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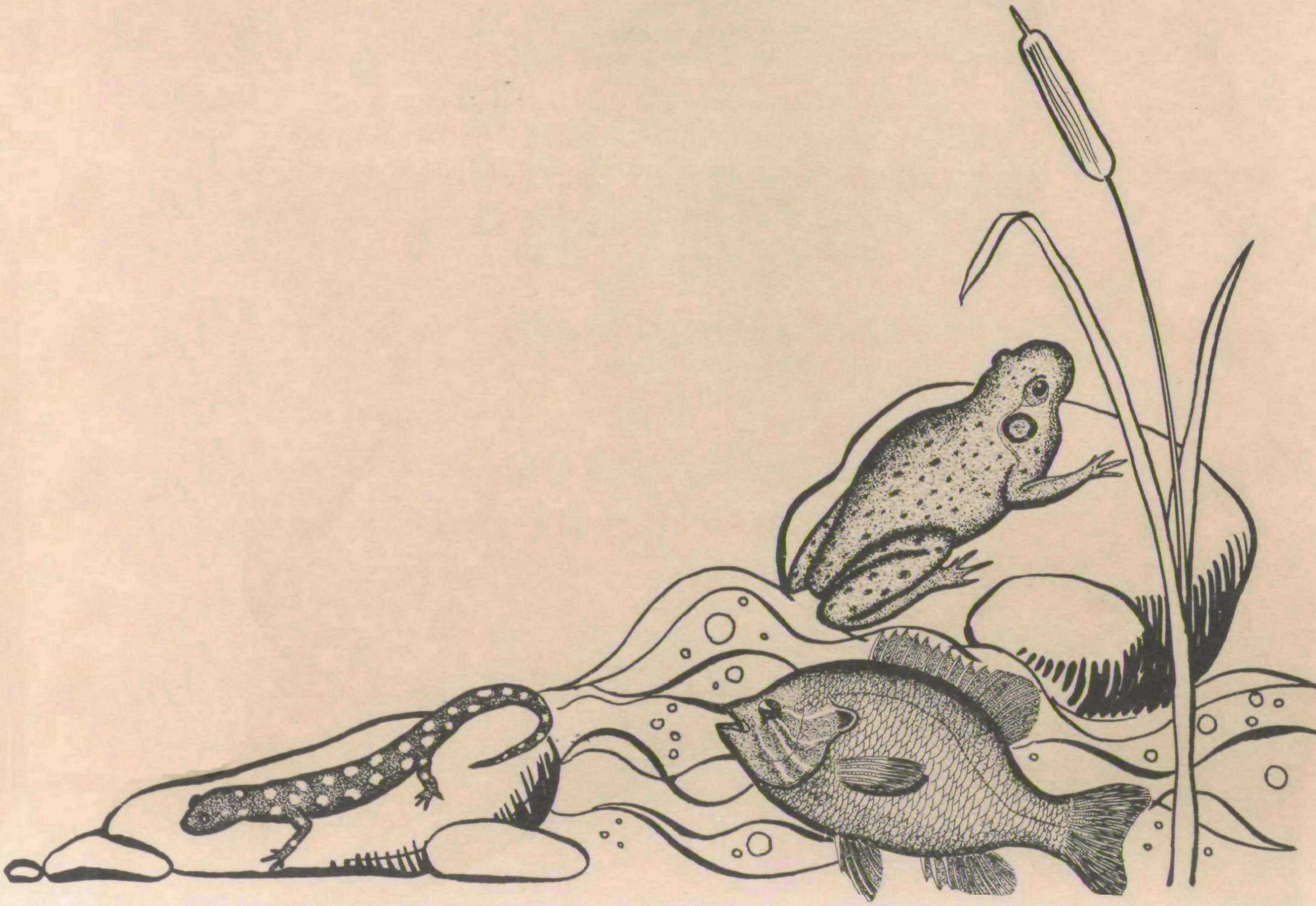
The Effect of Inorganic Sediment On Stream Biota



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THE EFFECT OF INORGANIC SEDIMENT ON STREAM BIOTA

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ABSTRACT

Fish and macroinvertebrate populations fluctuated over a four year period in response to varying quantities of sediment produced by a crushed limestone quarry. Light inputs which increased the suspended solids loads less than 40 mg/l resulted in a 25% reduction in macroinvertebrate density below the quarry. Heavy inputs caused increases of more than 120 mg/l including some deposition of sediment and resulted in a 60% reduction in population density of macroinvertebrates. Population diversity indices were unaffected by changes in density because most taxa responded to the same degree. Experimental introductions of sediment caused immediate increases in the rate of invertebrate drift proportional to the concentration of additional suspended solids.

The standing crop of fish decreased drastically when heavy sediment input occurred in the spring, but fish remained in pools during the summer when the input was very heavy and vacated the pools only after deposits of sediment accumulated.

After winter floods removed sediment deposits, fish returned to the pools during spring months and achieved levels of 50% normal standing crop by early June. Slight additional gains were noted during the summer even with light sediment input. Only spotted bass (*Micropterus punctulatus*) was resistant to sediment, but its growth rate was lower below the quarry than above. Most fish were much reduced in standing crop below the quarry.

This report was submitted in fulfillment of project 18050 DWC under the sponsorship of the Water Quality Office of the Environmental Protection Agency.

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CONCLUSIONS

1. Crushed rock quarries are potentially capable of polluting water courses with large quantities of inorganic sediment.
2. Both suspended and settled sediment caused negative responses in the populations of macroinvertebrates in riffles and fish in pools below the source of sediment.
3. When more than 80 mg/l inert solids were added to the normal suspended solids load the populations density of macroinvertebrates decreased to about 40% normal. When 20 to 40 mg/l were present for a part of each day the depression in population density was about 75% normal, but differences were not always detected by the particular method of sampling employed. Most species were affected similarly and, therefore, diversity was not altered. The ephemeropteran, *Tricorythoides*, increased in density during heavy sedimentation and adult stages of the beetle, *Stenelmis*, were also quite resistant.
4. Sediment which settled out in riffles also caused a decrease in population density to about 40% normal regardless of the suspended solids concentration.
5. The response of macroinvertebrate populations appears to be due to increased drift out of riffles in response to above normal concentrations of inert solids. The experimental introduction of sediment into a riffle above the quarry revealed an increase in drift rate in direct proportion to the

increase in suspended solids concentration up to about 160 mg/1.

6. The adjustments of population density in relation to suspended or settled solids was rapid, requiring only a few days to decrease significantly or to return to normal.
7. Populations of fish also responded to differences in suspended and settled solids, but the mode of response was somewhat more complex depending upon both the season of the year and the species of fish.
8. Only a single species of fish, the spotted bass *(Micropterus punctulatus)*, was resistant as a population to the sediment, but its rate of growth below the quarry was lower than above.
9. Almost all of the remaining species had distinctly lower populations below the quarry than above throughout the period of study. Although each species group tended to react somewhat differently, the population of fish as a whole was most sensitive to the load of suspended solids during the spring months. During spring 1969 additional suspended solids estimated to be 150 mg/1 or more caused a great decrease in density. Continued high inputs into the summer did not, however, cause further reductions until accumulations of sediment filled the pools and finally forced the fish to leave. Following the removal of the sediment by winter and spring floods, the fish in outlying segments of the stream invaded the afflicted pools during spring months and achieved standing crops about 50% normal by June. Further recovery during the summer was relatively slight.

10. The populations of fish failed to completely recover within two years following the decimation, during conditions of relatively light sediment input by the quarry. Since the affected area was relatively short and normal populations existed above and below the segment, it is concluded that recovery to normal would probably never be achieved under the observed conditions.
11. Reductions in the standing crops of fish and macroinvertebrates were detected in a short segment of stream which received a load of suspended inorganic solids of no more than, and during the spring and winter less than, 40 mg/l more than the normal concentration during a part of each day. Suspended material as well as settled sediment was responsible for significant reductions in population density.

RECOMMENDATIONS

Although they are not the only industry to produce significant amounts of sediment, crushed rock quarries, as illustrated by the test quarry, are capable of producing tremendous quantities of sediment. For example, this one quarry fed into this small creek approximately 1% of the total rock crushed during 1968 - more than 4,8000,000 kg or nearly 1100 tons of sediment. The U. S. Bureau of the Census (1967) estimates that there were scattered throughout the United States in 1963,1882 quarries whose total production was 460,834,000 short tons of crushed rock. The potential sediment pollution within this one type of industry is obviously substantial.

There are several ways in which quarries could reduce if not eliminate sediment pollution. The most obvious way is simply to eliminate passing the effluent back into the water course from which wash water was originally taken. Such a plan, which is presently under consideration at the test quarry, would not alter regular plant operations significantly and, if done carefully, could actually eliminate the time now required to clean the settling basins. A deep water-filled basin which occupies one part of the quarry proper will serve as a most adequate settling basin having a long life-time.

Since settling basins of some sort are already required by many states, it would seem highly desirable to go one step further and require a closed system of waste water disposal for all such operations. The arguments for such action are persuasive. The largest amounts of sediment invariably were produced at times when the quarry was busiest during which times, perhaps because manpower was necessary in other areas, the settling basins were permitted to fill up with sediment and overflow. Manhattan quarry had two brief episodes in November 1967 and July 1970 and in each of these months the amount of sediment which entered Deer Creek was fully one-third of the total annual contribution.

Even the adoption of a closed system of disposal would not necessarily eliminate sediment pollution. The impetus for removing the fine particles from the settling basins is through state regulations and not because the material is valuable. Although some crushed rock quarries do market the fine material as agricultural lime, topping for gravel roads or as coating for deep shaft coal mines, the supply far outstrips the demand so that the surplus must be deposited essentially as waste material. At Manhattan quarry almost none of the dredged particles is marketable and, therefore, all of it is hauled to a fairly flat plateau near the edge of the quarry in a site which is elevated above and in close proximity to DeWeese Branch. Toward the end of the study erosion gullies appeared indicating that rainstorms were carrying the sediment into DeWeese Creek. This, of course, negates the primary reason for removing the sediment from the settling basins, and serves notice that other regulations are necessary.

Until the dredged material finds a ready market it would seem necessary to require disposal of the sediment in low-lying areas from which it would not find its way readily into water courses. A pit in the quarry proper would be the best disposal site from a purely ecological standpoint.

There also appear to be steps within the crushing operation which tend to influence the amount of material which enters the settling basins. The dryscreening stage normally used is apparently very important in reducing the sediment output. The elimination of this step during 1968 was a major factor leading to increased sediment pollution.

In their first approximation toward a suspended solids criteria, the European Inland Fisheries Advisory Commission (1965) stated that "(b) it should usually be possible to maintain good or moderate fisheries in waters which normally contain 25 to 80 ppm suspended solids, although the yield might be lower than from water from category (a)". The Deer Creek investigation revealed significant damage to aquatic communities receiving 15 to 40 mg/l additional suspended solids or about double the normal concentration. These solids were added for 8 to 18 hours each day during most of the year and caused reduced standing crops of most fish and macroinvertebrates.

Thus criterion (b), while it may apply to the biota of continental Europe, may be too liberal for populations in the U.S. Certainly at the ranges from about 50 to 80 ppm or mg/l it appears that significant biotic reductions will definitely occur. Furthermore, the results of the experiments in which drift rate increased with the amount of suspended solids concentration indicate that even small quantities of sediment influence some components of the aquatic community.

INTRODUCTION

Sediment is a pervasive, ubiquitous pollutant which has been important in the past and continues to pose new problems as it reaches water courses in the U. S. in quantities estimated at four billion cubic yards annually. While some rivers have always carried significant loads of sediment, others are expanding this functional role in response to a variety of human activities. Poor farming and logging practices which resulted in major contributions in the past have now been joined by road and bridge building, and the proportion of sediment from urban construction may overtake the total agricultural yield in the near future (Wolman and Schick 1967).

Regardless of its origin, the movement of sediments from land to water courses is generally undesirable in every respect, although economic evaluations are uncertain at best. The useful life-span of reservoirs is closely related to the sediment load of feeder streams and sediment accumulations in navigable waterways and harbors are costly to remove. A considerable portion of flood damage results from the sediment which remains after flood waters have receded. Infertile sediments deposited on the floodplains not only damage questionably located croplands but also may reduce the natural fertility of the soil. Even moderate loads of sediment seriously impair the recreational value of rivers, lakes and reservoirs. They also add appreciably to the cost of water treatment.

The problem of evaluating the effects of suspended and deposited sediment is especially difficult because of the variety of types and diverse origins of the sediment and also because of its sporadic appearance both spatially and temporally. Studies of sediment effects, such as are summarized in the excellent review by Cordone and Kelley (1961), have been most often conducted in mountainous regions in association with large quantities of sediment generated through mining activities. These studies generally concluded that the biota of the streams was seriously harmed.

As is the case with many other pollutants, the impact of chronic inputs of sediment is little known although this is the most prevalent condition in the biotically rich streams of the eastern and central U. S.

Fish

Prior to settlement, much of the eastern United States was drained by streams which flowed clear and pure throughout most of the year. Trautman (1933, 1939, 1957) has described the changes that followed the settling of the state of Ohio, alterations which probably occurred in similar sequence in other states as well, and concluded that among the many pollutants which affected aquatic life, soil suspended in water was the one which had most drastically affected the fish fauna. Aitken (1936) made similar observations in Iowa. Ellis (1937) made 514 determinations of turbidity at 202 locations on major rivers throughout the U. S. and noted a gradual decrease in the proportion of sites having good mixed fish populations with increasing turbidity of water.

A questionaire survey sent to river boards in England, Scotland and Wales inquiring about the abundance of fish in streams containing suspended solids of industrial origin led to the conclusion that fisheries were apparently unharmed when the concentration of suspended solids averaged 100 ppm or less, but were definitely affected when it exceeded about 300 ppm (Herbert and Richards 1963). A critical level of 100 to 300 ppm was indicated.

Other more specific field studies also indicate deleterious effects of sediment on the fish and invertebrate populations of streams. Herbert, Alabaster, Dart and Lloyd (1961) found normal brown trout populations where the concentration of suspended sediment was 60 ppm, but only one-seventh the normal density in streams carrying 1000 to 6000 ppm of china-clay wastes. Saunders and Smith (1964) described a 70% decrease in the density of brook trout in response to silt eroded from potato fields and deposited in stream pools. The destruction of hiding places was the apparent cause of the decrease in density and the stocks quickly increased after the silt was scoured from the pools by high water. Both of these studies noted a scarcity of young trout indicating that reproduction was probably affected also.

Peters (1967) examined a trout stream flowing through irrigated agricultural land which caused increases in both the sediment load and the temperature of the water. The two physical factors occurred together so that the individual effects could not be separated. However, good populations of trout occurred where the average sediment load varied from 134 to 218 ppm during a two-year period. Low densities were found further downstream where the sediment load averaged from 156 to 324 ppm and the temperature rose to above 80°F on 7 consecutive days during one summer. Egg mortality was distinctly higher in the downstream stations.

The European Inland Fisheries Advisory Commission (1965) summarized much published and unpublished information including the following. In a river in France which supported a cyprinid fish fauna, fish were absent from areas containing up to 570 ppm solids from coal mines but reappeared further downstream where the concentration was about 100 ppm. No trout were found in another stream where the concentration of suspended stonedust from a granite-crushing mill ranged from 11,300 ppm near the mill to 185 ppm at the stream's junction with another stream. Small numbers of trout were present in certain mountain streams fed by melting snow where 1000 ppm suspended solids were present for 3 to 5 months of the year.

Two Norwegian streams contained good warm-water fish faunas in the presence of average suspended solids concentrations of 25 to 50 ppm with occasional concentrations up to 1331 ppm. Liepolt (1961) reported a trout fishery which was not harmed by dredging operations which raised the concentration of solids to about 160 ppm for short periods.

A section of the South Platte River, Colorado which carried 80 to 100 ppm suspended solids from a gravel washing operation was found to contain only 15% to 40% as many fish as a region above the gravel pit (Anon. 1967).

Sediment concentration can directly decrease the survival of trout and salmon eggs by diminishing the flow of interstitial water within the redds thereby limiting the amount of available oxygen. (Shapavolov 1937, Hobbs 1937, Ward 1938, Shapavolov and Berrian 1940, Neave 1947, Stuart 1953, Campbell 1954, Wickett 1954, McDonald and Shepard 1955, Coble 1961 and Peters 1965). Instances of high egg mortality associated with increased silting have also been recorded for species of fish which lay their eggs on surfaces, for example, yellow perch (*Perca flavescens*) (Munoy 1962) and the European pike-perch (*Lucioperca lucioperca*) (Wynarovich 1959).

Reis (1969) found that eggs of the zebra (*Brachydanio rerior*) hatched more quickly in suspensions of limestone dust of 18,000 to 30,000 ppm but did not experience greater mortality than controls. Newly hatched fry, however, died within

4 hours in suspensions greater than 4800 ppm. It is likely that the fry of many other species are relatively more susceptible to suspended sediment than older fish, but little data is available at this time.

Griffin (1938) stated that salmon and trout fingerlings lived for 3 to 4 weeks in concentrations of 300 to 750 ppm silt. Herbert and Merkens (1961) found that suspensions of kaolin and diatomaceous earth in concentrations of 270 ppm and higher resulted in decreased survival of yearling rainbow trout (*Salmo gairdneri*) with a slight effect noticed at 90 ppm. The incidence of fin rot and thickened gill epithelium was greater at the higher concentrations and it was suggested that the sediment may have somewhat reduced the potential of the trout to resist other stresses in the laboratory environment. The growth in length and weight of the survivors was not, however, impaired.

Increased mortality was noted in this same species over a 32-week span in fish kept in a 200 ppm wood fiber suspension but not at lower concentrations nor in 200 ppm coal-washery solids (Herbert and Richards 1963). However, growth was depressed increasingly at 50, 100 and 200 ppm suspensions of both solids.

Wallen (1951) tested the resistance of several species of fish to concentrations of sediment as high as 100,000 ppm and found surprising tolerance for short periods of time.

This ability would be mandatory for survival in the capricious environment of streams and rivers.

It seems fairly clear from the forgoing discussion that while eggs and fry may be quite susceptible to the direct action of suspended sediment, fingerlings and adults are quite resistant and are capable of enduring temporary periods of high concentrations of suspended solids.

Several instances of changes in the normal behavioral responses of fish in relation to changes in the suspended solids load have been noted. Sumner and Smith (1939) found that king salmon (*Oncorhynchus tshawytscha*) avoided the turbid water of the Yuba River, California and entered clear tributaries preferentially. Bachmann (1958) noted that slight turbidity increases caused cutthroat trout (*Salmo clarki*) to seek cover and stop feeding. Hofbauer (1962) noted decreased migration of the barbel (*Barbus fluviatilis*) during periods of increasing turbidity of the water and increased migration of the European eel (*Anguilla anguilla*).

Other workers have concluded that even high concentrations of suspended solids did not seemingly impede the upstream migrations of trout and salmon (Gibson 1933, Smith and Saunders 1958, Ward 1938). Cleary (1956) found evidence that smallmouth bass (*Micropterus dolomieui d.*) nested, spawned and hatched during sporadic periods of high turbidity in streams in Iowa. He also noted, however, that streams which remained turbid because of erosional silt for long periods of time seldom produced either smallmouth bass fingerlings or good smallmouth bass fishing.

The European Inland Fisheries Advisory Commission (1965) concluded that definite water quality criteria for finely divided solids could not be proposed because of the differential effect exerted by the many different kinds of solids currently entering water and because of the differential response of various species of fish to the same material. Nevertheless, the following tentative criteria was presented as a first approximation:

(a) there is no evidence that concentrations of suspended solids less than 25 ppm have any harmful effects on fisheries;

(b) it should usually be possible to maintain good or moderate fisheries in waters which normally contain 25 to 80 ppm suspended solids, although the yield might be lower than from waters from category (a);

(c) water normally containing from 80 to 400 ppm suspended solids are unlikely to support good freshwater fisheries although fisheries may sometimes be found at the lower concentrations within this range; and

(d) at the best, only poor fisheries are likely to be found in waters which normally contain more than 400 ppm suspended solids.

In this country the Ohio River Valley Sanitation Commission (ORSANCO) (1956) evaluated the available research and concluded that there was not enough information on which to base a criteria. Current efforts to establish a maximum level for suspended solids have similarly stumbled because of a lack of information. (National Technical Advisory Committee 1968).

Benthic Macroinvertebrates

The benthos of flowing water is strongly affected by the type of substrate available. Tarzwell (1937) and Gaufin and Tarzwell (1952) ranked different substrates on their ability to support macroinvertebrate populations using a scale of from 1 to 452. Shifting sand supported the fewest number of organisms and rated 1 on the scale while a combination of moss, gravel, rubble and *Elodea* rated over 400. Various substrates mixed with silt rated no higher than 27. It is not surprising, therefore, that studies of the effect of silt and fine sediment on benthic organisms have shown pronounced effects.

