Evaluation of the Recovery of Fish and Invertebrate Communities Following Reclamation of a Watershed Impacted by an Abandoned Coal Surface Mine

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ABSTRACT

A 5-yr study was conducted to measure the rates of recovery of fish and invertebrate communities following reclamation of a watershed impacted by an abandoned coal surface mine in Southwest Missouri. Quarterly monitoring of water quality information (pH, conductivity, and alkalinity) was conducted at 10 sites. Annual monitoring of biological (benthic invertebrate and fish community structure), physical (substrate grain size), and chemical (metals, pH, conductivity, and alkalinity) variables was conducted at 5 of the 10 sites. Prior to the reclamation effort the stream was nearly devoid of aquatic life above Hwy 2 for a distance of approximately 2 miles due to extremely low pH (<3) and elevated levels of calcium, magnesium, iron, zinc, aluminum, copper, strontium, boron, and cobalt. State water quality standards for zinc, copper, and cadmium were exceeded. Fish were present at reference sites (largemouth bass, white crappie, bluegill, minnows, and darters) but were absent at sites impacted by acid mine drainage within the project boundaries. Benthic invertebrates were similarly impacted. Reclamation activities were initiated late in 1991 and continued through 1995. Significant recovery of water quality, fish, and invertebrate communities were observed following the reclamation. Both chemical and biological approaches were useful in monitoring the recovery of the aquatic system following the watershed reclamation.

INTRODUCTION

The Clean Water Act (originally the Federal Water Pollution Control Act 1972; amended in 1977 and 1987) is the primary regulatory authority used in the United States to protect aquatic life from contaminant exposures associated with industry and mining (Hurdiburgh 1995). Water quality criteria, developed using single species laboratory toxicity data, establish maximum levels of individual toxic substances which are believed to be protective of aquatic life.

However, this water quality based approach is not always protective of aquatic life in natural ecosystems (LaPoint et al. 1989). In many cases, organisms are exposed to mixtures of contaminants which are not considered in water quality criteria (Kimball and Levin 1985). Further, the chemical form or ionized state of chemicals are frequently altered by the environment; such fluctuations are not always revealed in a water-quality based monitoring program (Chapman et al. 1992). In addition, secondary biological effects can occur due to alteration in competition, predation, or grazing (Giesy et al. 1979). These effects are difficult to predict using laboratory toxicity data or chemistry analysis alone.

Thus, biological assessment approaches are frequently used to measure the direct impacts of industrial and mining wastes on aquatic ecosystems (EPA 1994).

Direct measures of population and community structure of invertebrate and fish communities can provide an in-situ, integrated assessment of the effects of multiple chemicals on the environment. These measures provide direct assessments of the resources which we seek to protect, and thus can be more direct, interpretable, and cost-effective.

In 1977 the Surface Mining Control and Reclamation Act (SMCRA) was established to permit recovery of abandoned coal mines in the United States (Starnes 1996; U.S. Office of Surface Mining 1996). Acid drainage from abandoned coal mines represents a significant threat to aquatic resources due to the effects of low pH and increased metals such as copper, cadmium, silver, manganese, and zinc.

The West Branch of the Middle Fork of Tebo Creek, located in Southwest Missouri, drains approximately 1200 acres of abandoned coal surface mine properties located on private lands approximately 12 miles northeast of Clinton, MO. This tributary is a major hydrologic input to Truman Reservoir which is recognized as one of the most significant sport fisheries and recreational areas of the Midwest. Historically, leachates from the mining site have resulted in numerous fish kills in the stream. In addition, several acidic impoundments existed which represented a additional sources of pollution to Truman Reservoir.

Thus, the Abandoned Mine Lands Section, Land Reclamation Program, Missouri Department of Natural Resources (DNR), initiated the Tebo Creek Reclamation Project in 1991 to minimize current and future impacts of the site. This reclamation project involved recovery of 331 acres of acid-forming spoils, 92 acres of coal refuse, and 13 acres of acid impoundments. In addition, approximately 30 acres of wetlands were constructed to improve water quality. This paper describes a cooperative research project conducted between the Land Reclamation Division of the DNR and the Columbia Environmental Research Center (CERC), Biological Resources Division, USGS, Columbia, MO, USA. The project was conducted to measure the success of the watershed reclamation effort and to compare the relative utility of using chemical versus biological approaches as indicators of stream recovery.

