause a major sedimentation problem in the Guest River and Dump's Creek, two of the larger tributaries of the Clinch.

1967 Fly Ash Pond Spill

The first fish kill occurred when the dike surrounding a fly ash holding pond collapsed at Appalachian Power Company's 700-megawatt steam power generating plant near Carbo, Virginia. At this power plant native coal is utilized to produce steam which is used in the production of electrical power. Because the coal has a high ash content, approximately 960 tons of fly ash is produced daily. To efficiently remove such large quantities of ash from the furnace hoppers, water from the Clinch River is mixed with the ash to form a slurry. This mixture is pumped to large settling lagoons where the ash settles and the supernatant is recycled. Because of recycling, free lime (CaO) in the fly ash reacts with water to form $Ca(OH)_2$. This gradually raises the pH of the recirculating water and the water in the fly ash lagoons to extremely high pH values ranging from 12.0 to 12.7 (Anonymous, 1967b).

On June 1967 a 50-75 foot section of a dike surrounding one of the fly ash settling lagoons failed. Within less than an hour 400 acre feet (approximately 130 million gallons) poured into Dump's Creek which joins the Clinch River 0.5 miles downstream. This caustic slug equalled 40% of the daily flow of the Clinch at the time and resulted in blocking the normal flow for several minutes. It also raised the water level several feet and forced some of the waste approximately 0.5 miles upstream.

For four and one-half days following the spill the alkaline slug traveled downstream at a rate of approximately 0.85 miles an hour killing essentially all the fish in its path (Anonymous, 1967b). During this period 162,000 sport and rough fish were killed in 66 miles of the Clinch River in Virginia. An additional 54,600 sport and rough fish were killed in 24 river miles in Tennessee until the polluted mass was diluted, dispersed, and neutralized in the river by natural physical-chemical

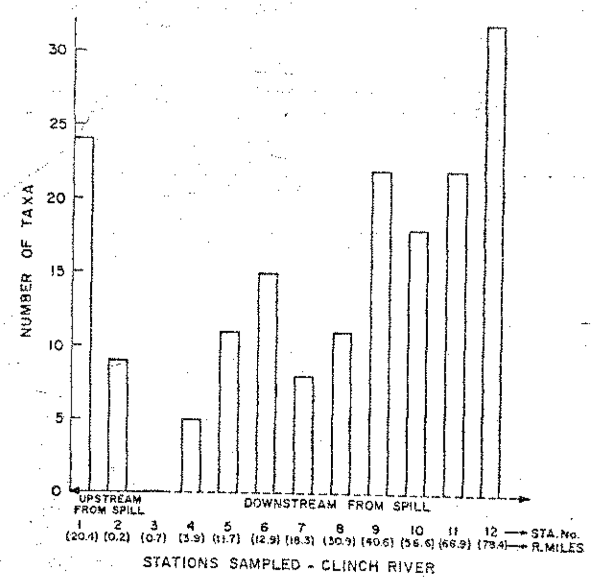


Figure 10. Number of taxa found at each station for June, 1967, bottom fauna survey.

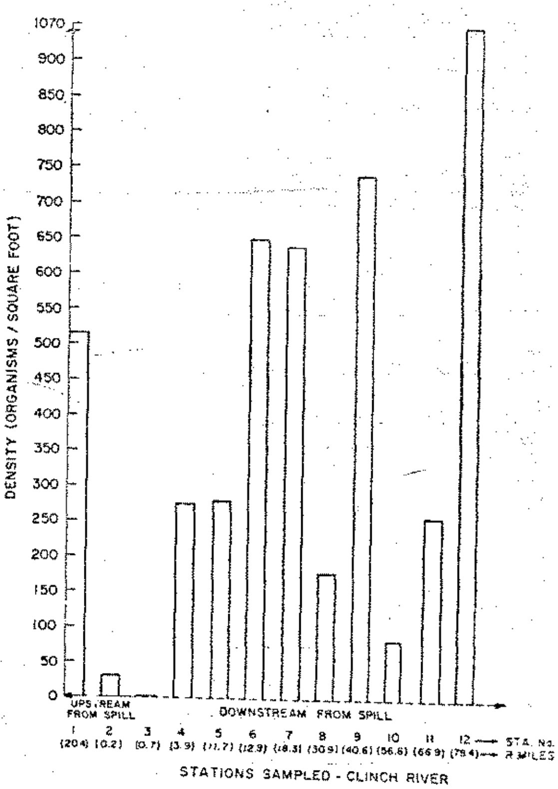


Figure 11. Density of organisms found at each station for June, 1967, bottom fauna survey.

forces. The chemical reactions involved in neutralization were:

1) $Ca(OH)_2 + Ca(HCO_3)_2 \rightarrow 2CaCO_3 + 2H_2O$

In addition CO_2 from the atmosphere reacted with the water to form:

2) $H_2O + CO_2 \rightleftarrows H_2CO_3$

3) $Ca(OH)_2 + H_2CO_3 \rightarrow CaCO_3 + 2H_2O$

The lethal agent was reported to have been the high pH of the alkaline water which was composed of 90% hydroxide alkalinity and 10% carbonate alkalinity. A secondary effect which may have contributed to the biological damage was a depression in the dissolved oxygen concentration caused by the decaying organic matter (Anonymous, 1967b).

