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Project Summary

Effects of Agriculture on Stream Fauna in Central Indiana

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From 1978 through 1980 the benthic macroinvertebrate and fish communities of three stream systems in Central Indiana were examined. The objective of this study was to describe the organization of these communities in relation to different land use. The influence of agriculture on the 14 stream segments ranged from virtually none to intense, and included some drainage from animal feed lots. The results of the study suggest the pattern of change caused by the increasing development of agriculture in small watershed streams.

Initially agriculture may lead to an expanded biomass of fish and macroinvertebrates without causing a large compositional reorganization. However, chironomids assume a dominant role for the macroinvertebrates while other benthic groups become secondary in importance. These benthic changes appear to occur without strongly influencing the fish community, except for an increase in standing crop.

Further development of agricultural stresses causes a sudden, pronounced shift in the composition of the fish community. Communities dominated by insectivores and piscivores (centrarchids in these streams) are converted to communities dominated by omnivores, herbivores, and detritivores. This alteration may occur with little or no change in standing crop biomass. At this stage the density of non-chironomid insect larvae becomes reduced.

Additional stress, such as organic loading from animal feed lots, causes further reductions in diversity and density of macroinvertebrates and in lowered standing crops of fish.

The near-stream, riparian part of the watershed is vital to the maintenance of healthy aquatic communities, acting as a buffer between plowed fields and farm animals and the aquatic system.

This Project Summary was developed by EPA's Environmental Research Laboratory, Corvallis, OR, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The negative effects of various diffuse and sporadic agricultural activities on water quality are usually assumed, but rarely measured. In 1977, a Model Implementation Program (MIP) was initiated by the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Agriculture (USDA) to demonstrate the benefits of improved water quality to be gained by implementing best management practices. The Indiana Heartland Model Implementation project was selected to be part of this program.

The overall Indiana project effort includes a study of land use (Holcombe Research Institute, Butler University), water quality monitoring and soil erosion modeling (Agricultural Engineering Dept., Purdue University), efforts to institute improved agricultural practices (USDA, Soil Conservation Service), and a biological investigation (Dept. of Zoology, DePauw University). The goal of the biological phase of this project was to monitor faunal changes that might occur in the study streams in response to the institution of better land management practices in the respective watersheds. Biological investigations of the streams included assessments of (1) benthic macroinvertebrates, (2) fish populations, (3) riparian vegetational patterns, and (4) stream morphology and habitat.

Sampling stations were established near the bases of six subtributaries of Eagle Creek and near a fixed monitoring station on Finley Branch. They were also established near the bases and about halfway up both north and south forks of Stotts Creek, as well as on the lower main stem. In addition to Eagle Creek (60%-75% cropland) and Stotts Creek (53%-58% cropland) a largely forested watershed, Rattlesnake Creek, was included in the biological sampling program in the event that suitable "control" tributaries were absent from the study streams.

Over the three-year period, the aquatic communities exhibited an unexpected stability in terms of standing crop and composition. No discernible improvement in the fish communities was observed. The biotic response implied in this study is non-linear in that an increment of improvement in water quality does not necessarily result in an increment of improvement in the aquatic community. Rather, the pattern discerned for these stream communities suggests that progressive basic improvements in environmental quality could occur with little or no evidence of benefit to the stream community until a critical level was reached, whereupon a sudden transformation would occur.

Results

Fish populations were assessed twice each year using an electric seine as the primary collecting tool. In addition to standing crop determinations, community analyses were performed on the data including Shannon diversity, evenness, a composite index incorporating both abundance values and diversity, cluster analysis, and trophic grouping.

These community parameters were examined in relation to (1) habitat structure, (2) Horton stream order, and (3) mean depth of the stations. Habitat structure tended to be fairly uniform from station to station (Fisher, 1979) and correlated poorly with the community parameters. Habitat evaluation utilized a numeric ranking system with regard to mean depth, bottom substrate, current, cover, and canopy. There was no correlation between community parameters and stream order (III-V in Stotts, II-III in Eagle, and III for Rattlesnake). During 1978 there was a positive correlation between mean depth and standing crop.

