EFFECTS OF CATTAILS (TYPHA) ON METAL REMOVAL FROM MINE DRAINAGE[1]

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Abstract. -- Natural and constructed wetlands have been shown to ameliorate acid mine drainage, but mechanisms for metal removal in wetland treatment systems are not well understood. Therefore, seven natural cattail wetlands in Monongalia County and five in Preston County, WV, which received drainage from surface coal mines were selected for study. Aboveground plant biomass in each wetland was estimated and plant samples were collected in June and September 1986 to evaluate bioconcentration of Fe and Mn. Sediment samples were collected to determine pH, Eh, texture, and extractable Fe and Mn. Plant biomass of these wetlands was less than 50% of biomass reported in the literature for wetlands managed for biomass. The average aboveground (leaves and stems) uptake of Mn by cattails in the spring was 5.37 kg/ha and 5.20 kg/ha for Monongalia and Preston Counties, respectively. In the fall, Monongalia County cattails accumulated 11.47 kg/ha and cattails in Preston County accumulated 6.19 kg/ha. Concentrations of Mn in the rhizomes were much lower than concentrations of plant tops. Iron uptake by aboveground plant parts was very low, less than 4 kg/ha, for both counties at both sampling times. Concentrations of Fe in the rhizomes were 30 to 100-fold greater than Fe concentrations in the plant tops. Calculations show that cattails in these wetlands removed less than 1% of the total Fe added to the wetlands by mine drainage. The pe + pH values of the sediment where cattails were growing were less than the values for areas with no cattails, indicating that cattails may lower the redox potential of the wetland enough to precipitate Fe and Mn.

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INTRODUCTION

In the search for safe, cost-effective ways to treat acid mine drainage increasing attention has been focused on the use of cattail (Typha) wetlands (Girts and Kleinmann 1986, Snyder and Aharrah 1984), because these wetland systems are capable of removing Fe and Mn from the drainage. Due to saturated soil conditions and the presence of decomposable organic matter, the biochemical oxygen demand of most wetlands far exceeds the rate of oxygen diffusion into the sediments (Ponnamperuma 1972, Gambrell and Patrick 1978). Without oxygen, the sediments become highly reduced as microbial respiration proceeds, using electron acceptors such as Fe, Mn, and SO_4^{2-}.

Cattail plants have morphological features such as arenchyema tissues which aid in the transport of oxygen from aboveground parts to the roots, thereby enabling the plant to grow in highly reduced environments (Armstrong 1978, Hutchinson 1975, Sebacher et al. 1985). The direct ameliorative effect of cattails is due to metal removal by plant uptake from acid mine drainage. Metals taken up by the plants are subsequently retained in the detritus after senescence of the plants. The indirect effect of the cattails on water quality is related to the fact that they modify the chemical and biological environments of the sediments.

Little quantitative data are available to provide information about the relative importance of direct or indirect mechanisms on the water treatment capabilities of cattail wetlands. Before the relative merits of wetland treatment schemes can be fully evaluated, it is necessary to understand the movement, retention, and transformation of metals in wetland ecosystems. This information is vital for development of design criteria for building manmade wetlands for treatment of acid mine drainage. This investigation was undertaken a) to determine the biomass and elemental composition of cattails growing in naturally occurring wetlands receiving mine drainage, b) to determine the seasonal changes in plant biomass, plant elemental composition, and plant uptake of Fe and Mn, c) to determine the temporal changes in extractable metals in sediments of cattail wetlands receiving mine drainage, and d) to determine the effect of the cattail plants on redox environment of sediments within the wetlands.

MATERIALS AND METHODS

Natural cattail wetlands (major species *Typha latifolia*) which received drainage from reclaimed surface coal mines were selected for study in two counties in northern West Virginia. Seven wetlands were located in Monongalia County and five were located in Preston County. The wetlands ranged in size from 40 m^2 to 1500 m^2. Waynesburg coal seam had been mined at all of the Monongalia County sites, and Upper and/or Lower Freeport coal had been mined at the Preston County sites.

