CERC Research Study Plan Title: Effects of Mining-Derived Metals Contamination on Native Floristic Quality

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USGS/BRD Center: Columbia Environmental Research Center

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I. Rationale and Justification:

In response to a request from the Missouri Department of Natural Resources (MDNR), in collaboration with U.S. Fish and Wildlife Service (USFWS), as the Missouri Trustee Council, the Columbia Environmental Research Center will conduct an assessment of the effects of contamination from mining-derived metals on native plant communities in southeast Missouri. Soils and vegetative communities adjacent to lead smelters, mine/mill wastes and tailings are known to contain elevated levels of metals (Sudhakar, 1992). However, the relative sensitivity of most native plants and soil microfauna are unknown (Leyval and others, 1997; Fletcher and others, 1998). The effects of mining-derived metals contamination have been demonstrated on numerous plants in the field and the laboratory (Andersson 1988, Das and others, 1997; Balsberg, 1998), but little work has been conducted to document the effects of metals contamination on the composition of vegetative communities in the Missouri Ozarks. We will compare floristic quality measures in six impact classes: 1) reference sites on summits with ambient levels of lead concentration (less than 100 ppm) without mine waste and with minimal evidence of human disturbance, 2) reference sites in riparian areas with ambient levels of lead concentration (less than 100 ppm) without mine waste and with minimal evidence of human disturbance, 3) chemically impacted sites on native soils with intermediate lead (100 to 1000 ppm) to high (greater than 1000 ppm) lead concentrations, where tailings and other mine waste are not present, and 4) mill-waste (chat or tailings) sites with intermediate to high lead concentrations, 5) sites where aerial deposition of smelting byproducts may have induced impacts via chemical compounds in addition to metals contamination, and 6) remediated/revegetated sites.

Southeast Missouri contains some of the highest concentrations of lead ore deposits in the world. Two major lead-producing areas of Southeast Missouri Lead Mining District include the "Old

Lead Belt" and the "New Lead Belt" (also known as the Viburnum Trend). Lead mining has occurred in these areas for generations.

The Old Lead Belt lies in the Meramec River Hills and St. Francois Knobs subsections of Missouri (Nigh and Schroeder, 2002). In the Meramec River Hills, small-scale surface mining of lead began around 1720, and much of the land was denuded of timber by the early nineteenth century. Much of the land is now in second growth native forest, and numerous small excavations, mine/mill wastes and tailing piles with high lead concentrations dot the landscape. Large scale mining operations began in both subsections during the twentieth century. Today, large tailings piles and impoundments, and mine/mill wastes cover the landscape.

The Viburnum Trend is located in both the Meramec River Hills and Current River Hills Subsections (Nigh and Schroeder, 2002). Mining in this area is relatively recent (or is ongoing), and has been dominated by large-scale operations. Tailings from mining in this area were typically disposed of in valley-fill impoundments.

In each of these areas MDNR has documented high soil lead concentrations near tailings piles and impoundments, mine/mill wastes, along "haul roads", downwind of smelters, and in residential soils where tailings have been transported as fill, driveway cover, and other human uses. Elevated lead concentrations found in tailings have been linked to high blood lead levels in children six years old and younger. Elevated lead concentrations have also been found in soils in proximity to smelting activities and mine waste (Sudhakar, 1992), and plants are known bioaccumulators of lead and other metals (Taylor and others, 1992; Brown and others, 1995). Eroding mill tailings contaminate adjacent soil and Ozark streams and have led to contaminated aquatic food chains and loss of biota including mussels and crayfish (Schmitt and others, 2007). In addition, sport-fish including smallmouth bass (*Micropterus dolomieu*), longear sunfish (*Lepomis megalotis*), and suckers are known to contain lead levels that exceed food consumption levels (Missouri Department of Health and Senior Services, 2005).

II. **Objectives**:

A. Compare Floristic Quality Assessment measures between reference sites on summits, reference sites in riparian zones, sites with chemically contaminated native soils, sites on chemically contaminated mine/mill waste, sites on native soils contaminated by by-products of smelting and sites that have been remediated and revegetated.
B. Perform regression analysis of $\overline{C}$ and FQI on lead concentration for sites with chemically contaminated native soils.

III. **Listing of Studies:**

A. Effects of Mining-Derived Metals Contamination on Native Floristic Quality

1) Principal Investigator(s): Matthew Struckhoff, Esther Stroh, Keith Grabner

2) Specific Objectives:

A. Test null hypothesis that there is no significant difference in mean Coefficient of Conservatism ($\overline{C}$) values between reference sites on summits, reference sites in riparian zones, sites with chemically contaminated native soils, sites with chemically contaminated mine/mill waste, sites with native soils contaminated by by-products of smelting and sites with remediated and revegetated mine /mill waste.

