RECOVERY OF MACROINVERTEBRATE COMMUNITIES FROM METAL POLLUTION IN THE SOUTH FORK AND MAINSTEM OF THE COEUR D'ALENE RIVER, IDAHO: 1968-1991

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AUTHORIZATION TO SUBMIT THESIS

This thesis of Wade Kelly Hoiland, submitted for the degree of Master of Science with a major in zoology and titled "Recovery of macroinvertebrate communites from metal pollution in the South Fork and Mainstem of the Coeur d'Alene River, Idaho: 1968-1991," has been reviewed in final form, as indicated by the signatures and dates given below. Permission is now granted to submit final copies to the College of Graduate Studies for approval.

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ABSTRACT

Mining has severely impacted the biota in the Coeur d'Alene River drainage of northern Idaho. The benthic community of the South Fork and mainstem was monitored from 1968-1971 and 1987-1991 to ascertain the effects of improved mine wastewater treatment and mine closures. Zinc concentrations decreased from 21 mg/l to 3 mg/l over this period. Subsequently, the benthic community showed a dramatic recovery as evidenced by large increases in species richness (0-18), Ephemeroptera-Plecoptera-Trichoptera index (0-8), and species diversity (0-1.8). Although considerable recovery has occurred, biotic parameters at impacted sites continue to lag behind those at reference sites, probably due to continued high zinc concentrations and poor habitat structure.

A rapid bioassessment study was conducted on the South Fork of the Coeur d'Alene River and selected tributaries in northern Idaho. Species richness, Ephemeroptera-Plecoptera-Trichoptera (EPT) index, and species diversity showed strong negative correlations with habitat assessment scores (mean r^2 =.68). Regression coefficients for percent dominant taxon, modified Hilsenhoff's index, and EPT/Chironomidae abundance were generally lower (mean r^2=.42). Zinc was negatively correlated with biotic metrics (r^2=.23-.58). Values for EPT (r^2=.60-.75) and species richness (r^2=.54-.65) provided the highest correlation coefficients of the six metrics measured. Conductivity (r^2=.18-.41) and pH (r^2=.08-.21) showed the weakest correlations with biotic metrics.

Streams affected by metal pollution also exhibited extreme habitat degradation due to activities involved in ore processing. As a result, macroinvertebrate communities may be severely impacted by habitat loss even where zinc concentrations are relatively low.

ACKNOWLEDGMENTS

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SECTION ONE

RECOVERY OF MACROINVERTEBRATE COMMUNITIES FROM METAL POLLUTION IN THE SOUTH FORK AND MAINSTEM OF THE COEUR D'ALENE RIVER, IDAHO: 1968-1991

INTRODUCTION

The South Fork and mainstem of the Coeur d'Alene River in northern Idaho have been affected by mining operations since mining began in 1885. Before 1968, waste rock or tailings containing variable amounts of copper, antimony, cadmium, lead, and zinc, among other metals, were discharged into the South Fork drainage. In late 1968, tailings ponds were constructed to contain sediments, but did little to decrease metal concentrations (Mink et al., 1971, Woodward-Clyde Consultants, 1986).

Although mine discharge contains many heavy metals, the availability of zinc from surrounding sediments together with it high toxicity, make it the most serious pollutant in the South Fork drainage (Mink et al., 1971, Reece et al., 1978, Ioannou, 1979, Callcott, 1989). Harmon (1976) estimated over 80% of total zinc loaded into the South Fork is from mine wastes deposited before 1968.

In 1968, Savage and Rabe began a study of the effects of mine wastes on macroinvertebrate communities in the South Fork and mainstem. No benthic invertebrates were observed at the Smelterville Flats below the effluent outflow of the Bunker

Hill complex and only one species was found in the mainstem. After tailings ponds were installed throughout the valley, a gradual recovery of invertebrates occurred (Savage and Rabe, 1973).

Harmon (1976) and Hornig et. al. (1988) reported on various physical and chemical changes in the river after 1971; however, little detail was given on the biota. The present study summarizes the recovery of benthic communities from both the South Fork and mainstem from 1968, before settling ponds were installed, to 1991 following a significant decrease in mining activity.

AREA DESCRIPTION

The North Fork of the Coeur d'Alene River is a relatively undisturbed river flowing primarily through national forest lands. The South Fork drains heavily industrialized areas. Near Enaville, the two forks converge to form the mainstem, which flows approximately 75 km through a broad valley to its mouth at Lake Coeur d'Alene (Figure 1.1).

The South Fork is a moderate sized fourth- to fifth-order stream approximately 45 km in length with its source in the Bitteroot Mountains. The three major tributaries, Canyon Creek, Ninemile Creek, and Big Creek all drain narrow valleys with extensive lode mining operations. Due to extensive channeling, the South Fork consists mostly of riffle habitat.

Downstream from Mullan, the floodplain is composed mainly of mine tailings deposited since 1885 (Ioannou, 1979). These tailings originated from various silver, lead, and zinc mines located in the Coeur d'Alene mining district. Little riparian vegetation exists along the river below Wallace to its mouth. The reference site on the South Fork above Mullan is characterized by streamside cover consisting of a dense canopy of western red-cedar (*Thuja plicata* Donn.), western hemlock [*Tsuga heterophylla* (Raf.) Sarg.], willow (*Salix* sp.), and various herbaceous plants.

According to Savage (1970), both the North and South Fork drainages have similar geologic substrates; however, little mining has occurred in the North Fork drainage. Extensive logging exists along many tributaries of the North Fork and some building is observed along its banks. From Enaville 40 km upstream, two roads flank the river. Riparian cover is extensive in roadless areas within the drainage area.

Mink et al. (1971) established 34 stations in the Coeur d'Alene River system but only three have been sampled throughout the study period: South Fork at Smelterville Flats (13), mainstem five km below the confluence of the North Fork and South Fork (9), and a reference station on the North Fork, three km above the confluence with the South Fork (34). In 1971 an additional reference site, two km east of Mullan above all mining activity, was added by Savage and Rabe (1973) on the South Fork (28) (Table 1.1).

METHODS

Selected chemical parameters at impacted and reference stations for 1968-1971, 1989 and 1991 are presented in Table 1.2. Water chemistries measured were alkalinity, conductivity, and pH.

Alkalinity was performed by titrating 100 ml samples with 0.02 N sulfuric acid using methyl orange as an indicator. Conductivity was taken instream using a YSI Model 33 conductivity meter. For heavy metals analysis, samples were collected in polyethylene bottles, kept cool, and within two days measured by inductively-coupled plasma (ICP) spectophotometry at the University of Idaho Veterinary Science Laboratory. The pH was determined in the lab using a Fisher Accumet Model 815 MP electronic pH meter.

Benthic samples were collected from 1968-1971, 1987-1989, and 1991 during the late summer months (August-September). Organisms were initially collected with a Surber sampler (1968-1987) and a Hess sampler from 1988-1991. Both methods sample a 0.093 m^2 area and employ fine mesh netting of less than 0.6 mm to capture invertebrates. Samples consisting of three to five replicates from each station were preserved in 85% ethanol in the field, transported to the lab, sorted, counted, and identified to lowest possible taxon using various keys. From 1968-1972, identification was often only to family. Chironomidae was identifed to subfamily throughout the study.