Plant populations in each wetland were determined by counting the number of plants per square meter. A 1 m x 1 m quadrat was randomly placed at five points in each wetland. All cattails within the quadrat were counted. The total aboveground portions (leaves and stems) and rhizomes of cattails were sampled near the water inflow, near the middle, and near the water outflow of each wetland. These samples were collected in June 1986 (Spring) and September 1986 (Fall). The plant samples were cleaned with distilled water and dried in a forced air oven at 65°C. Dried samples were ground in a Wiley mill having stainless steel blades. These samples were sent to Pennsylvania State University for Fe and Mn analyses, and analyzed on an Inductivity Coupled Plasmaspectrograph as described by Dahlquist and Knoll (1978). Some plant samples were also analyzed at West Virginia University for comparison. In this procedure (Ganje and Page, 1974), a 1.0-g sample of plant tissue was digested with 9.0 ml of 3:1 mixture of nitric and perchloric acids in a tall 200-mL beaker. The digested material was dissolved and brought to volume in a 50-mL volumetric flask with 0.1 N HCl. The concentration of metals in the solution were determined by atomic absorption spectrophotometry. Plant uptake of metals was calculated by multiplying tissue concentrations by biomass. Similar data were produced by both laboratories, so only one set of data is presented.

Sediment samples were collected from the same three points of cattail sampling. The sediment samples were collected with an auger to a depth of 10 cm from the soil-water interface and transferred to plastic bags. Soil pH and Eh for redox measurements were made in the fresh, wet sediments. Eh was measured by using a platinum electrode with Ag/AgCl reference electrode. Eh readings were noted when the drift in Eh was less than 5 mV/min. Sediment pH was measured with a standard glass electrode. The pe + pH values were calculated by dividing Eh by 59.2 and adding pH (Lindsay 1979). After pH and Eh were measured the sediments were air-dried and passed through a 2-mm sieve. Soil texture was determined by the pipette method (Soil Survey Staff 1972). Extractable Fe and Mn were determined by extracting the sediments with 0.1 N HCl using 1:10 ratio of sediment to extracting solution. The extracted elements were determined by atomic absorption spectrophotometry.

Additional samples for the study of effect of vegetation on pe + pH of the sediments were collected from one point outside and on the water entry side of each wetland. The pe + pH data were calculated as described above.

Monthly water quality samples were collected from November 1985 through January 1987 (unpublished data, Dr. Henry Rauch, Department of Geology and Geography, West Virginia University). In general, the Monongalia mine water was near neutral pH. The lowest pH at any sampling time was 6.3 and the highest was 8.2. In Preston County, the mine water tended to be somewhat more acid. Only one site consistently had pH values above 6.0. Water pH at all other sites was generally below 6.0 and commonly between pH 3.0 and 4.0. Total Fe and Mn varied, but the Preston County mine water generally contained slightly more of these metals than the Monongalia County mine water.

Statistical analysis (ANOVA) was done using SAS programs, and significance between counties and seasons was tested at alpha levels of 0.05.

RESULTS AND DISCUSSION

Primary Biomass Production of Cattails.

The direct or indirect ameliorative effect of cattail wetlands on acid mine drainage passing through them is related to primary biomass production within the wetland ecosystem. Biomass data for wetlands in this study are presented in table 1. Dry matter yield was used as an index for biomass production, and it was computed from plant density and dry matter yield per plant (plant vigor). Plant density in Monongalia County wetlands was significantly greater than in Preston County wetlands. Cattail growth in wetlands of Monongalia County was significantly more vigorous than the cattail growth in Preston County wetlands at both sampling times. During the spring season the mean per plant dry matter production in Monongalia County wetlands was 2.5 times the dry matter yield per plant in Preston County. At the fall sampling, the plant vigor in Monongalia County was 2.2 times greater than that of Preston County.

Biomass production was three times higher in Monongalia County than in Preston County at the spring sampling and almost three times higher at the fall sampling. Biomass production depended on plant density and plant vigor. Low levels of biomass production were caused by low plant density. Both plant vigor and biomass were significantly higher in fall-harvested cattails than in spring-harvested cattails.

