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The Effects of Mine and Domestic Wastes on Macroinvertebrate Community Structure in the Coeur d'Alene River

Introduction

Cities and industries in the Coeur d'Alene mining district of northern Idaho have discharged a wide range of waste materials into the South Fork of the Coeur d'Alene River since the beginning of mining activities in 1885. Mining, milling, and smelting of rich Pb-Ag-Zn ores have contributed fine inorganic solids from silt to colloidal in size as well as heavy metal ions including Zn, Cd, Cu, and Pb. Other industries, including a phosphoric acid plant, a fertilizer plant, and a sawmill, contribute high nutrient wastes, and cities discharge untreated domestic sewage directly into the river.

In 1932, Ellis conducted an investigation of the physicochemical and biological conditions of the river and found it nearly devoid of life from the city of Wallace on the South Fork to the mouth of the main stem at Coeur d'Alene Lake, a distance of 80 km. He attributed the absence of aquatic organisms to the large amounts of suspended solids and to the toxic action of Zn. Little was done to improve water quality until 1968 when settling ponds were constructed by the mining companies throughout the South Fork valley to impound all ore mill tailings, the main source of inorganic solids.

Subsequent studies by Minter (1970) and Wissmar (1972) indicated that phytoplankton and zooplankton populations, although present in the river and delta, were lower in density and diversity than populations in the St. Joe River or open waters of the lake. Sappington (1969) showed that Zn levels in the river were well above the median tolerance limit for cutthroat trout. An analysis of water quality conditions by Mink *et al.* (1971) indicated a significant reduction in suspended solids after impoundment but little change in concentration of toxic metal ions.

The present study was the first since Ellis' work in 1932 to examine the benthic macroinvertebrate community in the Coeur d'Alene River. Our objective was to determine the effect of reduction in tailings discharge on benthic community composition. This study entailed examination of unaltered sections of the river for control purposes and monitoring of the test stations before and after impoundment (1968-1971). The complex nature of the pollution discouraged a detailed analysis of inhibitory effects in this preliminary study. A following study will include a detailed qualitative and quantitative analysis of substrate components as well as water-quality determinations correlated with benthic community composition.

Sampling Sites

North Fork Control Station (34). The numbers assigned to station locations by Mink *et al.* (1971) were retained in this study for purposes of comparison. The North Fork control station was located about three kilometers upstream from the confluence (Fig. 1). Samples were collected from a riffle where water depth was 11-25 cm over a cobble substrate. The river width was approximately 18 m.

The North Fork, flowing through the Coeur d'Alene National Forest, has received a minimum of development and supports a diverse fauna including a good trout fishery maintained by planting. Rock formations in the North Fork basin are of the same age and type (Precambrian metasediments) that are present in the South Fork, and climatic conditions, altitude, and stream gradient are similar.

South Fork Stations (13, 23, 25, 28). Station 13 was located in the lower reaches of the South Fork, immediately below the effluent from a zinc plant, where zinc concentrations and the cumulative effects of all other wastes were maximal. Recovery of fauna at this station would be most significant in determining tolerance to high metal concentrations and reflecting general improvement in South Fork water-quality conditions. The river was 7.5 m wide and 20-30 cm deep. The cobble substrate was overlain by several cm of fine tailings when observed in 1968, before impoundment.

Grab samples were collected from stations 23, 25 and 28 in 1970 to determine upstream communities for comparison with station 13 and to locate altered and unaltered sections of the river. Station 23 was immediately below Wallace and the mouths of Canyon and Ninemile Creeks which were suspected sources of pollution. Station 25 was located just above the city of Wallace. The river width was approxi-