Biotic Analysis

Benthic communities were analyzed by the use of the Shannon-Weiner diversity index (Shannon, 1948), modified Hilsenhoff's Biotic Index (HBI) (Hilsenhoff, 1988, Merritt and Cummins, 1984, Wisseman, pers. comm.), species richness, and Ephemeroptera-Plecoptera-Trichoptera (EPT) index (Plafkin et al., 1989). The Information-Theoretic Index (Horn, 1966) was used to calculate the degree of taxonomic similarity between impacted and reference stations.

The Shannon-Weiner diversity index is a recommended measure of community structure since it is nearly independent of sample size and accounts for species richness and relative abundance within the community. High values generally indicate communities existing in unimpacted waters. The index is defined by Whilm and Dorris (1966, 1968, 1970):

$$H' : -\Sigma p\underline{i} \log p\underline{i}$$

where: $p\underline{i} = n\underline{i}/N$

$n\underline{i}$= number of individuals in species

N = total number of individuals in sample

A Modified Hilsenhoff's Biotic Index (Hilsenhoff, 1988, Merritt and Cummins, 1984, Wisseman, pers. comm.) is used to evaluate species tolerance to pollutants within a community:

$$\text{HBI}: \sum \frac{x\underline{i}t\underline{i}}{n}$$

where: $x_{\underline{i}}$ = number of individuals within a species

$t_{\underline{i}}$ = tolerance value of species

n = total number of organisms

Each species is given a tolerance value from 0-20 with 0 being most sensitive and 20 being most tolerant. Communities with HBIs above 5 are considered significantly impacted whereas those below 3.5 are not usually impacted (Hilsenhoff, 1988).

The EPT index is the number of insect species belonging to the orders Ephemeroptera, Plecoptera, and Trichoptera. These taxa are most sensitive to heavy metal pollutants (Winner et al., 1980, Clements et al., 1988a).

Horn's (1966) Information-Theoretic Index, based on the Shannon diversity index, was used to compare community taxa similarity.

RESULTS

Zinc concentrations at the Smelterville site, in 1968, 1970, and 1971 were 15, 19, and 8 mg/l, respectively (Table 1.3), while only trace amounts (<0.1 mg/l) occurred at the North Fork station. Samples from station 9, on the mainstem were 4.5, 3, and 1.2 mg/l for the same time period. By 1984, after most Bunker Hill operations had ceased (Carillo et al., 1982), zinc readings on the South Fork and mainstem had decreased to 3 mg/l and 0.8 mg/l, respectively. These levels remained similar in 1991 (Table 1.2-1.3). Samples from the North Fork and upper South Fork exhibited trace amounts of zinc (<0.1 mg/l) over the entire period of the study. (Water Resources Data for Idaho, 1968-1971, Mink et al., 1971, Woodward-Clyde Consultants, 1986, Callcott, 1989).

Species richness of macroinvertebrates from the South Fork at Smelterville increased from 0 in 1968 to 6 in 1987 and

15 in 1991. Similar increases were observed on the mainstem. Species numbers remained nearly the same at the reference sites throughout the study period (mean=26), excepting a higher number on the upper South Fork from 1987-1991 (Figure 1.2).

Species diversity (H') for the South Fork invertebrate community at Smelterville from 1968-1971 was less than 0.1. In 1987, H' had increased ten-fold to 1.0 and to 1.5 in 1991. Diversity for the community collected on the mainstem was 0 in 1968, about 1.0 in 1971, and 2.4 in 1991. Communities from both reference sites have maintained H' values near or above 3.0 throughout the study period (Figure 1.2).

Hilsenhoff's Biotic Index for communities from South Fork and mainstem stations have been near 5 or above throughout the study, whereas reference communities had HBIs consistently between 2.5-3.0, except for 1987 when indexes for both sites were considerably higher (Figure 1.2).

The EPT index for communities from the mainstem and South Fork were 0 in 1968 and recovered to 7 and 15, respectively, in 1991. In comparison, reference communities have maintained a high EPT index (mean=19) over the years (Figure 1.2).

The Information-Theoretic Index was calculated for samples from 1991. Community similarity, as defined by like taxa, was 62 percent between the mainstem and South Fork, while the reference communities had 67 percent similar taxa. Test stations were 37 percent similar to reference sites (Figure 1.3).

DISCUSSION

At impacted sites significant decreases in species richness, species diversity, and EPT values, and an increase in Hilsenhoff's Index values were noted (Figure 1.2). The reference stations which had zinc levels below 0.1 mg/l showed no significant change in these parameters during the study.

Many studies have shown the deleterious effects of zinc and other heavy metals on macroinvertebrate communities (Savage and Rabe, 1973, Vandenburg, 1974, Spehar et al., 1978, Armitage, 1980, Winner et al., 1980, Chadwick et al., 1986, Clements et al., 1988a, Clements et al., 1988b, Roline, 1988). Winner et al. (1980) found that metal-sensitive EPT taxa were replaced by the more tolerant Chironomidae downstream from heavy metal effluent discharge. Chadwick et al. (1986), investigated a stream in western Montana similar to this study and observed little recolonization of macroinvertebrates even five years after mine wastewater treatment and subsequent water quality had been dramatically improved.

By 1971, only a few zinc tolerant species had colonized downstream stations (Savage and Rabe, 1973). After tailings ponds were constructed in 1968, Savage noted turbidity and sedimentation problems had decreased dramatically. Further colonization was apparently retarded by other factors, possibly a combination of low pH and extreme metal concentrations.

After closure of the Bunker Hill complex in 1982 (Carillo et al. 1982), and a subsequent decrease of metal loading, insect communities in the South Fork and mainstem showed an appreciable recovery. Species richness had increased from zero to six at the South Fork station with one-third of those species comprising the relatively sensitive Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa. In addition, species diversity also exhibited a ten-fold increase from 1971 to 1987. Mainstem samples showed an even greater recovery to include the presence of 14 species of benthic invertebrates together with relatively high species diversity and EPT values (Figure 1.2).

Even though considerable recovery had taken place by 1991 at South Fork and mainstem stations, species richness and diversity were still much higher at reference sites on the North Fork and upper South Fork (Fig 1.2). Water samples from reference stations exhibited no measurable amount of zinc and pH values were near neutrality. The above conditions are apparently important in explaining the high biological integrity of the communities comprising the control sites.

These reference stations are similar to other unimpacted streams in the North Fork drainage as to species richness, diversity, EPT index values, and HBI values (Hoiland and Rabe, 1991).

Mainstem communities show greater recovery compared to the South Fork as evidenced by higher species richness and diversity values. These differences are no doubt influenced by the relatively clean water entering from the North Fork which merges with the South Fork 1.5 km above the mainstem station.

Winner (1980) showed that communities under heavy metal stress were dominated by chironomids (Order Diptera) and nearly devoid of other insects. In 1968, no insects were found at the South Fork station and only chironomids were present at the main stem site. By 1970, chironomids still made up 97% of the community at the main stem station and nearly 100% at the Smelterville site.

Winner et al. (1980) also suggested that as pollution decreases, more sensitive insects representing Trichoptera, Plecoptera, and Ephemeroptera, in that order, appear. Savage and Rabe (1973) noted, however, that Baetis tricaudatis (Dodds) was the first representative of the more sensitive EPT to appear at either impacted station. Baetis tricaudatis has been shown to be tolerant to various pollutants (Hilsenhoff, 1988, Wisseman, pers. comm.). In 1987, Arctopsyche grandis (order Trichoptera) was also observed at the Smelterville station while representatives of all three EPT groups were noted at the mainstem site.