Taft and Shapovalov (1935) always found lower summer populations in streams where mining occurred than in clear streams. Tebo (1955) found that silt loads of 261 to 390 ppm (turbidity measurements) created by dragging logs over the ground near the stream reduced benthic populations to 25% of their normal density. Periods of low sedimentation caused slight, statistically insignificant differences. Herbert, Alabaster, Dart and Lloyd (1961) described densities of invertebrates only about

11% normal in streams receiving 1000 to 6000 ppm suspended solids and approximately normal densities in a stream receiving only 60 ppm. Bartsch (1960) studied the effects of wastes from a glass manufacturing plant on the benthos of the Potomac River and found almost no organisms in the immediate zone of settling where the turbidity exceeded 5000 ppm. Recovery was gradually achieved, but the effect was still noticeable 13 miles downstream where the turbidity was normal.

Hynes (1963) described an example of replacement of the normal fauna by high numbers of Chironomus and Tubificidae due to sediment originating from a colliery, although an organic pollutant might also have had an effect. He also stated that suspended sediment may prevent light from reaching submerged aquatic plants and result in their reduction or elimination. Thus, animals dependent upon these plants for food, shelter, egg deposition sites, etc. could be affected indirectly.

The reduction of invertebrates could, in turn, exert an effect on fish which feed heavily upon them. Herbert, et. al. (1961) found little effect on trout, much of whose food consisted of terrestrial forms, but the impact on other species might be more serious.

This report summarizes four years of research which focused upon the quantitative effects of stonedust sediment arising from a crushed limestone quarry on fish and macroinvertebrate populations of a small, central Indiana stream.

The amount of stonedust passing from the quarry to the creek was quite variable from year to year depending upon the type of operation and the care with which settling basins were cleaned. During periods of low flow the stonedust tended to settle out in pools and riffles downstream from the quarry. It was felt that a study of two important biotic groups in relation to this differential pattern of sedimentation would lead to a better understanding of the impact that any inert sediment might exert on running-water ecosystems and, thereby, contribute to the rational formulation of water quality criteria for this important pollutant.

METHODS

Contributions of sediment from the crushed rock quarry to Deer Creek were monitored with a 90° V-notch weir containing a Stevens type-F water level recorder which provided estimates of daily volume of discharge. The suspended solids load here and elsewhere was determined by sampling with a depth-integrating wading-type hand sampler, model U. S. DH-48. Aliquots of from 25 to 200 ml were filtered through tared Gelman Type-A glass fiber filters, oven dried at 105°C for 24 hours, dessicated, and weighed finally on a Cenco No. 1581 balance, a method adapted from Banse, Falls and Hobson (1963) and Wyckoff (1964). Turbidity was determined routinely on a Spectronic 20 colorimeter using the Hach method, which was found by Langemeier (1965) to yield values which were 30% to 60% lower than the platinum wire technique.

Samples of sediment were analyzed for particle size distribution using the bottom-withdrawal tube method (Subcommittee on Sedimentation, Federal Inter-Agency River Basin Committee, 1943 and 1953). The various sizes of material in the riffles was determined five times during the study by taking three to five samples per riffle, drying them and sieving with a "Ro-Tap" shaker.

Macroinvertebrates were collected with a Surber sampler having a fine mesh net with 23 threads per inch and, on two occasions, with Hester Dendy plate samplers. Monthly collections consisting of three samples of each riffle were made only during summer and fall because of frequent flooding and high water during the remainder of the year.

Samples taken during 1968 through 1970 were classified to species where possible, while those collected in 1967 were recorded to order (Deol, 1967). Because no species keys are available for many forms, analyses were made at the genus level for uniformity. Taxonomic resources included West (1931), Johannsen (1934), Frison (1942), Ross (1944), Pennak (1953), Usinger (1963), Burks (1953), Gordon and Post (1965), Edmondson (1965), and Gaufin, Nebeker and Sessions (1966).

Diversity indices (Wihlm 1967, Wihlm and Dorris 1968) were computed for the pooled monthly samples from each riffle based both on order and genus.

A series of experiments were conducted at riffle A-2 upstream from the quarry to investigate the relationship between the rate of invertebrate drift and sediment loads. This particular riffle was selected because it held the greatest variety of substrate and bottom fauna. All tests were conducted during the early afternoon on clear days when the flow of Deer Creek was steady and the water was clear.

Placed at the foot of the riffle were nylon drift nets six feet long with mouth dimensions of one by two feet and a mesh size of 253 u. A modified garbage can which proved to be an adequate sediment dispenser was placed near the head of the riffle. Below the water line on the upstream side a large square hole was cut. A vertical baffle placed perpendicular to the direction of flow was soldered to the bottom and a smaller hole was cut in the downstream side. Sediment measured into the upstream chamber mixed thoroughly with the incoming water and maintained a fairly constant suspended solids load. The sediment introduced was fine material taken from the upper settling basin. The coarser fraction of this was trapped in the bottom of the can.

Each series of experiments consisted of alternating 15-minute periods of control and sediment introduction. Nets were replaced at the end of each period and any invertebrates contained by the nets were removed and preserved in 70% ethanol. Approximately mid-way through each period a water sample was taken half-way between the can and net for determination of suspended solids load.

Fish were collected by means of an electric seine constructed and operated in a manner similar to that described by Larimore (1961). The population densities in each study pool were estimated in 1967 and 1968 by a modified Schnabel method initially (Ricker 1958) which was based on the catches from three to seven days of collecting. A single pass was made per pool each day. All fish were identified, marked distinctively by fin-clipping, measured for total length to the closest mm and weighed to the nearest gram.

The recapture rate was less than expected, probably because of the lack of integrity of the blocking nets which quickly clogged with leafy debris and usually had toppled by the following day. These difficulties and others prompted the use of the DeLury (1947) method during 1969 and 1970.

The estimates by the DeLury method were completed within a single day for each pool, thus reducing greatly the incidence of exit and entry of fish. Each pool was electrofished three times in succession with a pause of one hour between the end of one pass and the beginning of the next. Fish were processed and placed in holding nets after each pass. A regression of catch in weight per pass against the previous cumulative catch extrapolated to the abscissal intercept provided the estimated weight of any specific species group for the pool. Weights proved to be less erratic than numbers and the data was sufficiently linear so the logarithmic transformation, as recommended by Libosvarsky (1962, 1966), was deemed unnecessary. An examination of the average weight of each species for each successive pass revealed no significant bias for size by the electrofishing apparatus.

For a few of the estimates, an overall pooled slope or "catchability" factor was used together with mean values for cumulative previous catch and catch per pass. This was usually necessary only where populations were small.

This same method was used to reestimate the populations of 1967 and 1968 by assuming that the catchability of a group was the same as during 1969 and 1970. Thus, an average catchability factor was the mean of the catchability factors for 1969 and 1970. In this adaptation of the DeLury method, the ordinate intercept always lies very close to the weight of fish captured in the first pass. Thus, it seemed reasonable to base estimates on the average weight of fish caught per day (A) during any particular series of collections and the average catchability factor, (-b), N = A/-b.

It is felt that while the DeLury method somewhat underestimated the actual population, the mark and recapture method rather strongly overestimated it. Generally the former were about 50% the value of the latter.

Estimates of growth rate were made for important species. The sculptured sides of scales were impressed in plastic and these impressions magnified 22.5 times with a Tri-Simplex Microprojector. Scales were read by at least two different readers and readings which did not agree were tested independently at least once more. The relationship between magnified scale radius and total length was generally good except for longear sunfish. The modified direct proportionality formula of Fraser (1916) and Lee (1920) was used to compute the estimated length at each age of life in a computer program modified from Gerking (1965) for an IBM 1620 computer.

Comparisons of the length/weight relationships for species populations above and below the quarry were also made combining data from 1967, 1968 and 1969. The pairs of regressions of log weight on log length were compared statistically by means of a single classification analysis of covariance.

THE STUDY STREAM

Deer Creek is a small stream in Putnam County, Indiana, which drains approximately 90 square miles. Arising in productive silty soils of the Russell-Fincastle Association (Ulrich 1966) on the southern edge of the Tipton Till Plain (Schneider 1966),it flows southwesterly for most of its 25 mile length. The middle third of the stream is situated on the Mitchell Plain which further south produces renowned building limestone and which is everywhere pocked with sink-holes and laced with caverns. The lower third cuts its path through the more deeply dissected Crawford Upland.

The section of Deer Creek investigated lies within the Upland at T 13N, R 5W, Sections 23, 24 and 26 near the town of Manhattan, Indiana. Its waters are enriched primarily by runoff from agricultural lands and treated domestic wastes entering Deer Creek four miles above the study section from the Indiana State Penal Farm. Oxygen depletion and fish kills have occurred in the past through faulty operation of the Farm waste treatment plant, but no incidents were noted during the period of study. Typical chemical and bacteriological characteristics during periods of low summer flows are shown in Table 1. Approximately one mile of stream between the Farm and study section was dredged and canalized previous to this study, and two bridges were constructed during the study.

Table 1: Chemical and bacterial analysis of Deer Creek water sampled above the quarry.

Analysis	July 16, 1967	July 23, 1967
B.O.D.	6.8	6.4
pH	8.1	7.8
Alk. (M.O.)	185.0	212.0
Chlorides	37.0	30.0
Total Solids	340.0	360.0
Vol. Total Solids	78.0	95.0
Susp. Solids	41.0	38.0
Vol. Susp. Solids	16.0	30.0
C.O.D.	60.0	--
P04	0.1	0.1
N03	0.2	0.2
E. Coli	9,300	2,100
Enterococci	2,000	110

The region averages 40 inches rainfall annually and the recorded discharge ranges from 4,430 cfs to 0 cfs and averages 62.7 cfs. Stable flows from July through November typically average less than 10 cfs. The gradient of the creek in the study section averages only 2.5 feet per lineal mile.

Five pools and seven riffles were chosen for study in a segment about 4000 meters long (Figure 1). Investigations of fish were restricted to pools and invertebrates to riffles in order to minimize disturbances. Most pools and riffles remained quite constant during the four years of the study (Tables 2 and 3), but some temporary alterations were caused by floods which washed out makeshift gravel bridges, by the construction of a bridge and, in the fall of 1968, by a beaver dam which raised the water level high enough to cover the riffles furthest downstream. The average composition of several determinations of the substrate of riffles is shown in Table 4.

The introduction of sediment-laden water mid-way in the study segment did not substantially alter the dissolved, chemical composition of the creek water nor did it affect the temperature or dissolved oxygen concentration even during periods of heaviest input.

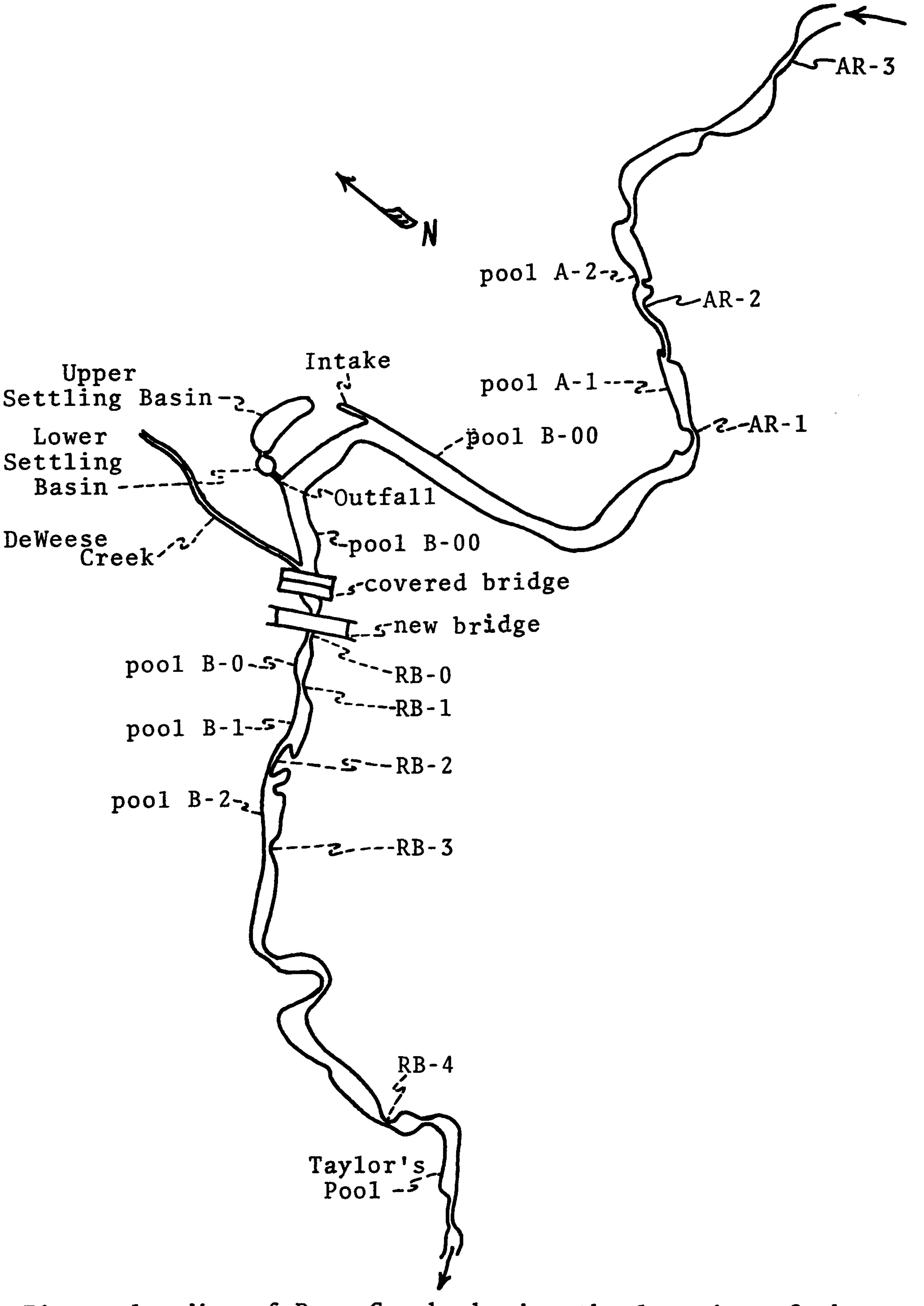

Figure 1: Map of Deer Creek showing the location of the study pools and riffles. Scale: 8 inches=1 mile

Table 2: Morphometry and composition of bottom material of the pools of Deer Creek in mid-July 1968.

	Pool					
Parameter	A2	A1	B0	B1	B2	Taylor's
Length - meters	100.6	163.8	41.1	63.0	113.0	112.8
Average Width - m	10.8	12.9	5.9	9.2	7.8	8.1
Surface Area - ha	0.1085	0.211	0.024	0.0531	0.0803	0.0912
Average Depth - cm	42.8	46.4	13.5	33.5	30.0	38.3
Total Volume - m^3	464.7	978.2	32.9	117.8	240.9	348.9
% Surface Area 30 cm	67.2	69.6	7.2	44.4	43.6	55.9
% Surface Area 61 cm	26.2	33.1	0.0	16.6	9.7	17.4
% Surface Area 91 cm	0.0	4.3	0.0	2.8	1.6	6.6
Bottom Material						
% gravel	52.8	18.0	84.6	80.6	40.0	46.8
% sand	35.9	58.0	0.0	0.0	30.0	33.2
% mud	11.3	22.0	15.4	16.1	30.0	18.9
% rock	0.0	2.0	0.0	3.2	0.0	1.0
% silt	0.0	0.0	0.0	0.0	0.0	0.0

Table 3: Measurements concerning the riffles sampled for invertebrates as determined during the summer of 1968.

Riffle Designation	Distance from Q0. (m)	Length of riffle (m)	Ave. Width of riffle (m)	Ave. Depth of riffle (cm)
AR-3	1127 m	20 m	5 m	30 cm
AR-2	966 m	25 m	8 m	18 cm
AR-1	805 m	25 m	5 m	46 cm
RB-0	113 m	26 m	3 m	15 cm
RB-1	178 m	21 m	8 m	15 cm
RB-2	274 m	46 m	4 m	20 cm
RB-3	407 m	10 m	4 m	20 cm
Taylor's	966 m	25 m	3 m	15 cm
Farm	2897 m	15 m	3 m	20 cm

Table 4: The average composition of the bottom substrate in the riffles of Deer Creek. Each value represents the average of several triplicate samples collected at various times during the study and represent percentages by weight.

Riffle	Large gravel and Rubble >4 mm diam	Gravel and Coarse Sand 0.125 to 4 mm	Fine Sand, Silt and Clay <0.125 mm
AR-3	45.7	27.8	23.3
AR-2	70.8	13.4	20.7
AR-1	66.0	32.0	1.0
RB-0	66.7	19.7	8.9
RB-1	74.5	17.5	8.4
RB-2	66.8	20.6	12.1
RB-3	66.5	22.0	11.0

OPERATION OF THE STONE QUARRY

Since the quantity of sediment entering Deer Creek from the quarry was strongly related to the mode of operation of the quarry, a brief description follows. Blasted limestone is carried to a massive grinder where raw blocks are broken into smaller chunks. The resulting mixture of fine and coarse rock is then normally screened dry to remove particles smaller than about 1 1/2 inches diameter. Up to 50% of the total crushed rock consists of this finer material, known locally as "fifty-three's", which is used for road topping.

The larger pieces are conveyed to a tower which also receives water pumped in from Deer Creek. The rock/water slurry is then screened for the desired sizes of crushed material which is carried to distribution bins, while the water with smaller particles is piped to an upper settling basin approximately 80 m long and 15 m wide. A smaller settling basin about 16 m diameter follows, after which the waste water enters Deer Creek.

The upper part of the upper settling basin normally becomes filled in with coarser materials rather quickly, necessitating a regular program of removal. The lower part of this basin and the lower basin fill up much more slowly as a rule and require thorough dredging only about twice each year. There is little commercial market for the dredged material and it is hauled away to a flat plateau near DeWeese Branch.

This procedure was generally adhered to except during late 1967 and all of 1968 when increased demands for crushed rock for construction of near-by U. S. Interstate Highway 70 resulted in double shifts and an altered operational procedure. Two alterations profoundly influenced the sediment input to Deer Creek: (1) the first screening stage was omitted with the result that all of the crushed material was mixed with water preceeding the final screening and (2) between mid-August 1967 and October 1, 1968 neither settling basin was completely dredged. These events led to an enormous increase in the quantity of sediment entering Deer Creek during 1968.

The limestone was 90% calcium carbonate, 8% magnesium carbonate and 2% other materials.

RESULTS

Amount of sedimentation in study pools

Characteristics of quarry effluent

The volume of effluent produced by the quarry was closely correlated with the amount of limestone crushed when calculated on a weekly basis (Figure 2), with an average of 0.6182 m^3 being produced for each ton of rock crushed. This relationship was used to estimate the volume of flow during 1969 and 1970.