When the dry matter production of cattails in this study was compared to the dry matter production in fertilized cattail stands managed for biomass production in Minnesota, Wisconsin, and Texas, the amount of dry matter produced by natural wetlands in this study was less than 50% of that produced in the managed wetlands (Bonnewell and Pratt 1978, Pratt and Andrews 1980). Thus, there is a great potential for increasing biomass production in cattail wetlands by proper management. The productivity of cattail wetlands is related to the nutritional status and biochemical environment of the substrate in which the cattails are growing. In general lower biomass production in Preston County was related to the pH of the sediment (table 2). A significant positive correlation coefficient (r = 0.73)

Table 1 -- Plant density, plant vigor, and biomass production of cattails in wetlands receiving mine drainage.

Property	Season	Monongalia Co.	Preston Co.
Plant density (plants/m^2)	Spring	12.9[1] 7.9 - 15.9[2]	7.9[1] 0.7 - 19.2[2]
Plant vigor (g dry matter/ plant)	Spring	39.0 20.1 - 81.7	16.5 11.0 - 24.2
	Fall	45.5 25.3 - 91.5	20.6 13.2 - 31.4
Biomass (g dry matter/m^2)	Spring	411.9 211.9 - 663.0	146.2 5.8 - 345.0
	Fall	554.3 264.5 - 1180.2	191.8 7.8 - 446.7

[1]Mean of seven sites in Monongalia County and five sites in Preston County.

[2]Range.

was observed between sediment pH and biomass. Other factors such as low sediment concentration of P could also have affected biomass production.

taken up by the growing plants. The actual amount of metal removal by the plant is dependent on the intensity factor, i.e. the concentration of metal in

Table 2 -- Properties of sediment in cattail wetlands receiving mine drainage.

Property	Season	Monongalia Co.	Preston Co.
pH	Spring	7.93[2] 7.64 - 8.11[3]	4.67[2] 2.34 - 6.07[3]
Iron[1]	Spring	5343 1992 - 10154	3503 1306 - 7616
	Fall	6418 2436 - 13,550	5625 2464 - 10,850
Manganese[1]	Spring	1536 430 - 2216	280 50 - 713
	Fall	1412 422 - 2617	357 53 - 697

[1]0.1 N HCl extractable iron and manganese (ug/g).
[2]Mean of seven sites in Monongalia County and five sites in Preston County.
[3]Range.

Properties of Sediments.

Wetland sediments have a natural tendency to converge to pH 7.0, irrespective of the initial soil pH (Sajwan and Lindsay 1986). In Preston County wetlands, sediments with pH values lower than 7.0 indicated the presence of nonequilibrium conditions, i.e. these sediments represented the wetlands which were constantly receiving an influx of highly acidic water.

There were significant differences in the extractable Mn concentrations between the sediments of Monongalia and Preston Counties (table 2). Extractable Mn concentrations in the Preston County sediments were significantly lower than Mn concentrations in sediments of Monongalia County. The correlation coefficient between the aboveground plant tissue Mn concentrations and concentration of extractable metals in the sediment was 0.52 which was nonsignificant.

No significant differences in the amounts of extractable Fe in sediments were found between counties or between seasons (table 2). No significant correlation was found between the amount of metals extracted from the sediment and the concentrations of the metals in the plant tissue. This lack of correlation was probably due to the nature of the substrate for plant growth. In wetlands receiving acid mine drainage, the extractable metals are indicators of the capacity factor for plant nutrition, i.e. the amount of metal which can be potentially

the soil solution. In normal plant growth media the intensity factor is governed by the capacity factor, but in wetlands receiving acid mine drainage the intensity factor is largely independent of the capacity factor due to differences in water chemistry of the drainage and sediment and to continuous influx of metals into the growth media. This continuous flow of mine drainage into the system is responsible for the lack of a significant correlation between extractable metals and concentrations in plant tissue.

Texture of the sediments in the Monongalia County wetlands was sandy loam, silt loam, or clay. Texture of wetland sediments in Preston Coundy was either clay loam or silty clay loam. These textures probably represent the textures of the surrounding minesoils.

Concentration and Uptake of Manganese and Iron in Cattails.