B. Test null hypothesis that there is no significant difference in Floristic Quality Index (FQI) values between reference sites on summits, reference sites in riparian zones, sites with chemically contaminated native soils, sites with chemically contaminated mine/mill waste, sites with native soils contaminated by by-products of smelting and sites with remediated and revegetated mine /mill waste.
C. Test null hypothesis that there is no significant difference in mean exotic species richness between reference sites on summits, reference sites in riparian zones, sites with chemically contaminated native soils, sites with chemically contaminated mine/mill waste, sites with native soils contaminated by by-products of smelting and sites with remediated and revegetated mine /mill waste.
D. Test null hypothesis that there is no significant difference in the mean ratio of vegetative cover between exotic and native species between reference sites on summits, reference sites in riparian zones, sites with chemically contaminated native soils, sites with chemically contaminated mine/mill waste, sites with native soils contaminated by by-products of smelting and sites with remediated and revegetated mine /mill waste.
E. Perform regression analysis of $\overline{C}$ and FQI on lead concentration for sites with chemically contaminated native soils.

3) Experimental Design or Methodological Approach:

The primary metric for comparisons between mine-impacted and reference sites will be derived from Floristic Quality Assessments (FQA) following Swink and Wilhelm (1979, 1994). Prior to sampling, each species known to occur in a region is assigned a Coefficient of Conservatism (C) based upon its tolerance for disturbance and its fidelity to non-degraded conditions. The C value for each species reflects that species' fidelity to particular environmental conditions, with a value of zero (0) representing the least fidelity (generalist species) and a ten (10) representing the highest fidelity. C values do not necessarily reflect rarity, though there is often a correlation between C value and rarity. Presence/absence data are used to calculate two indices: the mean Coefficient of Conservatism ($\overline{C}$) and the Floristic Quality Index (FQI), which is the product of $\overline{C}$ and the square root of the total number of species encountered in a plot. For this project, we will use coefficients of conservatism for Missouri flora developed by Ladd (1993).

Non-native species are generally not included in FQA analysis (Swink and Wilhelm, 1979, 1994). The impact of non-native species, if present, is reflected in the diminished ability of native species to occupy a site. Therefore, in order to directly assess the impact of metals contamination on exotic species abundance, we also will compare 1) mean exotic species richness and 2) the mean ratio of vegetative cover between exotic and native species between mining affected sites and non-affected sites.

In order to reduce environmental variability and to represent the extremes of the moisture and floristic diversity gradients, reference plots will be located on two common landforms: riparian zones and summits. For the purposes of this study, riparian zones include the relatively mesic terrestrial communities on low flats between slopes associated with intermittent streams, perennial creeks and rivers. Vegetation communities in riparian zones are among the most diverse community types in the Ozarks (Grabner, 2001, 2002; Becker, 1999; Nigh and others, 2000). Summits are relatively xeric landforms in the highest local landscape position and are among the least floristically diverse landforms in the Ozarks (Grabner, 2001 2002; Becker, 1999; Nigh and others, 2000).

In order to separate the effects of physical disturbance, especially the effect of mine waste (tailings or chat), from the chemical effects of metals contamination, we will sample and compare the following broadly defined impact classes: 1) reference sites on summits with ambient levels of lead concentration (less than 100 ppm) without mine waste and with minimal evidence of human disturbance, 2) reference sites in riparian areas with ambient levels of lead concentration (less than 100 ppm) without mine waste and with minimal evidence of human disturbance, 3) chemically impacted sites on native soils with intermediate lead (100 to 1000 ppm) to high (greater than 1000 ppm) lead concentrations, where tailings and other mine waste are not present, and 4) mill-waste (chat or tailings) sites with intermediate to high lead concentrations, 5) sites where aerial deposition of smelting byproducts may have induced impacts via chemical compounds in addition to metals contamination, and 6) remediated/revegetated sites.