The amount of suspended solids, however, varied greatly for the reasons mentioned previously. When the settling basins

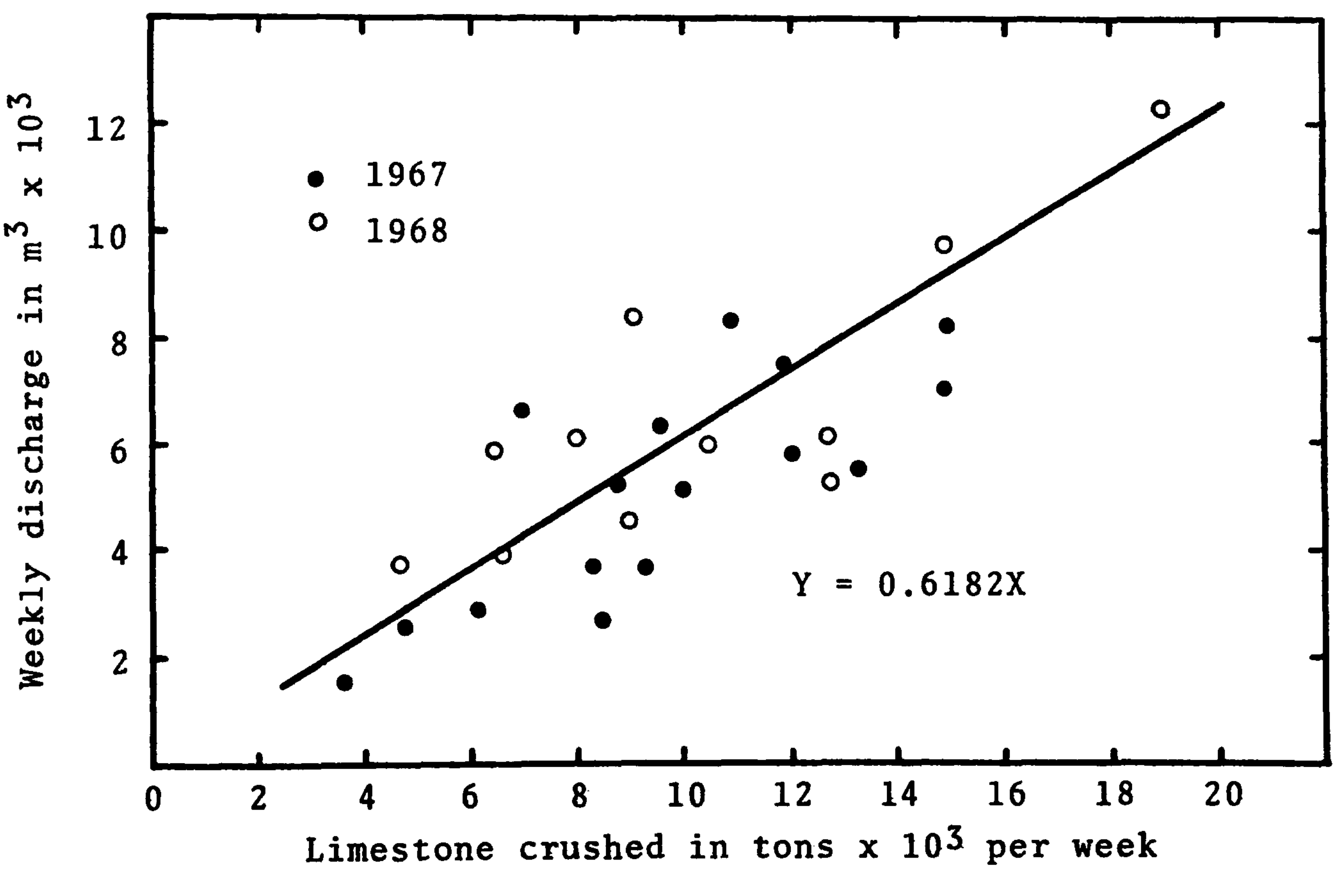

Figure 2: Relationship of weekly discharge from the quarry settling basins to weekly production of crushed limestone during 1967 and 1968.

were clean the mean concentration was about 0.047 g/1; when they were full the mean concentration was about 20.1 g/1, an increase of more than 400 fold. The size of the suspended particles in the effluent depended upon the concentration which, in turn, was dependent upon the state of the settling basins. When the suspended solids concentration was low, 90% of the weight consisted of particles less than about 10 u in diameter (Table 5). When the concentration was high, more than 50% of the weight consisted of particles exceeding 20 u in diameter while those smaller than 10 u formed a minute contribution.

Up to concentrations of about 350 mg/1 suspended solids, the turbidity of the effluent was linearly dependent upon and highly correlated with (r = 0.95) suspended solids concentration. This relationship is described for this particular effluent by the equation Y = 21.953 + 0.902, where Y equals the turbidity in Hach JTU's and X equals the suspended solids concentration in mg/1.

Sediment input from the quarry

Monthly contributions of sediment from the quarry to Deer Creek ranged from an estimated 157 kg in March, 1969 to more than 1,118,000 kg in August 1968 (Table 6). Relatively little sediment entered the creek during winter because of sporadic working conditions. Relatively little sediment was contributed when the settling basins were cleaned regularly during the summer.

Table 5: The distribution of particle sizes of quarry sediment as determined by the bottom tube withdrawal method. Values are given as the percent of material by weight which is finer than the indicated size.

Diameter microns	Pool B-00 No. 1 Nov. 1967	Pool B-00 No. 2 Nov. 1967	Effluent 6/26/68	Effluent 7/5/68	Effluent 7/24/68
125.0	99	90	95	98	98
62.5	98	90	91	96	97
44.2	97	90	88	91	95
31.2	96	90	87	85	85
22.1	94	90	85	46	39
15.6	90	89	56	2	1
11.0	89	85	8	-	-
7.8	46	79	2	-	-
5.5.	3	60	-	-	-

However, dramatic increases resulted as soon as the settling basins filled up, as they usually did whenever the quarry operated two shifts daily.

Sediment from the quarry first had an opportunity to settle out in the long tail of pool B-00 immediately upstream from the study pools and riffles. The volume of this pool was about 1020 m^3 in 1967 and could accommodate approximately 2,360,000 kg

Table 6: Amount of sediment contributed to Deer Creek from the limestone quarry near Manhattan, Indiana from 1967 through 1970.

Month	Sediment in kg x 10^3 during year			
	1967	1968	1969	1970
January	.80	.92	.61	.17
February	.40	3.73	1.47	1.47
March	1.08	11.51	.16	1.74
April	1.19	744.40*	1.96	2.33
May	.84	877.68*	1.90	4.40
June	1.45	671.81*	2.27	9.07*
July	3.53	943.27*	2.43	14.02*
August	2.98	1118.24*	3.04	1.06
September	2.56*	443.40*	1.74	1.20
October	6.60	1.52	10.31	0.91
November	9.24	.65	7.69	0.44
December	2.93	.79	1.33	n.a.
Total	27.84	4817.92	34.91	36.80

n.a. = not available

* = double work shifts

of stonedust assuming a displacement of 2330 kg/m^3. Thus, this pool exceeded the combined volumes of the other B-pools and acted as a settling basin with respect to these pools and riffles whose organisms were actually studied. It played a particularly important role during periods of heavy sediment entry by intercepting the larger particles.

Estimates of sedimentation in the study pools.

The rate of discharge of Deer Creek strongly influenced the process of sedimentation. Sediment accumulated in Deer Creek during the summer and fall when the discharge was low and these accumulations were mostly removed by floods during winter, spring and sometimes early summer. When the discharge of Deer Creek was very low, pool B-00 trapped considerable amounts of sediment so that the actual concentration of suspended solids in the water entering the study pools and riffles did not vary as much as would be expected considering the great differences in input.

Table 7 shows some point samples collected at different times throughout the study. The normal suspended solids load was generally between 15 and 40 mg/l during the summer, lower during the winter and, of course, much, much higher during periods of floods. The measured increase in suspended solids load shown by these and other point samples during periods of light input are in close agreement with the increases estimated from the average daily input of sediment from the quarry during a 10 hour day (or 18-hour day if the quarry operated double shifts) and the discharge rate. The increase in sediment loading due to stonedust from the quarry was in the vicinity of 20 to 40 mg/l bringing the total suspended solids load of the stream below the quarry from 35 to 80 mg/l, an increase of two to three times normal.

During periods of heavy input the suspended solids load was initially about four to five times normal, approximately 120 mg/l or more, and then increased sharply when pool B-00 filled up.

Series of suspended solids concentrations taken at various times at the heads of the B-riffles provided some indication of the sediment load passing through the pools and riffles and also an indication of the rates of sedimentation in the section (Table 8). This data together with estimates of discharge provided by the USGS gage station at Putnamville, Indiana, was used to estimate the daily rate of sediment accumulation in the B-pools and riffles (Table 9). There are many assumptions concerning uniform input from the quarry, length of the work day, absence of sampling bias, and, especially, the accuracy of the USGS gaging station during periods of low flow which cast doubt about the accuracy of the estimates, but several features seem worthy of further comment.

First, under light sediment input and low creek flow, a large part of the sediment entering Deer Creek settles out in

Table 7: Some measurements of the load of suspended solids (mg/l) and turbidity (JTU-Hach) at sampling stations above the quarry, riffle B-0, and the quarry input.

Date	Suspended solids load (mg/l)		Turbidity (Hach JTU)		Quarry input load (mg/l)	Stream flow (cfs)
	Above	RB-0	Above	RB-0		
7-6-67	22.0	60.5	54	68	61	3.0
10-3-67	30.0	35.0	67	75	100	0.5
10-11-67	10.5	37.0	36	73	228	7.4
11-7-67	9.5	99.0	31	80	355	2.4
11-17-67	18.0	42.5	43	70	1257	9.7
7-2-68	94.0	125.0	75	88	7609	8.3
7-18-68	22.5	132.0	22	70	1207	2.4
7-23-68	34.0	222.0	37	112	3686	2.5
8-13-68	52.0	2681.0	74	3950	33324	3.4
6-23-70	36.0	56.0	-	-	275	8.4
7-2-70	30.0	38.0	-	-	142	4.8
7-13-70	37.0	93.0	-	-	498	3.2
7-20-70	33.0	57.0	-	-	229	3.8
8-11-70	13.0	21.0	41	44	33	1.6

Table 8: Representative measurements of suspended solids loads (mg/l) at stations above and below the limestone quarry under conditions of light and heavy sediment input.

Date	Station						discharge cfs
	Quarry Outfall	Above Quarry	RB-0	RB-1	RB-2	RB-3	
		Light Input					
7-6-67	61	22.0	60.5	42.5	45.5	39.5	3.0
6-23-70	275	36.0	56.0	44.0	101.0	41.0	8.4
7-2-70	142	30.0	38.0	45.0	28.0	27.0	4.8
7-13-70	498	37.0	93.0	78.0	80.0	50.0	3.2
7-20-70	229	33.0	57.0	60.0	45.0	37.0	3.8
8-11-70	24	13.0	21.0	21.0	25.0	-	1.6
		Heavy Input					
11-17-67	1,207	16.0	42.5	41.0	40.0	40.5	9.7
5-3-68	8,904	-	85.0	74.5	62.5	62.0	11.0
7-12-68	36,005	-	77.0	74.5	54.0	45.0	3.4
7-17-68	19,055	18.5	95.5	73.0	49.0	42.0	2.7
7-18-68	25,716	22.5	132.0	104.0	81.5	62.5	2.4
7-19-68	26,764	18.2	250.5	185.0	131.5	75.0	2.4
7-22-68	14,132	28.5	139.5	166.0	104.0	82.5	2.0
8-12-68	2,768	52.0	156.0	-	-	117.0	5.3

Table 9: Estimated quantity of sediment (kilograms per day) settling in pools of Deer Creek.

Date	Discharge of Creek (cfs)	Daily Input of sediment (kg)	Suspended Solids Concentration of Effluent (g/l)	B-0	B-1	B-2	Total	% of sediment settled in B-pools
7-6-67	3.0	85	0.061	36.7		14.7	51.4	60%
11-17-67	9.7	705	1.257	11.9	4.0		15.9	2%
*5-3-68	11.0	20,653	8.904	118.4	215.4	9.0	412.8	2%
*7-12-68	3.4	80,130	36.005	16.6	113.8	50.0	180.2	0.2%
*7-17-68	2.7	46,848	19.055	99.0	105.8	30.8	235.6	0.5%
*7-18-68	2.4	64,131	25.716	109.6	88.1	74.4	272.1	0.4%
*7-19-68	2.4	49,206	26.764	256.4	209.4	221.2	687.0	1.4%
*7-22-68	2.0	29,136	14.132	115.8		70.1	185.9	0.6%
*8-12-68	5.3	3,710	2.768	337.2			337.2	9.1%
*6-23-70	8.4	448	0.275	164.4	41.2		205.6	45.9%
*7-2-70	4.8	501	0.142	78.2		7.8	86.0	17.2%
*7-13-70	3.2	617	0.498	78.3	146.2		224.5	36.4%
*7-20-70	3.8	532	0.229	74.4		49.6	124.0	23.3%

*double shifts at quarry

the study pools and riffles immediately downstream from the quarry. In a canalized stream with no well defined riffles and pools this probably could not have occurred. The proportion of sediment which was carried through the study pools without settling out increased with increasing flows of Deer Creek.

Secondly, under heavy sediment input and low creek flow most of the input sediment settled out in pool B-00, but the sedimentation rate in the B-pools downstream increased somewhat over the rate which occurred during light sediment input. The differences were not as great as might be thought, however. An average of 138 kg/day was deposited during periods of low flow and light sediment input, but double shifts were working on most of the days used in the calculations. Therefore, a deposition of less than 100 kg/day might be expected in a regular work day during the summer. During low flows, heavy sediment input and double shifts the average deposition increased to 330 kg/day.

The third trend which is evident from the data is a slight gradation in sedimentation rates with the upstream pools receiving more material than the downstream ones. This trend is rather remarkable considering the shallowness and small size of pool B-0.

The simplest, yet most reliable, method of determining settling rates of this light yellowish sediment was observation.

It contrasted strongly to the normally dark resident material and also had a distinctive slippery consistency even when mixed with bottom material. Series of substrate samples from riffles were taken when it was obvious that limestone sediment was accumulating, yet analyses of particle sizes did not reveal increased amounts of the finer material.

The question of how much sediment needs to be present for visual detection and how this relates to the estimated deposition rates may be illuminated by the following example. Consider the surface area of the bottom of the B-pools to be about the same as the surface area of the water - about 16,000 square meters. We determined experimentally that 1 kg stonedust displaces 430 cc volume, thus 0.233 kg would be required to build up a layer of sediment 0.1 mm thick over a surface area of 1 square meter. Considering only the pools and ignoring riffles, over 3700 kg of stonedust would be needed to coat the bottoms of the B-pools uniformly with 0.1 mm stonedust. Nearly 7 work weeks (single shift) would elapse before this would be achieved at a settling rate of 100 kg/day and low discharge from Deer Creek.

<u>Build-up of sediment deposits in the B-riffles and pools</u>

Large quantities of sediment entered Deer Creek during 1964, 1965 and 1966 such that by autumn of those years pools B-00 and B-0 were nearly full of sediment and pool B-1 had deposits up to ankle-deep. Pool B-2 accumulated substantially less sediment. Floods each winter and spring swept most of the sediment from the pools.

In 1967 trace quantities of sediment first appeared in August near the edges of the pools. Further depositions failed to occur because of the increasing volume of discharge from Deer Creek during the fall. Even the trace quantities had disappeared by November (Figure 3).

During 1968 heavy sediment input from the quarry began as soon as the weather permitted full operation of the quarry. However, monthly floods swept through the stream preventing substantial deposition of the sediment. Stable, low flows began in early June and by July pool B-00 had filled sufficiently so that finer materials began flowing into the downstream pools in ever increasing amounts. Measureable amounts had accumulated in nearly all pools by the end of July. By early September pools B-0 and B-1 were completely filled in and pool B-2 was beginning to receive great amounts of material. Even the riffles between the pools were filling in with settled material at this time, some areas having as much as three inches.

In late September the quarry increased the depth of the upper settling basin by constructing a low dam between it and the lower basin. In early October the Indiana State Board of Health directed the quarry to dredge the settling pools. The combination of these events markedly reduced further sedimentation.

Floods during the winter again swept the sediment from the pools and riffles. The settling basins were cleaned very

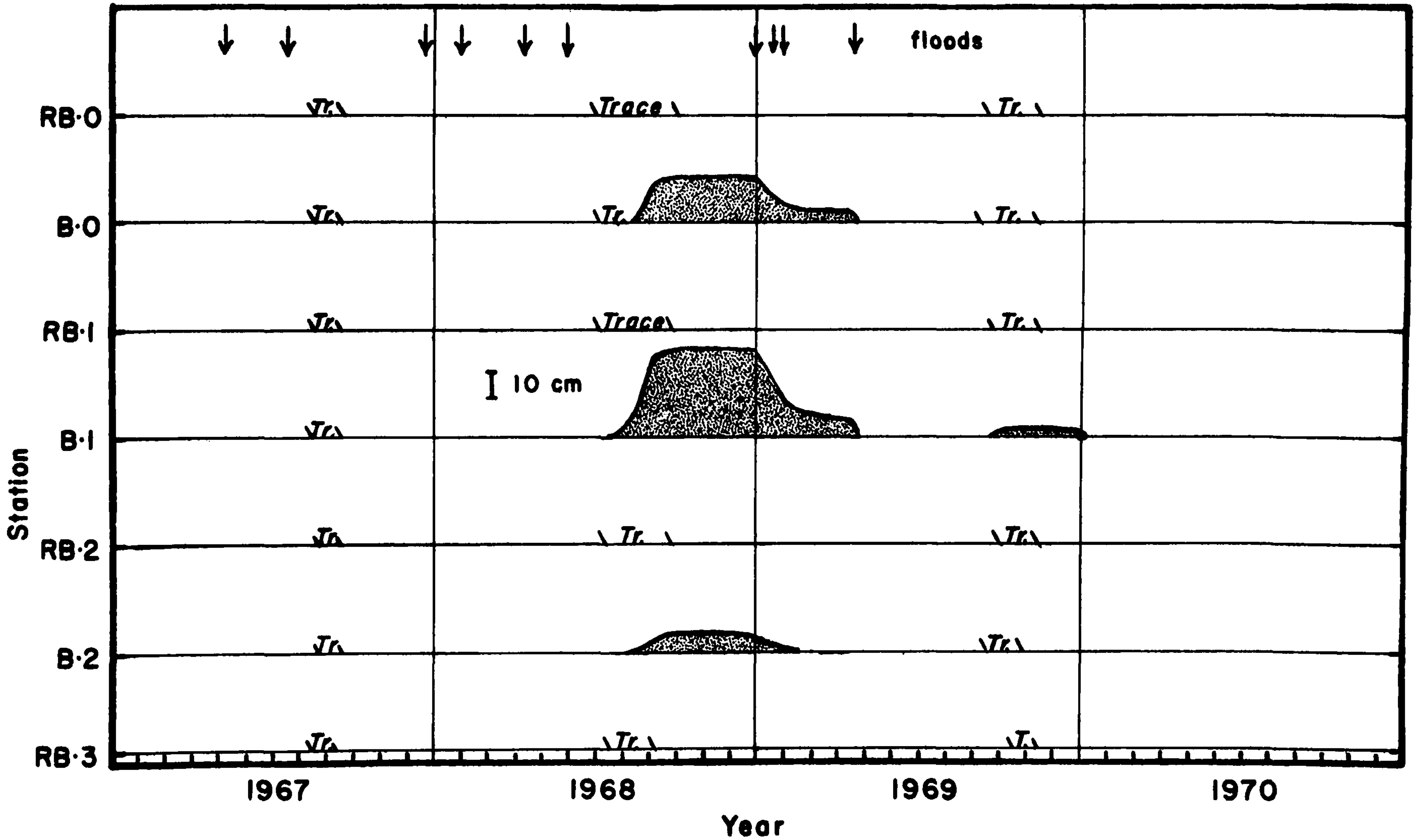

Figure 3: Patterns of sediment accumulation in the pools (B) and riffles (RB) of Deer Creek downstream from a crushed rock quarry.

regularly in 1969 and with the result that sediment input was light and no sediment was detected in the pools below the quarry. However, a different source of sediment appeared on September 1, 1969 when construction began on a new bridge located directly over riffle RB-0. Care was taken by the engineers so that very little sediment was generated by the phase of construction involving driving piles into the stream bed. However, adjacent land was denuded with the result that considerable amounts of eroded soil were swept into Deer Creek by frequent rains during September and October.

Most of this was trapped by pool B-1 in accumulations measuring 15 to 25 mm deep by October 10, 1969. Some mud mixed with sand was found in pool B-2 at this time, but there were no solid accumulations.

Effect of sediment on macroinvertebrate populations

Population density

Large numbers of macroinvertebrates were found in all riffles during the summers of 1967 and 1968. A list of taxa col lected appears in Appendix Table I. Somewhat lower densities were present in the summer of 1969, probably because of periods of unusually high water. July was usually the time of greatest density (Table 10) with a second peak occurring in September due to hatching of those larval forms that would overwinter. The density varied from 8 per square foot in December, 1967 in the riffles below the quarry (B-riffles) to nearly 1000 per square foot in the riffles above the quarry (A-riffles) in July, 1968. Most samples with high densities of invertebrates were due to extremely high numbers of a single genera; i.e. 537 *Simulium* per square foot in the A-riffles on July 2, 1968.

One of the first relations examined was the existence of a recovery zone between riffles B-0 and B-3. During some months in 1967 some recovery appeared between riffles B-0 and B-3 exhibited in regularly increasing densities of organisms. Because the differences could well have been caused by the nature of the riffles themselves, since they were not uniformly good with respect to habitat, it was decided that all of the B-riffles could be regarded as a unit and compared to the A-riffles which were also grouped as a unit. To remove seasonal variations in density, a simple B/A x 100 ratio was used with B being the average

Table 10: Average densities of the macroinvertebrates in the above and below riffles and estimated monthly input of sediment in kilograms. Density in numbers per 929 square centimeters (1 sq. ft.) ± 2 x S. E. B/A ratios given as B/A x 100.