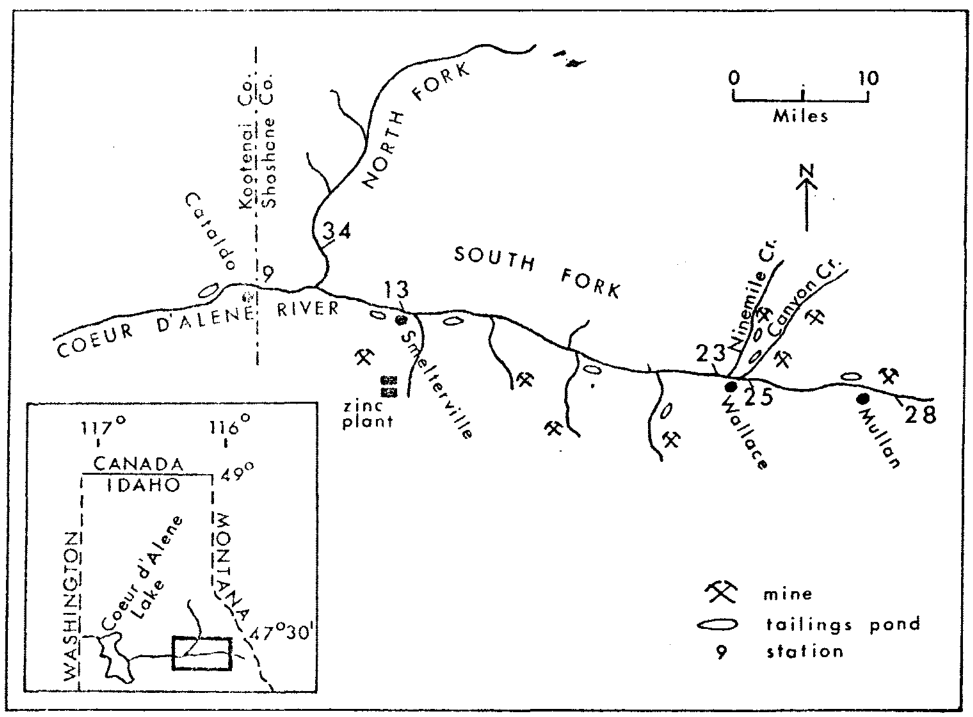

Figure 1. Map of the Coeur d'Alene River study area and station locations.

mately 3 m and the depth 15 cm at both stations over a cobble substrate. Station 28 was located above the city of Mullan and received no wastes from the one mine in the area. The substrate was small cobble and gravel, water depth 12-20 cm and stream width 3 m. This station was above all pollution sources and served as a control on the lower portions of the South Fork.

Main Stem Station (9). The main stem of the Coeur d'Alene River flows for 50 km through a broad valley containing several tributary lakes to its mouth at Coeur d'Alene Lake. Station 9 was located near Cataldo, far enough below the confluence to insure thorough mixing but above the extensive floodplain flats buried in old tailing sediments that occur below this site. The width of the river was about 23 m, and samples were collected from a shallow riffle near the center of the river where water depth was 10-15 cm over a cobble substrate.

Methods

A Surber square-foot sampler (0.1 m^2) was used to collect benthic organisms. Surface cobbles were brushed clean of attached organisms by hand, and a 3-pronged cultivating fork was used to dislodge and disturb smaller materials to a depth of at least 8 cm. The macroinvertebrates collected were placed in isopropyl alcohol and later identified and enumerated with the aid of a binocular microscope. The only taxa not separated to species level were the Chironomidae, Hydracarina, and Nematoda. Keys by Usinger (1968) were employed for most insect identification. Sampling was limited to the low-flow period in September as river depth precluded sampling by the Surber method during most of the year. Collections made at this time also insured minimum dilution and therefore maximum pollution impact.

The Shannon diversity index derived from information theory (Shannon, 1948) was used to summarize species and total counts:

$$\bar{d} = -\sum_{i=1}^{n} n_i/N \ \ln \ n_i/N$$

where n_i = the number of individuals in each species and
N = the total number of individuals in the sample.

This index is dimensionless, nearly independent of sample size and considers the distribution of individuals among the species, an important criterion of community maturity and pollutional status. A detailed basis for the application of this index to benthic community structure has been presented by Whilm and Dorris (1966, 1968) and by Whilm (1970). The $\bar{d}$ values found in the Coeur d'Alene River compare favorably with values obtained by these authors in clean and organically polluted streams. They found that $\bar{d}$ was 3.0 or greater in clean, productive stream riffles, 1.0-3.0 in moderately polluted areas, and less than 1.0 in zones of heavy pollution. The value of $\bar{d}$ is 0 when only one species is present.

