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Effects of mining-associated lead and zinc soil contamination on native floristic quality

Matthew A. Struckhoff*, Esther D. Stroh, Keith W. Grabner

U.S. Geological Survey Columbia Environmental Research Center, 4200 East New Haven Rd, Columbia, MO 65201, USA

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ABSTRACT

We assessed the quality of plant communities across a range of lead (Pb) and zinc (Zn) soil concentrations at a variety of sites associated with Pb mining in southeast Missouri, USA. In a novel application, two standard floristic quality measures, Mean Coefficient of Conservatism (Mean C) and Floristic Quality Index (FQI), were examined in relation to concentrations of Pb and Zn, soil nutrients, and other soil characteristics. Nonmetric Multidimensional Scaling and Regression Tree Analyses identified soil Pb and Zn concentrations as primary explanatory variables for plant community composition and indicated negative relationships between soil metals concentrations and both Mean C and FQI. Univariate regression also demonstrated significant negative relationships between metals concentrations and floristic quality. The negative effects of metals in native soils with otherwise relatively undisturbed conditions indicate that elevated soil metals concentrations adversely affect native floristic quality where no other human disturbance is evident.

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1. Introduction

We investigated associations between soil concentrations of lead (Pb) and zinc (Zn) and the floristic quality of otherwise relatively undisturbed plant communities adjacent to mine waste and a Pb smelter in the Southeast Missouri Mining District (SEMO), Missouri, USA (Fig. 1). Sites adjacent to Pb smelters and mine waste disposal sites are known to contain elevated soil metals concentrations (Kabata-Pendias and Pendias, 1992), and phytotoxic effects of metals contamination have been demonstrated in both field and laboratory experiments (Andersson, 1988; Das et al., 1997; Fargasova, 2001; Kabata-Pendias and Pendias, 1992; Pahlsson, 1989). Specifically, Pb inhibits plant growth and the activity of enzymes required for photosynthesis, interferes with cell division and respiration, reduces water absorption and transpiration, and reduces chlorophyll, carotenoid, and adenosine triphosphate (ATP) synthesis (Fargasova, 2001; Kabata-Pendias and Pendias, 1992). Although Zn is an essential micronutrient for plants, activity of enzymes involved in photosynthesis and hydrolysis can decrease in plants watered with solution concentrations as low as 650 μg/L Zn; solutions with Zn concentrations of 100–200 μg/L can disturb mitotic activity in root tips (Pahlsson, 1989).

A review by Fletcher et al., in 1988 showed that most phytotoxicity research has focused on agricultural species, and the sensitivity of most native plants to Pb and Zn was unknown. Little has changed in the intervening years; a *post-priori* search of the ECOTOX database (U.S. Environmental Protection Agency, 2009) using the 439 plant species found during this study yielded only seven studies examining the phytotoxic effects of either Zn or Pb. A handful of studies have documented negative community-level effects on native flora resulting from metals contamination related to mining activity (Beyer et al., 2011; Clark and Clark, 1981; LeJeune et al., 1996; Pierzynski and Fick, 2007; Thompson and Proctor, 1983), but only one (Kindscher et al., 2008) has used the particular measures of floristic quality described in this paper. Here, we use Floristic Quality Assessment (Swink and Wilhelm, 1994) to examine the effects of Pb and Zn contamination on the floristic quality of native plant communities. This approach is based on the premise that native plant species differ in sensitivity to disturbance and that the ecological integrity of a site is reflected by the suite of native species that occur there. Although not all locations have the necessary information to apply Floristic Quality Assessment (FQA) at present, other community-level metrics can be investigated in settings where FQA information is not yet available.

* Corresponding author. Tel.: +1 573 441 2781; fax: +1 573 876 1896.
E-mail addresses: mstruckhoff@usgs.gov (M.A. Struckhoff), estroh@usgs.gov (E.D. Stroh), kgrabner@usgs.gov (K.W. Grabner).

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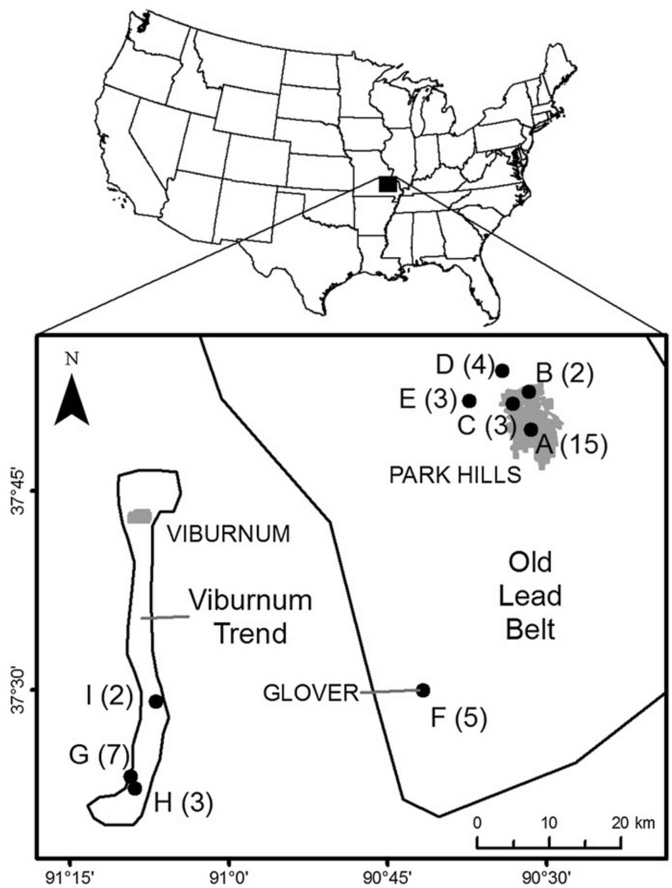

Fig. 1. Plant community sampling sites and towns (shaded areas) within subregions of the Southeast Missouri Mining District, Missouri, USA (numbers within parentheses indicate the number of plots at each site).