Ten days after the collapse of the dike the Virginia State Water Control Board conducted a bottom fauna survey at selected stations above and below the site of the spill to assess damage to the benthic fish food organisms (Anonymous, 1967a). They observed that:

1) Bottom dwelling fish food organisms appeared to have been completely eliminated for a distance of approximately 3 or 4 miles below the site of the spill (Figures 10, 11).

2) A drastic reduction in the number and kinds of bottom dwelling fish food organisms occurred in the Clinch River for 77 miles below the spill (Figures 10, 11).

3) Snails and mussels were eliminated for 11.5 miles below Carbo, Virginia.

4) The Virginia State Water Control Board, based on past experience, predicted that as far as total weight per square foot of stream bottom, the Clinch River would recover to its former productive capacity within three months after the spill. Both the Virginia and Tennessee Game Commissions believed that the stream organisms would appear in sufficient numbers for fish restocking in the fall of 1967 (Anonymous, 1967a).

Materials and Methods

During the summer and fall of 1969, a bottom fauna and fish survey of the Clinch River was conducted to study the extent of the biological recovery of the river following the 1967 fly ash spill. Particular emphasis was placed on studying the bottom fauna communities above and below the spill site because:

1) Benthic organisms are relatively sessile organisms and they cannot quickly avoid environmental stresses as fish often are able to do;

2) They have rather long and complex life histories and their presence or absence reflects the history of the environment;

3) Since they are members of the food web in an aquatic environment, their presence or absence directly effects fish populations;

4) Sampling techniques for bottom fauna are more reliable than techniques for fish; and

5) More biological information can be gained from studying this group of organisms per dollar invested than any other group.

The bottom fauna survey involved locating and sampling of twenty-one ecologically similar stations which extended from Blackford, Va. to Sneedville, Tenn., a distance of 120 river miles (Figure 12). Four stations were located above the site of the spill to serve as reference or control stations with which downstream stations could be compared. Twelve stations were located below the spill site to assess the river's recovery and to evaluate any contributing influences arising from industries, municipalities, or agricultural areas. Five additional stations were established on tributaries with pollution sources which could have effected the main river stations.

Sampling sites with comparable habitats and ecological similarity were selected so comparisons could be made between stations. After locating the stations, sampling was accomplished using a Turtox 8″ × 10″ × 18″ rectangular bottom net and a Surber square foot sampler. Care was taken that an equal collecting effort was made at each station. Each station was divided into three substations (left bank, right bank, and midchannel) and samples were taken from each substation with a bottom net since it had been observed that waste discharges were often restricted to certain portions of the river after discharge. Five Surber samples were taken along a transect through the riffle area for quantitative information. Immediately after collection, all samples were passed through a series of graded sieves (Tyler mesh Nos. 4, 10, and 35) and the organisms were removed and preserved in 70% ethanol for later identification and enumeration.

Fish samples were collected using a 10′ × 4′ seine of $\frac{1}{4}$ inch mesh. All specimens were preserved in formalin and stored in 70% alcohol in the Virginia Polytechnic Institute and State University museum. The collections were obtained at two stations above the spill site and at four stations below. Only the shallow areas and riffles were sampled.

Results and Discussion

The number of bottom fauna taxa found at each station are summarized in a histogram, Figure 13. A difference existed between upstream reference stations and stations immediately below the spill site for a distance of approximately 18 miles. At Reference Stations 1 through 4 the number of taxa varied between 48 and 54 while below the spill site there was a decrease at Station 7 to 43 taxa followed by an even more pronounced decrease at Station 8 to 33. This low value was followed by an increase in the number of species at the next three stations until at Station 11 there were 46 taxa, approximately the same number as were observed at the reference stations. At Station 13 a decrease in the number of species was found, followed by an increased number of species, equal to reference station values, at the remaining downstream stations.

In Figure 14, a graph of density which includes all snail and freshwater mussel species, the difference between the upstream reference stations and stations below the spill site was even more pronounced. Densities for the reference stations ranged between 145.2 and 24.6 organisms per square foot. In contrast, densities at Stations 8-11 varied between 2.4 and 18.8 organisms per square foot with the highest density being found at Station 11, the station located furthest downstream. Station 13 showed a reduction in density which appeared to be due to unsuitable substrate conditions for benthic colonization and the influence of the tributary that flows into the Clinch River just above this station.

Figure 15, a graph of density which does not include snails and mussel species, indicated a difference between Reference Stations 1-4 and Stations 7-11. In addition, Figure 15 also indicated that:

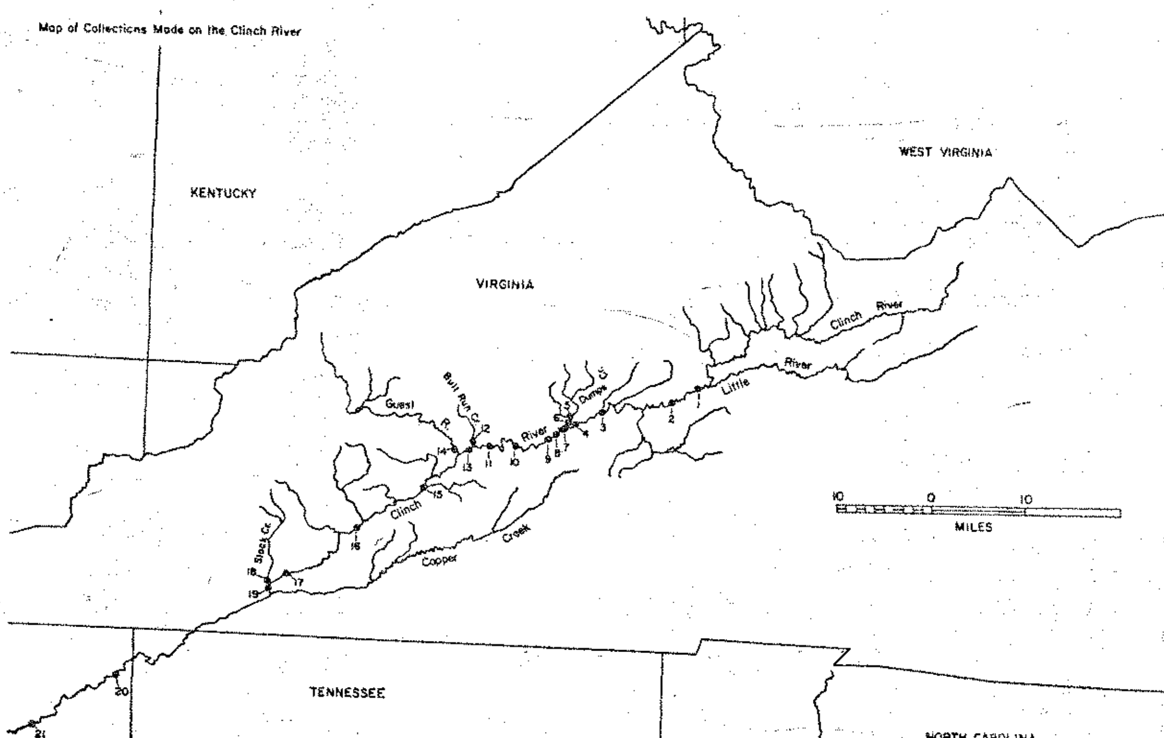


Figure 12. Diagram of sampling locations on Clinch River and related tributaries.

1) There was a reduction in the densities at Stations 1-4 and 13-21 when compared to the same stations in Figure 4. This was caused by the exclusion of the snail and mussel data since these groups made up large portions of the invertebrate community at each station.

2) Densities were not affected by excluding snail and mussel species at Stations 7-11 because molluscs had not become reestablished after the spill. This may be the result of reduced susceptibility to downstream drift when compared to the drift found for insect larvae and other invertebrates, longer life cycles than found for most other aquatic invertebrates, and the lack of an aerial stage in their life cycles, all of which would affect their rate and extent of recolonization.

The differences found in diversities and densities at Stations 7-11 indicate a possible recovery pattern. This pattern would involve a combination of interrelated factors which would include the amount of damage at each station from the spill, differing rates of recolonization by different organisms, and a continuing mild environmental stress upon a limited portion of the aquatic ecosystem being studied.

The continuing environmental stress appears to have been caused by a discharge from the Appalachian Power Company's plant above Station 7. This discharge channeled along the right bank for some distance before mixing and although it did not affect the overall diversity found at Station 7 it did appear to have an adverse effect upon aquatic organisms at downstream stations.

Community structure analyses of the bottom fauna collected at each of the sixteen sampling stations located on the Clinch River indicated that the bottom fauna community structures at stations below the spill site were similar to the control stations upstream (Table 7). In this study diversity ($\bar{d}$) was calculated for the left bank, right bank, and midchannel substations for all sixteen stations on the Clinch River using the following equation:

$$d = \Sigma (Ni/N) \log_2 (Ni/N)$$

A complete explanation of this technique is given by Wilhm and Dorris (1968).

"Clean water" areas have been found by Wilhm and Dorris (1968) to have $\bar{d}$ values exceeding 3.0. Border line values such as were found at the right bank substation at Station 7, left bank substation at Stations 1 and 21, and the midchannel