Date	A-riffles	B-riffles	B/A ratio x 100	Sediment input (kgms)	Sediment accumulation in B-riffles
1967					
Jan.	-	-	-	796	-
Feb.	-	-	-	400	-
March	-	-	-	1,082	-
April	167	61	36.7	1,189	-
May	63	20	31.5	841	-
June	128	88	68.8	1,449	-
July	498	480	96.3	3,527	-
August	226	123	58.4	2,977	slight
Sept.	221 (99)	130 (38)	59.5	2,557	-
Oct.	261 (39)	35 (17)	13.4	6,596	-
Nov.	-	-	-	9,236	-
Dec.	27 (8)	5 (4)	20.0	2,931	-
1968					
Jan.	-	-	-	920	-
Feb.	-	-	-	3,734	-
March	-	-	-	11,531	-

Table 10: (con't)

April		-	-	744,396	-
May	50 (26)	37 (20)	74.7	877,677	-
June	626 (105)	60 (16)	9.7	671,810	-
July	243 (16)	102 (27)	42.2	943,274	slight
August	318 (76)	58 (9)	18.1	1,118,241	heavy
Sept.	80 (42)	46 (9)	57.8	443,396	heavy
Oct.	70 (13)	149 (36)	212.8	1,521	-
Nov.	44 (11)	17 (10)	36.2	653	-
Dec.	-	-	-	793	-
1969					
Jan.	-	-	-	607	-
Feb.	-		-	1,465	
March	-		-	157	-
April	-	-	-	1,926	-
May	124 (39)	115 (51)	92.4	1,901	-
June	108 (36)	112 (31)	103.7	2,265	-
July	34 (11)	33 (20)	97.0	2,428	-
August	121 (25)	207 (82)	171.1	3,044	-
Sept.	177 (38)	123 (37)	69.4	1,737	slight
Oct.	72 (24)	18 (9)	25.0	10,307	slight
Nov.	52 (34)	12 (8)	23.1	7,689	-
Dec.	-	-	-	1,328	-

density of invertebrate samples from the B-riffles and A the average density from the A-riffles. Table 10 and Figure 4 summarize the B/A ratios over the period of collection - 1967 through 1969.

The average density of macroinvertebrates declined noticeably during periods of heavy sediment input (Table 11) resulting in a B/A ratio of only 37.0 considering a number of the most important genera. When the input was light - less than about 3500 kg/mo the B/A ratio averaged 74.6. B/A ratios calculated during periods of noticeable sediment accumulation were only 39.0 while during periods where no visible accumulation of sediment occurred the ratio was 71.0

Although there was an overlap in the periods of heavy sediment input and of sediment build-up, both conditions seemed to affect the invertebrate populations equally. When periods both of build-up and heavy input coincided there seemed to be no cumulative effect which resulted in even further decreases in density in the B-riffles.

Collections taken on July 26, 1968 yielded a B/A ratio that was higher than 100, the only series to do so. This was due to one of the three samples taken at RB-2 which contained nearly 2500 newly hatched *Cheumatopsyche*. It should be noted that the eggs hatched despite the considerable accumulation of sediment.

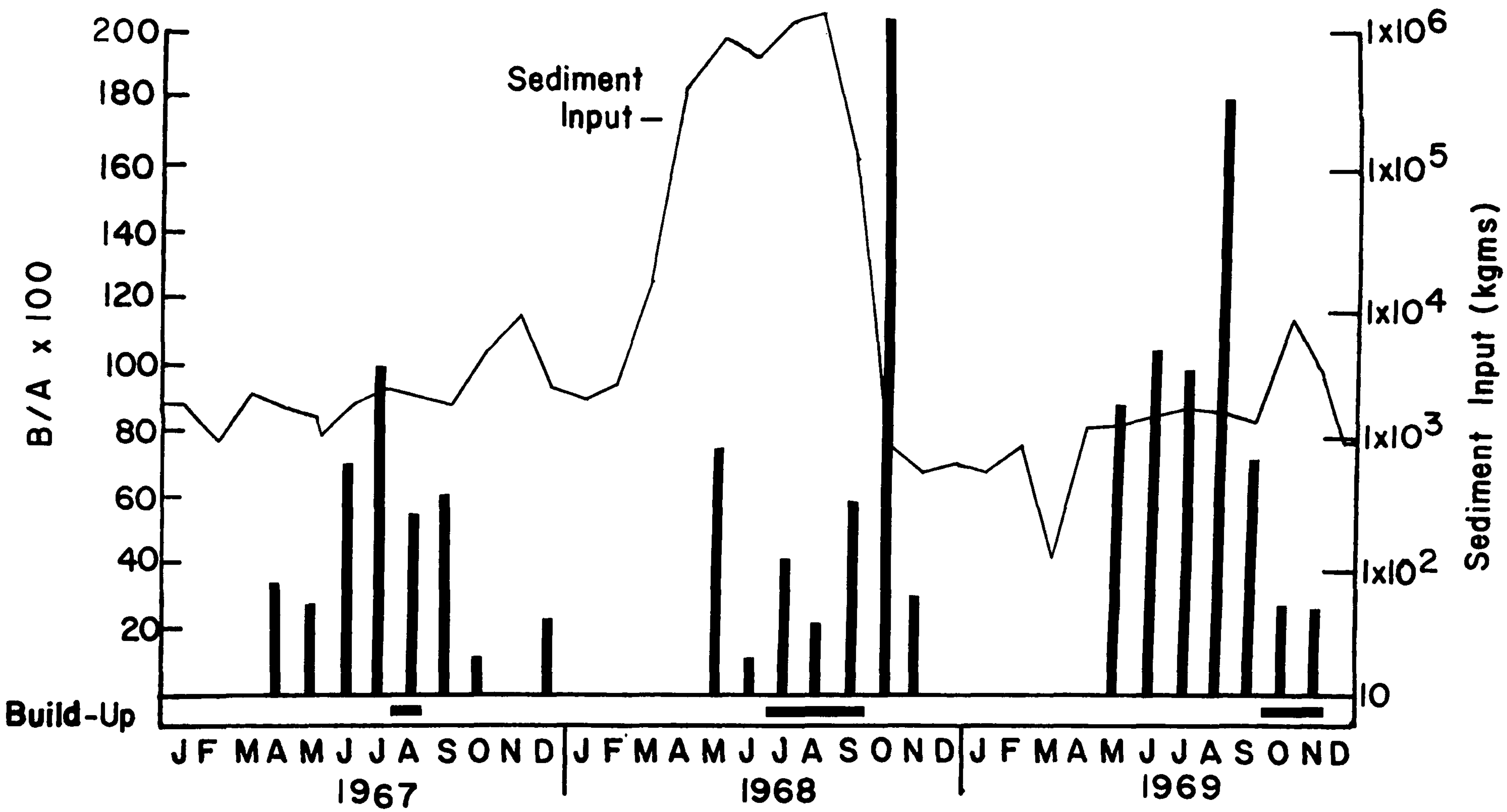

Figure 4: The density of invertebrates in the B-riffles as a percentage of the density in the A-riffles in relation to periods of sediment build-up in the B-riffles and to input of sediment.

Table 11: Average B/A ratios (x 100) for various taxa during periods of light and heavy sediment and periods of no build-up and build-up in the riffles.

Taxa	B/A x 100 ratios			
	Light input	Heavy input	No build-up	Build-up
Chironomidae	84.4	38.0	80.0	26.0
Cheumatopsyche	82.2	59.4	83.2	32.5
Caenis	109.1	11.1	95.4	11.5
Baetis	122.6	108.3	167.3	69.0
Stenomia	133.3	85.2	193.2	75.8
Tricorythoides	80.0	148.2	71.0	164.5
Stenelmis	107.4	25.9	117.7	59.0
Simulium	57.2	66.3	60.2	70.8
Overall average	74.6	37.0	71.0	39.0

Response of important taxa to sediment

Most of the ephemeropterans are quite specific in habitat and, therefore, the changes in the bottom composition of the riffles produced marked changes in the populations. Of the major genera found, *Tricorythoides* prefers a muddy or silty bottom type, *Baetis* and *Isonychia* prefer small rubble and pebbles, and *Stenomia* and *Caenis* prefer larger stones and rubble (Burks, 1956; Pennak, 1953). *Baetis* (Figure 5 and Table 11) was the predominant ephemeropteran. During periods of heavy sedimentation the B/A ratio was reduced from 122.6 to 108.0. Sediment build-up in the riffles reduced the B/A ratio even more drastically from 167.3 to 69.0. The reactions of *Stenomia* were quite similar to *Baetis*. During periods of heavy input, the B/A ratio was reduced from 133.3 to 85.2 and during periods of sediment build-up the B/A ratio was reduced from 193.3 to 75.8. While reacting to both sediment input and build-up, both of these genera showed stronger reactions to build-up. *Caenis* was found consistently in low numbers throughout the study period. However, during the July 1968 samples, the A-riffles contained very large numbers of this genus while the B-riffles did not. Because only these samples contained high numbers, it was difficult to ascertain whether this was due to chance or to the sediment. *Tricorythoides* was one of only two taxa which increased in numbers during periods of heavy sedimentation. This was probably due to its preference for a silt or mud substrate. During the periods of heavy input the B/A ratio for *Tricorythoides*

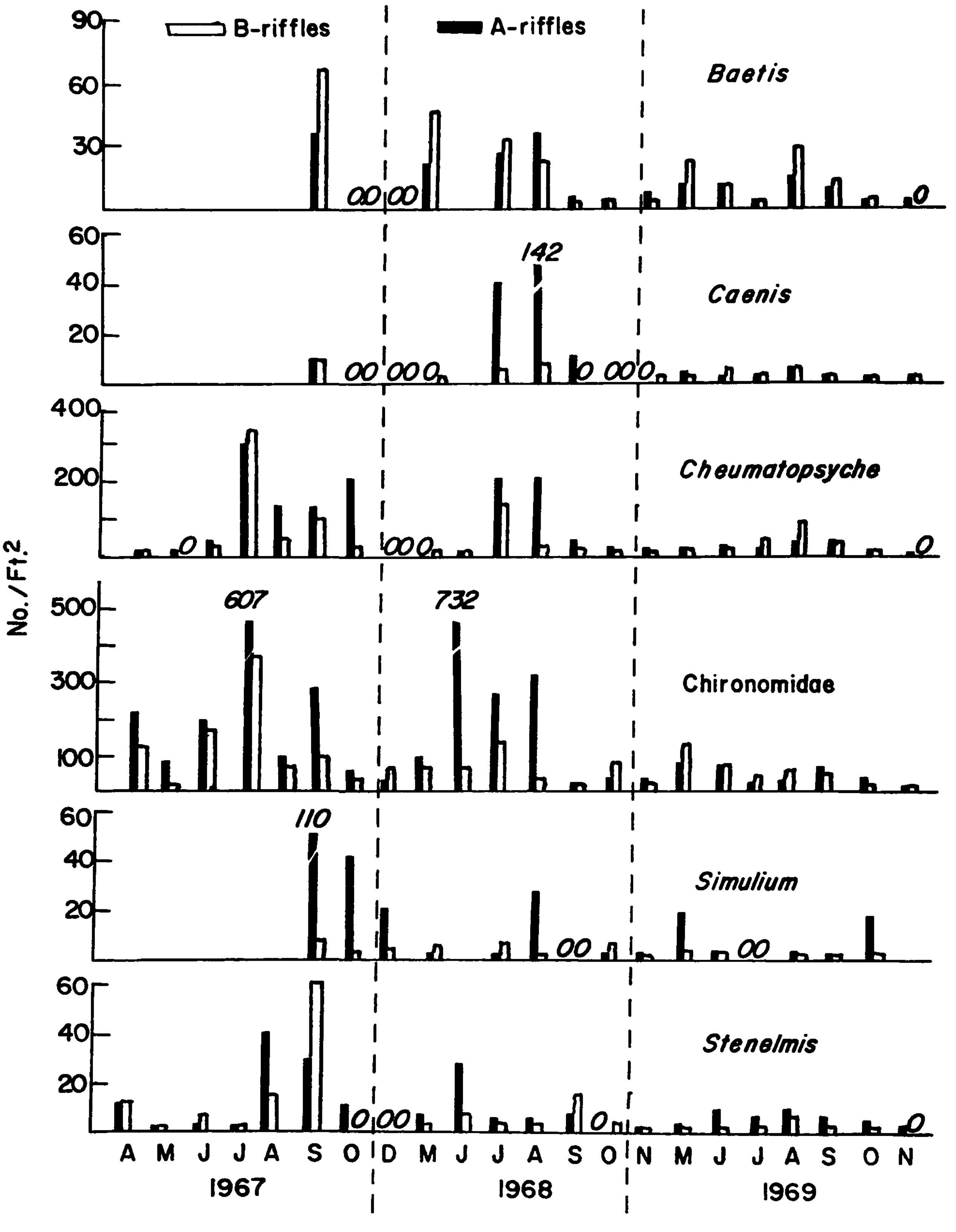

Figure 5: Average population density of the principal taxa in the riffles above and below the quarry outfall.

increased from 80.0 to 148.2. During the periods of build-up the B/A ratio increased from 70.1 to 164.5.

Only three genera of Trichoptera were found with any consistency. *Cheumatopsyche* was very abundant especially in the late summer months while *Hydropsyche* and *Ochrotrichia* were usually not abundant enough to provide information about a sediment response. *Cheumatopsyche* construct nets and require a substrate consisting of rubble, large gravel, or plants. The nets are cone shaped and are attached to the rubble with the mouth of the cone facing directly into the flow of the current so as to trap algae and organic detritis. The presence of suspended sediment can effectively clog the nets so the animals can not feed (Pennak, 1953; Hynes, 1963). During the periods of heavy sediment input, the B/A ratio for the *Cheumatopsyche* was reduced from 82.2 to 59.4. During the periods when there was sediment build-up in the riffles, the B/A ratio was further reduced from 83.2 to 32.5. An unusually large number of newly hatched *Cheumatopsyche* found in the B-riffles in the July 26, 1968 was due to a single sample that contained stems of submerged *Dianthera* upon which the *Cheumatopsyche* were hatching. This sample was considered to be unrepresentative and was deleted from the B/A ratios.

Both the young and adults of several coleopterans were noted in the riffles. The only abundant genus was *Stenelmis*, with *Dineutus*, and *Helictus* being found in small numbers. The adult Elmids are noted indicators of organic pollution due to their oxygen gathering mechanisms (Sinclair, 1964). However, since there was no change in the amount of available oxygen caused by the presence of the sediment, this could not be considered as a factor in limiting the number of *Stenelmis* below the effluent unless the sediment interfered with structural adaptations. Adult *Stenelmis* were found in the B-riffles even during the highest periods of sedimentation. It was noted that their entire bodies were so covered with the sediment that species identification was almost impossible. Even though the larval and adult forms prefer the same rubble habitat and both feed on algae and organic detritus, it was found that the young were more abundant in the A-riffles and the adults were more abundant below the effluent. This trend remained constant throughout the study period and, therefore, both the young and adults were considered as a single group. During the peiods of heavy sedimentation, the B/A ratio for the *Stenelmis* was reduced from 107.4 to 25.9. During the periods of sediment build-up in the riffles there was a reduction in the ratio from 117.4 to 59.0. The coleopterans, excluding the Elmids, increased in numbers during the periods of heavy input and build-up, even though their numbers were always much greater in the A-riffles than in the B-riffles. This was due to an increase in the number of adult *Berosus* present during sediment build-up in the back waters around the B-riffles. The adult *Berosus* often prefer a silty bottom and more quiet water. The individuals collected were probably those that had wandered from pools into the riffles. *Dineutus* adults were noted in the A-riffles during the entire study period, but were found only occasionally in the B-riffles. Since the sampling methods used were not suited to capturing these fast swimming beetles, no quantitative measurements could be made of the differences due to sedimentation. The other genera collected were not analyzed because they were either found in very low numbers or were mainly found in the A-riffles due to their close association with the *Dianthera* that was abundant there.

Several genera of Diptera were found in the riffles. Chironomidae and *Simulium* were the most abundant while *Tabanus, Tipula, Hexatoma,* and *Hemerodromia* were regularly noted in low numbers. The family Chironomidae was the most abundant of the taxa found in the riffles. As a family it prefers either a fine sand and silt habitat or rubble that is covered by a thick layer of filamentous algae. The principle food source is diatoms and organic detritus (Pennak, 1953). During periods of high sediment input, the B/A ratio for the Chironomidae was reduced from 84.4 to 38.0. Similar results were noted during periods of sediment build-up. When there was sediment build-up in the riffles, the B/A ratio was reduced from 80.0 to 26.0. With the Chironomidae making up as much as 75% of the total density, the reductions were always clearly reflected in reductions of the total number of organisms. The genus *Simulium* was quite common during late summer on the submerged stems and leaves of

Dianthera. The *Simulium* cling to vegetation or large rubble where they are scavengers of algae and organic detritus. As the populations were definitely related to the amount of *Dianthera* present, it was not possible to relate any direct effects of the sediment to this genus.

Response of community diversity to sediment

Diversity was measured by the index of Wilhm and Dorris (1968). This diversity index has the advantage of being independent of sample size and allows the comparison of the diversity of two or more different sized samples. The minimum diversity will occur if only one taxa is present and the maximum diversity will occur if each organism is of a different taxa. During periods of heavy input and riffle build-up, no trends were noted between riffles B-0 and B-3. Seasonal variations were noted in the indices, however, with the summer samples being more diverse than the spring or fall samples. The diversities were averaged for all of the A-riffles and the B-riffles for each sampling period.

As with density, average diversities were determined for periods that had light sediment input, heavy input, sediment build-up in the riffles and no sediment build-up. When there was light input and no build-up the diversity of the B-riffles was slightly lower than that of the A-riffles. During periods of heavy input and build-up, a slightly higher diversity was noted in the B-riffles than in the A-riffles. However, the differences in the diversities were not significant at the 95% level when tested by t-tests. This slight increase in diversity in the B-riffle during sedimentation probably resulted from the reduction in numbers of the more populous taxa with a retention of some of those that occurred in very small numbers.

Table 12: Average indices of diversity for the macro-invertebrate samples collected from A- and B-riffles during 1967, 1968 and 1969.

Date	Order diversity		Genus diversity	
	Above	Below	Above	Below
1967				
April	1.634	1.471	-	-
May	1.248	1.757	-	-
June	1.740	1.534	-	-
July	1.176	1.137	-	-
Aug.	1.910	2.136	-	-
Sept.	1.628	1.885	2.272	2.296
Nov.	0.855	0.898	1.070	1.169
Dec.	0.744	0.748	0.744	0.748
1968				
May	1.213	1.544	1.479	1.904
June	0.724	1.314	-	-
July	1.784	1.126	2.058	1.561
Aug.	1.855	1.925	2.482	2.969
Sept.	1.905	1.604	2.633	2.342
Oct.	1.661	0.691	2.061	1.197
Nov.	1.339	0.987	1.626	1.256

Table 12: (con't.)

1969				
May	1.439	1.256	2.219	1.160
June	1.405	1.552	2.124	2.207
July	1.869	1.459	2.505	2.112
Aug.	1.903	1.676	2.526	2.021
Sept.	1.290	1.408	2.019	2.107
Oct.	1.267	1.466	1.466	1.642
Nov.	1.249	1.178	1.897	1.678

The effect of sediment on the drift rate of macroinvertebrates

A series of experiments was designed to measure the effect of varying concentrations of suspended solids upon the rate of drift of macroinvertebrates. The results of the experiments indicate that this environmental factor is highly influential and help to clarify the mechanism involved in the regulation of population density by sediment.

The experiments consisted of collecting drift at the downstream end of the riffle for 15 minutes without adding sediment and following this with another 15 minute collection during which sediment was continually added. This alternation of conditions was repeated through one to several cycles. The normal suspended solids load in the creek during the control phases of each series ranged from 10 to 28 mg/l while during the test phases the sediment was introduced at uniform rates ranging from about 18 to 270 mg/l (Table 13).

The drift rate increased steadily with increasing suspended solids concentrations (Figure 6). The relationship was roughly linear up to concentrations of 160 mg/l additional stonedust. Only a few trials were made at concentrations higher than this, and it is possible that more determinations at high concentrations would extend the curve even further.

The increased rates of drift appear to be caused by suspended sediment rather than by settled sediment. Although

Table 13: Increased drift rates in relation to additions of stonedust during two to six test periods alternating with control periods.