Methodology

Site selection: MDNR and USFWS have identified eight sites for sampling: St Joe State Park and Viburnum Trend reference sites, Glover smelter, and the National, Elvins/Rivermines, Sweetwater, West Fork and Desloge tailings piles/impoundments. Reference data will be collected at St. Joe State Park and/or at other sites not affiliated with mining activity in the area of the Viburnum Trend (for example, Taum Sauk Mountain State Park or Mark Twain National Forest). Data for chemically impacted sites (communities in native soils without tailings or chat but with moderate to high lead concentrations) will be collected within 60 m (200 ft.) of tailings piles and impoundments at St. Joe State Park, National, Elvins/Rivermines, Sweetwater and West Fork. Data for mine/mill waste sites will be collected in communities on chat piles/tailings impoundments at National, Elvins/Rivermines, Sweetwater and West Fork. Data for remediated sites will be collected from areas where bio-solids and/or seeds have been applied to mine/mill waste at Desloge. We also will sample randomly located plots on the windward side of the smelter at Glover, MO.

Sampling location selection: In cooperation with MDNR and USFWS, USGS personnel will identify appropriate sample points based upon the following criteria:

1. Soil surface concentration of lead as determined using a hand-held Triton X-Ray Flourometer (XRF)
2. Presence or absence of mine waste (chat or tailings)
3. Impact class (reference riparian area, reference summit, contaminated native soil, contaminated mine/mill waste, remediated and revegetated mine/mill waste, or smelter impacted)
4. No logging activity for at least 50 years
5. No grazing within 30 years

Within each impact class, a sample point will be randomly identified that will represent the southwest corner of a sampling plot. We will record the location of the southwest corner of each plot using a Magellan (Thales) ProMark 3 GPS receiver with an external NAP100 antenna configured to collect readings using the Universal Traverse Mercator (UTM) Zone 15 N coordinate system and referenced to the North American Datum 1983 (NAD83). Data will be collected every second for a minimum of 10 minutes at each plot. Field data will post-processed against NOAA-National Geodetic Survey Continually Operating Reference Station (CORS; http://www.ngs.noaa.gov/CORS/Data.html) data using the Magellan Mobile Mapper Office Software. This system generates sub-meter post-processed horizontal accuracy. Data will be exported as 3-D shapefiles (.shp). Each site and/or location will be photographed from the southwest corner toward the northeast corner.

Vegetation sampling: Plots will measure 20 m x 20 m (400 m^2), with edges laid out in cardinal directions. If necessary, plots may be reoriented and reshaped (retaining the 400 m^2 search area) in order to remain within a given impact class or landform. Vegetation sampling will follow procedures used to sample and classify vegetation communities for the U.S. Nation Vegetation Classification System (USNVC; The Nature Conservancy, 1994); within the plot, each vegetation stratum (canopy/subcanopy, shrubs/sapling and groundflora) is sampled independently, and all species present are identified and assigned to a percent-cover class (Table 1). Cover estimates are based upon a vertical projection of foliar cover following methods described by Daubenmire (1959).

Table 1. Vegetative cover classes assigned to species within each strata of plots.

Code	Range of Class*	Class midpoint
01	>0-< 1%	0.3%
03	1-< 5%	3%
10	5-<15%	10%
20	15-<25%	20%
30	25-<35%	30%
40	35-<45%	40%
50	45-<55%	50%
60	55-<65%	60%
70	65-<75%	70%
80	75-<85%	80%
90	85-<95%	90%
98	95-<100%	97.5%

*Adopted from The Nature Conservancy, 1994b

Soil Sampling: We will collect soil from three fixed locations at each plot: southwest corner, plot center, and northeast corner. We will use a shovel or metal spade to expose topsoil (0 to 20 cm) and subsoil (20-35 cm), then remove samples from the exposed soil surfaces using a small plastic or stainless steel scoop or spade. For both topsoil and subsoil, samples from all three sampling points in the plot will combined in a plastic sealable bag, which will be labeled with the following information: Study indicator (USGS-FQI-2008), sample number (USGS-FQI-2008-###), collector, date, time, site, plot, and soil layer. Soil samples will be transferred to MDNR or USFWS-Columbia Field Office, who will process and analyze samples for the presence of heavy metals using an XRF. Ten percent of the XRF samples will be submitted to the Missouri Department of Natural Resources for lab confirmation of metals analysis and for the presence of Nitrogen, Phosphorus, and Potassium.

Data Analysis: We will calculate the average coefficient of conservatism ($\overline{C}$) for each plot. We will then use these values to calculate the Floristic Quality Index for each plot by multiplying $\overline{C}$ by the square root of the total number of native species. Grand $\overline{C}$, mean FQI, mean exotic species richness and the mean ratio of vegetative cover between exotic and native species will be calculated for in each impact class (reference summit, reference riparian, contaminated native soils, contaminated mine/mill waste, smelter site, and remediated/revegetated). Analysis of Variance (ANOVA; $\alpha = 0.05$; Snedecore and Cochran, 1989) will be used to test for differences between impact classes in grand $\overline{C}$, mean FQI, mean exotic species richness and the mean ratio of vegetative cover between exotic and native species. Data will be analyzed for each vegetation stratum separately and for all strata combined.