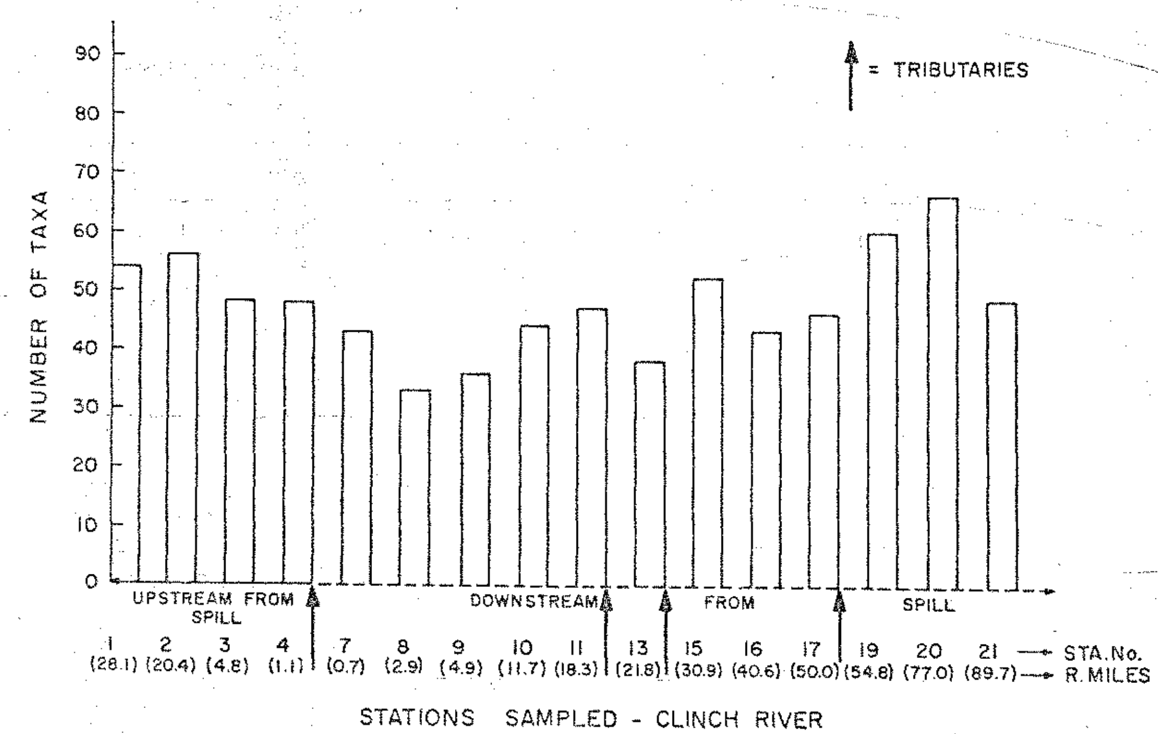


Figure 13. Number of taxa found at each station for 1969 bottom fauna survey.

TABLE 7. — Diversity values obtained with the index $\bar{d} = -\Sigma(Ni/N)\log_2(Ni/N)$ for bottom fauna collected at stations sampled on the Clinch River.

Substations	Above Spill				Stations											
	1	2	3	4	7	8	9	10	11	13	15	16	17	19	20	21
Left Bank	2.97	3.65	3.75	3.79	4.21	4.35	3.76	3.29	3.61	3.81	3.95	3.85	3.67	4.19	4.19	2.98
Midchannel	3.22	3.33	3.27	3.93	3.28	3.64	2.88	3.19	4.17	3.64	3.26	3.30	2.48	3.41	2.26	3.37
Right Bank	3.32	3.86	3.94	4.03	2.92	4.06	4.01	4.06	3.87	4.01	3.86	3.31	3.79	3.54	4.03	3.27

substation at Stations 17 and 20 indicate areas of moderate pollution. However, it appears that the Clinch River has substantially recovered from the fly ash pond spill when the community structure of the bottom fauna is used as a criterion.

Results for the fish collections are given in Figures 16 and 17. Figure 16 gives the number of different fish species, made up mostly of minnows and darters, found at each station. Reference Stations 1 and 2 had 19 and 17 different species respectively, while Station 7 below the spill site had 11 species. This difference may be attributed to the decreased availability of fish food organisms and/or the power plant's waste discharges. Further downstream at Station 9 the number of taxa had increased to the same level as observed at the upstream control stations but a drop at Station 11 to 2 taxa was found. Field observations made at the time of collection showed a large amount of silting at Station 11 which may have caused the reduction in diversity. Fish densities for each station, Figure 17, showed the same variations as were noted for the bottom fauna — a reduction in density immediately below the spill site followed by an increase the further downstream the samples were taken.

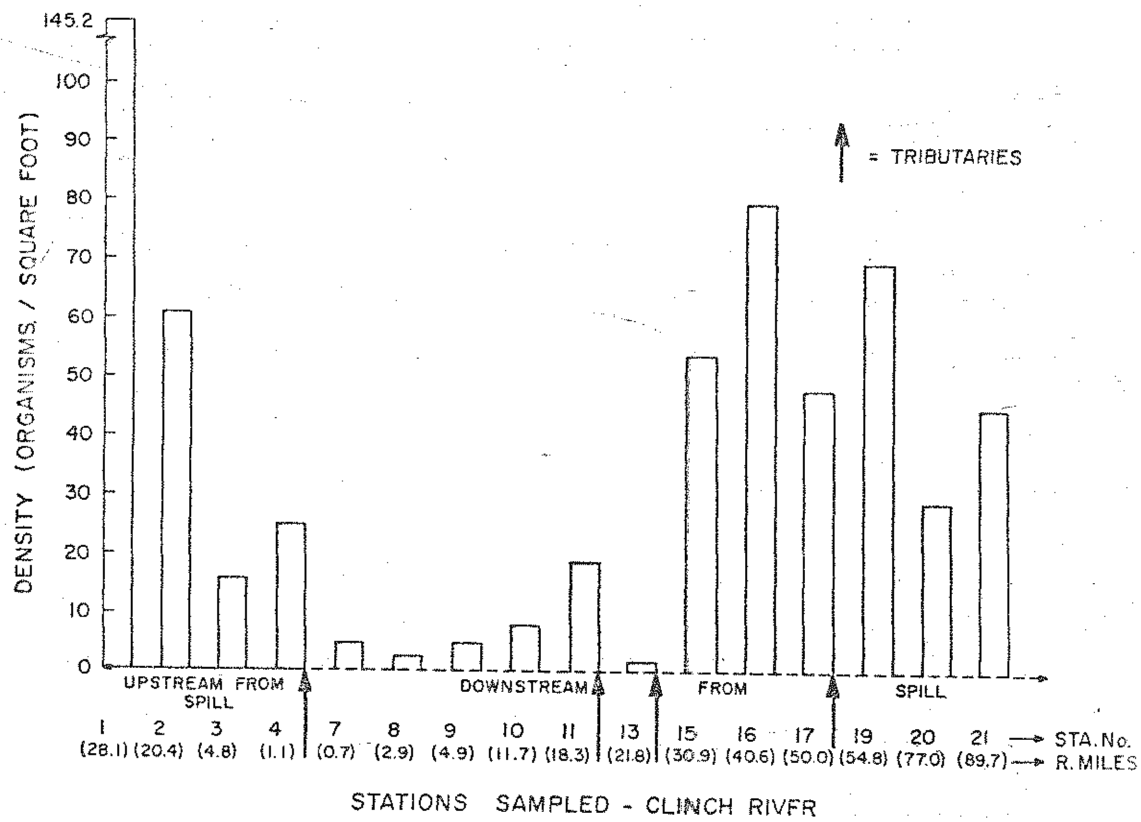


Figure 14. Density of organisms, including molluscs, at each station for 1969 survey.