MATERIALS AND METHODS

Site descriptions

Sampling stations for the Tebo Reclamation Project are illustrated in Figure 1 and described in Table 1. Site 1 was immediately above County Road NE 880, and served as an upstream reference station. Station 2 was immediately below Road NE 880, and represented a major source of surface-mine runoff. Stations 2, 3, and 4 were located within the immediate area of the reclamation. Station 5 was located at Hwy 2, which represents the lower end of the physical reclamation effort. Stations 6, 7, 8, and 9 were located downstream of the reclamation site and represented the stream recovery zone (Figure 1; Table 1). Site 11, located approximately 5 miles southwest of the reclamation area on Sand Creek (County Road NE 301) served the reference location for estimating undisturbed conditions.

Quarterly water quality assessments

A total of 10 sites were monitored for baseline water quality (Table 1; Figure 1). Dissolved oxygen, temperature, pH, conductivity, and alkalinity were monitored.

Table 1. Description of sampling stations used in the study. For additional spatial orientation refer to Figure 1.

Site	Sample type[1]	Sample Zone
1	B/F/WQ	reference
2	WQ	impact
3	WQ	impact

4	WQ	impact
5	B/F/WQ	impact
6	WQ	recovery
7	B/F/WQ	recovery
8	B/F/WQ	recovery
9	WQ	recovery
11	B/F/WQ	reference

[1] Benthic (B), fish (F), and water quality (WQ) samples, respectively.

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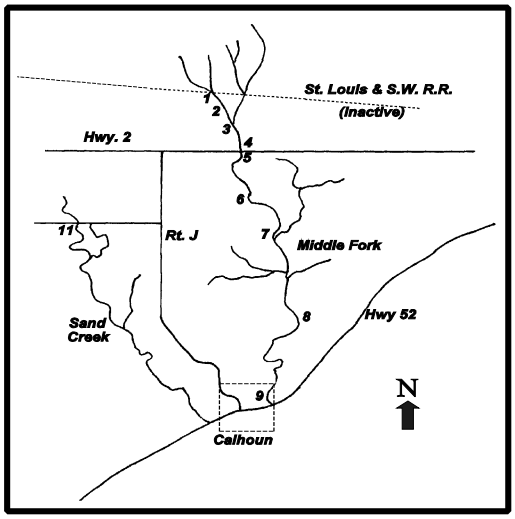
Figure 1. Location of sampling sites during the 5-yr Tebo Creek Reclamation Project.



Annual biological assessments

On an annual basis intensive biological, physical, and chemical measures were performed at 5 sites following procedures outlined in EPA (1994). Measures included benthic invertebrate community structure, fish community structure, substrate grain size, pH, alkalinity, conductivity, and metals.

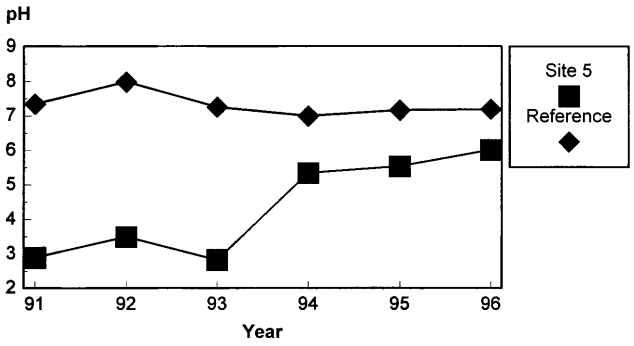
At each site 5 replicate invertebrate samples were taken from a pool habitat. A stovepipe sampler (30-cm diameter) was driven into the substrate to a depth of approximately 10 cm. Substrates, organic matter, and invertebrates were removed using a fine net and transferred to a WILDCO benthic sieve bucket (535 um mesh) and washed to retain invertebrates. All invertebrate samples were preserved in 90% ethanol until identification in the laboratory. At each site 5 replicate substrate samples were taken using a 15-cm diameter stovepipe sampler. Materials were wet-sieved to 5 size classes (<0.063 mm, 0.063-0.500 mm, 0.50-2.00 mm, 2.00-6.3 mm, 6.3-25.4 mm, and >25.4 mm) and then weighed to determine relative contribution of each fraction. Weights were determined to the nearest g.