Water-quality data were derived from a study run concurrently by the Idaho Bureau of Mines and Geology (Mink *et al.*, 1971; upublished data).

Results and Discussion

Water-Quality Conditions. Comparison of altered and unaltered (28, 34) sites in Table 1 indicates the degree of contamination of the South Fork and main stem of the Coeur d'Alene River. Comparison between years reveals only one significant change

TABLE 1. Physicochemical data from stations in the Coeur d'Alene River during low flow in September, 1968-1971.

Date	Station	Flow cfs	pH	D.O. mg/l	Temp. C	E. C. umhos	Turb. JTU	Alk. mg/l	Zn mg/l	Cd mg/l	Cu mg/l	Fl mg/l	Ca mg/l	Na mg/l	Mg mg/l
9/6/68[1]	34	284	8.0	9.2	18	58	0	21	0.00	–	–	–	–	–	–
	9	438	7.1	8.9	16	180	25	14	4.15	–	–	–	–	–	–
	13	112	5.5	8.8	17	420	490	3	15.05	–	–	–	–	–	–
9/8/69[1]	34	219	7.2	9.0	13	29	0	28	0.10	0.01	0.10	–	3.4	1.6	2.0
	9	338	6.2	8.8	14	113	<25	26	5.30	0.05	0.10	–	10.7	5.3	5.2
	13	102	6.2	8.8	15	220	25	20	21.00	0.05	0.10	–	28.6	12.2	10.2
9/30/70[2]	34	–	7.0	10.2	7	50	0	–	0.10	0.02	0.05	1.8	–	–	–
	9	390	6.6	10.1	8	185	<25	–	5.10	0.05	0.05	4.0	–	–	–
	13	106	6.1	10.1	8	525	25	–	17.30	0.20	0.05	15.0	–	–	–
	23	–	7.0	10.7	3	180	<25	–	3.10	–	–	7.0	–	–	–
	25	–	7.2	11.2	3	130	0	–	0.30	–	–	3.5	–	–	–
	28	–	7.4	10.7	3	80	0	–	0.10	–	–	1.9	–	–	–
10/1/71[2]	34	–	6.7	9.9	12	46	0	–	0.10	0.05	0.05	–	–	–	–
	9	–	6.4	10.0	13	144	<25	–	4.20	0.05	0.06	–	–	–	–
	13	126	5.7	10.3	13	358	25	–	19.90	0.20	0.05	–	–	–	–

[1] Mink *et al.*, 1971.
[2] Mink, unpubl. data.

in water quality following tailings impoundment, a decrease in turbidity from 490 Jackson Turbidimeter Units (JTU) at station 13 in 1968 to 25 JTU in subsequent years. At the lower turbidity level the water appears slightly cloudy, but the river bed is visible at all stations. Low pH levels have been recorded consistently over the past few years at station 13. This condition is a potentially limiting factor for more sensitive aquatic species.

In spite of the raw-sewage load entering the South Fork, oxygen levels were high due to a high natural aeration rate. Nitrate and phosphate measurements made by Mink *et al.* (1971) revealed moderate concentrations of these nutrients (low flow mean of 0.33 mg/l NO_3 and 0.24 mg/l PO_4). An overall mean B.O.D. for the South Fork of 2.12 was reported. Coliform counts reaching 160,000/100 ml (MPN) indicated the degree of bacterial loading present. The North Fork count was 34/100 ml.

The concentrations of Zn present in the river during low flow are above lethal levels to most fish (Skidmore, 1964). Cadmium and Cu have been shown to act synergistically with Zn, and therefore the presence of these metals is significant although the concentrations are low (McKee and Wolf, 1963). Fluoride concentrations exceed maximum recommended levels of 1.5 mg/l (Water Quality Criteria, 1968) at all stations. Although natural alkalinity and conductivity levels are low, high levels of Na, Ca, and Mg ions, derived from ore processing, may provide some antagonistic effect to the toxic metals. Wissmar (1972) noted this effect in bioassay tests with lake phytoplankton.