The modified Hilsenhoff's Index is a measure of community structure based on pollutant tolerance values (Hilsenhoff, 1988, Wisseman, pers. comm.). Initial colonizers of both test stations consisted of zinc-tolerant insects resulting in high HBI values (Fig 1.2). Even though species richness has increased from 1971-1991, organisms tolerant to pollution still comprise a very high percentage of impacted communities.

By 1987, samples from the mainstem showed more diversity with insects from four orders and twelve families. In 1991, however, the zinc-tolerant Chironomidae still made up over two-thirds of the community as in 1987.

By 1987, the South Fork communities were comprised mainly of insects from two families, Baetidae and Simuliidae, but in 1991 were represented by Ephemeroptera, Plecoptera, Trichoptera, Coleoptera, and Diptera. Surprisingly, Baetis, which made up over one-third of the population in 1987, was not observed in 1991 samples.

Stable aquatic communities usually contain complex and diverse trophic relationships. A macroinvertebrate aggregation consists of representatives of all major trophic groups including scrapers, collector-gatherers, collector-filters, shredders, and predators (Cummins, 1973). All above groups except shredders were well represented in the North Fork samples. Shredders, which feed on course particulate organic matter (CPOM), were lacking probably due to the width of the stream (25 m) and the subsequent lack of CPOM. In larger streams, such as the North Fork, riparian has less influence in providing CPOM than in smaller streams (Cummins, 1973).

In comparison, South Fork communities were comprised mainly of collector-filterers and collector-gatherers (Figure 1.4). These functional groups feed on detritus and FPOM which were in abundance in the South Fork and mainstem, but was not as prevalent in the North Fork. Although no algae analysis was done, observations indicated dense growths of filamentous algae. These mats serve as attachment sites for collector-filterers (Plafkin et al., 1989).

Riparian vegetation is sparse along the South Fork. Direct sunlight makes conditions favorable for algae growth on rocks and along shores. Even so, few scrapers were found, suggesting that the water may be too toxic to support this functional group. In addition, few shredders were observed in samples from the South Fork, probably due in part to a small input of allochthonous material.

Although considerable macroinvertebrate recovery has occurred since 1970, community trophic structure of impacted stations is still largely dissimilar to reference sites. Community similarity analysis shows impacted communities to be most similar to each other while reference communities cluster together. Between impacted and reference stations, the mainstem and North Fork communities are most similar, with the South Fork and North Fork communities being least similar (Figure 1.3). The low similarity of taxa between impacted and reference sites indicates that recovery of benthic communities from the South Fork and mainstem has not been complete.

Even though mining in the valley has decreased considerably, ionizable zinc from jig tailings and seepage from tailings ponds will most likely prevent macroinvertebrate communities in the South Fork and mainstem of the Coeur d'Alene River from significant recovery in the near future.

CONCLUSIONS

Massive amounts of mine wastes deposited into the South Fork of the Coeur d'Alene River and its tributaries have had tremendous biotic impacts. Zinc readily leaches from these tailings and is toxic to fish and benthic invertebrates.

Prior to 1968 only one species of macroinvertebrates was observed in the South Fork or mainstem. Only after tailings ponds were erected in late 1968 did invertebrate communities start to recover. As zinc in the South Fork decreased from 21 mg/l to 3 mg/l at Smelterville, there has been a substantial increase in most biotic measurements including species richness, diversity, and number of taxa of sensitive EPT. This recovery has not been complete, however, as evidenced by biotic measurements of impacted sites being significantly lower than those measurements from reference sites. Continued high zinc levels and habitat degradation will most likely keep the macroinvertebrate communities from further colonization.

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Figure 1.1. Map of study area. Impacted sites: 9 and 13. Reference sites: 34 and 28. Major mines denoted by crossed picks.

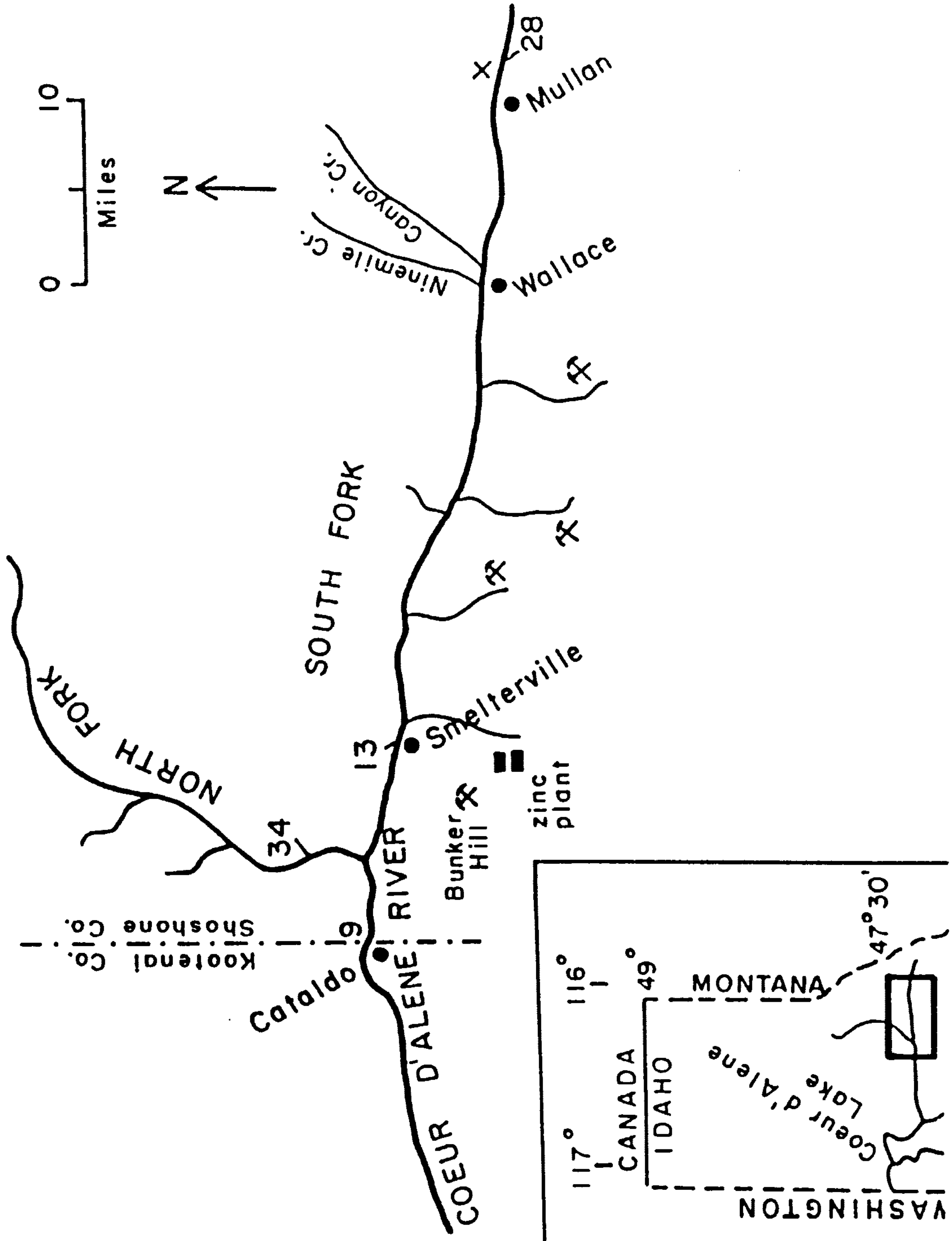
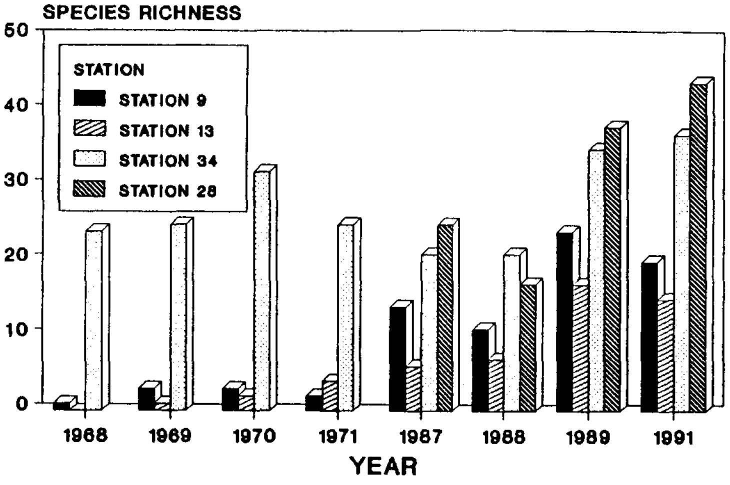
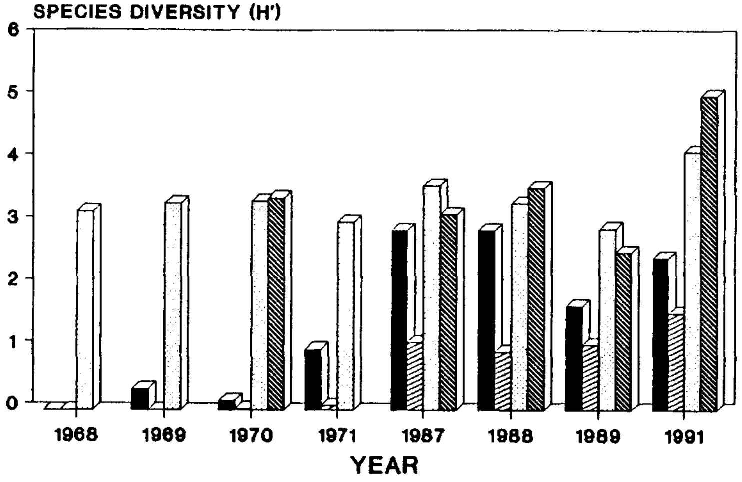