Conclusions

From the preliminary survey, conducted two years after the alkaline fly ash pond spill, the following tentative conclusions seem justified:

1) Aquatic communities of bottom fauna that were completely eliminated below the power plant at Station 7 had recovered to the point where the number of different kinds of organisms found at this station were approximately the same as found at upstream reference stations unaffected by the spill.

2) Communities of benthic organisms at Station 8-11 indicate a linear recovery pattern; i.e., the further downstream the station is located the higher the density and diversity values.

3) Large portions of the communities at the reference stations and at stations 30 miles or further downstream from the plant consisted of molluscs. However, these aquatic invertebrates had not recovered at Station 7-11 below the site of the spill. This failure to recolonize appeared to be due to their inherent inability to reinvade and recolonize areas below the spill site as fast as aquatic insects.

4) Community structure analyses indicated that benthic communities below the site of the spill were similar to those found at stations above the spill site and were characteristic of "clean water" situations as defined by Wilhm and Dorris (1968).

5) Different species of minnows and darters had recolonized stations below the plant but had not attained the density levels found at upstream reference stations.

6) Two years after the spill, the Clinch River had not fully recovered. However, fish food organisms such as mayflies, stoneflies, hellgrammites, and midge larvae were present at all the areas affected by the spill and should support a productive sport fishery.

1970 Acid Spill

While undertaking the second year's bottom fauna survey a second industrial spill occurred at the Appalachian Power Plant on June 19, 1970, just after benthic samples had been collected at six stations above the plant and at four stations below. This spill involved the release of an un-

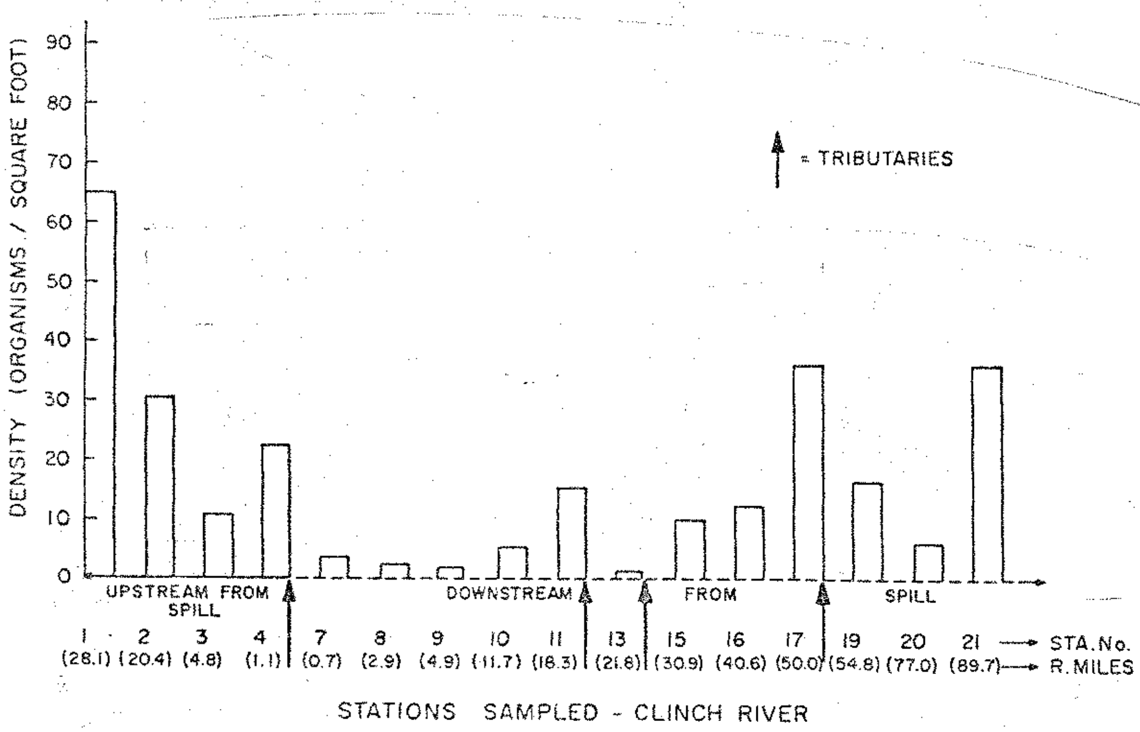


Figure 15. Density of organisms, excluding molluscs, at each station for 1969 survey.

determined amount of sulfuric acid which killed approximately 5,300 fish. Cursory examinations by representatives of the Virginia State Water Control Board indicated that stream damage began approximately one mile below the power plant and extended a distance of 13.5 river miles downstream to St. Paul, Virginia (Soukup, 1970).