Manganese

The plant tissue analyses for Mn (table 3) suggest another reason for the yield differential between cattails growing in Preston and Monongalia Counties. The lower cattail yields in Preston County could be due to the high levels of Mn in the plant tissue. There was a significant increase in the plant tissue concentrations of Mn from spring to fall samples for Monongalia County, but the seasonal concentration differences were not significant for Preston County. This lack of increase in Mn concentration with growing season in Preston County is possibly due to the fact that the concentrations during the spring season had already reached the maximum value for bioconcentration in the cattail, so there could not have been any further concentration increases.

at the fall sampling. At the fall sampling Fe concentration in Monongalia County cattails was 9.2 times greater than Fe concentration in Preston County cattails. These seasonal differences could be due to the formation of iron oxide coatings that were observed on the roots of cattails growing in Preston County.

Table 3 -- Concentration and uptake of manganese in cattails sampled from wetlands receiving mine drainage.

Plant Parts	Season	Monongalia Co.	Preston Co.
Rhizomes (ug/g)	Spring	665[1] 625 - 705[2]	885[1] 498 - 1278[2]
	Fall	795 567 - 972	684 394 - 1119
Leaves + Stems (ug/g)	Spring	1202 702 - 1824	3109 1879 -4071
	Fall	2202 586 - 2912	3189 2653 - 3970
Leaves + Stems (kg/ha)	Spring	5.37 2.64 - 7.92	5.20 0.11 - 11.60
	Fall	11.47 3.72 - 23.22	6.19 0.25 - 15.95

[1]Mean of seven sites in Monongalia County and five sites in Preston County.
[2]Range.

During the spring season the mean Mn concentration in cattails of Preston County was 2.5 times greater than the mean Mn concentration in cattails of Monongalia County (table 3). Even with these large differences in concentrations of Mn the differences in uptake of Mn at the spring sampling between counties were statistically nonsignificant. This lack of a sizable difference in uptake is related to low biomass production in cattail wetlands of Preston County.

Rhizome samples were too few for statistical analyses. In general the concentrations of Mn in the rhizomes were lower than the concentrations in the leaves and stems (table 3). In Preston County the concentration differences between rhizomes and aboveground plant portions were four-fold or greater.

Iron

Fe concentrations in cattail tissues in Preston County were significantly different at both sampling times from those in Monongalia County (table 4). Iron concentration in Preston County cattails was 3.4 times greater than Fe concentration in Monongalia County cattails in the spring, but this difference was reversed

Under reducing conditions, Fe^{2+} is thought to be oxidized to the less soluble Fe^{3+} by oxidative agents released from the roots, thus creating a coating or plaque of an insoluble Fe^{3+} compound on the root surface (Taylor et al. 1984). Iron oxide coatings are a survival mechanism for cattails growing in a contaminated environment, because the coatings do not allow further uptake of Fe (Taylor and Crowder, 1984, Taylor et al. 1984). Since no additional Fe was taken up by the plant, Fe concentration decreased as the plant continued to grow. Plants growing in Monongalia County may have continued taking up Fe during the growing season. The high concentrations of Fe found in Preston County rhizomes (table 4) are probably due to the coatings.

Seasonal differences in Fe uptake were significant for the cattails growing in Monongalia County while they were not significant for cattails in Preston County. In absolute terms, the amounts of Fe removed by plants were extremely low, i.e. 2.67 and 3.74 kg/ha for the spring and fall sampling periods in Monongalia County. The amounts taken up in Preston County were smaller, i.e. 1.07 kg/ha and 0.76 kg/ha for the spring and fall sampling, respectively.

Table 4 -- Concentration and uptake of iron in cattails sampled from wetlands receiving mine drainage.

Plant Parts	Season	Monongalia Co.	Preston Co.
Rhizomes (ug/g)	Spring	---	15,288[2]
		---	9648 - 19,506[3]
	Fall	5392[2]	11,170
		1000 - 10,818[3]	8036 - 14,650
Leaves + Stems (ug/g)	Spring	595	2043
		109 - 1539	213 - 5369
	Fall	1919	208
		409 - 7352	88 - 344
Leaves + Stems (kg/ha)[1]	Spring	2.67	1.07
		0.23 - 5.47	0.04 - 2.80
	Fall	3.74	0.76
		1.56 - 5.31	0.06 - 1.31

[1]Uptake in kg/ha was calculated by multiplying concentration (ug/g) by biomass.
[2]Rhizome data are means of four sites in each county. All other data are means of seven sites in Monongalia County and five sites in Preston Co.
[3]Range.