0
10
Miles
N
Mullan
28
Wallace
Canyon Cr.
Ninemile Cr.
SOUTH FORK
NORTH FORK
Smelterville
13
34
9
zinc plant
Bunker Hill
Shoshone Co.
Kootenai Co.
Cataldo
COEUR D'ALENE RIVER
117°
116°
49°
47°30'
MONTANA
CANADA
IDAHO
Coeur d'Alene Lake
VASHINGTON

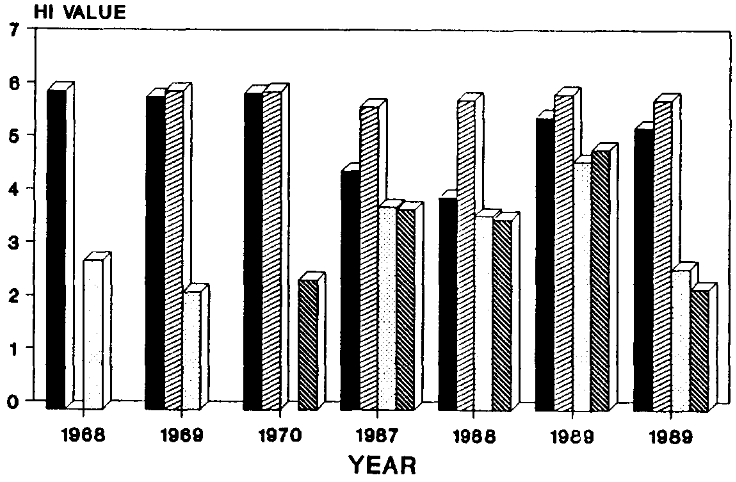
Figure 1.2. a.) Species Richness b.) Species Diversity c.) Hilsenhoff's Index and d.) EPT Index for impacted and reference stations.


SPECIES RICHNESS
50
40
30
20
10
0
STATION
STATION 9
STATION 13
STATION 34
STATION 28
1968
1969
1970
1971
1987
1988
1989
1991
YEAR

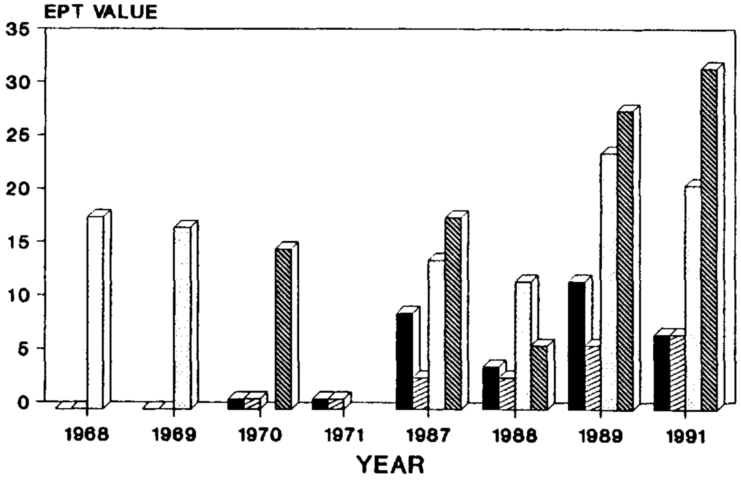
a


SPECIES DIVERSITY (H')
6
5
4
3
2
1
0
1968
1969
1970
1971
1987
1988
1989
1991
YEAR

b


HI VALUE
7
6
5
4
3
2
1
0
1968
1969
1970
1987
1988
1989
1989
YEAR

c


EPT VALUE
35
30
25
20
15
10
5
0
1968
1969
1970
1971
1987
1988
1989
1991
YEAR

d

Figure 1.3. Community similarity between impacted and reference stations.