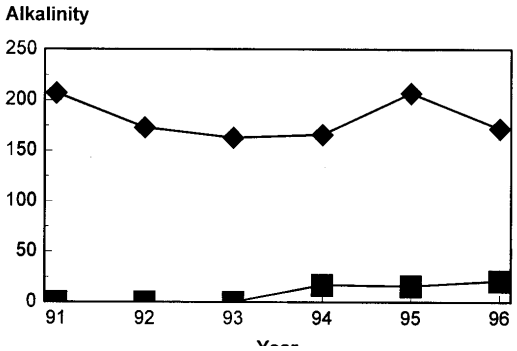
At each benthic community assessment site a fish community assessment was also conducted. A standard pool area at each site (approximately 400 m^2 area) was seined (3 mm mesh) one time. Fish were identified to species, enumerated, and returned to the stream. Water quality was determined at each benthic/fish collection site as described above for the quarterly water quality monitoring. Additionally, aqueous metals were determined. Samples were filtered using Nucleopore Polycarbonate Membranes (0.4 um pore size) and a polysulfone filtration apparatus. Samples were then acidified to pH<2 using ultra-pure HNO_3 and refrigerated until analysis by ICAP analysis.

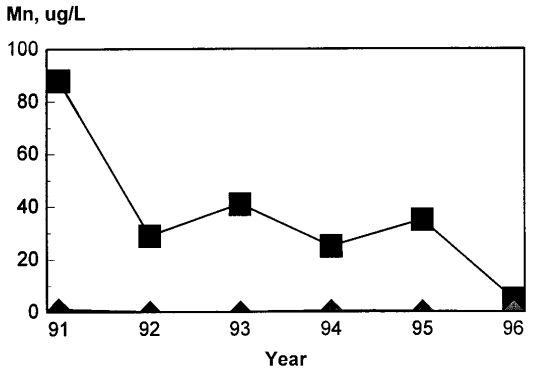
Figure 2. Changes in water quality at site

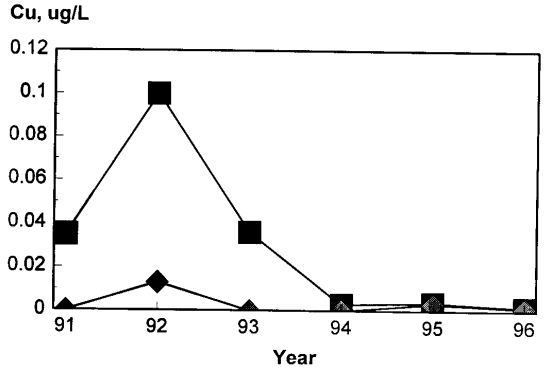
5 and the reference site during the 5 - yr study.

RESULTS AND DISCUSSION









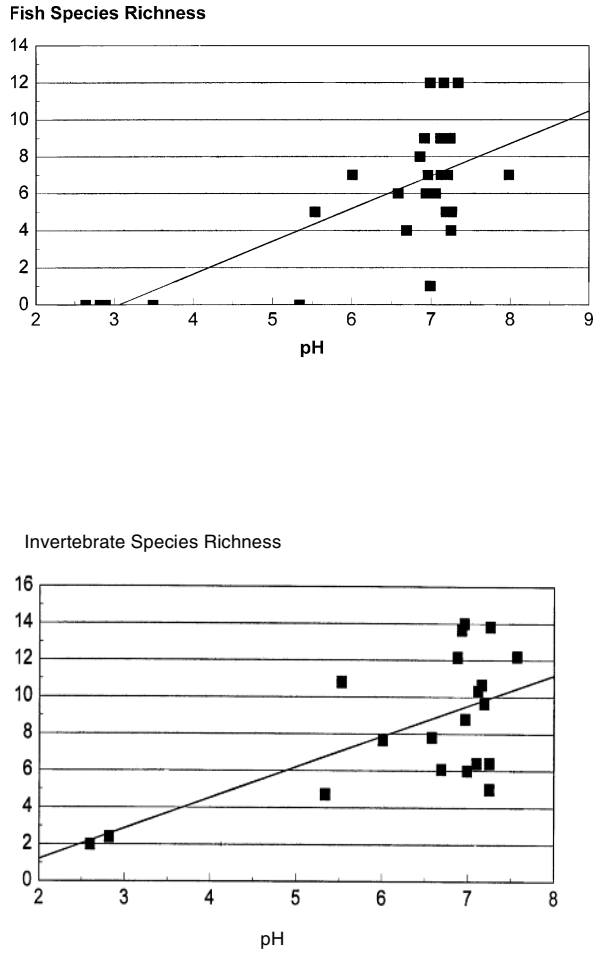
Prior to the restoration effort the stream was nearly devoid of aquatic life above Highway 2 due to the high level of acidity and dissolved metals. Fish were absent, and the invertebrate community was dominated by only a few extremely tolerant species of Chironomidae. Water quality conditions were extremely degraded from station 1 downstream to station 6 (1 mile N of County Road NE 1130; approximately 2 miles south of Hwy 2).