Materials and Methods

Immediately after notification of the spill a series of cursory examinations were made on the bottom fauna, using the same collecting techniques as previously described, to determine the extent of the damaged area. These examinations were followed by thorough sampling of the stations in the affected area (as delimited by the cursory examinations) and were continued at two week intervals for the next sixty days. Additional samples were collected every four weeks at three unaffected stations during the same period. In all, seven ecologically comparable stations were included in the survey, consisting of one reference (control) station, four stations in the affected area, and two delimiting stations. Station No. 4, located 1.1 river miles above the power plant, served as the upstream reference station with which the affected stations were compared. Stations Nos. 7, 8, 9, and 10, located below the spill site, were located to assess the effects of the spill and to follow the restoration of the damaged ecosystem. Two delimiting stations, Stations Nos. 11 and 13, were established 6.6 and 10.1 river miles below Station No. 10 to verify whether or not the effects of the spill were restricted to that section of the river from Carbo to St. Paul, Virginia.

Results

The total number of organisms found at each station were calculated and plotted (Figure 18). The data from Stations 4, 11, and 13 indicated that these stations were unaffected by the spill. However, seasonal variations did exist as evidenced by the increase in the number of organisms in July, the second sampling period, and the decrease in the number of organisms in August during the third collecting period. At Stations 7-10, the low pH shock caused an immediate de-

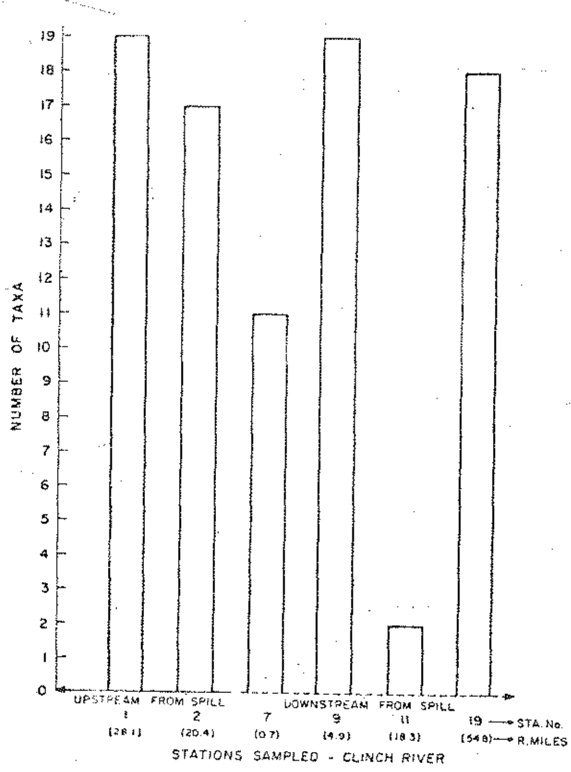
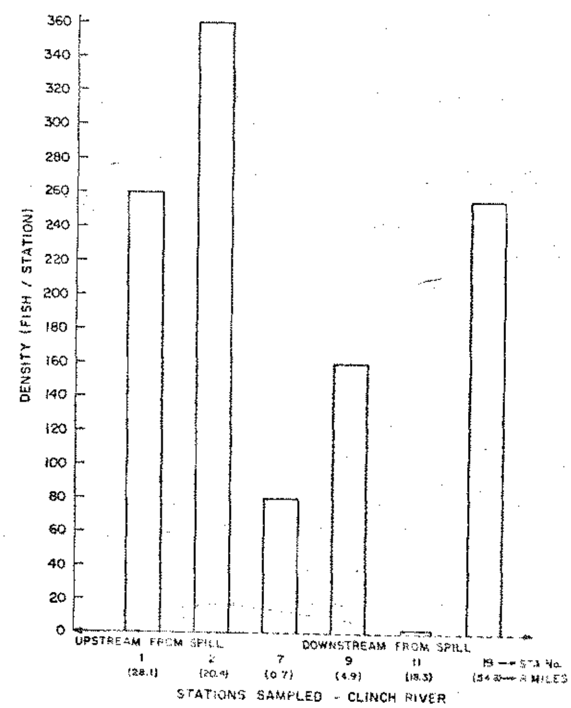


Figure 16. Number of fish taxa found at sampling stations for November, 1969, survey.



Number 17. Density of fish at each sampling station for November, 1969, survey.

crease in the number of organisms. This was the result of the elimination of all mayfly and mollusc species and reductions in the number of organisms per species for all other species except hellgrammites and adult beetles. The hellgrammite and adult beetle species appeared to have been unaffected by the pH shock.

Two weeks after the spill, the third sampling period, there were increases in the number of organisms/station at Stations 7-10. These increases were probably the result of population development by species that had survived the spill since new species were rarely found at any of the stations. By the fourth sampling period, four weeks after the spill, organisms which probably arrived by stream drift became more abundant making up between 4 and 10% of the total number of organisms. They would have made up a larger percentage had it not been for the three genera, *Hydropsyche* sp., *Cheumatopsyche* sp., and *Simulium* sp. Since these organisms are vertically distributed in the substrate (Coleman and Hynes, 1970) it was felt that their population increases were probably due to development of egg masses and immature forms located deep in the substrate which were unaffected by the low pH shock. The eclosion of these immatures would account for the extremely high numerical values found for the fourth sampling period. After the rapid increase in the number of benthic organisms a stabilization period followed as values decreased and remained fairly stable during the fifth and sixth sampling periods.