The two collecting stations on Rattlesnake Creek differed widely in standing crop (Table 1) with 73 kg/ha at the upper station and 173 kg/ha in the downstream station. Shannon diversities at both stations were relatively high, ranging from 1.8 to 2.5. The mean size of fish was larger than the fish at most of the agriculturalized stations. The trophic structures of the Rattlesnake Creek fish communities were very comparable, with more than 25% piscivores (mostly centrarchids), 40%-50% insectivores, and only 25%-30% herbivores, omnivores, and detritivores.

In the agricultural watersheds, the standing crops of fish also varied greatly. With some exceptions, the mean size of fish was smaller primarily because the communities were dominated by minnows, and Shannon diversities were generally lower.

Two sites in Stotts Creek (S1 and S5) supported fish communities whose trophic structure was fairly comparable to those in Rattlesnake Creek, but other sites, particularly those influenced by swine feed lots, were dominated by detritivores, omnivores, and herbivores.

Among the Eagle Creek sites, both E5 and E6 contained populations trophically similar to those of Rattlesnake Creek, but other sites deviated substantially with piscivores and insectivores constituting less than half of the biomass of fish.

The cluster analysis produced results very comparable to the trophic analysis in that stations having communities dominated by piscivores and insectivores (R-stations, E5, E6, and S1) tended to cluster together, as did stations dominated by omnivores, herbivores, and detritivores. A plot of the percent piscivores and insectivores in relation to standing crop illustrates the two basically different kinds of fish communities found among the 14 collecting stations (Figure 1). Subwatersheds containing more cropland were consistently characterized by lower percentages of piscivores and insectivores. Spearman's correlation coefficient was -.714 for the Eagle Creek system and -.90 for Stotts Creek (Hyde *et al.* 1982).

The analysis of the benthic macroinvertebrate populations proceeded from two basic assumptions: (1) that the water quality in each drainage area would be at least as good as that in the least disturbed stream or reach of that watershed, and (2) that the assessments of water quality are possible using identifications only to the family level and that any further identification to genus and species would not significantly alter those assessments. It was also assumed that the composition of the benthic community would change naturally as the year progressed because most of the organisms spend only part of their lives in that environment.

The insects were the dominant group of organisms in the benthic community and the analyses emphasize those animals. The mean annual diversity based upon density of insect families at each site was used for a preliminary ranking of the sites and also for more detailed analyses. Biomass was less useful because its magnitude depended upon which instars were present. The growth rate and,

Table 1. Mean Standing Crops and Trophic Composition of Fish in Eagle Creek (E), Stotts Creek (S), and Rattlesnake Creek (R) During 1978, 1979, and 1980

Sampling Station	Standing Crop - kg/ha	% Composition: Piscivores	Insectivores	Herbivores	Omnivores	Detritivores
			Eagle Creek			
E1	91	11.3	32.1	8.6	46.3	0.9
E2	152	10.4	35.6	16.1	32.6	5.5
E3	111	9.5	26.1	16.9	40.7	6.3
E4	68	12.0	16.1	24.0	42.1	5.9
E5	215	26.2	47.0	6.4	19.1	1.6
E6	142	30.5	49.9	12.4	7.2	3.2
E8	252	10.5	26.1	7.5	54.0	2.1
			Stotts Creek			
S1	91	17.3	54.3	6.6	13.9	6.3
S3	194	7.9	32.6	14.4	31.9	6.2
S5	177	25.5	37.5	15.6	18.7	3.1
S7	69	2.4	27.9	32.9	30.1	6.7
S9	141	3.5	33.5	21.8	29.6	9.0
			Rattlesnake Creek			
R1	73	28.2	42.6	2.1	23.8	3.3
R3	173	26.4	56.2	5.9	9.3	2.1