2. Materials and methods

2.1. Study area

In the Southeast Missouri Mining District, Pb has been mined in two subregions known as the Old Lead Belt and the Viburnum Trend (Fig. 1). Large-scale mines operated in the Old Lead Belt for more than a century until the 1970s, at which time mining shifted to the Viburnum Trend where it continues to the present day (U.S. Fish and Wildlife Service and Missouri Department of Natural Resources, 2008). The lead smelter at Glover operated from 1968 to 2003, at which time the facility was placed in a non-functional “care and maintenance” status (The Doe Run Company, 2003). Waste from the mining operations include piles of chat (a coarse-grained by-product of outdated physical-separation processes) and impoundments of tailings (a fine-grained by-product of modern chemical-separation processes), which contain millions of cubic meters of mine waste with Pb and Zn concentrations as high as 17,000 and 25,000 mg/kg (NewFields, Inc., 2006). These are sources of terrestrial and aquatic contamination via seepage and erosion (Besser et al., 2009). Background levels of Pb and Zn within the mining regions are 62 and 71 mg/kg respectively (NewFields, Inc., 2006); concentrations adjacent to mine waste are much higher than background levels and can exceed 10,000 mg/kg for Pb and 2300 mg/kg for Zn (U.S. Environmental Protection Agency, 2006). Contamination from these sites has contributed to the loss of biota, including mussels and crayfish, from aquatic systems (Schmitt et al., 2007).

Presettlement vegetation across the region was a mixture of forests and woodlands dominated by oak and pine, with inclusions of dolomite and igneous glade complexes; present-day vegetation is dominated by second-growth oak and pine-oak forests and woodlands, with lesser amounts of pasture in valley bottoms and on moderate slopes (Nigh and Schroeder, 2002). Effects of metals contamination on terrestrial vegetation in the region had not been documented prior to the initiation of this study.

2.2. Data collection

2.2.1. Plot selection

Within the study areas, we identified 8 sampling sites adjacent to mine waste and 1 site adjacent to the smelter at Glover, Missouri (Fig. 1). These sites were all on native soils with no evidence of chat, tailings or other obvious deposits of mine waste. We selected sites with relatively undisturbed second-growth oak and pine-oak forests and woodlands and their associated suite of ground flora species (Nigh and Schroeder, 2002). Sites were considered relatively undisturbed if existing vegetation indicated no evidence of logging, grazing, or other human disturbance. Evidence of logging included remnant stumps or skidder trails. Evidence of grazing included persistent animal tracks attributable to domestic livestock or dominance by plant species commonly used in pasture mixes, particularly tall fescue (*Schedonorus phoenix* (Scop.) Holub). Other evidence of human activity included roads or all-terrain vehicle trails, utility right-of-ways, or evidence of soil grading.

Within sites meeting these criteria, several potential plot locations were randomly generated using geographic information system software from which one was randomly selected for sampling. Plots measured 20 m $\times$ 20 m (400 m^2), with edges laid out in cardinal directions. If necessary, plots were reoriented and reshaped (retaining the 400 m^2 search area) in order to remain within the dominant plant community type. We recorded the location of the southwest corner of each plot using a handheld global positioning system (GPS) receiver, and each plot was photographed from the GPS point toward the opposing corner. We sampled 44 plots in 9 sites; 27 plots at five sites in the Old Lead Belt, 12 plots three sites in the Viburnum Trend, and 5 plots in one site adjacent to the Pb smelter at Glover (Fig. 1). Sampling began in early June 2008 and concluded in early September 2008.

2.2.2. Plant community sampling

Plant communities were sampled in three strata: the canopy and subcanopy layer (woody species taller than 5 m), the shrub and sapling layer (woody species between 1 and 5 m tall), and the ground flora layer (herbaceous flora and woody stems providing foliar cover under 1 m). Within each stratum, we identified each species present and estimated to the nearest one percent its foliar cover within the entire 400 m^2 plot (Daubenmire, 1959). Nomenclature followed the USDA PLANTS database (U.S. Department of Agriculture, Natural Resource Conservation Service, 2008). The primary references for plant identification were *Flora of Missouri* (Steyermark, 1963), and *Steyermark's Flora of Missouri Volume 1* (Yatskievych, 1999) and *Volume 2* (Yatskievych, 2006). Plants that were difficult to identify in the field were collected for identification purposes and compared against reference specimens in both the USGS Columbia Environmental Research Center herbarium and the Missouri Botanical Garden reference collection for the Flora of Missouri Project. Identifications of most collected specimens were confirmed with the author of the revised *Flora of Missouri* (G. Yatskievych, personal communication).