Community structure analyses were run on the combined collections from each station using the technique developed by Wilhm and Dorris (1968). The results of this evaluation, expressed as diversity indexes ($\bar{d}$) were plotted to form a histogram (Figure 19). Stations sampled before the spill, denoted by an asterisk, had $\bar{d}$ values either above 3.0 or within 0.08 of that figure indicating "clean water" areas (Wilhm and Dorris, 1968). However, a moderately stressed situation was indicated since diversity indices were lower at Stations 8, 9, and 10 when compared to Reference Station No. 4. These reductions were probably the result of a combination of interrelated factors which may include stream damage from the previous fly ash pond spill and continued discharges from the

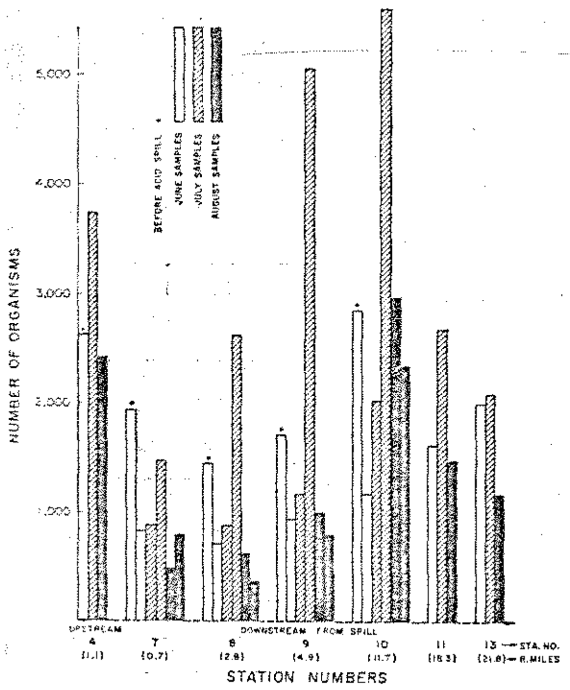


Figure 18. Number of organisms per station for June 19, 1970, acid spill.

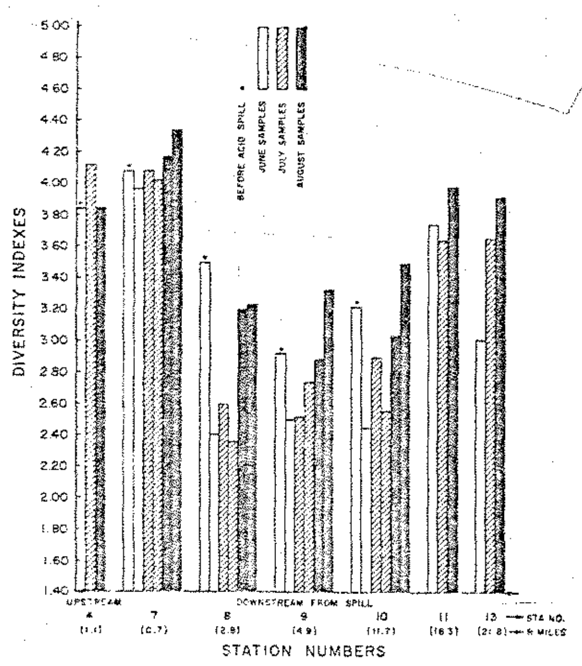


Figure 19. Diversity indexes for each station for the June 19, 1970, acid spill.

power plant. Station 7 did not show a decrease because effluents from the power plant were confined to the right side of the river and did not affect the station's overall community structure of aquatic organisms. Biological recovery from the previous alkaline spill also appeared to be further advanced at this station than at the Stations 8-10.

After the acid spill, diversity indices at Stations 8, 9, and 10 dropped to between 2.40 and 2.50 indicating that the community structure of the benthic organisms had been altered and were characteristic of streams with moderate pollution (Wilhm and Dorris, 1968). The reduction in $\bar{d}$ values was the result of decreased diversities (i.e., number of different species found) at each station. The number of taxa dropped from an average of 49 to 30 for the three stations, with the largest decrease occurring at Station 9 which had 48 taxa before the spill and 25 after.

Two weeks after the spill, the third sampling period, diversity values began to increase. This pattern of increased $\bar{d}$ values with time, continued at Station 9 during the fourth sampling period but was disrupted at Stations 8 and 10 where values decreased. At these stations disproportional population increases by *Simulium* sp., *Hydropsyche* sp., and *Cheumatopsyche* sp. altered the overall community structure and reduced diversity indices. By the fifth sampling, six weeks after the spill, these organisms were reduced in numbers and $\bar{d}$ values increased to above 3.0 or within 0.11 of that value showing that the invertebrate communities at each station were within the same "clean water" range as noted before the spill. Diversity values for sampling period six were all above 3.0 indicating stream recovery using community structure analyses.

Diversity values were also calculated for each substation sample and Surber sample at each station. These indices were tabulated along with the values previously mentioned for the combined collections, by station number and comparisons were made between values for each station and between the different stations (Table 8). Examination of indices showed very little difference between the numerical values of the combined samples and the substation and the Surber samples except at Stations 7 and 8. At these stations $\bar{d}$ values were consistently lower for the right bank substation because of the power plant's effluent which channeled along the right bank before becoming completely mixed.