In August 1991, at the onset of the reclamation project, pH levels at stations 2, 3, 4, 5, and 6 were less than pH 3.6, which is well below levels supportive of fish and invertebrates (Figure 3; Table 2).

The pH at stations 1 and 11 (reference sites) and stations 7, 8, and 9 (downstream recovery zone) exceeded pH of 6.5 which is typical of normal, ambient conditions for the area. Stations 2 and 5, at the upper and lowermost portions of the reclamation area (Figure 1) exhibited low alkalinity and high levels of calcium, magnesium, iron, zinc, aluminum, copper, strontium, boron, and cobalt; Missouri state water quality standards for zinc, copper, and cadmium were exceeded (Table 2). Impacted sites typically contained high levels of iron precipitates, which imparted an orange, rust-colored hue to bottom sediments. Metal levels at downstream stations (7 and 8) and Sands Creek (station 11) were much lower. Fish were absent at sites 2, 3, 4, and 5 at this time. In contrast, many fish species, including largemouth bass, white crappie, bluegill, minnows, and darters were found at stations 7,8, 9, and the Sands Creek site (reference station 11) (Figure 1). Reclamation activities were initiated late

Site	Year	pH	alkalinity (mg/L)	Zn (ug/L)	Cd (ug/L)	Cu (ug/L)
5 (lower end site)	**1991**	2.87	0	510	34	34
7 (4 miles downstream)		6.87	09	0	0	0
8 (6 miles downstream)		7.21	117	0	0	0
reference		7.35	206	0	0	0
5 (lower end site)	**1992**	3.50	0	1,300	15	100
7 (4 miles downstream)		7.05	83	0	0	110
8 (6 miles downstream)		6.91	31	0	0	80
reference		7.98	173	0	0	10
5 (lower end site)	**1993**	2.82	0	6,600	50	40
7 (4 miles downstream)		7.12	111	100	0	0
8 (6 miles downstream)		7.25	98	0	0	0
reference		7.25	163	0	0	0
5 (lower end site)	**1994**	5.33	17	1,000	5	3
7 (4 miles downstream)		6.58	98	0	1	0
8 (6 miles downstream)		6.69	61	0	1	0
reference		6.99	166	0	1	0
5 (lower end site)	**1995**	5.53	17	1,600	8	4
7 (4 miles downstream)		6.96	91	0	0	6
8 (6 miles downstream)		6.93	83	0	0	2
reference		7.16	208	0	0	3
metals criteria				**100**	**12**	**20**

Figure 3. Relationships between fish and Invertebrate Species Richness and pH over the 5 - yr Study Duration.



in 1991 and continued through 1995. The relative success and rate of progression of the reclamation is illustrated by the temporal pH data from station 5, which is located at the extreme southern edge of the reclamation site (Figure 2). The pH of station 5 remained less than 4 until January of 1993.

At this point, significant progress in the reclamation effort had been made, which was reflected in a dramatic increase in the pH of water. However, in 1993 many large floods occurred from May through August which produced excessive erosional runoff. Significant damage was received at the site, including damaged gabions, side-cutting of channels, and surface erosion. At station 5 pH levels again declined until remediation efforts were completed at the end of 1994. Since October 1994, pH levels at station 5 have remained at pH 5 or higher. Levels of dissolved metals, including manganese and copper are also decreasing following the restoration (Figure 2;Table 2).

Most recent chemical and biological sampling was conducted in October 1995. Significant recovery of water quality, fish, and invertebrate populations were observed. Although the pH at station 5 was only 5.5, fish (green sunfish) were observed for the first time in over 5 years. The pH at station 5 was actually lower in October 1995 than previous samples in January, March, June, and August which probably is due to a combination of extremely low water conditions late in 1995 and a continuing seep located above Hwy 2. This problem is continuing to be investigated.