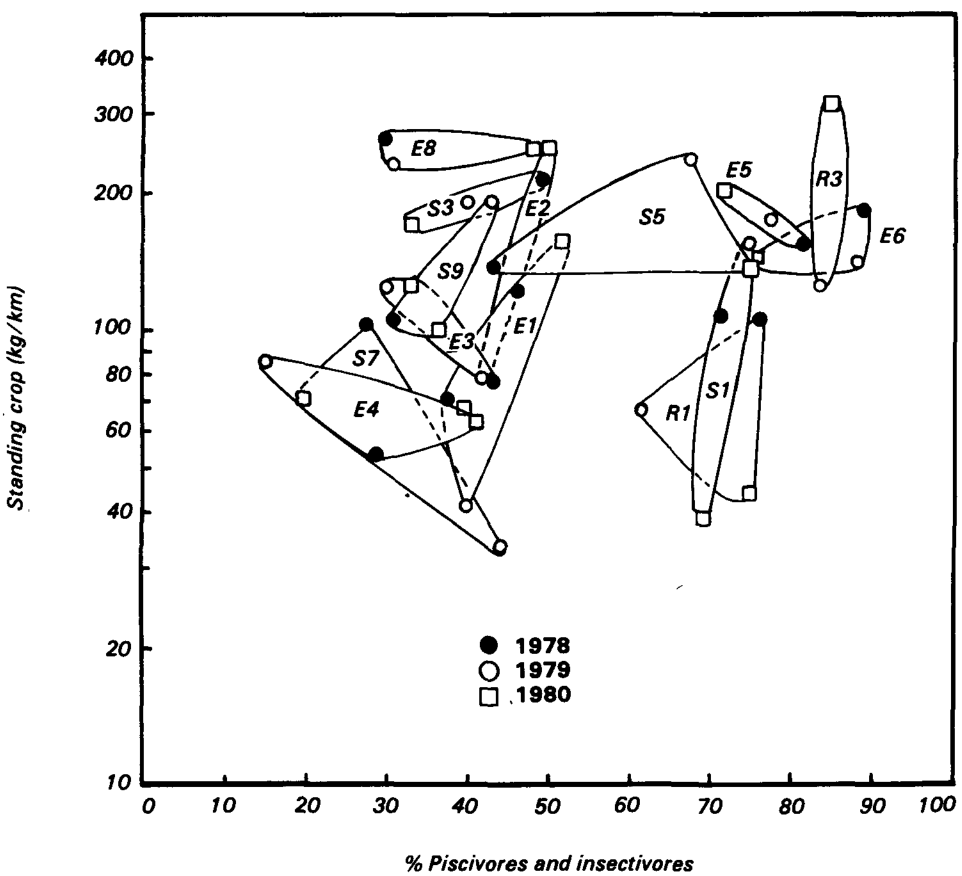

Figure 1. Standing crop and proportion of piscivores and insectivores of study segments. Each point is a mean of two determinations.

hence, synchrony of instars varied from site to site in any month.

The benthic macroinvertebrate populations of Eagle, Stotts, and Rattlesnake Creek which ranked highest were used as standards for evaluating the other sites. Their respective compositions were similar with the number of insect families ranging from 10 to 20.

Chironomidae were major components of all sites during May and June, but diminished in importance in July and August at the "good" sites while maintaining high densities at the "poor" sites. During this period benthic diversity correlated negatively to % cropland in subwatersheds ($r = -.771$) of Eagle Creek. After the decline of Chironomidae at the "good" sites Trichoptera, especially Hydropsychidae, became the dominant insect group with other major contributions from the Baetidae, Elmidae, and Simuliidae.

Organic and inorganic pollutants were major influences on the macroinvertebrate communities. The nonpoint source inorganic sediments tended to depress the density, except for the Chironomidae, without greatly altering the composition. Point source pollutants, on the other hand, altered the taxonomic composition of the community. Many of the less common families collected at other sites never occurred while others occurred infrequently and, when present, in small numbers. These may represent contributions from upstream drift. These affected communities are dominated by Chironomidae, Oligochaeta, and Nematoda, which on occasion reach higher than expected densities. The same pattern was exhibited where pastured cattle had access to the creek, except for an initially higher number of families (represented by few specimens).