Date	Mean suspended solids concentration mg/l $\pm$2SE			Mean drift per 15 minutes $\pm$2SE		% Increase
	Control	Test	Added Solids	Control	Test	
8-10-70	9.7$\pm$1.7	28.3$\pm$ 2.2	18.6	32.0$\pm$4.3	40.3$\pm$ 4.4	25.9
8-10-70	11.0$\pm$0.8	65.3$\pm$ 9.7	54.3	25.0$\pm$6.2	33.0$\pm$10.0	32.0
8-21-70	24.0$\pm$1.2	108.3$\pm$13.0	84.3	19.7$\pm$5.2	28.7$\pm$ 8.4	45.7
7-23-70	20.3$\pm$1.3	125.0$\pm$ 4.0	104.7	62.0$\pm$6.4	117.5$\pm$25.0	89.5
7-22-70	27.7$\pm$1.3	162.0$\pm$ 2.8	135.5	62.0$\pm$2.0	135.5$\pm$41.0	118.5
10-12-69	19.0$\pm$0.0	173.5$\pm$38.2	154.5	30.0$\pm$9.0	60.5$\pm$26.7	101.7
6-26-70	20.2$\pm$8.6	291.5$\pm$46.5	271.3	51.0$\pm$2.5	96.3$\pm$33.2	88.8

there was some visible deposition by the end of some series, there was no tendency for the drift rate to increase with time during the control phase. During series in which larger quantities of sediment were added there was actually a lag in the response with a rather slow initial increase and then a steady increase with subsequent test periods.

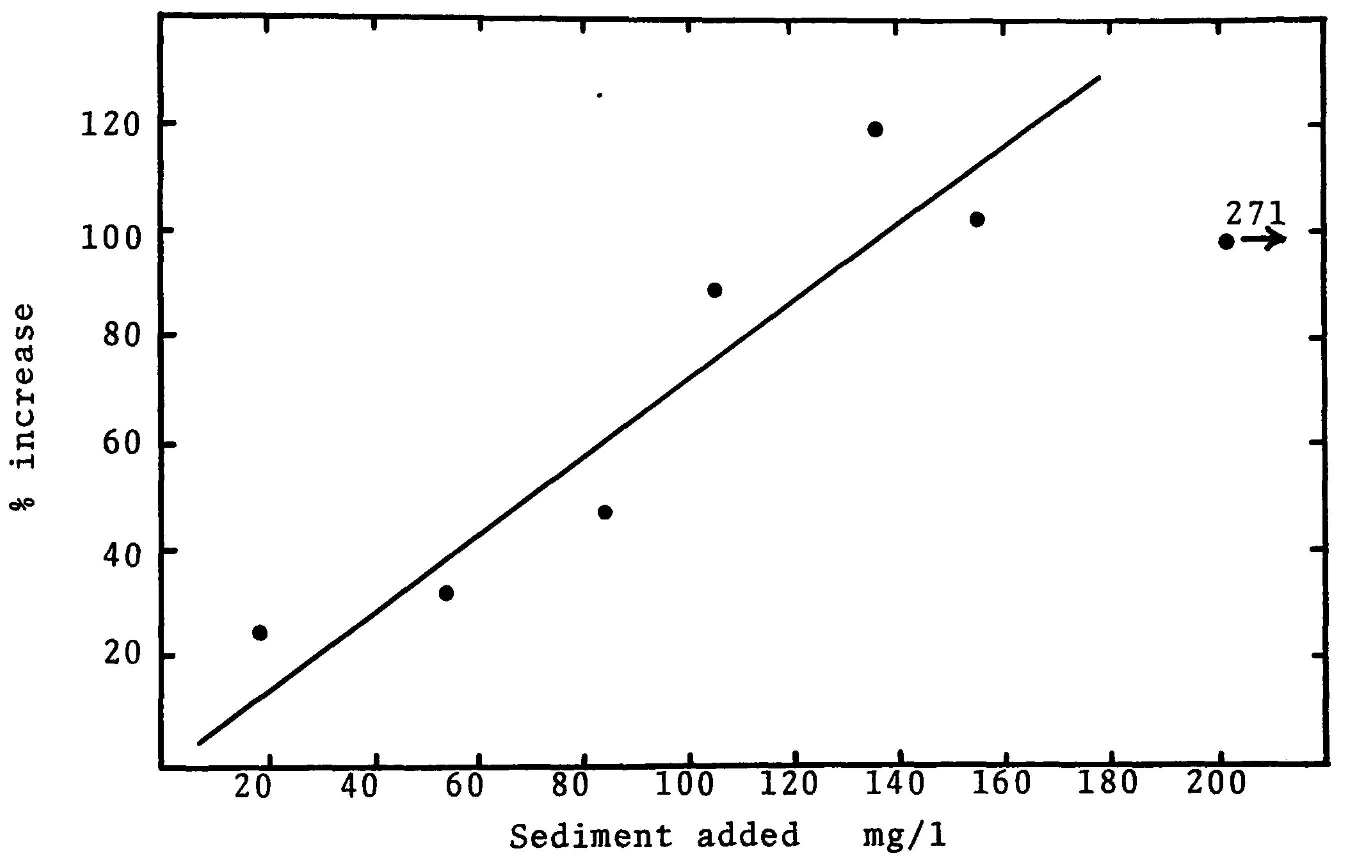

Figure 6: Drift rate as a function of the concentration of stonedust sediment added during 15 minute test-periods alternated with 15 minute control periods.

The species composition of the drifting organisms was essentially similar to that of the riffle itself (Table 14). Regular monthly Surber samples of the riffle invertebrates showed that chironomidae comprised about 60% of the population with other taxa contributing various proportions of the remainder. The organisms drifting from the riffle during both test periods and control periods also consisted of about 60% chironomids with other taxa in approximately the same proportion as their abundance in the riffle. Thus the total macroinvertebrate fauna seems to be affected similarly by the sediment.

In every series there was a rather uniform, but statistically nonsignificant, difference in the size of the organisms drifting from the riffle during the control and test phases (Table 14). The average total body length of drift during the sediment phase was 5% to 10% smaller than during the control phase. This magnitude of difference was maintained regardless of the amount of sediment introduced. Although t-tests of the test and control data were nonsignificant, this regularity suggests that smaller organisms are somewhat more influenced by the sediment than larger individuals.

Table 14: Average body length (mm) of all drift organisms and proportion of drift which were chironomidae in control and test phases of the sediment introduction experiments.

Date	Average Body Length (mm)		Percent chironomidae		Additional Sediment
	Control	Test	Control	Test	mg/1
8-10-70	2.76	2.60	56.3	62.3	18.6
8-10-70	2.78	2.72	62.8	51.5	54.3
8-21-70	2.66	2.50	60.6	69.0	84.3
7-23-70	2.55	2.36	65.6	66.4	104.7
7-22-70	3.03	2.64	72.0	60.0	135.3
10-12-69	2.63	2.41	76.9	63.6	154.5
6-26-70	2.85	2.55	63.6	69.8	271.3

The effect of sediment on the population density of fish

The standing crop of fish in each study pool was determined several times each year during the summer and fall months. Spring collections would have been valuable, but sufficiently low flows were never stabilized until early June and often later.

A total of 49 species of fish were collected and identified (Appendix Table II). No doubt other species were present in the intervening riffles which were not taken. The majority of these were species which, in terms of weight and/or numbers, contributed relatively little to the overall standing crop of fish. Catostomids and centrarchids formed the vast majority of the total weight of the collective populations, while cyprinids with the exception of carp, were never abundant.

Important species of fish were separated into eight groups, some with a single species and others with multiple species of similar ecological characteristics. They are as follows:

(1) suckers and redhorse, dominated by golden redhorse *(Moxostoma erythrurum)* with smaller contributions from black redhorse *(M. duquesnei)*, silver redhorse *(M. anisurum)*, shorthead redhorse *(M. macrolepidotum)*, common white sucker *(Catostomus commersoni)* and spotted sucker *(Minytrema melanops)*;

(2) hog suckers *(Hypentelium nigricans)*, a form which is more a riffle dweller than an inhabitant of pools;

(3) carpsuckers, primarily central quillback carpsucker *(Carpiodes cyprinus hinei)* with some northern river *(C. carpio carpio)*

and rarely highfin carpsuckers *(C. velifer)*;

(4) carp *(Cyprinus carpio)*;

(5) gizzard shad *(Dorosoma cepedianum)*;

(6) sunfish, rock bass and crappie, 95% of which were longear sunfish *(Lepomis megalotis)* and the remainder divided among 7 other species;

(7) bass, mostly spotted bass *(Micropterus punctulatus)* followed by smallmouth bass *(M. dolomieui)* and rarely largemouth bass *(M. salmoides)*;

(8) miscellaneous species including, in order of importance, drum *(Aplodinotus grunniens)*, yellow bullhead *(Ictalurus natalis)*, longnose gar *(Lepisosteus osseus)*, channel catfish *(Ictalurus punctatus)* and a scattering of others.

The weight and size of the fish in each group was the basis of the population estimations. Appendix Tables III through VI present the catch data and population estimations for each pool. The various pools, despite some morphological and physical differences, were similar enough so that the electrofishing seine performed about the same in each pool. Catchability values (-b) were examined for trends from pool to pool for each group of fish and none were found. Likewise, differences from time to time during the year were not evident, but it was felt that perhaps fish were more susceptible to the gear when the water was cool in the fall. Overall summer catchabilities for each group of fish were quite similar in 1969 and 1970 (Table 15), and the mean of these was used to estimate the standing crop from the catch data collected in 1967 and 1968. The total weight of fish captured in three electrofishing passes constituted from 46% to over 90% of the estimated standing crop of all groups (Table 16). Thus each estimate is based upon a sample of about 75% of the total population.

Table 15: Catchability values (-b) for the summers of 1969 and 1970.

Group	1969	1970
Suckers and Redhorse	0.575	0.508
Hog suckers	0.520	0.283
Carpsuckers	0.800	0.834
Carp	0.221	0.625
Gizzard shad	0.390	0.712
Sunfish and crappie	0.241	0.242
Bass	0.452	0.123
Other species	0.481	0.578

Table 16: Total weight of fish captured in three passes as a percent of the estimated standing crop.

Date	Pool			
	A-1	A-2	B-0/1	B-2
June/July 1969	.736	.461	.644	.849
August 1969	-	-	.893	.788
October 1969	-	-	.978	.770
June 1970	.992	.798	.893	.634
August 1970	.694	.768	.659	.830

The standing crop of fish in the pools above the quarry decreased from a high of about 220 kg/ha in 1967 to approximately 160 kg/ha from 1968 through 1970 (Figure 7). The quantity of fish in the pools below the quarry fluctuated tremendously during this period in response to the quantity of sediment introduced from the quarry.

At the beginning of the investigation the fish populations in the pools below the quarry were probably in a state of recovery from considerable amounts of sediment which had accumulated in the two upper pools by fall of 1966. In June, 1967 the B-pools contained about 40% as many fish (kg/ha) as the A-pools. An influx during the next two months increased this to 60% normal. Heavy contributions of sediment issued from the quarry during most of 1968. Estimations conducted in June, 1968 revealed a decrease in population abundance to only about 25% normal which, since no sediment had yet settled out into the B-pools, can probably be attributed to the increased suspended solids loads and not to settled sediment.

By the end of July 1968, pool B-00 was completely filled with sediment, pool B-0 contained 25 to 40 mm sediment over three-quarters of the bottom, and the bottom of pool B-1 was evenly coated by a layer of stonedust 85 to 125 mm thick. Parts of pool B-2 even accumulated up to 25 mm sediment. In spite of this settled material the fish populations as a whole were considerably greater than they were in June.

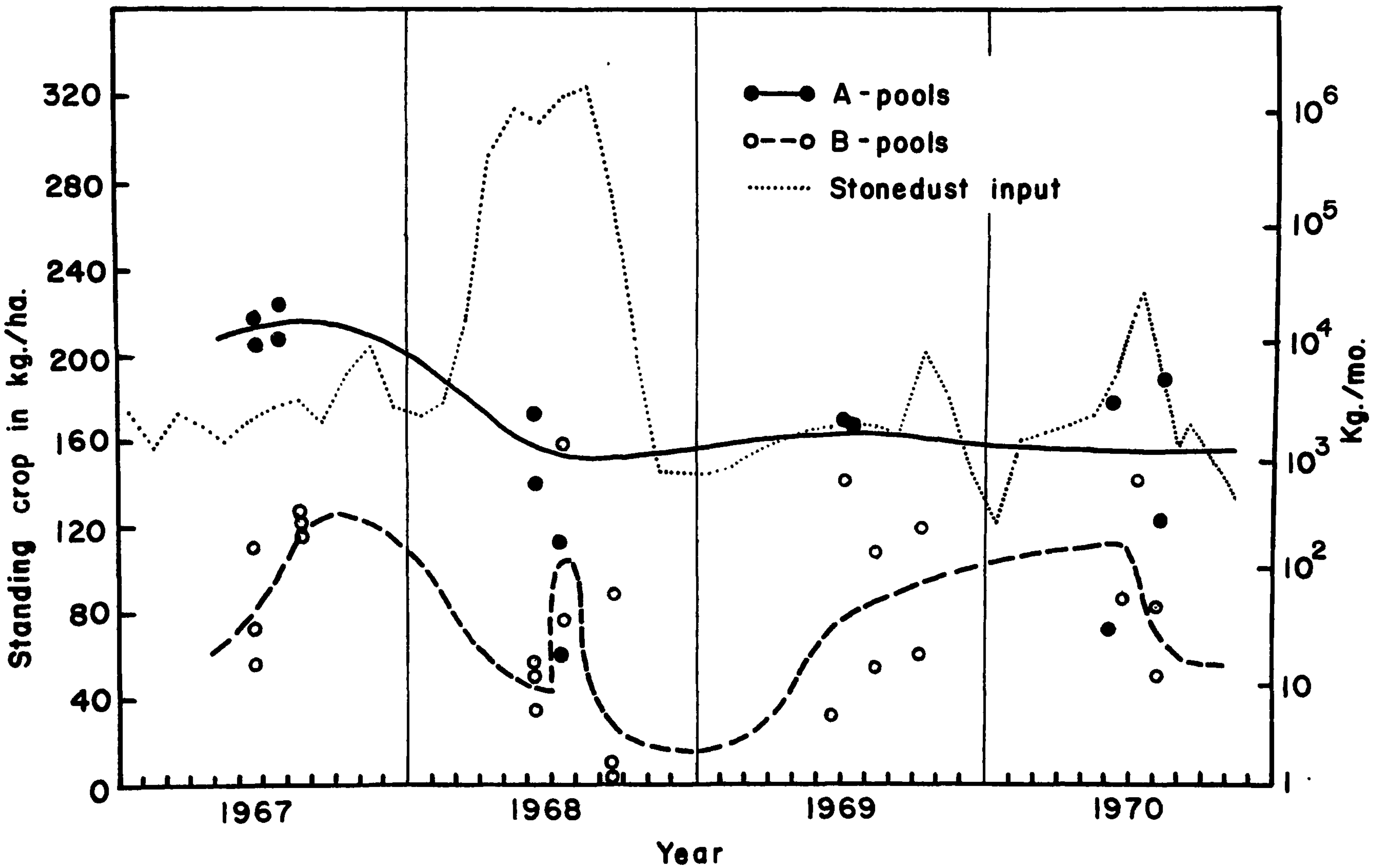

Figure 7: Estimated standing crop of fish in two pools above (A) and three pools below (B) a crushed rock quarry.

This increase is attributed to the influx of fish which were forced out of pool B-00 and the mouth of DeWeese Creek by the accumulating sediment because this is exactly what occurred to the fish in pools B-0 and B-1 during August and September. In mid-September 1968 no fish lived in pool B-0 and few in B-1 because both had completely filled in with sediment. Pool B-2, having up to 50 mm stonedust accumulations in its deeper, downstream section, supported an estimated 90 kg/ha of fish. At this same time, Taylor's Pool, located 1/4 mile downstream from pool B-2, contained a normal standing crop of fish, although not a normal species composition.

In early October 1968 the quarry cleaned its settling basin thoroughly and increased its depth with a dam. No large inputs of sediment occurred thereafter for some time, but the deep sediment deposits remained until winter floods swept them downstream.

Fish returned to the pools with the removal of the sediment, and achieved population levels about 50% normal by the end of June 1969. Continued slow gains to about 60% normal were made during the remainder of the summer and early fall, despite an acute dose of soil sediment injected into pool B-1 as the result of bridge construction during September. Further recovery was noted by June 1970 when the populations reached 70% of the A-pool standing crop.

From mid-June through July 1970 another marked increase in the amount of sediment coming from the quarry occurred because more rock was crushed during the double-shift days and the attendant difficulty of keeping the settling basins clean. A sharp decrease in the standing crop occurred almost exclusively because gizzard shad vacated the B-pools during this period.

An examination of the individual response of each species group of fish is necessary at this point, since each group appeared to respond somewhat differently.

Suckers and redhorse - These fish rather quickly moved back into the B-pools in the spring after vacating them during periods of sediment build-up (Figure 8, A). A return toward normal during late summer was facilitated mainly through the appearance of concentrations of young redhorse, coming either from natural reproduction in the immediate area or from migration into the B-pools. Larger individuals of all species in this group, except the spotted sucker, tended to avoid the B-pools, with the result that the average weight of suckers and redhorse in the pools below the quarry outfall never equalled and often was only 50% as great as those above the quarry. Their absence probably accounts for the fact that recovery as measured by standing crop was never more than about 80% by the end of the study. The increased load of suspended solids during mid-summer 1970 did not, however, cause further adverse affects.

Hog suckers - This species differs from other suckers in frequenting riffles perhaps more than pools and, since riffles

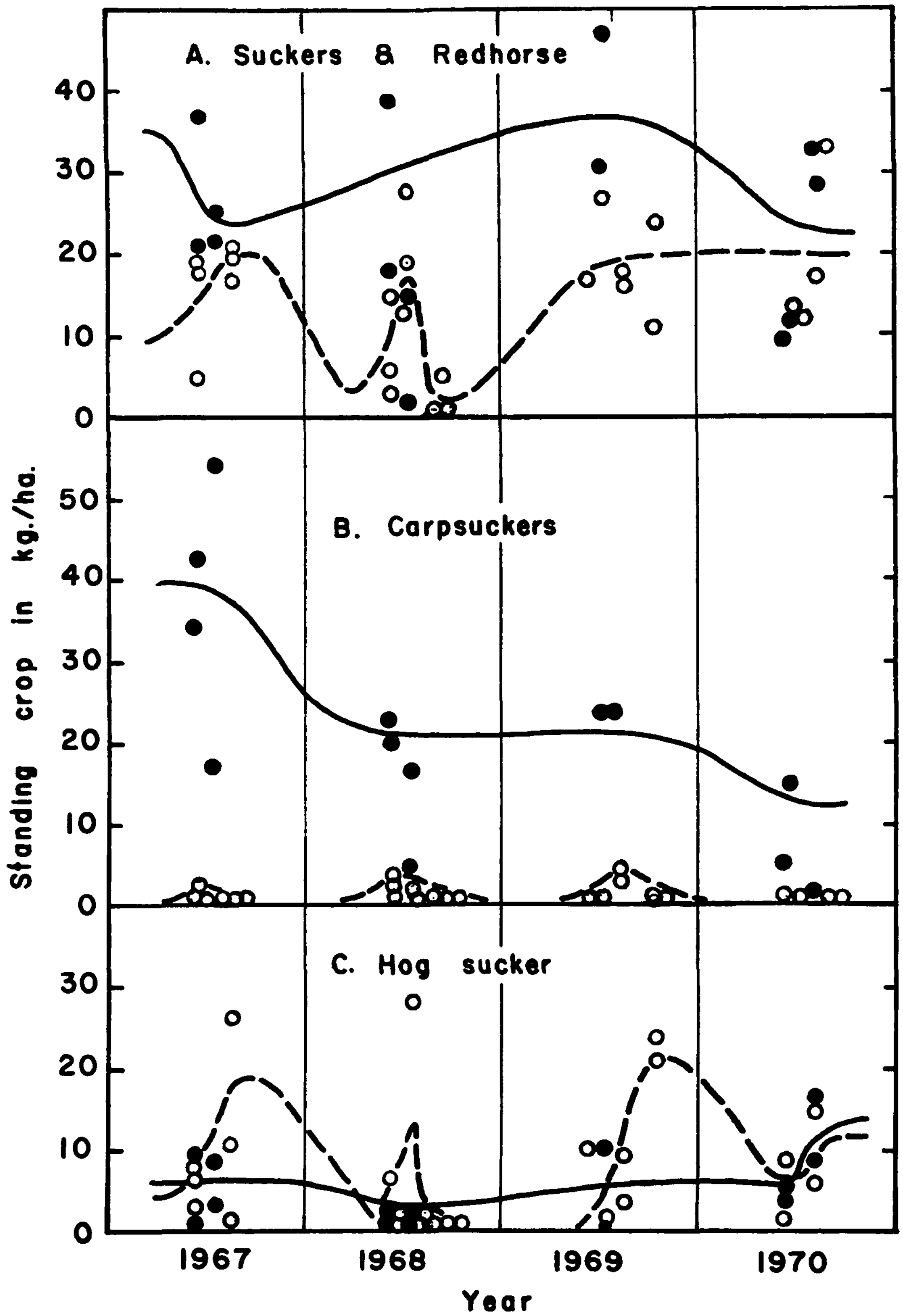

Figure 8: Estimated standing crop of three species groups of fish in two pools above (●——●) and three pools below (o– –o) a crushed rock quarry.

themselves were not electrofished, only a proportion of the total population was available for capture. The larger standing crops in the B-pools (Figure 8, C) probably is due to the fact that the B-riffles were larger than the A-riffles. The extent to which they are responsive to sediment as a population is impossible to access here. The average sizes above and below the quarry were roughly comparable.