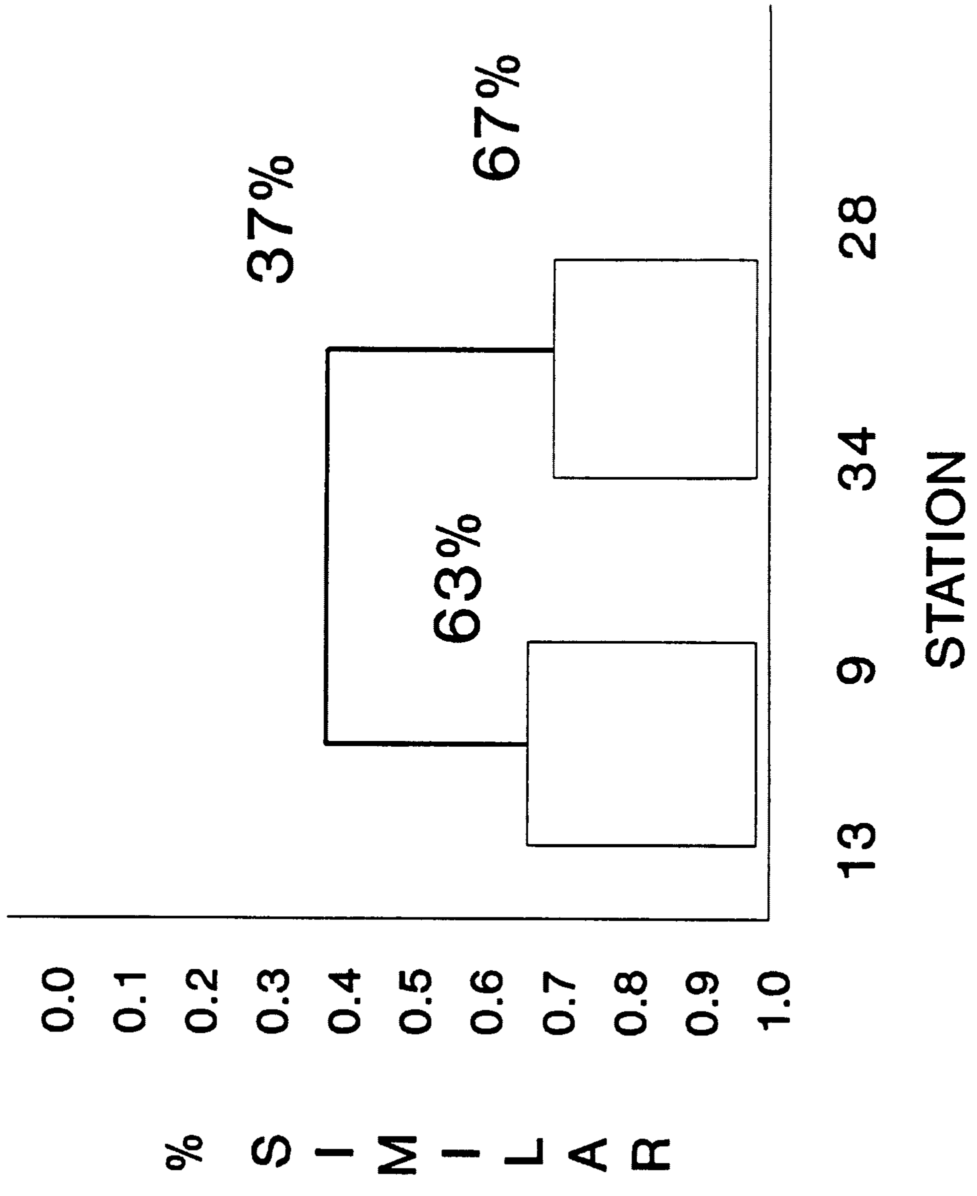
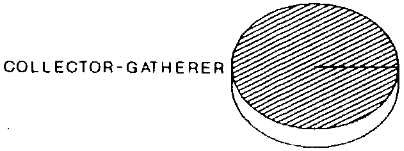
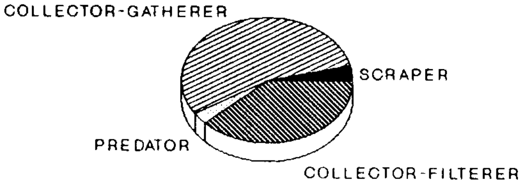

% SIMILAR
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
37%
63%
67%
13
9
34
28
STATION

Figure 1.4. 1968 and 1991 functional group comparison at Smelterville and North Fork stations.

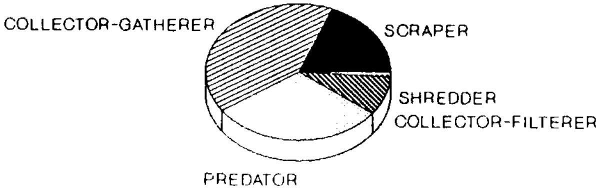
SOUTH FORK



1970



1991



1987

NORTH FORK

Table 1.1 Location of study sites on the North Fork, South Fork and mainstem of the Coeur d'Alene River

Station 9	Mainstem Coeur d'Alene River; 1.5 km downstream from North Fork and South Fork confluence
Station 13	South Fork Coeur d'Alene River at airport bridge near Smelterville
Station 28	South Fork Coeur d'Alene River 1 km above Lucky Friday Mine; 50 m upstream of bridge
Station 34	North Fork Coeur d'Alene River 3 km upstream from confluence with South Fork

Table 1.2. Chemical data from stations in the Coeur d'Alene drainage: 1968-1991.

Date	Station	pH	Alkalinity (mg/l)	Conductivity (umhos)	Zn (mg/l)
1968[1]	North Fork	8.0	21	58	0.0
	Mainstem	7.1	14	180	4.15
	South Fork at Smelterville	7.2	3	420	15.05
1969[1]	North Fork	7.2	28	29	0.10
	Mainstem	6.2	26	113	5.30
	South Fork at Smelterville	6.2	20	220	21.00
1970[2]	North Fork	7.0	-	50	0.10
	Mainstem	6.6	-	185	5.10
	South Fork at Smelterville	6.1	-	525	17.30
	South Fork above Mullan	7.4	-	80	0.10
1989	North Fork	-	24	53	0.02
	Mainstem	-	26	120	0.70
	South Fork at Smelterville	-	38	190	2.00
	South Fork above Mullan	-	40	78	0.03
1991	North Fork	7.4	25	47	0.05
	Mainstem	7.3	27	118	0.54
	South Fork at Smelterville	7.3	34	174	2.13
	South Fork above Mullan	7.4	38	67	0.05

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[1] Mink et al. 1971

[2] Mink, unpublished data

Table 1.3. Mean yearly total zinc concentrations (mg/l) for South Fork and mainstem stations.

	YEAR									
STATION	1968	1970	1971	1972	1975	1979	1982	1984	1988	1991
SOUTH FORK AT SMELTERVILLE	15.0[1]	19.0[1]	7.9[1]	14.8[2]	5.8[2]	5.5[2]	3.7[2]	3.3[2]	3.0[2]	2.1
MAINSTEM	4.5[4]	3.1[2]	1.2[2]	2.7[2]	2.4[2]	3.3[2]	1.1[2]	0.8[2]	0.4[3]	0.5

[1] U.S. Geological Survey (1968-1971)

[2] Woodward-Clyde Consultants (1986)

[3] Callcott (1989)

[4] Mink et al. 1971

Table 1.4. Mean yearly total zinc loading (kg/yr) into the South Fork of the Coeur d'Alene River: 1968-1976. From Harmon (1976).

	YEAR						
	1968	1970	1971	1972	1973	1975	1976
TOTAL ZINC	1,393,800	2,168,500	2,718,000	1,389,814	1,434,500	1,726,500	1,058,417

SECTION 2

EFFECTS OF INCREASING ZINC LEVELS AND HABITAT DEGRADATION ON MACROINVERTEBRATE COMMUNITIES IN THREE NORTH IDAHO STREAMS

INTRODUCTION

Heavy metals are toxic to most aquatic benthic macroinvertebrates and have been shown to decrease community diversity and density (Savage and Rabe, 1973, Vandenburg, 1974, Spehar et al., 1978, Armitage, 1980, Winner et al., 1980, LaPoint et al., 1984, Chadwick et al., 1986, Clements et al., 1988, Roline, 1988). Winner et al. (1980) showed that sensitive species comprising the orders Ephemeroptera, Plecoptera, and Trichoptera are replaced by the more tolerant Chironomidae as heavy metal pollution increases. Chadwick et al. (1986) found that macroinvertebrate communities had not completely recolonized metal impacted streams even five years after mine wastewater treatment had improved.