Detectable improvements in benthic communities followed cessation of bridge building and bulldozing, but not in areas subjected to persistent, chronic problems.

Table 2 summarizes the degree to which stream communities are altered by differing degrees of agriculturalization. With regard to fish communities, the term "moderate" agriculture indicates that all the normal components are present, whereas, under "heavy" agricultural usage a pronounced change occurs as bass, sunfish, and some insectivores are lost from the community.

Stream Morphology, Habitat, and Streambank Vegetation

The major tributaries of the streams were examined at several sites for (1) stream habitat, (2) channel morphology, (3) bottom substrate, and (4) adjacent land use. All sites were located in the lower half of the drainage basins.

Stream habitat structure included seven parameters, including for both riffles and pools such characteristics as length, width, depth, flow, aquatic flora, bottom composition, and cover. Point determinations were made with a meter pole at 5 m intervals, a technique similar to that used by Gormann and Karr (1978). Flow rates were determined with a Mikasa flow meter. Seven categories of bottom composition were identified using the Wentworth scale.

Two aspects of land use were examined: (1) the predominant type of land use adjacent to the stream, and (2) the presence or absence of a different kind of interface or buffer strip immediately adjacent to the stream. The various types of predominant land use were (1) cultivated fields of soybeans or corn, (2) meadows, (3) woods and forests, and (4) residential areas. Buffer strips or interfaces, when present, consisted of either grasses, scattered trees or woods.

Within a geographic region there tends to be a remarkable consistency in the dimensions of stream channels in watersheds of similar size (Dunne and Leopold, 1978). Most subtributaries were 25 to 75 km^2 in drainage basin area and might be expected to maintain quite similar channel dimensions if land use throughout the basins was equitable. Increased sediment input results in aggradation with a resultant increase in channel width and decrease in depth (Bovee and Milhous, 1978). Reduced sediment loading would reverse this tendency. Mean pool depth was examined in relation to land use and potential erosion. The deepest pool from each watershed was assigned a value of 100 and the mean depth of other pools rated as a percent of this reference depth. The data were then grouped with respect to predominant land use and the presence or absence of different kinds of buffer vegetational communities. Figure 2 summarizes the findings.

Table 2. Summary of Community Characteristics Under Different Intensities of Agriculture

Characteristic	Degree of Agriculturalization: Minimal	Moderate	Heavy
Macroinvertebrates			
Shannon diversity (density of insect families)	*>1.5*	*1.3 to 1.5*	*<1.3*
Number of insect families	*12 to 15*	*8 to 12*	*<8*
Chironimidae (temporal pattern)	*High: May June Low: July August*	*Relatively high throughout summer*	*Dominant group throughout summer*
Oligochaeta (density)	*Low*	*Fluctuating*	*High*
Other families (density)	*High*	*Declines for uncommon families*	*Declines for all families*
Hydropsychidae	*Dominant throughout summer*	*Common, but not always dominant*	*Present in low numbers*
Ephemeroptera	*Large numbers in May*	*Present*	*Irregularly present*
Fish			
Standing crop	*50-150 kg/ha*	*100-300 kg/ha*	*200-300 kg/ha*
Centrarchids	*20-30%*	*20-30%*	*10%*
Insectivores	*40-60%*	*40-60%*	*25-40%*
Omnivores + Detritivores	*10-25%*	*10-25%*	*40-50%*
Herbivores	*10%*	*10-30%*	*10-30%*
Shannon diversity (No.)	*2.0-2.5*	*1.8-2.0*	*1.8-2.0*

In both watersheds, pools which were flanked by woods were approximately 50% deeper than pools adjacent to areas of altered land use, either residential areas, meadows or cultivated fields. Wherever these latter areas were buffered from the stream by a strip of natural grass or trees the stream also tended to be considerably deeper. Wherever woods were separated by some other buffer vegetation the pools tended to be more shallow. This study was conducted without regard to the width of the buffer strip. Mean pool depth was negatively correlated with % cropland in subwatersheds ($r = -.912$).