Carpsuckers - Carpsuckers were the most sensitive fish with respect to the sediment. Their minor presence in midsummer in the B-pools (Figure 8, B) resulted from young fish which entered in small numbers. Above the quarry, carpsuckers were an important component in the overall fish population.

Carp - Individuals were often found in highly turbid water, but as a popúlation carp were seldom more than 50% as abundant below the quarry as above (Figure 9, A). Carp are not generally numerous in streams of west-central Indiana because of the scarcity of suitable spawning areas. Thus, the ones which are present are usually large individuals which have migrated into the smaller streams from some downstream region (Benda and Gammon 1967). Large numbers of young-of-the-year carp were first collected in Deer Creek in the fall of 1966. This 1966 year class contributed significantly to the overall fish population throughout the period of study, gradually diminishing in importance each year. Judging from the similarity in the average weight of individuals above and below the quarry there was no size-dependent response to the sediment.

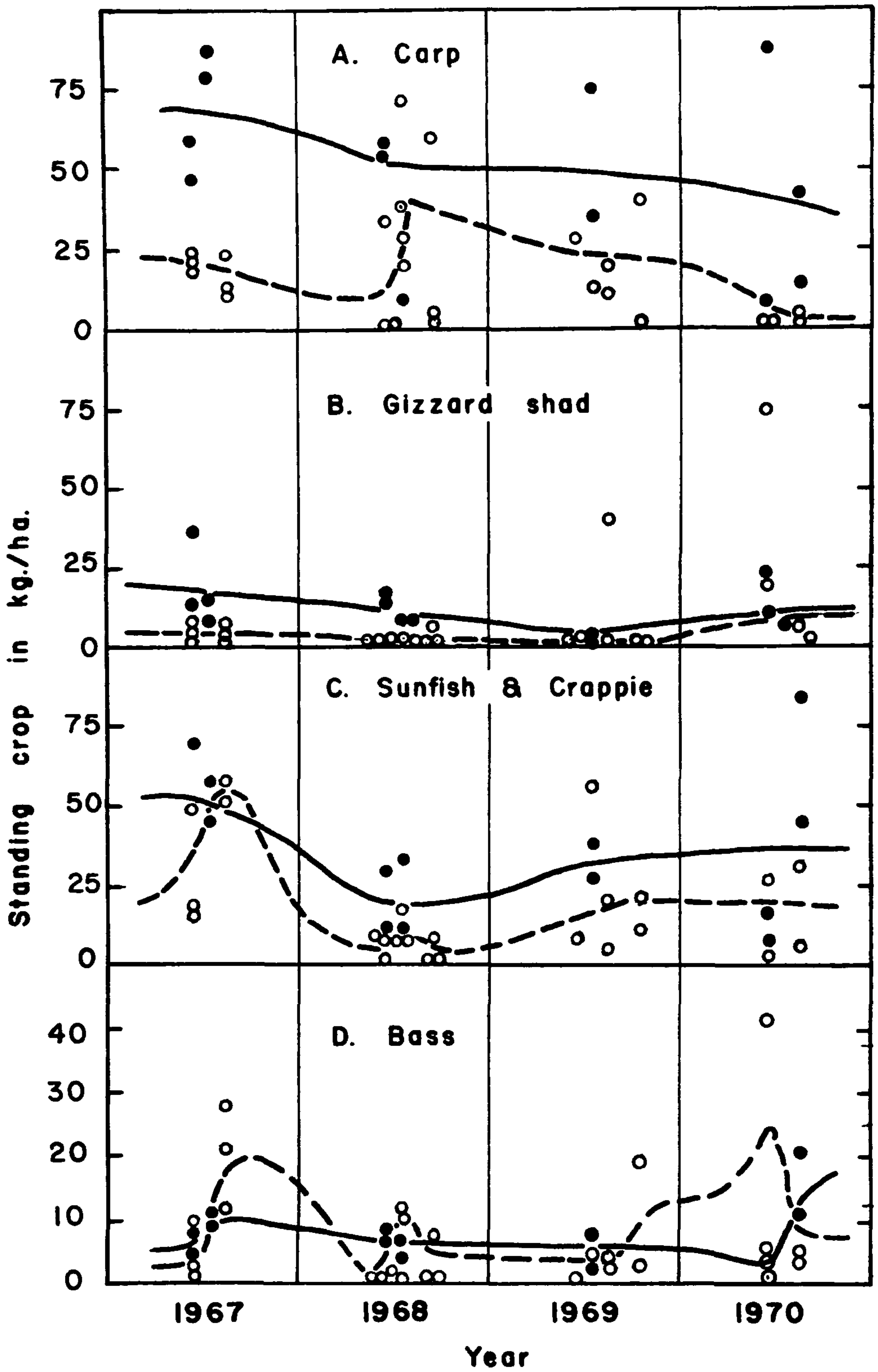

Figure 9: Estimated standing crop of four species groups of fish in two pools above (●—●) and three pools below (o--o) a crushed rock quarry.

Gizzard shad - This species' range in Deer Creek extends only a small distance upstream from pool A-2. Annual replenishment of the population may depend upon migrations of fish into the study area from further downstream, since the eggs are pelagic and probably are carried out of the study section before they can hatch. Small and relatively constant numbers were present above the quarry, but only in late summer 1969 and early summer 1970 when the suspended solids load was at its lowest point did concentrations of shad appear in the B-pools.

Thus, it seems that gizzard shad are quite sensitive to inorganic sediment or to the turbidity which accompanies it.

Sunfish and crappie - The standing crop of this group was about 50% as much in the B-pools as in the A-pools both in numbers and weight. Average weights did not differ significantly. The various species in this group appeared to respond to the sediment in about the same degree.

Bass - The three species of bass were not very important contributors to the standing crop of fish in terms of weight and numbers, averaging less than 10 kg/ha during much of the study. Only four largemouth bass were taken during the four years. Smallmouth bass were fairly common above the quarry, comprising about 24% of the catch, but were relatively uncommon below, making up only 12% of the catch of bass. Usually only small numbers of the smaller and younger smallmouth bass appeared in the catch below the quarry.

Spotted bass was much more common and generally supported the occasional larger densities which occurred in the B-pools including Taylor's pool. Furthermore, this species was one of the last species to leave a pool which was filling with sediment and among the first to return when the sediment was swept away by floods.

Most populations of fish, then, with a few exceptions were uniformly held to subnormal densities by even the lowest rates of sediment input characteristic of this quarry. Carpsuckers were extremely sensitive to the sediment and were virtually absent immediately downstream from the quarry. Smallmouth bass also seemed to be more sensitive than most species. Gizzard shad tolerated the lower concentrations of introduced stonedust, but avoided slightly higher concentrations. Spotted bass, alone of all the resident species, appeared to be unaffected by even fairly high concentrations of the suspended solids and might be called resistant.

The effect of sediment on the growth of fish

The rate of growth of fish is responsive to many environmental factors. Thus, the growth rates of important species of fish were estimated for the populations above the quarry and below to see if this characteristic was affected by the sediment.

Correction factors for each species were obtained by examining the relation between magnified scale radius and total length. For most species the relationship was linear (Table 17) and the correction factor (C) for each species except longear sunfish was used in the back-calculations. The results for longear sunfish were judged inadequate and a value of zero was used.

Table 17: The relationship between magnified scale radius (SR) (x22.5) in millimeters and the total length (TL) in millimeters.

Species	N	Regression Equation	C	Corr. Coef.
Smallmouth bass	33	SR = -19.30 + 0.406 TL	47.50	.972
Spotted bass	39	SR = - 4.24 + 0.363 TL	11.68	.946
White crappie	36	SR = - 2.47 + 0.313 TL	7.89	.854
Longear sunfish	515	SR = 10.00 + 0.358 TL	-27.93	.829
Golden redhorse	179	SR = -14.44 + 0.441 TL	32.73	.945
Black redhorse	40	SR = - 8.86 + 0.375 TL	23.62	.928
Spotted sucker	38	SR = -10.75 + 0.441 TL	24.39	.938
Gizzard shad	133	SR = -19.99 + 0.476 TL	41.99	.894

The estimated rates of growth of eight species of fish collected above and below the quarry are summarized in Table 18. Pairs of lengths for each age were tested for statistical differences by means of the t-test and only in two species were the values distinctively different.

Golden redhorse *(Moxostoma erythrurum)* were severely affected within the zone of sedimentation. The differences between pairs of estimated lengths at ages I through IV are statistically significant at the 99% level and the difference at age V at the 95% level (Table 18). The maximum difference in length - about 25 mm - occurred by the end of the second year of life and appeared then to be maintained for several more years. This effect correlates well with the observation that the older, larger individuals leave the zone of sedimentation, thus, subjecting themselves to the effects only during their younger years.

Spotted bass *(Micropterus punctulatus)* also grew at a significantly slower rate below the quarry than above. Spotted bass above the quarry were about 25 mm longer than those below at the end of the first year of life and this discrepancy gradually increased until a 50 mm difference occurred by the end of the fourth year. The tolerance of this species toward the sediment apparently resulted in individuals remaining in areas where normal growth was not possible.

For other species, the growth rates above and below the quarry were similar. This probably indicates an avoidance of the sedimentation zone, as shown in the distribution pattern during periods of heavy sediment input.

Table 18: Calculated mean total lengths and standard error of means at each age for fish collected from pools above and below the crushed limestone quarry.

Age Class	Above Quarry N	Above Quarry Mean Length in mm.	Above Quarry Stand. Error	Below Quarry N	Below Quarry Mean Length in mm.	Below Quarry Stand. Error
		Smallmouth bass *(Micropterus dolomieu)*				
I	14	100.9	4.943	19	97.0	2.835
II	12	148.2	5.991	11	149.4	5.017
III	11	194.2	11.858	8	198.0	5.512
IV	8	221.5	8.864	4	227.7	4.267
V	4	281.6	3.131	-	-	-
VI	2	315.6	0.0	-	-	-
		Spotted bass *(Micropterus punctulatus)*				
I	20	75:4	4.863	19	51.9	2.052
II	18	125.3	9.180	17	92.1	4.863
III	14	170.6	10.066	16	131.2	5.119
IV	14	208.8	11.655	9	158.2	5.138
V	6	216.5	10.867	6	195.5	9.286
VI	2	237.2	22.030	5	243.1	15.951
VII	2	258.8	24.261	3	295.0	12.669
VIII	-	-	-	1	331.0	-
		White crappie *(Pomoxis annularis)*				
I	17	62.5	4.307	19	64.6	3.967
II	13	107.8	8.189	14	120.8	6.032
III	5	148.6	14.268	8	166.7	3.2401
IV	2	187.6	17.430	1	172.0	0.0

Table 18 (con't.)

Age Class	Above Quarry N	Above Quarry Mean Length in mm.	Above Quarry Stand. Error	Below Quarry N	Below Quarry Mean Length in mm.	Below Quarry Stand. Error
		Longear sunfish *(Lepomis megalotis)*				
I	237	32.4	0.582	274	31.1	0.442
II	233	59.1	0.802	265	60.4	0.612
III	217	79.9	0.904	209	82.1	0.839
IV	173	97.3	1.134	142	99.5	1.080
V	105	111.5	1.478	71	111.1	1.331
VI	36	119.8	1.800	11	121.0	2.907
VII	7	132.3	4.074	2	121.2	7.133
VIII	1	131.4	0.0	-	-	-
		Golden redhorse *(Moxostoma erythrurum)*				
I	61	87.9	4.161	87	74.6	1.013
II	53	156.0	5.586	36	128.7	3.588
III	36	221.5	7.009	23	174.7	5.342
IV	20	264.9	5.352	15	221.6	8.998
V	7	304.2	5.921	10	264.7	11.761
VI	1	329.5	0.0	6	287.4	15.748
VII	1	340.9	0.0	3	282.9	24.033
VIII	-	-	-	2	293.7	37.375
		Black redhorse *(Moxostoma duquesnei)*				
I	10	70.1	5.430	29	77.9	2.889
II	9	129.0	7.005	6	145.6	9.616
III	8	198.9	6.753	4	211.1	6.602
IV	5	260.9	7.640	1	264.9	0.0

Table 18 (con't.)

Age Class	Above Quarry N	Above Quarry Mean Length in mm.	Above Quarry Stand. Error	Below Quarry N	Below Quarry Mean Length in mm.	Below Quarry Stand. Error
		Spotted sucker *(Minytrema melanops)*				
I	16	68.1	3.935	22	70.1	3.363
II	16	121.3	7.362	19	127.1	6.575
III	13	186.7	9.494	12	210.1	21.868
IV	11	240.5	9.337	6	210.6	9.088
V	2	251.0	13.437	-	-	-
VI	1	241.9	0.0	-	-	-
VII	1	287.6	0.0	-	-	-
		Gizzard shad *(Dorosoma cepedianum)*				
I	78	112.5	1.880	40	118.0	1.930
II	71	157.9	2.644	36	162.7	2.360
III	39	198.4	4.273	3	163.1	3.827
IV	17	233.8	8.214	-	-	-
V	2	220.2	6.311	-	-	-
VI	1	225.7	0.0	-	-	-

The effect of sediment on the length/weight relationship

It has been shown that the growth rate of most species of fish was unaffected by the sediment pollution under natural conditions and that perhaps this occurred because of movement into and out of the zone of sediment loading in response to the sediment load. Direct measurement of the direction and rate of movement was not achieved in this study. Shetter-type directional weirs placed at riffles B-0 and B-3 for this purpose during 1969 were quickly destroyed by floods and were not replaced.

Lacking this direct information concerning the period of time fish spent in the zone of sedimentation, an examination of the length/weight relationship was made on the presumption that fish of many species might enter the zone below the quarry for shorter periods than an entire growing season. For most species an insufficient number of individuals were collected to attempt a year-by-year analysis of the relationship; therefore, comparisons were made on combined samples. Adequate data was available for longear sunfish so that much finer comparisons were possible.

The pairs of regressions of log weight on log length shown in Table 19 were compared statistically by means of a single classification analysis of covariance. There was no difference in the relationship above and below the quarry for smallmouth bass *(Micropterus dolomieui)*, white crappie *(Pomoxis annularis)*, golden redhorse *(Moxostoma erythrurum)* and carp *(Cyprinus carpio)*.

A statistically significant difference was found for spotted bass with the population below the quarry having the steeper slope. At the smaller sizes the differences are minute, but with larger fish there is rather strong divergence. This probably is due to the greater range in size of the fish obtained below the quarry where nearly all of the larger spotted bass were collected. Small individuals are quite slender, while large fish tend to be quite chunky.

Spotted sucker *(Minytrema melanops)* and gizzard shad *(Dorosoma cepedianum)* also had statistically different log:log relationships with, again, steeper slopes in the population below the quarry.

For longear sunfish *(Lepomis megalotis)* some of the comparisons were different at a statistically significant level, but there was no logical relationship to the pattern of sediment input.

Thus, the fish in the zone of sediment loading do not appear to have been affected with respect to the length/weight relationship. It is possible, again, that they vacate the area before overall conditions deteriorate strongly enough to have an effect.

The effect of sediment on spawning

On several occasions when riffles were being sampled for invertebrates in the spring, concentrations of redhorse, species unidentified, were noted in the B-riffles. Previous periods of high water had swept all vestiges of sediment from the riffles and, although no eggs were taken in the Surber samples nor were direct observations made of spawning activities, it seems likely that spawning of these catostomids could well have occurred. Although stonedust sediment was being introduced at these times the water was generally so high and turbid that it had little effect insofar as increasing turbidity is concerned. There is nothing, therefore, that indicates a deleterious effect of the introduced sediment on spawning of suckers and redhorse.

In August, 1967 when the concentration of suspended solids below the quarry was beginning to increase noticeably, the Hester-Dendy plate samples in the upper B-riffles were used as spawning surfaces by resident minnows, species unidentified. Further observations particularly during the heaviest periods were, unfortunately, not made.

In 1968 a fine gravel bar extended out into Deer Creek from the mouth of DeWeese Branch. The mouth of this tributary was electrofished several times during the study and found to contain a very dense sub-population of a variety of the usual species. As water levels became lower near mid-summer, this bar emerged to isolate the clear waters of DeWeese Branch from the turbid waters of Deer Creek. Spawning activity was first noted on July 7, 1968 when the quarry was not operating, when 11 longear sunfish nests were observed within 10- 12 feet of each other near the tip of the gravel bar on the DeWeese Branch side. Each nest was actively defended by a male. On this same date two unidentified fish, not sunfish, were noted on the Deer Creek side of the gravel bar, but no nests were constructed and the thin, white layer of sediment which covered the gravel looked undisturbed.

Observations were continued through July 11 when perhaps half of the nests were still guarded by male sunfish. The turbidity of the spawning area increased noticeably during this period as eddy currents carried more and more stonedust into the mouth of DeWeese Branch whose flow diminished during this same period. The turbidity of the water in the vicinity of the nests made observations from directly above difficult although most of the nests were in water less than one foot deep. Nevertheless, the guarding males maintained their vigilance. A careful search for other sunfish nests downstream from the quarry revealed a single abandoned nest near the head of pool B-0 which was covered by a thin layer of sediment and had probably been unoccupied for several days at least. Other suitable areas were vacant.

DISCUSSION

Many researchers have pointed to the relative instability of streams compared to lakes and to the resulting need for resident organisms to adapt to changing environmental conditions. The influence of man has often increased the magnitude of otherwise normal environmental processes and prolonged formerly short-term, adverse conditions. It is not difficult to imagine a river biota which would be resistant to acute doses of sediment periodically swept through the stream by recurrent floods, but it is impossible to conceive this same biota as being unaffected by permanently increased loads of sediment.

It is assumed that the effects on biota of introduced limestone dust sediment is similar to that of any inert particulate matter of similar size and hardness and that this effect is purely physical, with any accompanying slight chemical changes falling well within the capacity of adaptability by the stream organisms. Furthermore, it seems likely that the mode of physical effect is other than to directly increase the mortality rates since even during periods of great sediment input, fish and insect larvae were found living in water heavily loaded with stonedust. A possible exception might be newly hatched fish fry or insect larvae.

There were no factors present anytime during the study, except for the sediment, which were experienced by the populations of organisms downstream from the quarry outfall and not also experienced by those upstream. Therefore, the observed changes in population structure were solely due to the influence of sediment on these populations of macroinvertebrates and fish.

The macroinvertebrate populations in the riffles below the quarry outfall responded to significant introductions of sediment by becoming reduced in population density. The normal load of suspended solids in Deer Creek tended to range from 15 to 40 mg/l during low summer flows. During 1967 when the quarry used two consecutive settling basins and kept them in good operating condition, the suspended solids concentration of the effluent averaged only slightly higher than this about 47 mg/l, although the nature of the suspended matter differed considerably. The single settling basin in use during 1969 and 1970 led to somewhat increased concentrations of suspended solids which averaged about 75 mg/l at the effluent outfall in 1969.

The actual concentration of suspended solids reaching the study riffles during these extended periods of light sediment input varied considerably depending upon the rate of discharge of Deer Creek, the state of the settling basins, the variability of suspended solids concentration in the effluent water, etc., but the range was probably from 40 to 80 mg/l for a major part of each work day with a return to normal concentrations during the night and on Sundays. An increase in the load of suspended solids of about 40 mg/l above normal loads would, according to the drift experiments, cause a 25% increase in the drift rate and this, in turn, would cause a reduction in the population density. Although the population density averaged 75% normal during these periods of relatively light sediment input, differences were not always detected by means of the monthly samples consisting of three Surber samples at each riffle. A more intensive sampling program would be required before an effect would be detectable for a majority of samplings.

When the suspended solids load in the study riffles rose to about four times the normal concentration, a level of about 120 mg/l or about 80 mg/l more than normal, the population density of macroinvertebrates decreased to a degree detectable even by the relatively simple means employed in this study. Such increases in the sediment concentration would increase the drift rate by at least 90%.