There have been few reports in the literature dealing with the tolerance of aquatic insects to metals. Hynes (1960) mentions the relatively high resistance of insects to metal toxicity. Acute toxicity tests conducted by Warnick and Bell (1969) indicated that aquatic insects are less sensitive to high concentrations of metals than are fish. Plecoptera, Ephemeroptera, and Trichoptera nymphs were unaffected by concentrations up to 64 mg/l of most metals after 16 days of exposure in soft water (40 mg/l total alkalinity). Jones (1940), investigating the Ystwyth River in Wales, found a diverse insect community and a few Platyhelminthes and Hydracarina at 1.2 mg/l Zn whereas Mollusca, Crustacea, Oligochaeta, and Hirudinea as well as Vertebrata were absent. He also noted seven insect genera where Zn concentrations were 57 mg/l. Recent bioassay tests conducted by Goettl *et al.* (1971) indicated high resistance of stoneflies to Zn and other metals except while molting. Silver proved to be most toxic to these insects. Long-term bioassay tests are still lacking.

North Fork Community. The North Fork site contained a productive and diverse macroinvertebrate community during all four years of sampling. A list of benthos found in a five-sample collection in 1968 is presented in Table 2. While some annual changes in density and composition occurred at this station, $\overline{d}$ was greater than 3.0 for all years (Table 3). The abundance of fish-food organisms in the North Fork is indicative of an above-average food grade level for trout as defined by Madsen (1935).

The high variability in numbers of organisms per sample found in a homogeneous riffle in this river is consistent with the results of other investigators (Needham and Usinger, 1956; Egglishaw, 1969) and indicates a contagious (clumped) distribution. It is this variability that makes it necessary to collect a prohibitively large number of samples to obtain a statistically significant estimate of true numbers (Hales, 1961).

The diversity ($\overline{d}$) of a benthic community can be estimated in a few samples, however. Pielou (1966) showed that an asymptote is reached in the cumulative value

TABLE 2. Composition and density of the macroinvertebrate community in five Surber samples from the North Fork, September, 1968.

Taxon	Sample 1	2	3	4	5
Trichoptera					
Lepidostoma sp.	126	101	127	97	31
Hydropsyche sp.	2	141	148	7	162
Glossosoma sp.	141	12	6	15	19
Apatania sp.	19			6	
Plecoptera					
Claassenia sabulosa (Banks)	1	1	1		
Isogenus sp.	5	2	3		3
Arcynopteryx parallela (Frison)		1	8		1
Alloperla sp.			1	1	1
Pteronarcella sp.			2		
Ephemeroptera					
Ephemerella doddsi (Needham)	1	5	5	1	5
Ephemerella grandis	1	6	4	1	2
Ephemerella inermis (Eaton)	2	27	35	6	4
Ephemerella (*walkeri* group)		1			
Paraleptophlebia heteronea (McDunn)		3	4	1	
Baetis tricaudatus (Dodds)	1	34	19	3	8
Pseudocloeon sp.		35	32	3	15
Rhithrogena sp.		7	20	2	
Cinygmula sp.	7	5	3	12	3
Diptera					
Atherix variegata (Walker)	11			12	8
Chironomidae	68	27	47	25	35
Simulium sp.		2	1		1
Tipula sp.	4		2		
Coleoptera					
Zaitzevia sp.	4	5	4	2	5
Heterlimnius sp.	11	8	16	4	12
Hydracarina	7	2		1	
Pelecypoda			1		
TOTAL	411	425	489	199	315

TABLE 3. Diversity ($\bar{d}$), density (N) and number of species (s) of macroinvertebrates at each sampling station, 1968-1971.

