Ecological Effects of Lead Mining in Streams of the Missouri Ozarks

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ABSTRACT

The Viburnum Trend extends through the Black River drainage of southeast Missouri and is one of the largest producers of lead ore in the world. Mining interests seek to expand lead exploration in the adjacent Mark Twain National Forest and the Ozark National Scenic Riverways areas of southeastern Missouri. We studied the structure of fish and invertebrate communities at 12 sites in or near the Black River watershed to determine if existing lead mining activities were affecting aquatic biological communities. Stream surveys were conducted at four reference sites with no known upstream mining activities; eight sites downstream of known mining areas were also sampled. Surface and porewater samples collected in riffle habitats (i.e., coarse substrate) were analyzed for metals, major cations, dissolved organic carbon, sulfate, and ammonia. Physical stream habitat was characterized using microhabitat-level variables (i.e., velocity, depth, substrate composition) as well as landscape-level variables (i.e., watershed area, land use, and channel morphology). Surface and porewater concentrations of lead and zinc were below chronic water quality criteria (5 and 212 µg/L, respectively) at all sites. However, sculpins, crayfish, and snails were absent from several sites immediately below active mines. Fish densities were also lower at some sites downstream of mines. These results support the findings of previous biomarker and toxicity studies indicating that mining is affecting biota in the Black River drainage near the Viburnum Trend.

INTRODUCTION

- Recent proposals to expand areas of prospecting for deposits of lead ore in the Mark Twain National Forest (MTNF) of southeast Missouri raised concerns about potential surface and ground-water quality degradation due to lead mining. In response to concerns about potential impacts in federal lands (MTNF and the Ozark National Scenic Riverways), the USGS is evaluating the effects of current and proposed mining activities on surface and ground waters in the Missouri Ozarks.
- These investigations have found elevated concentrations of lead and other elemental contaminants associated with lead mining. Biochemical effects indicate exposure of fish to environmental lead from sites closest to mines and tailings (Whyte et al. 2002; Allert et al. 2003; and Besser et al. 2003).

STUDY AREA

- We selected 12 sites (Figure 1 and Table 1) to characterize the influence of mining activities on metal concentrations and other constituents in surface and pore water, as well as aquatic organisms (fish, benthic invertebrates, crayfish and snails).
- Four sites are designated as 'reference' sites. These sites were either upstream of mining activity (Site MT3) or in watersheds without mining activity (Sites MT8, MT11, MT12).
- Eight sites were designated as 'impact' sites. These sites were located downstream of known mining areas.

OBJECTIVES

- Characterize water quality of surface water and pore water; metal concentrations in surface (Cd, Pb, Zn) and pore water (Cd, Pb, Zn, Ni, Co); and habitat characteristics relative to mining activities.
- Characterize fish and invertebrate communities relative to mining activities and impacts.
- Evaluate relationships between fish and invertebrate communities and water quality, metal concentrations, and habitat variables.

METHODS

Figure 1. Location of sites and mines of the New Lead Belt (Viburnum Trend) in southeast Missouri. Green = Reference. Red = mine impacted. Blue = recovery.

Table 1. Study site locations.

Site No.	Site Description
MT1	West Fork Black River at Sutton Bluff
MT2	West Fork Black River at West Fork
MT3	West Fork Black River at Greeley
MT4	Bee Fork Creek
MT5	Logan Creek
MT6	Sweetwater Creek
MT7	Middle Fork Black River
MT8	Sinking Creek
MT9	Strother Creek
MT10	Courtois Creek
MT11	Blair Creek
MT12	Huzzah Creek