4) Listing of SOP Numbers and Titles:

1. Vegetation sampling: The Nature Conservancy (1994), Daubenmire (1959)
2. FQI calculations: Swink and Wilhelm (1979, 1994)
3. Analysis of variance: Snedecore and Cochran (1989)
4. Soil sampling: as per MDNR and USFWS instructions
5. Field X-Ray Flourometry: as per XRF user manual

5) Listing of Critical Data:

1. Plot location and identifier information (UTM Zone 15N, NAD83)
2. Cover value for each species in each stratum of each plot (nearest 10 percent)
3. $\overline{C}$ calculation for each stratum in each plot
4. FQI calculation for each stratum in each plot
5. Grand $\overline{C}$ calculation for each impact class
6. Average FQI calculation for each impact class
7. Mean exotic species richness calculation for each impact class
8. Mean ratio of vegetative cover between exotic and native species calculations for each impact class
9. Lead, zinc and cadmium concentrations for composite samples of topsoil and subsoil for each plot
10. ANOVA results comparing grand Mean $\overline{C}$, average FQI, mean exotic species richness, and mean ratio of exotic species cover to native species cover between impact classes

6) Statistical Treatment: We will calculate the average coefficient of conservatism ($\overline{C}$) for each plot. We will then use these values to calculate the Floristic Quality Index for each plot by multiplying $\overline{C}$ by the square root of the total number of native species. Grand $\overline{C}$, mean FQI, mean exotic species richness and the mean ratio of vegetative cover between exotic and native species will be calculated for in each impact class (reference summit, reference riparian, contaminated native soils, contaminated mine/mill waste, smelter site, and remediated/revegetated). Analysis of Variance (ANOVA; $\alpha = 0.05$; Snedecore and Cochran, 1989) will be used to test for differences between impact classes in grand $\overline{C}$, mean FQI, mean exotic species richness and the mean ratio of vegetative cover between exotic and native species. Data will be analyzed for each vegetation stratum separately and for all strata combined.

7) Acceptance or Rejection Criteria for Results: The null hypothesis (no difference between impact classes) will be rejected if Analysis of Variance ($\alpha = 0.05$) yields a *p* value of less than 0.05.

8) Special Safety Requirements: Only those personnel who have received training in the proper use of hand-held X-Ray Flourometer (XRF) devices will be allowed to operate XRF devices. All personnel involved in sampling (including those not operating the XRF device) will wear radiation dosage meters ("radiation badges") during the operation of XRF devices. Persons collecting soil will wear protective gloves and will employ good hand-washing practices.

9) Animal Care and Use Requirements:
No animals will be tested or used during this experiment.

10) Quality Assurance Requirements: Quality assurance will be based upon strict adherence to standards agreed upon by USGS, MDNR, and USFWS. We will follow USDA PLANTS database (USDA-NRCS, 2008) naming conventions. Unknown specimens will be labeled with plot information, given an *in-situ* description, and compared against herbarium specimens for final identification.

11) Endpoint of Study, Based on Accomplishments: An electronic copy of a draft manuscript will be submitted to MDNR and USFWS for review and comment. Results will be published in as a USGS Open File Report or in a peer-reviewed journal with the prior consent of the Missouri Trustee Council.

12) Schedule of Study and the Outputs Expected:

Calendar Year	2008	2008	2008	2009	2009
Month	May	June-Aug	Sept-Dec	Feb	June
Reconnaissance	X				
Vegetation and soil sampling		X			
Soil nutrient and metals analysis (MDNR or USFWS)			X		
FQI data Analysis			X		
Draft Report Delivery				Feb 15	
Final Report Delivery					June1

13) Place where Data will be Stored and Archived: Data will be stored and archived according to standard CERC procedures. Hard copies will be stored in building A3 which has state of the art fire protection. Electronic copies of data will be stored on individual laptop computers, with weekly backups on the CERC main server IGSKRGCBGS00714/ecostudies.

14) Relationship to Cooperator Needs: The assessment conducted within this study plan has been specifically requested by the Missouri Department of Natural Resources in collaboration with U.S Fish and Wildlife Service as the Missouri Trustee Council. Data will be used in various regulatory and management programs related to the effects of mining on terrestrial ecosystems of the Ozark Plateau Ecoregion.

15) Literature Cited

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