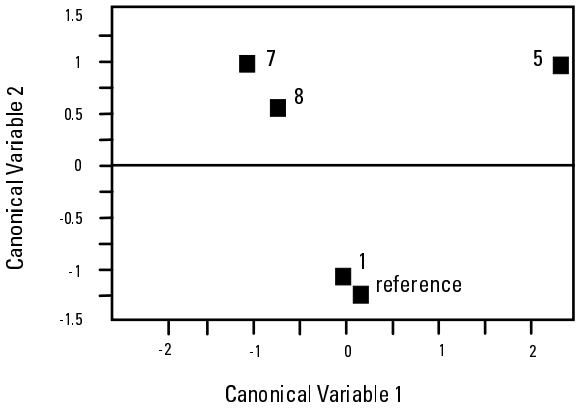
Data from 1991 to 1995 were combined in Figure 3 to demonstrate the relationship between biological communities and pH. The data indicate that fish cannot tolerate pH levels below pH=6.5. As seen in Figure 3, the number of fish and invertebrate species increases dramatically at pH 6.5. However, in some cases species richness is still low such as at station 1 where fish recolonization is restricted. The highest diversity of both fish and invertebrates was observed at the Sands Creek reference site (site 11). However, as the restoration progresses, additional fish and invertebrate species are expected to move into the downstream stations below the reclaimed watershed.

Table 3. Bivariate correlations between selected biological and chemical variables combined over the 5-yr study.

	Fish #sp	inv #sp	pH	alk	Cd	Cu
fish#sp	---					
inv.#sp	.19	---				
pH	.54	.59	---			
alk	.32	.13	.75	---		
Cd	-.48	-.47	-.82	-.49	---	
Cu	-.45	-.38	-.85	-.08	.88	---

Figure 4. Cannonical correlation of eighteen variables used to discriminate between sites at the Tebo Creek Reclamation Project.

Bivariate correlations were used to compare the relationship between various biological and chemical variables (Table 3). High



negative correlations were observed between pH and cadmium (r=-0.82) and copper r=-85) due to the increased solubility of these metals at low pH. Fish and invertebrate species richness were positively correlated with pH (r=0.54 and 0.59, respectively) and negatively correlated with Cd (r=-0.48 and -0.47, respectively) and Cu (r=-0.45 and -0.38) (Table 3).

Canonical correlation was also used to discriminate between the various sites by comparing a multivariate dataset of 4 biological variables (fish total numbers, fish species richness, invertebrate total numbers, invertebrate species richness) and fourteen chemical measures (pH, dissolved oxygen, conductivity, hardness, alkalinity, Al, Cd, Cr, Cu, Fe, Mg, Mn, Mo, and Pb) (e.g. total 18 variables) combined across the entire study period (Figure 4). This multivariate approach clearly distinguished between site 5 (highly impacted) and the other sites. Sites 7 and 8, located in the lower impact zone, grouped together but were distinct from the two reference sites (site 1 and Sands Creek) due to the intermediate effects of ow pH and metals. As recovery progresses, the sites should converge as chemical and biological conditions continue to improve.

Neither chemical nor biological approaches were clearly superior in this study. At extremely impacted sites, the biological variables could not distinguish between sites due to the total absence of species. In this case pH alone was effective in monitoring restoration success. As pH increased, however, both chemical and biological assessment were useful. Chemical assessments must continued to be relied upon because they are clearly tied to regulatory limits. However, analysis of metals is expensive and can take several months to receive results. Biological measures, however, can be done rapidly in the field if taxonomy is held to a basic level. Increased resolution can be achieved by archiving samples for later identification to a higher level of taxonomic resolution. However, increased taxonomic resolution can come at a higher monetary and time cost that approaches that of metals analysis. However, when water quality conditions improve, greater resolution of both chemical and biological approaches are necessary to determine if remaining impacts are caused by continued mining

impacts or other factors such as temperature, dissolved oxygen, physical habitat, or hydrologic limitations. For example, a few remaining acid seeps and over-razing near the Tebo Creek Reclamation Site is known to be contributing to additional water quality impacts to the project site. Multi-disciplinary chemical, biological, and hydrologic assessments can be used to isolate and identify multiple sources of impacts and are necessary to insure that reclaimed aquatic resources meet their optimum potential.

SUMMARY

The Tebo Creek Reclamation Project has resulted in significant improvement in water quality and fish populations in the West Fork of Tebo Creek. In 1995 fish populations were observed within portions of the reclamation area which occurred within one year of pH stabilization. Some small seeps continue to contribute acid to the stream. However, the restoration effort has solved the major problems impacting the stream. Both chemical and biological approaches were useful in monitoring the recovery of stream resources; the relative value of each approach, however, depended on the severity of impact and the stage and needs of the assessment.

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