Although the results indicated here are not clear-cut, they strongly suggest that the presence of a vegetative buffering interface between agricultural fields, pastures, and residences and the stream is very important to the stream ecosystem, influencing not only the standing crop of fish, but also its composition to some extent. The smaller the stream the more importantly this buffer strip would act.

Conclusions

Stream fauna can be used to assess the degree to which agriculture influences water quality; the results of this study indicate the pattern of changes which attend the increasing agricultural development of a forested watershed. Parallel evaluations were obtained both from fish and macroinvertebrates for most situations, but more was learned from a combination of the two groups than from either one alone.

Standing crop estimates of fish were not, in themselves, of great value in evaluating chronic agricultural effects, although depressions in biomass occurred in response to sporadic problems with animal feed lots and to chronic problems with a chemical recycling plant and landfill. The best indicator of agricultural effects on fish is the proportion of piscivores (primarily centrarchids in the study streams) and insectivores in the fish community in combination with biomass estimates.

Initially agriculture may lead to increased biomass of fish and macroinvertebrates without changing community composition. As agricultural development expands, however, chironomids assume a dominant role while other macrobenthic groups decline in importance. The fish community remains dominated by piscivores and insectivores and may actually increase in biomass. Continued development of agriculture causes a sudden, pronounced shift in the fish community as piscivores and then insectivores become reduced in abundance and the communities become dominated by omnivores, detritivores, and herbivores. This alteration occurs with little or no change in standing crop. The density of non-chironomid insect families becomes much reduced.

Recognition of the different velocities of change which occur as the result of agricultural development is vital to evaluating the "health" of stream communities. A stream which appears to be excellent from a fishing standpoint may stand on the brink of sudden biotic changes. Likewise, a stream which has lost its piscivores may, with some reasonable degree of assistance, be returned to a much more desirable biotic state.

Recommendations

Any program designed to improve water quality in agricultual watersheds should identify and evaluate all potential areas of point-source pollution, including animal feed lots, landfills, etc. A substantial improvement in water quality could accrue from intensified efforts to examine and regulate these sites. A related problem which is common in the midwest is the pasturing of farm animals with free access to streams. The cost-benefits of fencing or otherwise excluding animals should be examined.

Following the control of point-source problems, we recommend the preservation and/or establishment of permanent riparian forests to act as buffer zones between cropland or pasture and streams. Research should be undertaken to determine the minimum effective width for a variety of streams. Efforts of farmers to increase food production are most in conflict with the goals of water quality improvement with respect to this riparian zone, which is rapidly disappearing in many watersheds.

The third area of agriculture which strongly affects water quality is that of cultivated fields or cropland. All