Reference
Mine impacted
Recovery

BIOLOGICAL ASSESSMENT

- Sampling occurred during September 2003.
- Fish samples were collected using three techniques: electrofishing, kick seining (4.5-m^2, 6-mm mesh seine) in riffle habitats, and sweep seining (6-mm mesh, various lengths) through the entire site.
- Grab samples of surface water were collected and analyzed for temperature, pH, conductivity, dissolved oxygen, alkalinity, hardness, ammonia, chl-a, dissolved organic carbon, particulate organic carbon, and sulfate.
- Pore water was collected using peepers and analyzed for temperature, pH, conductivity, dissolved oxygen, alkalinity, hardness, ammonia, dissolved organic carbon, and sulfate.
- Micro-habitat measurements included current velocity, depth, particle size of substrate (at location of benthic invertebrate sampling), canopy, embeddedness, and bank stability. Macro-habitat variables included substrate particle size in glides and channel morphology. GIS data included area of watershed and area of mine tailings within watersheds.
- Three replicate invertebrate samples were collected using a 0.1-m^2 Hess sampler with a 0.3-mm mesh collection bag in coarse substrate (riffle habitat).

STATISTICAL ANALYSIS

- Principal component, correlation and stepwise regression analyses were conducted on the untransformed data (SAS 2000).

METAL ANALYSIS

- Metals in filtered (0.45 µm) surface and pore water were analyzed using ICP-mass spectroscopy (May et al. 1997). Surface water was analyzed for Cd, Pb, and Zn. Pore water was analyzed for Cd, Pb, Zn, Ni, and Co. Samples were acidified to 1% v/v with ultra-pure nitric acid and analyzed without digestion.

RESULTS AND DISCUSSION

WATER QUALITY

Table 2. Quality of selected surface and porewater variables. nd = not detected

Site No.	Temp (°C)	Field pH	Cond (µS/cm)	Hard (mg/L as $CaCO_3$)	Sulfate (mg/L)
Surface water					
MT1	18.8	8.13	386	192	35
MT2	20.1	8.13	414	205	40
MT3	17.8	8.41	344	187	1.0
MT4	17.7	7.95	463	193	79
MT5	18.4	7.88	576	197	93
MT6	17.7	8.01	214	101	24
MT7	21.3	7.72	451	206	89
MT8	21.4	7.42	223	113	0.33
MT9	19.3	7.97	854	422	nd
MT10	18.7	8.11	447	231	48
MT11	17.5	8.14	307	166	nd
MT12	19.8	8.12	455	216	44
Pore water					
MT1	18.5	7.96	378	185	30
MT2	20.9	7.90	412	203	44
MT3	17.3	8.38	340	183	0.57
MT4	17.1	7.94	445	177	75
MT5	19.9	7.73	556	181	85
MT6	18.3	7.79	201	97	11
MT7	22.9	7.65	453	212	91
MT8	21.8	7.40	222	104	0.17
MT9	17.6	7.92	840	403	nd
MT10	19.5	8.03	457	240	52
MT11	17.5	8.04	304	168	nd
MT12	18.3	8.14	445	212	41

Reference
Mine impacted
Recovery

Deploying porewater samplers (peepers) in riffle habitat.

FISH COMMUNITY STRUCTURE

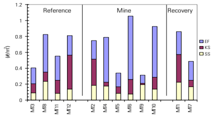

Figure 2. Density of fish for each sampling method, by site. EF = electrofishing, KS = kick seining, SS = sweep seining.

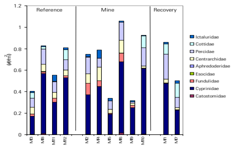

Figure 3. Density (#/m²) of fish collected, by site (all methods).

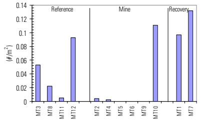

Figure 4. Density (#/m²) of sculpins collected, by site.

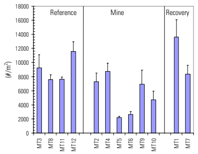

Figure 5. Density (#/m²) of invertebrates collected with Hess sampler, by site.