Date	Station	$\bar{d}$[1]	N[2]	s[2]
Sept. 1968	34	3.329	1844	26
	9	0.000	625	1
	13	–	–	–
Sept. 1969	34	3.481	815	28
	9	0.214	880	3
	13	0.000	180	1
Sept. 1970	34	3.356	1925	32
	9	0.192	1560	4
	13	0.030	690	2
	23	0.199	66	2
	25	2.225	310	13
	28	3.488	340	20
Sept. 1971	34	3.030	1745	25
	9	0.986	170	2
	13	0.073	655	4

[1] Average diversity value per sample.
[2] Value for a sample size of 5 square feet ($0.5m^2$) at stations 34, 9, and 13 and 2 square feet ($0.2m^2$) at stations 23, 25, and 28.

of $\bar{d}$ as sample size is increased. At optimum sample size, the effect of new rare species balances the effect of more individuals of common species, and no further increase in $\bar{d}$ occurs. Thus $\bar{d}$ at the asymptotic level is a good estimate of true community diversity as it is defined by the Shannon index.

Whilm and Dorris (1968) found 95 percent of the asymptotic value by the fourth sample in a stream and the fifth sample on a population sampling board. Ten samples from the North Fork were pooled before this study was initiated to determine the optimum sample size for a meaningful value of $\bar{d}$ in the Coeur d'Alene River. The results as shown in Figure 2 indicated no significant change in $\bar{d}$ after the second sample. Subsequently two to five samples were collected at each station during this study.

South Fork and Main Stem Communities. Siltation of a river interferes with colonization by benthic fauna in two ways—physical damage to delicate appendages by abrasion and destruction of the substrate habitat. In 1968, before tailings impoundment, the cobble substrate at station 13 was overlain by at least 15 cm of fine sediments. No macroinvertebrates were found. At station 9, the cobbles were coated and the underlying gravels impacted by fines. Midge fly larvae and pupae (Chironomidae: Orthocladinae) were the only organisms found in the samples. Their numbers indicated a well-established population. These small, wormlike dipterans, commonly found in lake muds, feed upon and form pupal cases from the organic detritus present in the sediments.

By autumn of 1969, coincident with the reduction in turbidity, the silt depth at station 13 had been reduced to a coating approximately 1 cm thick consisting of 25 percent organic and 75 percent inorganic material. Chironomidae had colonized the riffle in low numbers. Larvae, pupae, and newly emerged adults were present, indicating tolerance at all stages to Zn concentration of 21 mg/l. At station 9 (5 mg/l Zn) there were three populations of aquatic insects established including Elmidae adults (*Heterlimnius* sp.) and Rhagionidae larvae (*Atherix variegata*) as well as an increased abundance of Chironomidae. The probable food chain of this community is shown in Figure 3.

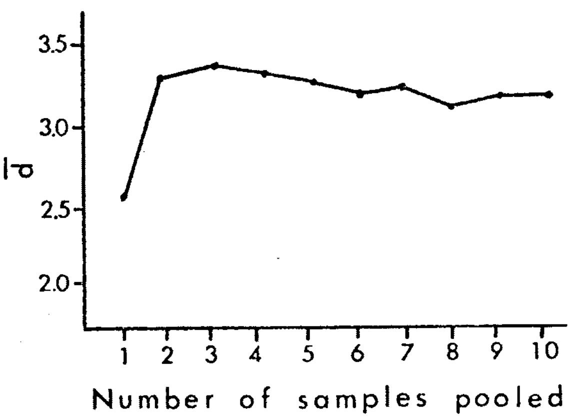

Figure 2. Cumulative value of $\bar{d}$* for ten Surber samples from the North Fork of the Coeur d'Alene River.