Removal of Iron from Water by Cattail Plants.

In order to calculate total removal of Fe by cattails, biomass of the aboveground and belowground parts of the plants must be known. Biomass of rhizomes was not determined in this study, so it was estimated. Biomass of *Typha latifolia* rhizomes varies but it is commonly 50% of the total biomass (Personal communication, Dr. D.C. Pratt, Botany Department, University of Minnesota). Therefore, for our calculations, we assumed that aboveground and belowground biomass were equal.

To calculate an example of Fe removal by cattails in this study, a site in Preston County was chosen because it had the highest concentration of Fe (19,506 ug/g) in the rhizomes. Aboveground and belowground biomass each equal 287.2 g/m^2.

To estimate uptake by the rhizomes, biomass must be multiplied by the Fe concentration. So, 287.2 g/m^2 X 19,506 ug/g = 5,602,123.2 ug/m^2, or approximately 56 kg/ha of Fe were removed by the rhizomes during the growing season.

This site had a median flow rate of 0.5 L/sec, so 15,768,000 L/yr will flow into this Preston County wetland. The median concentration of Fe entering this wetland was 10 mg/L. Therefore 157,680,000 mg/yr or 157.7 kg of Fe per year will be added to this wetland. Since the area of this wetland is 61.27 m^2, additional calculations show that approximately 25,700 kg/ha of Fe will enter this wetland during a year. Since the cattail plants are removing only 57.31 kg/ha (56 kg/ha for the rhizomes and 1.31 kg/ha for the tops), the plants are removing only about 0.2% of the total Fe entering the wetland.

Effect of Cattail Wetlands on Redox Environment.

Metals can be removed from water by various mechanisms, and data on the redox environment within a cattail wetland may give some information on possible mechanisms of removal. Sediment of one site in Preston County, had a positive Eh of 230 mV, but the Eh of sediments at all other sites ranged from - 247 to - 18 mV. These Eh values suggest that reduction may be a major mechanism for the removal of iron. The pe + pH values of the sediments with cattails were close to 4.24 (table 5), where SO_4^{2-} and Fe^{3+} can be reduced to form insoluble FeS_2 at pH 7.0 (Lindsay 1979).

The role of cattails in enhancing the reduced environment in wetlands was confirmed when redox potentials were determined in wetland sediments with and without cattails (table 5). The data indicate that the presence of cattails has a significant effect on redox environment, making it more reducing. Cattails can lower the redox potential of the sediments enough to precipitate Fe in its sulfide form.

Table 5 -- Redox environment in sediment of cattail wetlands receiving mine drainage.

Property	Monongalia Co.	Preston Co.
pH	7.95[1] 7.64 - 8.11[2]	4.63[1] 2.34 - 6.07[2]
pe + pH (with cattails)	4.57 3.93 - 5.36	4.31 2.62 - 6.20
pe + pH (without cattails)	10.63 8.79 - 13.25	9.82 4.97 - 13.27

[1]Mean of seven sites in Monongalia County and five sites in Preston County.
[2]Range.

CONCLUSIONS

Amounts of metals removed from mine drainage by cattail wetlands depend upon cattail biomass and concentration of metals in plants. In this study biomass production appeared to be related to the quality of the sediment in the wetland. Low pH and high Mn levels were related to reduced cattail biomass in some wetlands. To increase metal removal from mine drainage by plant accumulation, emphasis should be placed on increasing dry matter production rather than on increased bioconcentration.

Data from this study also indicate that plant uptake is not a major mechanism for the attenuation of metals in mine drainage. Eh values and pe + pH calculations show that cattail wetlands have reducing environments. The presence of cattails in a wetland actually promotes a more reducing environment. Chemical reduction within the wetland may be a mechanism by which metals like Fe are removed. Additional research will be required to determine other possible mechanisms of metal removal from mine drainage flowing through cattail wetlands.

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