METAL CONCENTRATIONS IN WATER

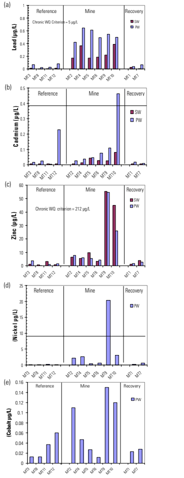

Figure 6. Metal concentrations in surface and pore waters, (a) lead; (b) cadmium; (c) zinc, (d) nickel, and (e) cobalt. Chronic water quality criteria (WQC) is adjusted for hardness and the dissolved conversion factor (USEPA 2002). WQC are listed on graph or marked by horizontal line. SW = Surface water, PW = Pore water.

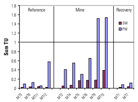

Figure 7. Toxic Units (TU) for surface and porewater metals, based on chronic water quality criteria (WQC) (USEPA 2002). TU = metal concentration / WQC.

- Water quality of surface and pore waters from sites downstream of mine tailings were generally elevated in conductivity, hardness, and sulfate (Table 2).
- Density of fish collected by each sampling method was similar across sites (Figure 2). Density of fish was generally lower at sites most affected by mining (MT2, MT5, MT9).
- The distributions of fish families were generally similar across sites (Figure 3). Cyprinidae was the most common fish family collected by all methods.
- The distribution and abundance of sculpins may be impacted by mining (Figure 4). Sites downstream of mining (except for MT10) had few or no sculpins.
- Density of invertebrates (Figure 5) was generally lower at mine sites.
- Metal concentrations (Figure 6) in pore water were greater than surface water.
- Cumulative metal toxic units differed between surface and pore waters (Figure 7). Toxic units exceeded 1.0 only in pore waters, and only at sites (MT9, MT10) downstream of mining.
- Toxic units were dominated by the influence of cadmium and zinc in surface waters, and by the influence of nickel, cadmium, and zinc in pore waters.
- Sites were discriminated using Principal Component Analysis (Figure 8). Mine impacted sites were discriminated primarily by water quality (hard, cond, Ni in PW), habitat (canopy; substrate >38 mm) and density of Ozark sculpins.
- Correlation analysis showed that fish species richness was related to only habitat variables (Table 3), however density of fish and invertebrates were correlated with both habitat variables and water quality. Density of sculpins was only correlated with habitat variables.
- Stepwise regression of fish species richness, and densities of sculpins and invertebrates suggested that habitat variables greatly affect fish and invertebrate communities (Table 4).

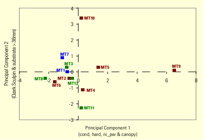

Figure 8. Principal Component Analysis.

Table 3. Correlation (r values) of fish, water quality, habitat and GIS variables. EF = electrofishing; SS = sweep seine. TU = toxic units.

Parameter	Fish Species Richness
SS species richness	0.735
Distribution of particles in glides	0.634
Parameter	**Fish Density (#/m²)**
EF density (#/m²)	0.691
EF Species Richness	0.807
Hard (mg/L as $CaCO_3$)	-0.648
Cond (µS/cm)	-0.605
Ave width (m) of riffle	0.583
Ave width (m) of site	0.572
Ave riffle canopy	-0.643
Parameter	**Sculpin Density**
Substrate >38 mm	-0.583
Substrate 38 < x < 19 mm	0.749
Ave Depth (cm) at Riffle	0.609
Parameter	**Invertebrate Density (#/m²)**
Pb (µg/L) in PW	-0.650
Area of Tailings (m²)	-0.643
Ave width (m) of Reach	0.574
Ave 50 percentile of substrate in glides	-0.587
Ave 84 percentile of substrate in glides	-0.578
Distribution of substrate in glides	0.677
Skewness of substrate in glides	0.611

significant negative correlation ($p < 0.05$)
significant positive correlation ($p < 0.05$)

Table 4. Stepwise regression (ascending cumulative R^2) of fish, water quality, habitat, and GIS variables.