Relative frequencies of organisms were calculated and plotted for each station, Figure 20. The frequency values were obtained by dividing the number of organisms of a group, tolerant or nontolerant, by the total number of organisms at the station. The tolerant and nontolerant classifications were determined by comparison of samples before and after the spill. If an organism was present in significant numbers before the spill and absent afterwards it was considered a nontolerant species and vice versa. In this graph the differences between Stations 8-10 and Reference Control Stations 4, 11, and 13 are more obvious. At Stations 4, 11, and 13 the frequencies for nontolerant species were between 30 and 60% during the entire sampling period. At stations 8-10 nontolerant species made up less than 25% of the total population before the acid spill because of the power plant's discharges and incomplete re-

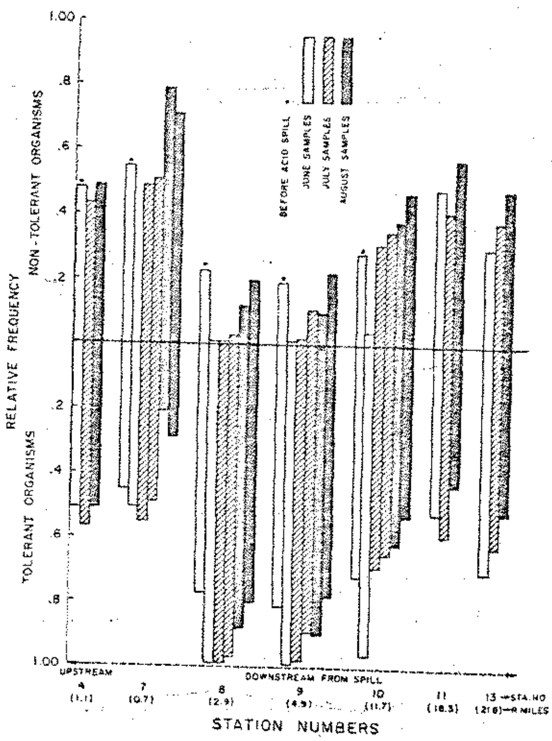


Figure 20. Relative frequencies per station for the June 19, 1970, acid spill.

covery from the alkaline spill. After the acid spill nontolerant organisms were almost completely eliminated at each station. Two weeks later, the third sampling period, they began to recover and continued to do so until the sixth sampling period when frequencies of 20, 22, and 50% were noted for the respective stations.

Conclusions

The following observations were made after comparing benthic samples collected before and after the June 19th acid spill.

(1) Aquatic communities of mayfly and mollusc species were completely eliminated by the low pH shock for a distance of 11.7 river miles. Reductions in the number of individuals per species were also noted for all other species except hellgramites and beetles which appeared tolerant of the acid shock.

19 Km

(2) Community structure analyses indicated that the stream invertebrate communities were altered by the acid spill and were characteristic of streams with moderate pollution.

(3) By the fifth sampling period, six weeks after the spill, diversity values were within the same clean water range as noted before the spill.

(4) The relative frequencies of organisms nontolerant of the pH shock were still increasing by the end of the sampling period.

(5) Sixty days after the acid spill the river had

TABLE 8. — Diversity values obtained with the index $\bar{d} = -(Ni/N)\log_2(Ni/N)$ for bottom fauna collected after the June 19, 1970, acid spill on the Clinch River.

Station Number	Date	Collection	Left Bank	Midchannel	Right Bank	Surber
4	6-17-70	3.84	4.22	3.44	3.86	3.16
4	7-21-70	4.12	3.80	3.93	4.27	3.17
4	8-15-70	3.84	3.71	3.59	3.63	3.46
7	6-12-70	4.08	4.26	3.73	3.32	3.49
7	6-23-70	3.97	3.93	3.52	3.15	3.75
7	7-7-70	4.07	4.03	3.62	2.42	3.46
7	7-20-70	4.02	3.73	3.41	2.91	3.61
7	8-5-70	4.17	3.74	3.95	1.55	3.65
7	8-16-70	4.34	4.00	3.98	3.51	3.73
8	6-18-70	3.50	3.53	3.67	3.34	2.34
8	6-23-70	2.40	2.11	2.47	2.09	1.77
8	7-8-70	2.59	2.51	2.24	2.49	2.05
8	7-21-70	2.36	2.67	2.38	1.85	2.32
8	8-6-70	3.20	3.01	2.97	3.15	2.25
8	8-16-70	3.23	2.88	3.00	2.85	2.81
9	6-18-70	2.92	3.94	2.83	3.80	2.17
9	6-24-70	2.50	2.41	2.54	2.04	1.70
9	7-8-70	2.51	2.96	2.23	1.64	1.84
9	7-22-70	2.73	2.43	2.69	2.66	2.58
9	8-6-70	2.89	3.06	2.30	2.56	2.57
9	8-17-70	3.33	3.40	2.95	3.23	3.20
10	6-19-70	3.23	3.69	3.04	2.96	2.48
10	6-24-70	2.45	3.01	1.96	2.45	2.05
10	7-9-70	2.90	2.65	3.10	2.64	2.55
10	7-23-70	2.55	2.49	2.36	2.73	2.32
10	8-7-70	3.04	2.78	2.57	3.06	3.23
10	8-17-70	3.50	3.50	2.93	3.21	3.22
11	6-22-70	3.74	3.55	3.51	3.63	3.01
11	7-23-70	3.65	3.24	3.51	3.22	3.47
11	8-18-70	3.98	3.64	3.66	3.91	3.90
13	6-25-70	3.01	3.66	2.28	3.29	2.78
13	7-24-70	3.66	3.96	3.26	3.40	3.19
13	8-18-70	3.91	4.45	3.39	3.90	3.71

recovered to the point that representative species of aquatic insects found before the spill were present at all the affected stations. Mollusc species were slower to recolonize and had still not recovered by the end of the summer.

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