$$^{*}\ \bar{d} = -\sum_{i=1}^{n} n_i/N \ln n_i/N$$

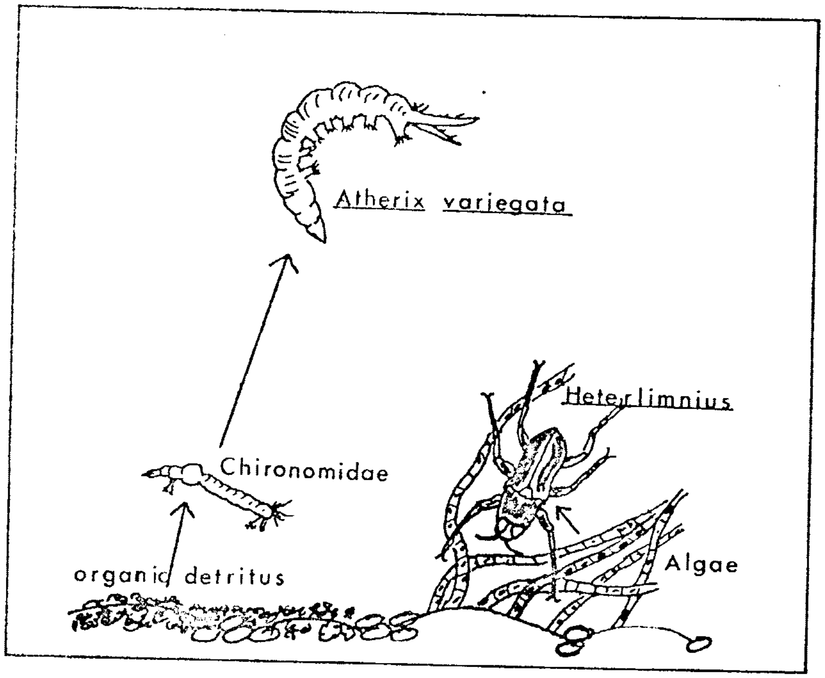

Figure 3. Food chain of populations present at station 9, 1969.

Most riffle beetles are considered clean-water organisms; thus the presence here of *Heterlimnius* was somewhat unexpected. Plentiful food supply (periphytic algae) and a well-aerated riffle evidently provided an adequate habitat for a few adults.

In 1970, a heavy growth of algae comprising *Oscillatoria, Chlorella, Chlamydomonas,* and *Nitzchia* covered the river bed at all test stations. This bloom was apparently a response to the increased light penetration and stable substrate conditions resulting from the decrease in silt load and was supported by the rich nutrient supply.

The composition of the benthic fauna at the South Fork and main stem stations sampled in September, 1970 is listed in Table 4. Little change occurred between 1969 and 1970 at stations 9 and 13. At station 9, Hydracarina appeared regularly, though in low numbers. The Chironomidae increased considerably in density at station 13, but no additional populations became established.

The scarce benthic community at station 23 indicates a major source of disturbance in the Wallace-Canyon Creek area. At station 25, there was evidence of some sewage pollution, and a Zn level of 0.3 mg/l indicated mine contamination. No turbidity was observed, however, and the substrate was free of silts and attached algae. The diversity value of 2.225 and the faunal composition at this station indicate a moderately polluted situation. Pollution-sensitive Ephemeroptera were absent (*Baetis tricaudatus* appears to be fairly tolerant in this area), and dipteran larvae predominated. Control station 28 was in an unaltered section of stream and supported a diverse benthic fauna. Trout were also observed at this station.

In 1971, the attached algal growth at stations 9 and 13 was noticeably greater than in 1970. The density of the well-established Chironomidae had decreased at station 9, although the size of the *A. variegata* population was nearly the same. Elmidae and Hydracarina were not present in the samples. The station 13 fauna was essentially

TABLE 4. Composition and density of the macroinvertebrate communities at the South Fork and main stem stations on September 30, 1970.

Taxon	Station 9[1]	13[1]	23[2]	25[2]	28[2]
Trichoptera					
Hydropsyche sp.					18
Glossosoma sp.				1	104
Rhyacophilidae					22
Psychomyiidae				10	
Brachycentridae				6	6
Limnephilidae				4	2
Hydroptilidae					6
Plecoptera					
Isogenus sp.					2
Alloperla sp.				30	28
Nemouridae				10	8
Ephemeroptera					
Ephemerella sp. A					80
Ephemerella sp. B					6
Baetis tricaudatus	2	2	2	154	26
Baetis sp. B					10
Epeorus sp.					10
Cinygmula sp.					24
Coeloptera					
Elmidae					10
Diptera					
Tipulidae				72	8
Psychodidae					1
Chironomidae	1520	688	64	20	66
Muscidae				1	
Heleidae				1	
Atherix variegata	32				
Nematoda				4	
Hydracarina	3				

[1] Total number of organisms in five Surber samples.
[2] Total number of organisms in two Surber samples.

unchanged. The Chironomidae remained fairly abundant. In addition, two *Baetis tricaudatus* nymphs, one adult Dytiscidae, and one Psychodidae larva were collected.