The South Fork of the Coeur d'Alene River in northern Idaho served as a deposit site for mine tailings since lode mining was introduced in 1885. Until 1968, when holding ponds were constructed, mine wastes were released directly into the South Fork and adjacent tributaries (Mink et al., 1971). These tailings deposits contain various amounts of antimony, cadmium, copper, lead, and especially zinc, resulting in the reduction of stream community structure and function (Savage and Rabe, 1973, Hornig et al., 1988, Hoiland, 1992).

Wai et al. (1985) lists the numerous studies performed within the Coeur d'Alene drainage dealing with mining waste impacts. Few studies have been performed on South Fork tributaries, however. In addition, no studies using rapid bioassessment methodology, as outlined by Plafkin et al. (1989), have been conducted in the Northern Rockies ecoregion relating to effects of heavy metal pollution on macroinvertebrate communities.

The objective of this study was to correlate habitat assessment scores and zinc concentrations with biotic metrics used to measure the structure and function of macroinvertebrate communities inhabiting the main channel and tributaries of the South Fork of the Coeur d'Alene River.

AREA DESCRIPTION

The South Fork is a fourth- to fifth- order stream, approximately 48 kilometers in length, with its source in the Bitteroot Mountains. Near Enaville, Idaho, the South Fork converges with the North Fork to form the mainstem of the Coeur d'Alene River which flows approximately 75 km through a broad valley to its mouth at Lake Coeur d'Alene (Figure 2.1).

The four major tributaries, Canyon Creek, Ninemile Creek, Pine Creek, and Big Creek, as well as the South Fork, all drain narrow valleys with extensive lode mining operations. Due to channelization, the South Fork consists mostly of riffle and run habitat.

Downstream from Mullan, the floodplain is composed mainly of mine tailings deposited since 1885 (Mink et al., 1971). These waste deposits originated from various silver, lead and zinc mines located in the Coeur d'Alene mining district. Little riparian vegetation exists along the river downstream from Wallace to its mouth. The reference site on the South Fork upstream from Mullan is characterized by streamside cover consisting of a dense canopy of western red cedar (_Thuja plicata_ Donn.), western hemlock [_Tsuga heterophylla_ (Raf.) Sarg.], willow (_Salix_ sp.), and various herbaceous plants.

Canyon Creek and Ninemile Creek drain narrow, high-gradient, canyons where extensive underground exploration and mining has occurred. Upstream mines were the primary source of heavy metals in the Canyon Creek drainage. The Day Mine and various other smaller upstream sites have contributed to the tailings which line nearly the length of Ninemile Creek. The geology of both basins is similar, with rocks mainly of the Precambrian Belt Series (Hobbs et al., 1965).

METHODS

Ten stations were sampled, including two reference sites, one upstream from Mullan for comparison with South Fork stations, and one on Canyon Creek upstream from Burke to serve as a reference for impacted sites on Ninemile and Canyon Creek.

Stations on the South Fork were located upstream and downstream from the confluence of Canyon and Ninemile Creeks.

Three evenly spaced stations were sampled along both Ninemile and Canyon Creeks (Figure 2.1).

Selected chemical tests and macroinvertebrate samplings were performed in March and September 1991 with streams at seasonal low flow. Water chemical parameters analyzed were alkalinity, conductivity, pH, temperature, and zinc concentration.

Alkalinity was performed by titrating 100 ml samples with 0.02 N sulfuric acid, using methyl orange as an indicator. Conductivity was taken instream using a YSI Model 33 conductivity meter. For heavy metals analysis, samples were collected in polyethylene bottles, kept cool, and within two days measured by inductively-coupled plasma (ICP) spectophotometry at the University of Idaho Veterinary Science Laboratory. The pH was determined in the lab using a Fisher Accumet Model 815 MP electronic pH meter. Water temperatures were obtained as each station was sampled throughout the day.

Benthic macroinvertebrate samples were collected using a Hess sampler. Samples consisting of three to six replicates for each station were preserved in 85% ethanol in the field, transported to the laboratory, sorted, counted, and identified to the lowest possible taxon using various keys (Baumann et al., 1977, Wiggins, 1977, Merritt and Cummins, 1984).

Biotic analysis

Benthic communities were analyzed by the use of metrics outlined by Plafkin et al. (1989) to include, modified

Hilsenhoff's Biotic Index (HBI) (Hilsenhoff, 1988, Merritt and Cummins, 1984, Wisseman, pers. comm.), species richness, Ephemeroptera-Plecoptera-Trichoptera (EPT) index, EPT/Chironomidae abundance, and percent dominant taxon. In addition, species diversity was calculated using the Shannon-Weiner diversity index (Shannon, 1948).

The Shannon-Weiner diversity index is a recommended measure of community structure since it is nearly independent of sample size and accounts for species richness and relative abundance within the community. High values generally indicate communities existing in unimpacted waters. The index is defined by Whilm and Dorris (1966, 1968, 1970):

$$H': -\Sigma p_i \log p_i$$

where: $p_i = n_i/N$

n_i = number of individuals in species

N = total number of individuals in sample

A Modified Hilsenhoff's Biotic Index (Hilsenhoff, 1988, Merritt and Cummins, 1984, Wisseman, pers. comm.) is used to evaluate species tolerance to pollutants within a community:

$$HBI: \sum \frac{x_i t_i}{n}$$

where: x_i = number of individuals within a species

t_i = tolerance value of species

n = total number of organisms

Each species is given a tolerance value from 0-20 with 0 being most sensitive and 20 being most tolerant. Communities with HBIs above 5 are considered significantly impacted, whereas those below 3.5 are not usually affected (Hilsenhoff, 1988).

The EPT index is the number of insect species belonging to the orders Ephemeroptera, Plecoptera, and Trichoptera. These taxa are most sensitive to heavy metal pollutants (Winner et al., 1980, Clements et al., 1988).

At each station a habitat assessment was performed using selected protocols set forth by Plafkin et al., (1989), to include channel alteration, pool/riffle ratio, bank stability, streamside cover, bottom substrate, and embeddedness.

RESULTS

Habitat assessment ratings for reference stations were close to a perfect score of 50 (Table 2.1). Severe habitat degradation was characteristic of all impacted sites. A score of 15 was recorded upstream of Wallace on the South Fork and at the mid-reach of Canyon Creek. A 0 score was given for the upper reach of Ninemile Creek. Channelization and lack of streamside cover were the most significant factors contributing to these low values.

Bottom substrate and embeddedness scores were nearly identical at all sites, so subsequently were not used in the final analysis.

Width, velocity, conductivity, and zinc concentrations were generally higher at downstream sites. Zinc concentrations in Canyon Creek were highest at the downstream stations (1.5, 3.0 mg/l) as compared to upstream sites (0.0, 0.2 mg/l). Zinc levels in Ninemile Creek, however, did not follow this pattern (4.5-5.2 mg/l). Zinc concentrations recorded form the main South Fork were ten times higher downstream (0.9 mg/l) from the confluence of Canyon and Ninemile Creeks than upstream (0.07 mg/l), even though little difference in biotic metrics was observed between the upstream and downstream sites (Table 2.2-2.3).

At all impacted sites, bioassessment scores were lower than reference values. Mean bioassessment scores of invertebrate communities in Canyon and Ninemile Creeks generally decreased as zinc increased. In Canyon Creek, all six metrics scored lower downstream, as compared to upstream (Table 2.4-2.5).

Individual biological metrics provided a strong regression against habitat assessment scores (r^2=.39 -.75). The EPT index (r^2=.60-.75) and species richness (r^2=.54-.65) provided the highest correlation coefficients. Percent dominant taxon (r^2=.35-.43) and the ratio of EPT to Chironomidae abundance showed the lowest regression coefficients (r^2=.39-.44) (Table 2.6).