Reductions in population density appeared to occur even in the absence of visible accumulations of sediment in the bottom substrate. This observation is supported by the drift experiments in which the drift rate responded to suspended material in the absence of significant settling. In all probability, however, stonedust in undetected quantities did settle in the dead spaces of the bottom substrate, and this could well have been a factor in the resulting decrease in population density in addition to the reaction to suspended solids. The bodies of many of the invertebrates collected during times of very slight sediment accumulations were coated with a fine layer of sediment.

On a few occasions sediment was deposited suddenly in the riffles and remained for some time because of low discharge of the stream. The deposition of soil particles in the fall of 1969 was the most noticeable and prolonged period. The suspended solids load of water passing through the afflicted riffles was relatively low, but the mere presence of the settled sediment caused a definite and strong decrease in the population density. Thus, it is concluded that both settled sediment and increased loads of suspended sediment deleteriously affected the populations of macroinvertebrates in the riffles of streams.

It has been well documented that organic pollutants drastically alter species composition and diversity of the fauna and flora of streams (Wilhm 1967 and others). The various members of the macroinvertebrate fauna apparently have different capabilities to resist the effects wrought by a variety of organic pollutants. Thus, some susceptible members are eliminated while resistant forms may actually increase as the result of reduced competition. It is obvious that sediment pollution has a different influence, affecting nearly all components of the population equally without significant changes in either the relative proportions of the components or the apparent diversity. The population density decreases resulting from heavy sediment inputs were accompanied by slight increases in the diversity index, perhaps because the sediment caused reductions in numbers proportionate to the density of both rare and common species. Some variability in response was noted in some genera. *Caenis* was the most sensitive, while *Tricorythoides* and *Berosus* were resistant. These taxa, however, were numerically of minor importance. Chironomids and *Cheumatopsyche* accounting for as much as 90% of the total population were generally reduced to about 35% of their normal density during heavy sedimentation.

When sediment input was reduced or when floods scoured the riffles of all accumulated sediment, recovery was found to be apparently complete within a few days presumably because of the natural drift into the riffles. Thus, in this situation the macroinvertebrate populations responded quickly both positively and negatively to changes in the load of suspended solids.

This interesting response has been of practical use to the Division of Water Pollution Control, Indiana State Board of Health,in some of their efforts (Winters, *personal communication*). In November 1969,a case of possible pollution was investigated in Shelbyville, Indiana,where a fiberglas batt insulation industry was discharging effluent at four points into the Little Blue River just above its confluence with the Big Blue River. The most obvious pollutants were particles of glass wool, lime solids from the water softening system and latex particles which turned the stream turbid and heavily coated the bottom. Qualitative samples of bottom fauna were collected at four stations with similar bottom substrate: (1) in the Little Blue River upstream from the industry, (2) downstream on this stream, (3) in the Big Blue River upstream from the confluence with the Little Blue River and (4) below the confluence of the two streams. The number of genera collected decreased from 23 above the plant to 3 below in Little Blue River and in Big Blue River the number dropped from 30 to 4.

We were asked at this point to comment on the possibility that the settled solids alone were responsible for the observed decrease in genera. In the light of the results of the Deer Creek study, it was obvious that inert solids alone could not have caused such a reduction and suggested that some other pollutants must also be present. Further investigation revealed significant concentrations of phenol in the waste water.

The fish populations did not respond as quickly to changes in suspended solids loads as did the macroinvertebrates and a different approach is required for evaluating the effects of sediment on this goup. As with the invertebrates, fish were probably not killed directly by the sediment since some were found even in a veritable slurry of stonedust. On at least one occasion carp passed from the stream into the effluent settling basins during high water and could be seen swimming around in these basins for several weeks.

The zone of major disturbance was restricted to perhaps a mile or so downstream from the quarry with normal populations upstream and near-normal populations further downstream. Recovery of fish populations which are decimated by severe sedimentation seems to be accomplished primarily by the invasion of fish from these outlying regions and secondarily through natural reproduction in the area. The rate of recovery is rapid initially. Severe sedimentation reduced population levels drastically late in 1968 and probably also in 1966. The deposits of sediment were probably removed by flood early in the following years and fish returned during the spring. By June the standing crops had recovered to 50% of normal. In the absence of serious sedimentation there was also a very slight additional gain through the summer months.

The scattered literature on movements of resident stream fishes generally indicates increased rates of movement during the spring prior to spawning associated with increasing day-length, discharge rates, or temperature. Shetter (1938) operated a two-way fish trap on Canada Creek in Michigan and found that there was little movement during the winter, very high rates of catch from mid-April through May, rather limited movement during the summer months and a secondary increase in September and October.

The studies of Gerking (1950, 1953, 1959) and Funk (1957) and others indicate a strong attachment of individuals of many species to specific and restricted areas of streams or lakes. A certain proportion of individuals, however, seem to stray from place to place thereby providing a mechanism for colonizing new areas. These general concepts do not rule out the possibility that individuals may leave their home territory for short periods of time and subsequently return, perhaps after spawning.

Bowman (1970) recently summarized the life history of the black redhorse (*Moxostoma duquesnei*) and found that adults tended to overwinter in deeper pools beginning in October or November. They left these in March or early April and moved both upstream and downstream for several miles to suitable spawning riffles. After spawning they moved into pools where they tended to remain throughout the summer. Schooling behavior changed in September with schools tending to aggregate near the bank or in the main current of the river prior to a return to the deeper overwintering pools. Benda and Gammon (1968) noted a mass movement of most resident species to deeper pools in October or November when the temperature fell below about 12°C (55°F).

The young fish produced because of these seasonal movements away from home areas, together with the colonizing potential of individuals which tend to stray, are believed to play an important role in colonizing segments of streams from which fish have been eliminated. Larimore, Childers and Heckrotte (1959) studied the repopulation of a stream which had complete removal of its fish and invertebrate population through drought and rotenone. They also noted the seasonal movements described above. Recovery was rapid initially with many species returning within two weeks after normal flow was resumed in the spring, but permanent populations of some species were not established until two year later. The degree of recovery of the standing crop was impossible to evaluate.

Gunning and Berra (1968) and Berra and Gunning (1970) experimentally decimated short segments of a number of small streams in Louisiana. Sharpfin chubsuckers *(Erimyzon tenuis)* returned to one area in numbers and total weight exceeding the original level within one year of decimation. Longear sunfish *(Lepomis megalotis megalotis)* repopulated four of six segments to levels equalling or exceeding the original density within one year. The main repopulation occurred between March and late summer and was mainly accomplished by sunfish which were at least two years old.

In this study we have observed both the repopulation process following the decimation of the total populations of fish in the two upper B-pools and the original decimation process brought about by sediment. The studies previously summarized help to interpret the response of the various components of the population and the fish population as a whole to the sediment pollution.

The almost total absence of carpsuckers, mostly *Carpiodes cyprinus hinei*, downstream from the quarry in comparison to their common occurrence both above the quarry and in the lower part of Deer Creek attests to the fact that even the very lowest amounts of sediment entering from the quarry created conditions unfavorable to the species. The same sensitivity to a somewhat reduced degree applied to smallmouth bass *(Micropterus dolomieui)* and gizzard shad *(Dorosoma cepedianum)*. Gizzard shad, which invaded the study stretch of Deer Creek from further downstream, were usually absent or occurred in very small numbers at times when the suspended solids loads exceeded the minimum input by the quarry. Even a slight increase, such as occurred in mid-summer 1970, caused them to leave the area. Needless to say these species were almost never taken below the quarry during periods of relatively heavy sediment input.

Suckers and redhorse (mostly *Moxostoma erythrurum*) tended to recover during periods of light sediment input but never quite achieved levels typical of the stream above the quarry, even after two years of relatively low input during which the summer loads of suspended solids seldom exceeded 80 mg/l. The numerical density of suckers and redhorse was often much greater below the quarry than above, indicating that recolonization for this group may be accomplished through natural reproduction within the area and/or by direct invasion of young individuals. Near normal standing crops were re-established two years after the elimination of fish from the upper B-pools, but the growth rate of golden redhorse was lower than normal.

Carp *(Cyprinus carpio)* were never more than half as abundant in terms of weight below the quarry as above and showed no signs of achieving normal levels even after two years of relatively light sediment input. All sizes were affected equally.

Longear sunfish *(Lepomis megalotis megalotis)* of all sizes moved into the decimated zone following the removal of sediment but never approached the abundance of the population above the quarry even after two years. There is evidence that natural reproduction was inhibited in the area.

The only species which was apparently resistant to sediment was spotted bass *(Micropterus puctulatus)* which were sometimes present in greater weight in the pools below the quarry than in those above. This resistance was purchased at the price of growing more slowly, however.

The lack of recovery within a two-year period following decimation of the population of fish is evidence that a depressive effect is exerted on mixed, warmwater populations of fish by suspended solids loads which include not more than 40 mg/l additional inorganic fine sediment. This effect was found under conditions where the additional sediment was added only during about 10 hours of each day, 6 days a week. This level is regarded as a very conservative one because the determinations mostly were made during periods of low stable flows when the concentrations would be greatest.

The ultimate effect of the sediment in eliminating existing populations of fish is the obliteration of habitat as was also shown by Saunders and Smith (1965), but avoidance reactions were obvious in this study which clearly were with regard to suspended sediment in the absence of significant deposition. Recovery of the population after a severe decimation was accomplished during the spring months when movement of fish is maximum, except during the spring of 1968. During this period there was a substantial increase in the load of suspended solids, on the order of 150-200 mg/1 over normal, but no sediment was deposited in the study pools. A marked reduction in population density resulted through movement of fish out of the B-pools and perhaps an avoidance of the zone by fish from other areas which may well have been moving upstream and down at this time.

This response contrasts strongly to what occurred later in the summer when fish were literally forced to leave because of accumulating sediment. At this time the suspended solids loads were much, much higher ranging from at least 200 mg/1 to 2000 mg/1, yet the fish were extremely reluctant to move and, in fact, did not move out of the pools until habitat was obliterated.

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APPENDICES

Appendix I: List of the macroinvertebrate taxa collected from the riffles of Deer Creek during 1967, 1968 and 1969.

Order	Family	Genus	Species
Ephemeroptera	Baetidae	*Baetis*	*cingulatus*
		B.	*phoebus*
		B.	*baetis*
	Siphlonurinae	*Ameletus*	*sp.*
		Isonychia	*sp.*
	Baetinae	*Callibaetis*	*sp.*
		Neocloeon	*sp.*
	Caenidae	*Caenis*	*sp.*
	Heptageniidae	*Arthoplea*	*sp.*
		Rhithrogena	*sp.*
		Stenomia	*carolina*
		S.	*rubrum*
		S.	*femoratum*
		S.	*ithica*
	Ephemeridae	*Hexagenia*	*sp.*
		Ephoron	*sp.*
	Potomanthidae	*Potomanthus*	*verticis*
	Tricorythoidae	*Tricorythodes*	*sp.*
Trichoptera	Hydropsychidae	*Hydropsyche*	*orris*
		H.	*bifida*
		H.	*frisoni*
		H.	*simulans*
		Cheumatopsyche	*sp.*
	Hydroptylidae	*Hydroptila*	*sp.*
		Agraylea	*sp.*
		Mayatrichia	*sp.*
		Ochrotrichia	*sp.*
	Limnaphilidae	*Neophylax*	*sp.*
	Rhaycophilidae	*Rhaychophila*	*sp.*
		Amphizoa	*sp.*
Coloeptera	Elmidae	*Narpus?*	*sp.*
		Stenelmis	*sexilineata*
		S.	*6-vittata*
		Dubiraphia	*4-notata*
		Ancyronyx	*variegatus*
	Hydrophilidae	*Berosus*	*peregrinus*
		Laccobius	*agrilis*
	Haliplidae	*Peltodytes*	*edentulus*

Appendix I: (con't.)

Order	Family	Genus	Species
Coleoptera (con't.)	Staphylinidae		
	Psephenidae		
	Curculionidae		
	Gyrinidae	*Dineutus*	*sp.*
	Dryopidae	*Helictus*	*striatus*
		H.	*fastigiatus*
	Chrysomelidae	*Donacia*	*sp.*
		Altica	*sp.*
	Heteroceridae	*Heterocerus*	*sp.*
Diptera	Chironomidae	*Pentaneura*	*sp.*
		Chironomus	*sp.*
		other	
	Simuliidae	*Simulium*	*sp. a*
		S.	*vittatum*
	Tipulidae	*Tipula*	*sp.*
		Hexatoma	*sp.*
	Heleidae	*Bezzia*	*sp.*
	Empididae	*Hemerodromia*	*sp.*
	Chaoborus	*Frivittatus*	*sp.*
	Ceratopogonidae	*Culicoides*	*sp.*
Odonata	Argionidae	*Agrion*	*sp.*
	Calopterygida	*Hetaernia*	*sp.*
	Lestidae	*Lestes*	*sp.*
Neuroptera	Sailodea	*Corydalus*	*sp.*
Plecoptera	Perlidae	*Isoperla*	*sp.*
		Neoperla	*sp.*
		Perlesta	*sp.*
	Perlodidae	*Isogenus*	*sp.*
		Isoperla	*sp.*
Hemiptera	Corixidae		
	Gymnocerata		
	Cicadellidae		
	Gerridae	*Trepobates*	*sp.*
	Veliidae	*Rhagouelia*	*obesa*
Homoptera	Aphididae		
Hymenoptera	Scdioidae		
Collembola	Smynthuridae	*Smynthurides*	*sp.*

Appendix I: (con't.)

Order	Family	Genus	Species
Oligochaeta	Tubificidae		
Nematoda			
Gordiida	Gordia		
Gastropoda	Pulmonata	*Physida*	*sp.*
	Physidae	*Physa*	*sp.*
	Bulimidae	*Bulmis*	*sp.*
	Phanorbidae	*Helisoma*	*sp.*
Pelecypoda			
Chelicerata	Arachinidae	*Araneida*	*sp.*
Hirudinea	Hirudidae		
Triciadida	Planariidae	*Dugesia*	*sp.*
Megaloptera	Aialidae	*Sialis*	*sp.*

Table II: List of species of fish collected in Deer Creek during the study. A=abundant, C=common, R=rare O=occasional.

Common Name	Scientific Name	Abundance
Brook Lamprey	*Lampetra lamottei*	O
Longnose Gar	*Lepisosteus osseus*	C
Shortnose Gar	*L. platostomus*	R
Golden Redhorse	*Moxostoma erythrurum*	A
Black Redhorse	*Moxostoma duquesnei*	A
Silver Redhorse	*Moxostoma anisurum*	C
Shorthead Redhorse	*Moxostoma macrolepidotum*	C
Common White Sucker	*Catostomus commersoni*	O
Spotted Sucker	*Minytrema melanops*	C
Creek Chubsucker	*Erimyzon oblongus*	R
Hog Sucker	*Hypentelium nigricans*	A
Central Quillback Carpsucker	*Carpiodes cyprinus hinei*	A
Northern River Carpsucker	*Carpiodes carpio carpio*	O
Highfin Carpsucker	*Carpiodes velifer*	R
Bigmouth buffalo	*Ictiobus cyprinellus*	R
Bluntnose minnow	*Pimephales notatus*	A
Silverjaw minnow	*Ericymba buccata*	A
Suckermouth minnow	*Phenacobius mirabilis*	C
Stoneroller	*Campostomum anomalum*	A
Spotfin Shiner	*Notropis spilopterus*	A
Striped Shiner	*Notropis crysocephalus*	A
Redfin Shiner	*Notropis umbratilis*	O
Sand Shiner	*Notropis stramineus*	O
Creek Chub	*Semotilus atromaculatus*	R
Carp	*Cyprinus carpio*	A
Goldfish	*Carassius auratus*	R
Gizzard Shad	*Dorosoma cepedianum*	A
Blackstripe Topminnow	*Fundulus notatus*	C
Brook Silversides	*Labidesthes sicculus*	O
Channel Catfish	*Ictalurus punctatus*	C
Flathead Catfish	*Pilodictus olivarus*	O
Yellow Bullhead	*Ictalurus natalis*	C
Black Bullhead	*Ictalurus melas*	R
Freshwater Drum	*Aplodinotus grunniens*	C
Smallmouth Bass	*Micropterus dolomieui*	C
Spotted Bass	*Micropterus punctulatus*	C
Largemouth Bass	*Micropterus salmoides*	R
Longear Sunfish	*Lepomis megalotis*	A
Green Sunfish	*Lepomis cyanellus*	C
Bluegill Sunfish	*Lepomis macrochirus*	C
Orangespot Sunfish	*Lepomis humilis*	O
Rock Bass	*Ambloplites rupestris*	O
Warmouth	*Chaenobryttus gulosus*	R
White Crappie	*Pomoxis annularis*	C
Black Crappie	*Pomoxis nigromaculatus*	O
Log Perch	*Percina caprodes*	O
Orangethroat Darter	*Etheostoma spectabile*	O
Greenside Darter	*Etheostoma blennioides*	R
Blackside Darter	*Percina maculata*	R

Table III: Average total weight (kg) and number of fish captured per electro-fishing pass in pools of Deer Creek during 1967 and 1968.

Species Group	Pool A-1	Pool A-2	Pool B-0	Pool B-1	Pool B-2
			June 26 - 28, 1967		
Suckers & Redhorse	2.20(12.6)	1.32(10.3)	0.31(4.7)	0.14(1.7)	0.74(4.0)
Hog sucker	-	0.44(4.3)	0.10(3.2)	0.14(1.0)	0.08(1.7)
Carpsuckers	3.83(11.7)	3.29(11.0)	0.01(0.2)	0.01(0.2)	0.10(0.5)
Carp	2.19(27.7)	2.96(35.7)	0.26(4.5)	0.51(2.7)	0.75(3.5)
Gizzard Shad	2.15(23.7)	0.84(13.0)	0.13(2.2)	0.08(1.5)	0.20(3.2)
Sunfish & Crappie	1.01(59.3)	1.99(90.7)	0.38(15.2)	0.23(10.2)	0.27(12.7)
Bass	0.13(0.7)	0.30(2.7)	0.08(1.7)	0.06(0.7)	0.01(0.2)
Other Species	0.03(0.3)	0.36(1.0)	-	-	0.10(0.2)
Total	11.54(136.0)	10.34(168.7)	1.28(32.0)	1.17(18.2)	2.24(26.2)

Table III: (con't)

Species Group	Pool				
	A-1	A-2	B-0	B-1	B-2
			<u>July 24 - August 18, 1967</u>		
Suckers & Redhorse	1.33(10.0)	1.58(11.0)	0.36(10.0)	0.59(10.0)	0.67(16.7)
Hogsuckers	0.14(2.0)	0.40(4.0)	0.34(5.5)	0.23(2.5)	0.03(1.5)
Carpsuckers	4.88(15.3)	1.64(5.5)	-	-	-
Carp	4.07(40.3)	3.95(29.5)	0.15(1.0)	0.32(2.2)	0.70(5.2)
Gizzard Shad	0.94(8.0)	0.48(5.0)	-	0.12(1.2)	0.26(2.2)
Sunfish & Crappie	1.23(53.7)	1.63(74.0)	0.29(15.2)	0.69(43.2)	1.02(60.2)
Bass	0.24(4.0)	0.36(4.0)	0.27(3.7)	0.33(2.2)	0.20(3.0)
Other Species	0.17(0.3)	0.09(1.5)	0.01(0.2)	0.07(0.5)	0.04(0.5)
Total	13.00(133.6)	8.55(134.5)	1.40(35.7)	2.361(62.0)	2.921(89.5)

Table III: (con't.)

Species Group	Pool				
	A-1	A-2	B-0	B-1	B-2
			June 6 - 11, 1968		
Suckers & Redhorse	2.06(9.7)	2.31(9.7)	0.19(1.0)	0.18(0.7)	0.13(0.7)
Hog suckers	0.05(1.0)	0.11(2.0)	0.06(1.5)	-	0.05(0.7)
Carpsuckers	3.52(10.0)	2.01(5.0)	0.05(0.2)	0.14(0.6)	0.10(0.6)
Carp	5.10(9.2)	2.50(6.0)	-	0.76(0.6)	-
Gizzard Shad	1.66(14.0)	0.94(8.7)	-	0.01(0.6)	-
Sunfish & Crappie	0.62(21.5)	0.80(25.3)	0.05(2.3)	0.11(5.3)	0.43(2.7)
Bass	0.48(2.0)	0.18(2.0)	0.01(0.2)	-	-
Other Species	0.53(1.2)	0.11(0.7)	-	0.13(0.3)	0.52(0.3)
Total	14.02(68.6)	8.97(59.4)	0.37(5.1)	1.33(8.0)	0.84(5.0)

Table III: (con't.)