Thus, three years after tailings impoundment and reduction in suspended and settled inorganic solids, only very limited benthic communities have colonized the river. Further colonization is apparently being inhibited by continued adverse water-quality and/or substrate conditions. Diverse benthic communities in the North Fork and upper reaches of the South Fork are indicative of the potential communities that could inhabit presently altered portions of the river when a favorable habitat is attained.

Acknowledgments

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Literature Cited

Egglishaw, H. J. 1969. The distribution of benthic invertebrates on substrate in fast-flowing streams. Jour. An. Ecol. 38: 19-33.

Ellis, M. M. 1932. Pollution of the Coeur d'Alene River and adjacent waters by mine wastes. Manuscript report to the commissioner. U.S. Bureau of Fisheries, Washington, D.C. 61 p.

Goettl, J. P. Jr., J. R. Sinley, and P. H. Davies. 1971. Water Pollution Studies. Job Prog. Rept. F-33-R-6 Colo. Div. Game, Fish and Parks. 130 p.

Hynes, H. B. N. 1960. Biology of polluted waters. Liverpool Univ. Press.

Jones, J. R. E. 1940. A study of the zinc polluted River Ystwyth in North Cardiganshire, Wales. Ann. App. Biol. 27: 368-380.

Madsen, M. J. 1935. A biological survey of streams and lakes of Fort Apache and San Carlos Indian Reservations, Arizona. U.S. Bureau of Fisheries (mimeo). 16 p.

McKee, J. E. and H. W. Wolf. 1963. Water Quality Criteria, 2nd ed.: California State Water Quality Control Board, Sacramento, CA. Pub. No. 3-A, 404 p.

Mink, L. L. 1970-71. Unpublished data on water quality of the Coeur d'Alene River. Idaho Bur. Mines & Geol., Moscow, Idaho.

————, R. E. Williams, and A. T. Wallace. 1971. Effect of industrial and domestic effluents on the water quality of the Coeur d'Alene River basin. Pamph. 149, Idaho Bur. Mines & Geol., Moscow, Idaho. 65 p.

Minter, R. F. 1971. Plankton population structure in the lower Coeur d'Alene River, Delta and Lake. M.S. Thesis, University of Idaho, Moscow, Idaho. 72 p.

Needham, P. R., and R. L. Usinger. 1956. Variability in the macrofauna of a single riffle in Prosser Creek, California, as indicated by the Surber sampler. Hilgardia. 24: 383-409.

Pielou, E. C. 1966. The measurement of diversity in different types of biological collections. Theor. Biol. 13: 131-144.

Sappington, C. W. 1969. The acute toxicity of zinc to cutthroat trout. M.S. Thesis, University of Idaho, Moscow, Idaho. 22 p.

Shannon, C. E. 1948. The mathematical theory of communication. *In* C. E. Shannon and W. Weaver, The mathematical theory of communication. Univ. of Illinois Press, Urbana, Ill.

Skidmore, J. F. 1964. Toxicity of zinc compounds to aquatic animals with special reference to fish. Quart. Rev. Biol. 39: 227-248.

Usinger, R. L. 1968. Aquatic Insects of California. University of California Press.

Warnick, S. L., and H. L. Bell. 1969. The acute toxicity of some heavy metals to different species of aquatic insects. JWPCF. 41: 280-285.

Water Quality Criteria. 1968. Report of the National Technical Advisory Committee to the Secretary of the Interior. FWPCA. 234 p.

Whilm, J. L. 1970. Biological parameters for water quality criteria. Bioscience. 18: 477-481.

————, and T. C. Dorris. 1966. Species diversity of benthic macroinvertebrates in a stream receiving domestic and oil refinery effluents. Amer. Midl. Nat. 76: 427-449.

————, and ————. 1968. Range of diversity index in benthic macroinvertebrate populations. JWPCF. 42: R221-R224.

Wissmar, R. C. 1972. Some effects of mine drainage on primary production in Coeur d'Alene River and Lake, Idaho. Ph.D. Thesis, University of Idaho, Moscow, Idaho. 61 p.

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