Zinc exhibited moderate correlations with species richness (r^2=.40), EPT (r^2=.41), percent dominant taxon (r^2=.52), species diversity (r^2=.56), and modified Hilsenhoff's index (r^2=.58). The ratio of EPT/Chironomidae abundance provided the lowest regression coefficient with zinc (r^2=.23).

Biotic metrics and pH showed a poor correlation (r^2=.08-.21) while conductivity was weakly correlated with biotic metric scores (r^2=.18-.41) (Table 2.6).

DISCUSSION

Degradation of community structure was expected at the impacted site below the confluence of Canyon Creek and Ninemile Creek due to a ten-fold increase in zinc concentrations. However, little difference was observed in most biotic measurements. This can possibly be explained by the fact that macroinvertebrate communities upstream from the confluence of Canyon and Ninemile Creeks were already severely impacted. Zinc did not appear to be a factor at this site, since zinc levels were below 1.0 mg/l, but instead, loss of habitat due mainly to highway construction was thought to be more important.

Most species of the sensitive EPT orders observed at reference sites were absent from communities impacted from zinc. Some exceptions were the tolerant (tolerance value 6) ephemeroptern Baetis tricaudatis and the sensitive (tolerance value 0) plecoptern Sweltsa complex. At moderately impacted sites, these were many times the dominant taxa. Overall, however, as zinc concentrations increased, the benthic community consisted of more tolerant chironomids and fewer sensitive EPT. This trend is reflected in the increasing values of Hilsenhoff's index as zinc increased.

During the fall, chironomids comprised less than 10% of the community at reference sites; however, as zinc increased downstream, chironomid dominance also increased. Midge larvae comprised about half of the community at both South Fork impacted stations with the dominant taxon being Orthocladius sp. at the upper station and Rheocrictopus sp. at the lower site. Both taxa have been shown to be tolerant of metal pollution (Wisseman pers. comm.).

A similar pattern was noted on Canyon Creek and on Ninemile Creek except that as zinc levels increased above 2.0 mg/l, Eukiefferiella sp. became the dominant taxon. Spring data samples did not follow this trend; however, zinc-tolerant chironomids were still more abundant at impacted sites than at reference stations.

Hughes (1985) defined ecological integrity as the conditions found in relatively unimpacted streams typical for the ecoregion. Natural vegetation exists with no channel modifications and no point or non-point pollution sources. Our reference sites fit this description, with abundant riparian, no sources of pollution, or channelization. Impacted sites, in comparison, showed little ecological integrity.

Narrow canyons, along with massive amounts of tailings, have contributed to channelization, which has decreased natural sinuosity, increased velocity, and eliminated pools, therefore resulting in a continuous riffle. In channelized streams, macroinvertebrate densities have been shown to decrease by 67% (Moyle 1976). Additional habitat loss and high zinc levels made it difficult to assess the effect of channelization on macroinvertebrate densities.

The loss of riparian vegetation results in more exposure to light, less stable banks, and reduced allochthonous input into the stream. In this study, however, the effects of bank vegetation loss on invertebrates are clouded by high zinc concentrations. The loss of scraper and shredder functional groups were noted but it was difficult to ascertain if this loss was due to habitat degradation or zinc toxicity.

Loss of riparian has also resulted in reduced shoreline stability. Small (<20 mm), highly erodible mine wastes, comprising a large portion of the streambed, are picked up and redeposited even at moderate flow (Ioannou 1979). This continual perturbation makes it difficult for macroinvertebrates to recolonize such unstable sites.

CONCLUSIONS

Historic mine tailings comprise a large portion of the floodplains of Canyon and Ninemile Creeks, as well as the South Fork. Surface water has been contaminated by the leaching of zinc from these wastes. As zinc concentrations increase, there has been a resultant loss in the structure and function of macroinvertebrate communities. It is difficult to determine whether the loss in biological integrity is due to habitat degradation, chemical toxicity, or both. In the Coeur d'Alene mining district, streams that have been impacted by metals also exhibit physical habitat degradation since mine wastes, which are the source of zinc, have also contributed to habitat degradation. Few cases, if any, exist where one or the other situation prevails, but rather, past mining activities have simultaneously created the two situations.

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Figure 2.1. Map of study area. Station 1: reference for sites 2 and 3. Station 4: reference for sites 5,6,7,8,9, and 10.

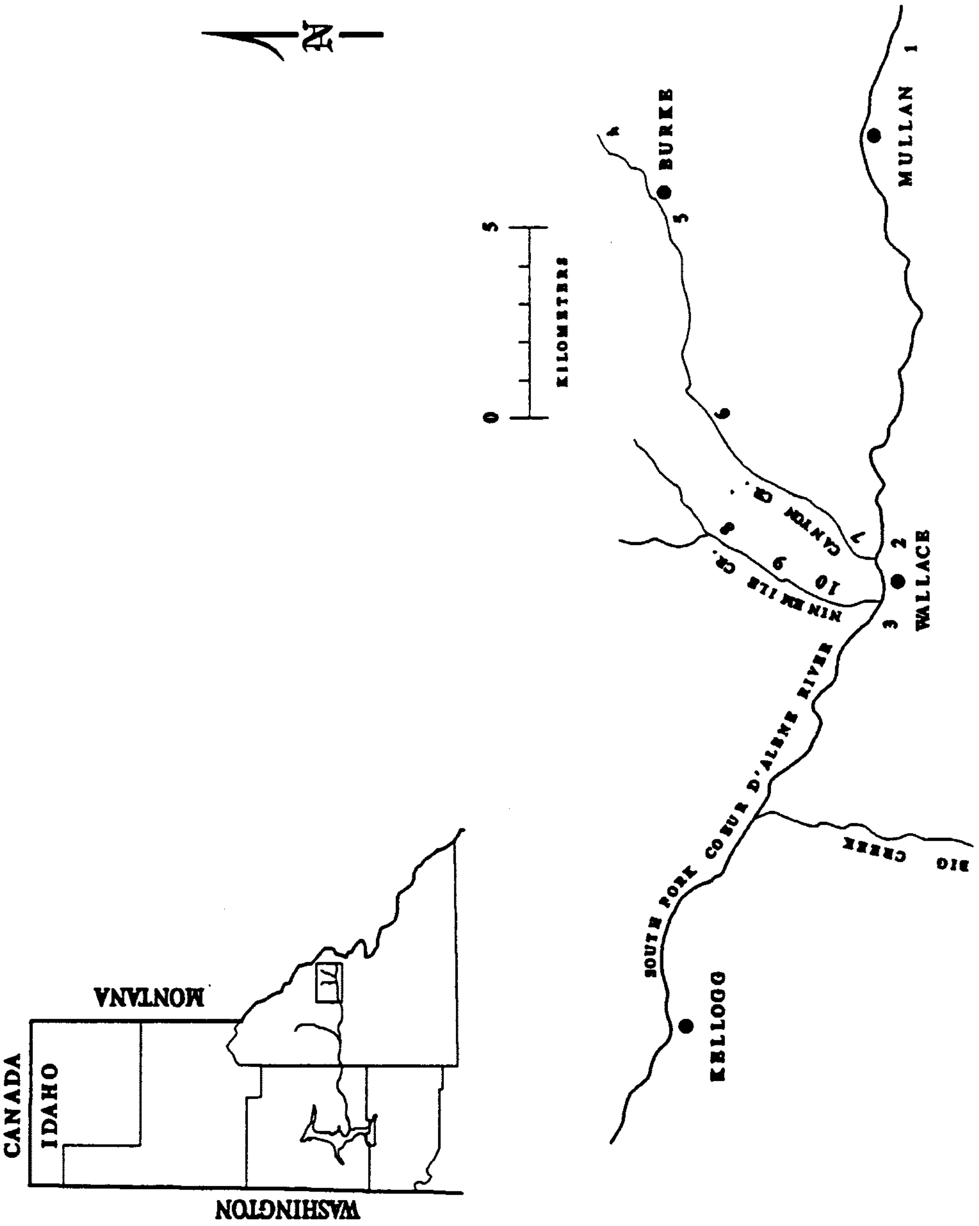
N
0
5
KILOMETERS
MULLAN
1
BURKE
4
5
6
CANYON CR.
7
WALLACE
2
3
8
9
10
NINEMILE CR.
SOUTH FORK COEUR D'ALENE RIVER
BIG CREEK
KELLOGG
CANADA
IDAHO
MONTANA
WASHINGTON