Species Group	Pool				
	A-1	A-2	B-0	B-1	B-2
			July 10 - 28, 1968		
Suckers & Redhorse	0.19(1.2)	0.91(4.3)	0.25(4.0)	0.82(3.0)	0.57(5.0)
Hog suckers	0.04(0.5)	0.93(1.0)	0.27(4.0)	-	-
Carpsuckers	2.87(7.5)	0.45(1.3)	0.01(3.0)	-	0.01(1.0)
Carp	0.83(1.7)	1.72(6.0)	0.75(2.0)	0.64(2.0)	0.70(2.0)
Gizzard Shad	1.00(8.5)	0.51(5.7)	-	-	-
Sunfish & Crappie	0.65(30.0)	0.87(45.3)	0.11(6.0)	0.10(7.0)	0.13(9.0)
Bass	0.24(2.3)	0.20(1.7)	0.08(3.0)	0.18(1.0)	-
Other Species	0.78(4.5)	0.28(5.3)	0.07(2.0)	0.01(1.0)	0.16(4.0)
Total	6.59(56.2)	5.86(70.5)	1.52(24.0)	1.65(14.0)	1.56(21.0)

Table III: (con't.)

Species Group	Pool				
	A-1	A-2	B-0	B-1	B-2
			September 19, 1968		
Suckers & Redhorse	-	-	-	-	0.23(3.0)
Hog suckers	-	-	-	-	-
Carpsuckers	-	-	-	0.01(1.0)	-
Carp	-	-	-	0.12(1.0)	2.03(3.0)
Gizzard Shad	-	-	-	-	0.32(1.0)
Sunfish & Crappie	-	-	-	0.02(1.0)	0.17(4.0)
Bass	-	-	-	0.01(1.0)	0.17(2.0)
Other Species	-	-	-	-	-
Total	-	-	-	0.157(4.0)	2.93(13.0)

Table IV: Total weight (Kg) and number of fish captured in three electrofishing passes in the study pools of Deer Creek during 1969 and 1970.

Species Group	Pool			
	A-1	A-2	B-0/1	B-2
		June/July 1969		
Suckers & Redhorse	5.69(23)	5.09(24)	1.05(25)	1.99(16)
Hog sucker	-	1.04(8)	0.79(9)	0.18(2)
Carpsuckers	5.28(16)	2.72(11)	-	-
Carp	8.68(23)	2.89(8)	1.53(4)	0.59(2)
Gizzard Shad	0.18(2)	-	0.06(1)	0.04(1)
Sunfish & Crappie	3.75(336)	2.42(161)	2.45(172)	0.56(41)
Bass	0.66(4)	0.81(7)	0.28(4)	0.01(1)
Other Species	1.26(7)	0.46(3)	1.63(4)	-
Total	25.50(411)	15.43(222)	7.79(219)	3.37(63)
		August 1969		
Suckers & Redhorse		-	1.32(25)	1.33(7)
Hog sucker	-	-	0.76(17)	0.29(22)
Carpsuckers	-	-	0.64(3)	0.22(1)
Carp	-	-	0.50(1)	0.90(2)
Gizzard Shad	-	-	2.59(14)	-
Sunfish & Crappie	-	-	1.12(84)	0.39(40)
Bass	-	-	0.33(7)	0.28(5)
Other Species	-	-	0.19(8)	-
Total		-	7.45(159)	3.41(77)

Table IV: (con't.)

Species Group	Pool			
	A-1	A-2	B-0/1	B-2
			October 1969	
Suckers & Redhorse	-	-	0.82(42)	1.54(17)
Hog sucker	-	-	1.73(41)	1.33(43)
Carpsuckers	-	-	-	-
Carp	-	-	-	2.04(1)
Gizzard Shad	-	-	-	-
Sunfish & Crappie	-	-	1.55(160)	0.86(98)
Bass	-	-	0.40(13)	1.56(17)
Other Species	-	-		-
Total	-	-	4.50(256)	7.33(176)
			June 1970	
Suckers & Redhorse	1.82(11)	0.96(4)	1.08(28)	0.90(7)
Hog sucker	0.39(13)	0.29(7)	0.72(9)	0.12(5)
Carpsuckers	0.97(3)	1.52(4)	-	-
Carp	20.07(15)	0.92(2)	-	-
Gizzard Shad	5.20(33)	1.03(10)	5.59(35)	1.88(11)
Sunfish & Crappie	1.54(80)	1.09(48)	1.26(63)	0.27(13)
Bass	0.30(4)	-	0.36(7)	1.19(5)
Other Species	2.39(9)	0.32(3)	0.93(3)	0.10(1)
Total	32.68(168)	6.13(78)	9.94(145)	4.46(42)

Table IV: (con't.)

Species Group	Pool			
	A-1	A-2	B-0/1	B-2
		August 1970		
Suckers & Redhorse	4.91(57)	3.48(18)	0.97(13)	2.45(21)
Hog sucker	1.69(25)	1.52(16)	0.77(14)	0.36(7)
Carpsuckers	0.03(5)	-	-	0.01(1)
Carp	2.95(6)	4.68(7)	0.36(1)	-
Gizzard Shad	-	0.73(3)	0.46(1)	-
Sunfish & Crappie	6.11(439)	5.40(289)	1.43(103)	0.35(31)
Bass	1.51(26)	0.38(19)	0.13(17)	0.30(12)
Other Species	0.54(5)	0.18(5)	0.01(1)	-
Total	17.74(563)	16.37(357)	4.13(150)	3.47(72)

Table V: Estimated standing crop of fish (kg/ha) in pools of Deer Creek 1967 through 1970.

Species Group	Pool				
	A-1	A-2	B-0	B-1	B-2
			June 26 - 29, 1967		
Suckers & Redhorse	37.00	20.85	18.00	4.76	19.08
Hog sucker	-	9.31	8.04	6.42	2.87
Carpsuckers	42.55	34.22	0.04	0.18	1.65
Carp	46.94	59.68	19.13	21.67	24.93
Gizzard Shad	35.51	13.07	7.60	2.70	5.22
Sunfish & Crappie	38.03	70.57	49.02	16.99	15.60
Bass	4.11	8.94	9.08	3.79	0.10
Other Species	0.57	0.58	-	-	2.55
Total	204.71	217.32	110.90	56.49	71.98

Table V: (con't.)

Species Group	Pool				
	A-1	A-2	B-0	B-1	B-2
	July 24-26 (A-pools) and August 15-18, 1967 (B-pools)				
Suckers & Redhorse	22.33	24.96	20.63	19.76	17.37
Hog sucker	3.22	8.42	26.37	10.39	1.05
Carpsuckers	54.21	17.15	-	-	-
Carp	87.48	79.67	10.70	13.70	23.31
Gizzard Shad	15.43	7.43	-	4.08	6.52
Sunfish & Crappie	46.51	57.59	37.30	52.02	59.59
Bass	7.47	10.57	28.73	20.89	9.68
Other Species	2.95	1.47	0.06	2.57	1.01
Total	224.16	207.26	123.81	123.41	118.52

Table V: (con't.)

Species Group	Pool				
	A-1	A-2	B-0	B-1	B-2
			June 6 - 11, 1968		
Suckers & Redhorse	18.02	39.35	14.79	6.36	2.96
Hog sucker	0.64	2.43	6.54	-	1.49
Carpsuckers	20.42	22.73	2.37	3.20	1.56
Carp	57.14	54.42	-	33.62	-
Gizzard Shad	14.27	15.76	-	0.47	-
Sunfish & Crappie	12.25	30.71	9.17	8.68	2.22
Bass	7.92	5.84	1.75	-	-
Other Species	4.73	1.95	-	4.67	42.80
Total	140.13	173.21	34.62	57.01	41.03

Table V: (con't.)

Species Group	Pool				
	A-1	A-2	B-0	B-1	B-2
			July 10 - 28, 1968		
Suckers & Redhorse	1.64	15.54	18.96	28.40	13.05
Hog sucker	0.47	2.14	28.25	-	-
Carpsuckers	16.62	5.04	0.46	-	0.05
Carp	9.29	37.39	73.88	28.49	20.61
Gizzard Shad	8.57	8.44	-	-	-
Sunfish & Crappie	12.74	33.12	18.33	7.89	6.97
Bass	3.93	6.49	11.04	11.81	-
Other Species	7.03	4.85	5.21	0.53	3.75
Total	60.30	112.95	156.13	77.12	44.43

Table V: (con't.)

Species Group	Pool				
	A-1	A-2	B-0	B-1	B-2
			September 19, 1968		
Suckers & Redhorse			-	-	5.39
Hog sucker			-	-	-
Carpsuckers			-	0.23	-
Carp			-	5.52	59.90
Gizzard Shad			-	-	7.27
Sunfish & Crappie			-	1.49	8.94
Bass			-	0.26	7.47
Other Species			-	-	-
Total			-	7.50	88.97

Table V : (con't.)

Species Group	Pool A-1	A-2	B-0/1	B-2
		June 23 - July 14, 1969		
Suckers & Redhorse	30.65	47.16	17.83	27.36
Hog sucker		9.93	10.98	1.81
Carpsuckers	23.87	23.95	-	-
Carp	76.75	35.06	29.44	13.66
Gizzard Shad	0.74	-	0.66	0.49
Sunfish & Crappie	27.65	38.47	56.00	8.67
Bass	2.88	7.81	3.59	0.10
Other Species	6.60	4.67	23.42	-
Total	169.14	167.05	141.92	52.09
		August 14 - 15, 1969		
Suckers & Redhorse			15.77	18.55
Hog sucker			9.09	3.49
Carpsuckers			4.62	2.96
Carp			11.91	20.66
Gizzard Shad			40.95	-
Sunfish & Crappie			19.25	5.11
Bass			4.28	3.13
Other Species			2.35	-
Total			108.22	53.90

Table V : (con't.)

Species Group	Pool			
	A-1	A-2	B-0/1	B-2
		October 7 - 10, 1969		
Suckers & Redhorse			11.30	24.02
Hog sucker			23.87	20.66
Carpsuckers			-	-
Carp			-	41.73
Gizzard Shad			-	-
Sunfish & Crappie			21.44	12.45
Bass			3.06	19.73
Other Species			-	-
Total			59.67	118.59
		June 11 - 25, 1970		
Suckers & Redhorse	9.69	11.70	13.36	12.23
Hog sucker	5.12	3.89	8.96	1.46
Carpsuckers	5.05	14.94	-	-
Carp	88.30	9.74	-	
Gizzard Shad	22.62	10.42	74.25	21.52
Sunfish & Crappie	8.06	16.76	27.41	3.51
Bass	4.53	-	5.44	44.76
Other Species	12.84	3.34	11.83	1.25
Total	178.20	70.80	141.92	85.40

Table V : (con't.)

Species Group	Pool			
	A-1	A-2	B-0/1	B-2
		August 4 - 10, 1970		
Suckers & Redhorse	28.51	33.24	17.51	33.27
Hog sucker	9.98	16.63	14.58	6.45
Carpsuckers	0.24	-	-	0.04
Carp	14.10	43.26	3.98	-
Gizzard Shad	-	6.80	6.64	-
Sunfish & Crappie	44.03	84.29	31.45	6.93
Bass	21.52	10.18	5.25	3.65
Other Species	2.84	2.16	0.30	-
Total	122.07	188.76	80.70	50.33

Table VI: Estimated standing crop of fish (No/ha) in pools of Deer Creek - 1967 through 1970.

Species Group	Pool A-1	Pool A-2	Pool B-0	Pool B-1	Pool B-2
	June 26 - 29, 1967				
Suckers & redhorse	213	163	273	59	104
Hog sucker	-	92	251	45	61
Carpsuckers	129	115	1	6	8
Carp	594	719	330	118	115
Gizzard shad	390	201	127	49	83
Sunfish crappie	2337	3208	1961	772	743
Bass	21	79	189	47	11
Other species	8	16	-	-	7
Total	3591	4577	3132	1096	1133
	July 24 - 25, 1967				
Suckers & redhorse	168	173	573	335	434
Hog sucker	45	85	425	113	52
Carpsuckers	170	57	-		-
Carp	866	595	73	96	174
Gizzard shad	132	77	-	41	57
Sunfish & crappie	2022	2618	1963	3251	3505
Bass	127	119	405	142	147
Other species	6	24	30	17	13
Total	3536	3630	3470	3996	4383
	June 6 - 11, 1968				
Suckers & redhorse	86	165	77	25	16
Hog sucker	12	46	156	-	-
Carpsuckers	58	56	8	13	9
Carp	103	131	-	25	-
Gizzard shad	120	145	-	19	-
Sunfish crappie	422	960	399	413	139
Bass	33	68	24	-	-
Other species	11	12	-	10	23
Total	845	1582	664	506	210

Table VI: (con't.)

Species Group	Pool A-1	Pool A-2	Pool B-0	Pool B-1	Pool B-2
July 10 - 28, 1968					
Suckers & redhorse	11	73	306	104	115
Hog sucker	6	2	415	-	-
Carpsuckers	44	15	153	-	17
Carp	20	131	197	89	59
Gizzard shad	73	95	-	-	
Sunfish & crappie	579	1743	1018	564	465
Bass	37	54	442	66	-
Other species	40	93	158	35	94
Total	810	2206	2689	858	750
September 19, 1968					
Suckers & redhorse			-	-	69
Hog sucker			-	-	-
Carpsuckers			-	23	-
Carp			-	44	88
Gizzard shad			-	-	23
Sunfish & crappie			-	78	208
Bass			-	65	87
Other species			-	-	-
Total			-	211	475

Species Group	Pool A-1	Pool A-2	Pool B-0/1	Pool B-2
June 23 - July 14, 1969				
Suckers & redhorse	124	222	153	220
Hog sucker	-	77	125	20
Carpsuckers	72	97	-	-
Carp	203	97	77	46
Gizzard shad	8	-	11	11
Sunfish & crappie	2475	2563	3927	639
Bass	17	68	51	17
Other species	37	30	58	-
Total	2936	3154	4402	953

Table VI: (con't.)

Species Group	Pool	B-0/1	B-2
	August 14 - 15, 1969		
Suckers & redhorse		501	98
Hog sucker		203	268
Carpsuckers		22	13
Carp		24	46
Gizzard shad		221	-
Sunfish & crappie		1447	521
Bass		92	56
Other species		98	-
Total		1911	1002
	October 7 - 10, 1969		
Suckers & redhorse		578	265
Hog sucker		566	668
Carpsuckers			-
Carp		-	20
Gizzard shad		-	-
Sunfish & crappie		2212	1420
Bass		92	215
Other species		-	-
Total		3448	2588

Species Group	Pool A-1	A-2	B-0/1	B-2
	June/July 1970			
Suckers & redhorse	53	49	318	95
Hog sucker	168	95	101	58
Carpsuckers	16	39	-	-
Carp	66	21	-	-
Gizzard shad	148	101	464	126
Sunfish & crappie	424	728	1827	167
Bass	60	-	105	188
Other species	48	31	38	12
Total	983	1065	2994	761

Table VI: (con't.)

Species Group	Pool A-1	A-2	B-0/1	B-2
	August 1970			
Suckers & redhorse	297	173	233	286
Hog sucker	149	175	265	122
Carpsuckers	27	-		4
Carp	29	65	11	-
Gizzard shad	-	28	14	-
Sunfish & crappie	3145	4436	2246	630
Bass	371	55	656	146
Other species	26	62	16	-
Total	4280	5147	3728	1471.

Table VII: Average weight of fish (grams) captured in the pools of Deer Creek above (A) and below (B) the limestone quarry.

Species Group	A-1	A-2	B-0	B-1	B-2
	Pool				
	June 20 - 29, 1967				
Suckers & redhorse	174	128	66	81	184
Hog sucker	-	101	32	142	47
Carpsuckers	328	299	38	32	193
Carp	79	83	58	184	215
Gizzard shad	91	65	60	55	63
Sunfish & crappie	17	22	25	22	21
Bass	195	113	48	80	9
	July 24-25, 1967		August 15-18, 1967		
Suckers & redhorse	133	144	36	59	40
Hog sucker	71	99	62	92	20
Carpsuckers	318	299	-		-
Carp	101	134	146	142	134
Gizzard shad	117	96	-	99	114
Sunfish & crappie	23	22	19	16	17
Bass	59	89	71	147	66
	June 6 - 11, 1968				
Suckers & redhorse	211	239	192	256	180
Hog sucker	54	53	42	-	67
Carpsuckers	352	403	279	244	179
Carp	552	416	-	1321	-
Gizzard shad	119	109	-	25	-
Sunfish & crappie	29	32	23	21	16
Bass	240	86	72	-	-
	July 10 - 28, 1968				
Suckers & redhorse	150	212	62	272	113
Hog sucker	80	93	68	-	-
Carpsuckers	382	344	3	-	3
Carp	474	286	375	320	350
Gizzard shad	117	89	-	-	-
Sunfish & crappie	22	19	18	14	15
Bass	1056	121	25	180	-

TableVII: (con't.)

Species Group	Pool A-1	Pool A-2	Pool B-0	Pool B-1	Pool B-2
September 19, 1968					
Suckers & redhorse			-	-	78
Hog sucker				-	-
Carpsuckers			-	10	
Carp				124	678
Gizzard shad			-		322
Sunfish & crappie			-	19	43
Bass				4	86

Species Group	Pool A-1	Pool A-2	Pool B-0/1	Pool B-2
June 23 - July 14, 1969				
Suckers & redhorse	247	212	117	124
Hog sucker	-	130	88	92
Carpsuckers	330	248	-	-
Carp	377	361	383	297
Gizzard shad	91	-	60	45
Sunfish & crappie	11	15	14	14
Bass	116	165	70	6
August 14 - 15, 1969				
Suckers & redhorse			31	190
Hog sucker			45	13
Carpsuckers			212	220
Carp			500	450
Gizzard shad			185	-
Sunfish & crappie			13	10
Bass			47	55
October 7 - 10, 1969				
Suckers & redhorse			20	91
Hog sucker			42	31
Carpsuckers				-
Carp			-	2041
Gizzard shad			-	-
Sunfish & crappie			10	9
Bass			31	92
June 11 - July 7, 1970				
Suckers & redhorse	240	167	48	129
Hog sucker	41	30	81	25
Carpsuckers	380	323	-	-
Carp	460	1338	-	-
Gizzard shad	103	153	160	171
Sunfish & crappie	19	20	21	24
Bass	-	76	52	238

TableVII: (con't.)

Species Group	Pool A-1	A-2	B-0/1	B-2
	August 4 - 11, 1970			
Suckers & redhorse	96	192	75	116
Hog sucker	67	95	55	53
Carpsuckers	9	-	-	8
Carp	492	669	362	
Gizzard shad	-	243	461	-
Sunfish & crappie	14	19	14	11
Bass	58	20	8	25

BIBLIOGRAPHIC:

J. R. Gammon, DePauw University. The Effect of Inorganic Sediment on Stream Biota. Final Report Water Quality Office of E.P.A. Grant No. 18050 DWC, December 1970

ACCESSION NO.

ABSTRACT

Fish and macroinvertebrate populations fluctuated over a four year period in response to varying quantities of sediment produced by a crushed limestone quarry. Light inputs which increased the suspended solids less than 40 mg/l during a part of each day caused a 25% reduction in macroinvertebrate populations below the quarry. Heavy inputs caused elevations of more than 120 mg/l with some periods of sediment accumulation and a 60% reduction in macroinvertebrate populations. Diversity indices were not affected.

KEY WORDS:

Stonedust pollution
Sedimentation rates
Stream fisheries
Aquatic insects
Standing crop
Growth rates
Fish behavior
Insect behavior

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1 Accession Number	2 Subject Field & Group	
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27 *Abstract*

Fish and macroinvertebrate populations fluctuated over a four year period in response to varying quantities of sediment produced by a crushed limestone quarry. Light inputs which increased the suspended solids less than 40 mg/l during a part of each day caused a 25% reduction in macroinvertebrate populations below the quarry. Heavy inputs caused elevations of more than 120 mg/l with some periods of sediment accumulation and a 60% reduction in macroinvertebrate populations. Diversity indices were not affected. Experimental sediment introductions caused immediate increases in drift rate proportional to the concentration of suspended solids. The standing crop of fish decreased drastically when heavy sediment input occurred in the spring, but fish remained in pools during the summer when sediment input was very heavy and left the pools only after deposits of sediment accumulated. After winter floods removed sediment deposits, fish returned to the pools during spring months and achieved 50% normal standing crop by June. Only slight improvements occurred during summer even with light sediment input. Only spotted bass *(Micropterus punctulatus)* was resistant to sediment, but its growth rate was lower below the quarry than above. Most fish were much reduced in standing crop below the quarry.

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