Fish Species Richness	Parameter Estimate	p	R^2
Bank Stability	40.3	0.0001	0.66
Riffle canopy	-30.9	0.0007	0.84
Reach canopy	27.1	0.0090	0.92
Distribution of particles in glides	17.5	0.0008	0.96
Embeddedness in glides	0.083	0.0296	0.99
Sculpin Density (#/m²)			
Substrate 38 < x < 19 mm	0.030	< 0.0001	0.74
Substrate <0.02 mm	-0.716	0.0002	0.81
Area of Watershed (m²)	-0.074	0.0032	0.91
Ave Depth (cm) at Site	1.07	0.0007	0.98
Embeddedness in glides	0.710	0.0006	0.99
Invertebrate Density (#/m²)			
Bank Stability	-942	0.0066	0.46
Substrate 38 < x < 19 mm	-0.283	0.1915	0.73
Substrate 9 < x < 2 mm	-1.220	0.0970	0.87
Area of Watershed (m²)	2.01	0.0026	0.92
Distribution of particles in glides	1156	0.0003	0.94

highly significant negative correlation ($p < 0.001$)
significant negative correlation ($p < 0.05$)
significant positive correlation ($p < 0.05$)
highly significant positive correlation ($p < 0.001$)

Huzzah Creek

CONCLUSIONS

- Metal concentrations, conductivity, and hardness from stream sites near mining activities were increased relative to reference sites. Surface and pore water trends were similar, although there were higher concentrations of metals in pore water.
- Conductivity and hardness may be good surrogate measures for the impacts of mining in Ozark streams.
- Fish communities were affected at sites downstream of mining sites. Sculpins were absent from several sites impacted by mining, which may reflect their sensitivity to metals (Besser et al. 2004). *SETAC 2004 Poster Number PH093*
- Benthic invertebrate data showed similar trends as fish densities, with reduced density of invertebrates at several sites downstream of mining.
- Physical habitat variables were significantly correlated with fish and invertebrate community indices, therefore, habitat variables, such as depth, velocity, bank stability and embeddedness must be considered when assessing the impact on fish communities from mining.

REFERENCES

Allert, A.L., Besser, J.M., Fairchild, J.F., Kunz, J.L., Schmitt, C.J., Ingersoll, C.G., and May, T.W. 2003. Toxicity of sediment and pore water from stream and reservoir sites downstream of lead mining areas. Poster presented at the 24th Annual Meeting of SETAC, November 2003, Austin, TX.

Besser, J.M., Brumbaugh, W.G., Brunson, E.L, Allert, A.L., and Schmitt, C.J. 2003. Metal bioavailability in stream and reservoir sediments downstream of lead-mining areas. Poster presented at the 24th Annual Meeting of SETAC, November 2003, Austin, TX.

Besser, J.M., Ivey, C.D., Kunz, J.L., Greer, I.E., Ingersoll, C.G., Mount, D.R., and Stephan, C.E. 2004. Acute and chronic toxicity of cadmium, copper, and zinc to mottled sculpin and rainbow trout. Poster presented at the 25th Annual Meeting of SETAC, November 2004, Portland, OR. *SETAC 2004 Poster Number PH093.*

May, T.W., Wiedmeyer, R.H., Brumbaugh, W.G., and Schmitt, C.J. 1997. The determination of metals in sediment pore waters and in 1N HCl-extracted sediments by ICP-MS. Atomic Spectroscopy 18:133-139.

Statistical Analysis System Institute (SAS). 2000. SAS/STAT Guide for Personal Computers, Version 6, 4th ed., Volumes 1 & 2. SAS Institute, Cary, North Carolina.

U.S. Environmental Protection Agency (USEPA). 2002. National Recommended Water Quality Criteria: 2002. EPA-822-R-02-47. Accessed November 9, 2004 at http://www.epa.gov/waterscience/pc/revcom.pdf.

Whyte, J., Schmitt, C.J., Brumbaugh, W.G., Annis, M., and Tillitt, D.E. 2002. Biomarkers of metal exposure in fish from existing and proposed mining area of Missouri. Presentation at the 23rd Annual Meeting of SETAC, November 2002, Salt Lake City, UT.

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