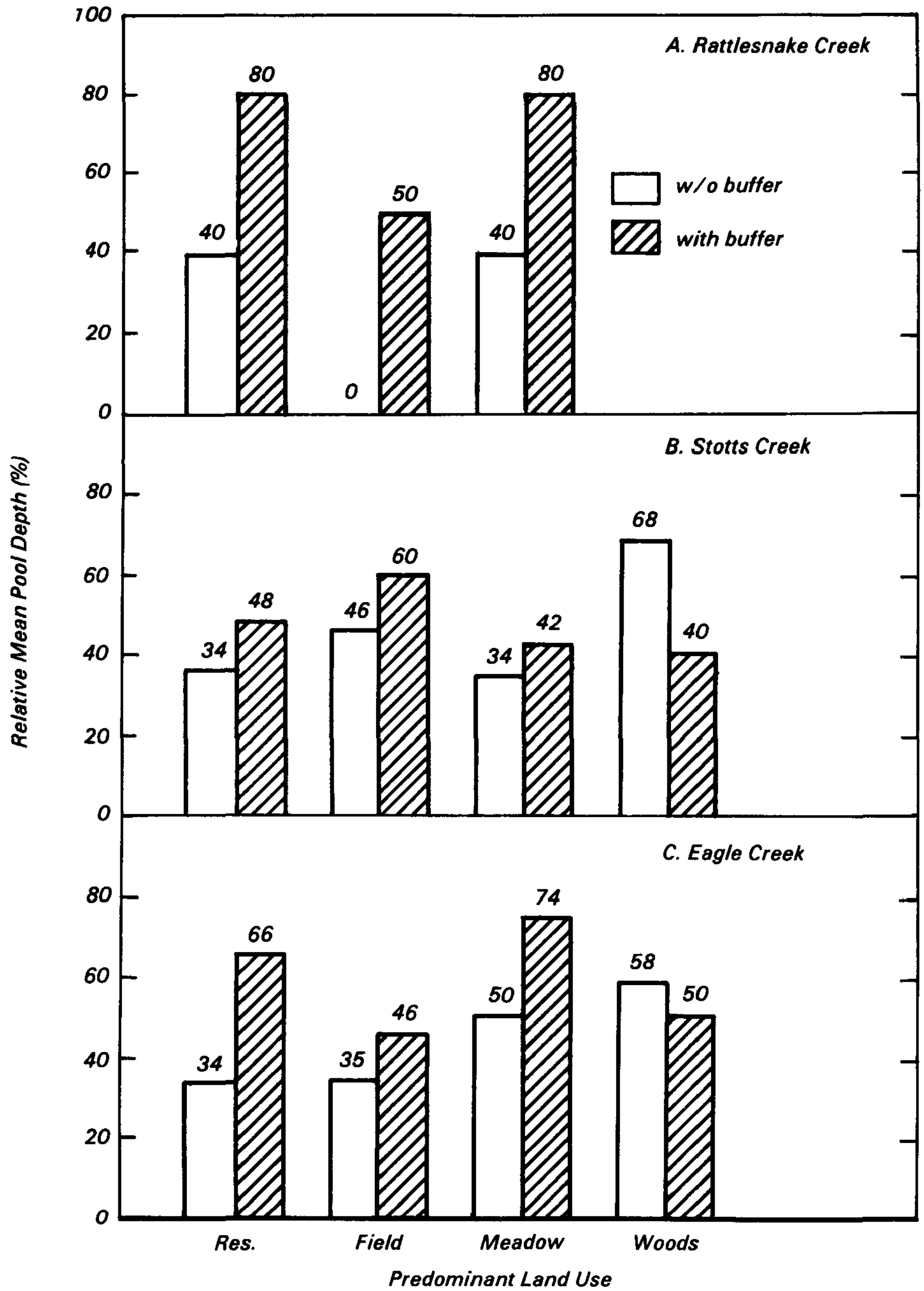

Figure 2. Mean relative depth of stream pools in areas of different land uses, with and without a buffer interface.

segments of society are in agreement about the desirability of reducing erosion and confining soil, nutrients, herbicides, and pesticides to tilled fields. The current beginning revolution in tillage practices and the widespread adoption of best management practices could substantially reduce the entry of nonpoint source pollutants from croplands to streams and thereby benefit aquatic life.

In conjunction with the above efforts, a general assessment of biotic communities of agricultural watersheds should be undertaken. Much information that already exists in the files of state Departments of Fish and Wildlife and in scientific literature may be reviewed and interpreted anew. Additional new studies of important streams should be made. Priority rankings of stream systems should follow with the goal of maintaining those having good water quality and instituting programs for those whch appear to be most amenable to improvement.

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The complete report, entitled "Effects of Agriculture on Stream Fauna in Central Indiana," (Order No. PB 83-188 755; Cost: $13.00, subject to change) will be available only from:
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