Table 2.1. Mean habitat assessment scores for test $^{\#}$ and reference stations * in South Fork Coeur d'Alene Drainage. March 1991. Maximum possible points for each metric in parentheses.

HABITAT PARAMETER	South Fork		Canyon Creek		Ninemile Creek
CHANNEL ALTERATION (15)	14^{*}	$2^{\#}$	14^{*}	$3^{\#}$	$1^{\#}$
POOL/RIFFLE RATIO (15)	15	3	15	4	2
BANK STABILITY (10)	10	8	10	2	1
STREAMSIDE COVER (10)	10	1	9	0	1
TOTALS (50)	49	14	48	9	5

Table 2.2. Selected physical characteristics and water chemistries of stations on South Fork Coeur d'Alene River, Canyon Creek, and Ninemile Creek. March 1991.

STATION

SITE	SOUTH FORK			CANYON CREEK				NINEMILE CREEK		
	1	2	3	4	5	6	7	8	9	10
CHARACTERISTIC										
LENGTH (m)	30	30	30	20	25	30	30	30	30	30
WIDTH (m)	7	17	21	8	8	7	8.5	5	5	7
DEPTH (cm)	21	45	32	15	22	24	27	16	21	21
VELOCITY (cm/s)	42	54	31	35	64	82	71	38	45	43
CONDUCTIVITY (μmohs)	34	80	79	40	46	52	62	55	95	80
ALKALINITY (mg/l)	29	34	46	28	32	36	34	46	45	49
TEMPERATURE (°C)	4	6	6	4	5.5	6	6	10	8	5
pH	7.4	8.2	7.8	7.6	7.0	7.8	7.8	7.1	7.6	7.6
ZINC (mg/l)	0.01	0.18	1.18	0.02	0.32	1.58	3.8	5.29	2.39	2.6

Station 1 - Reference for South Fork stations

Station 2 - South Fork upstream of confluence of Canyon and Ninemile Creeks

Station 3 - South Fork downstream of confluence of Canyon and Ninemile Creeks

Station 4 - Reference for Canyon and Ninemile Creeks impacted sites

Station 5 - Canyon Creek 100 m downstream of Star mine

Station 6 - Canyon Creek 5 km upstream of Wallace

Station 7 - Canyon Creek 100 m upstream of mouth

Station 8 - Ninemile Creek 100 m upstream of Day Mine

Station 9 - Ninemile Creek 5 km upstream of Wallace

Station 10 - Ninemile Creek 2 km upstream of Wallace

Table 2.3. Selected physical characteristics and water chemistries of stations on South Fork Coeur d'Alene River, Canyon Creek, and Ninemile Creek. September 1991.

STATION

CHARACTERISTICS	SOUTH FORK				CANYON CREEK			NINEMILE CREEK		
	1	2	3	4	5	6	7	8	9	10
LENGTH (m)	30	30	30	30	30	25	30	30	30	30
WIDTH (m)	4	13	22	5	5.5	9	8	4.5	5	4
DEPTH (cm)	20	31	32	20	29	19	25	13	16	12
VELOCITY (cm/s)	63	100	71	33	53	74	107	70	80	82
CONDUCTIVITY (μmohs)	75	125	115	15	59	73	89	105	90	100
ALKALINITY (mg/l)	11	13	20	3	12	16	20	14	16	18
TEMPERATURE (°C)	10	13	13	7	10	12	10	10	9	8
pH	7.4	8.4	8.0	7.1	7.7	7.8	7.6	7.6	7.3	7.6
ZINC (mg/l)	0.05	0.07	0.88	0.0	0.21	1.49	3.05	5.17	4.53	5.1

Table 2.4. Mean zinc concentrations and biotic metric scores at stations on South Fork Coeur d'Alene River, Canyon Creek, and Ninemile Creek. March 1991.

	South Fork			Canyon Creek				Ninemile Creek		
STATION	1	2	3	4	5	6	7	8	9	10
ZINC	0.01	0.18	1.18	0.02	0.32	1.58	3.8	5.29	2.39	2.61
SPECIES DIVERSITY	3.73	3.11	3.1	3.63	2.85	2.35	1.54	2.05	2.91	2.22
SPECIES RICHNESS	22.8	19	14	21	12	10	5	6	11	9
EPT	16	12	7	17	9	5	2	2	9	5
MOD HILSENHOFF INDEX	3.14	3.75	4.21	1.81	2.52	2.28	4.25	3.9	4.43	6.07
EPT/ CHIRONOMIDAE	2.0	1.0	1.4	9.41	8.83	4.5	0.8	1.8	1.1	0.5
% DOMINANT TAXON	23.9	28.1	30.5	22.3	35.1	50.6	65.6	44.8	30.9	54.2

Table 2.5. Mean biotic metric scores and zinc concentrations at stations on South Fork Coeur d'Alene River, Canyon Creek, and Ninemile Creek. September 1991.

	South Fork			Canyon Creek				Ninemile Creek		
STATION	1	2	3	4	5	6	7	8	9	10
ZINC	0.05	0.07	0.88	0.0	0.21	1.49	3.05	5.17	4.53	5.06
SPECIES DIVERSITY	4.17	2.81	2.79	3.99	2.95	2.35	1.4	1.32	1.25	2.13
SPECIES RICHNESS	25	17	13	24	15	10	8	18	81	13
EPT	17	10	7	20	9	2	3	8	5	6
MOD HILSENHOFF INDEX	2.23	3.98	4.63	1.64	3.21	4.21	6.97	5.11	6.09	6.07
EPT/ CHIRONOMIDAE	5.3	2.16	1.63	8.84	4.26	1.57	0.26	1.56	0.48	0.4
% DOMINANT TAXON	18.9	43.6	35.9	17.6	27.1	31	75.1	54.8	73.3	58.8

Table 2.6. Correlations (r^2 values) between biotic metrics and habitat assessment and water chemistries. Values significant at the P<.001 level.

	H'	SR	EPT	HI	EPT/CHIR	DOM. TAXON
CHANNEL ALTERATION	.62	.63	.74	.58	.44	.43
POOL\RIFFLE	.59	.61	.75	.57	.43	.39
BANK STABILITY	.58	.54	.60	.39	.26	.38
STREAMSIDE COVER	.58	.65	.74	.48	.39	.35
CONDUCTIVITY (μmhos)	.24	.18	.33	.41	.30	.22
ZINC (mg/l)	.56	.40	.41	.58	.23	.52
pH	.10	.08	.16	.14	.21	.08