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A geochemical study of toxic metal translocation in an urban brownfield wetland

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ABSTRACT

Rhizosphere soil and dominant plant samples were collected at a brownfield site in New Jersey, USA, during summer 2005 to evaluate plant metal uptake from the contaminated soils. Metal concentrations varied from 4.25 to 978 μg g^{-1} for As, 9.68–209 μg g^{-1} for Cr, 23.9–1870 μg g^{-1} for Cu, and 24.8–6502 μg g^{-1} for Zn. A wide range of metal uptake efficiencies in the roots, stems and leaves was found in this study. Data showed that (1) *Betula populifolia* has high Zn, Cu and As accumulations in the root, and high concentrations of Cu and Zn in the stem and the leaf; (2) *Rhus copallinum* has high accumulation of Zn and Cr in the leaf and Cu in the stem; (3) *Polygonum cuspidatum* has high accumulations of Cu and As in the root; and (4) *Artemisia vulgaris* shows high Cu accumulation in the leaf and the stem.

1. Introduction

"Brownfields", which are primarily located in urban industrial areas, have presented both economic and environmental concerns for decades. Numerous studies have shown that contaminated soils and sediments often contain mixed organic and inorganic contaminants (e.g., Feng et al., 1998, 2004, 2011a,b; Gallagher et al., 2008; Onwueme and Feng, 2006; Yu et al., 2001; Zhang et al., 2001, 2009). Such contamination can pose both environmental and human health problems (Roy et al., 2005). To mitigate the risk associated with high soil metal concentration and foster sustainable development initiatives within the urban context, remediation of soil metals in brownfields has become an important and timely issue (Thornton et al., 2007). Previous studies have shown that the promising methods for soil metal removal include chemical/physical remediation, phytoremediation and micro remediation. Furthermore, bio-removal/stabilization approaches have the advantages of cost-effectiveness, environmental friendliness and fewer side effects, comparing to traditional chemical/physical remediation (Ferro et al., 1999; Glass, 1999; Wu et al., 2010). There are two basic approaches for plants to remediate brownfield, one is phytostabilization, which is the process of the absorption and catchment of pollutants within the rhizosphere (Berti and Cunningham, 2000); the other one is phytoextraction, where metals are translocated into plant tissue that can be harvested (Blaylock and Huang, 2000). An efficient transfer and sequestration of metal within the plant tissue is essential to the application of phytoextraction as an economical and non-invasive method of remediation of contaminated sites. Accumulation of metals in plant tissue is mainly determined by metal uptake efficiencies by plants and metal bioavailability in the soil (Pilon-Smits, 2005).

As essential micro-nutrients metals play a critical role in plant metabolism. However, high concentrations of metals are toxic to plants and can inhibit metabolism growth and reproduction. It is well documented that plants are capable of absorbing metals from the soil and storing these metals into various tissues (Das et al., 2010; Gallagher et al., 2008; Lacerda et al., 1997; Martin et al., 2003, 2006; Naftel et al., 2002; Weis and Weis, 2004; Williams et al., 1994). Metal ions can form chelating compounds with chelators (e.g., nicotianamine, organic acids, glutathione, phytochelatin, and metallothionein protein) in plant tissue cells, so that metal toxicity is reduced within the cells (Cobbett and Goldsbrough, 2000; Pilon-Smits, 2005). These metal chelating compounds can be further sequestered in cell vascular in the roots (Pilon-Smits, 2005). However, metals can also pass through the root tissue cell wall and root xylem, become transported into stem xylem with assistance of transporter proteins, or chelators (Pilon-Smits, 2005). Then, the metals can further transfer from stem xylem into leaf tissue where metals can be bound by chelators and sequestered in leaf symplast vacuole or the cell wall (Burken,

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2003; Cobbett and Goldsbrough, 2000). Previous studies show that metal bioavailability and toxicity are dependent on soil pH, redox potential, biota, mineral and organic contents, and complicated by synergistic interactions between these variables (Martin et al., 2003, 2006; Morrissey and Guerinot, 2009; Naftel et al., 2002). Therefore, understanding the biogeochemical processes and mechanisms that control the mobility of metals in soils, sediments and their translocation to plants is a critical aspect of brownfield bioremediation and rehabilitation. This study defines the efficiencies of plant uptake of several soil metals found at elevated concentrations. The results will improve our understanding of the potential for phytoremediation and phytostabilization in naturally assembled plant communities that colonize in urban brownfields.

2. Materials and methods

2.1. Study area

This study was conducted at Liberty State Park (LSP), Jersey City, New Jersey, located on the west bank of Upper New York Bay (centered at 40°42′14″N; 74°03′14″W). Used as a railroad yard for over a century the Central Rail Road of New Jersey filed for bankruptcy and closed in 1969 (Gallagher et al., 2008). Since then, the 1 km^2 study site has remained isolated and undisturbed. Nevertheless, soil metal concentrations remain relatively high and unevenly distributed (Gallagher et al., 2008). Using a previously established vegetative assemblage survey (USACE, 2004a,b), 22 sampling stations were selected for this study by comparing assemblage boundary maps and aerial photography that give adequate representation of the represented assemblages. These included two sites from the successional old field assemblage, 4 each within the common reed/mugwort and the maritime shrub land assemblages, and 12 within the successional northern hardwood assemblage (Fig. 1).

2.2. Plant materials

Plant tissue samples (root, stem and leaves) of eight (8) species, which include three woody species and five herbaceous species, were collected at the 22 stations within the park during the summer of 2005 (Fig. 1). The coordinates were recorded with GPS (Corvallis Microtechnology MC-GPS, accuracy 1 m). The woody species include *Betula populifolia* (gray birch, $n = 8$), *Rhus copallinum* (winged sumac, $n = 5$), and *Populus deltoids* (eastern cottonwood, $n = 3$), and the five herbaceous species are *Artemisia vulgaris* (mugwort, $n = 4$), *Onoclea sensibilis* ($n = 1$), *Phragmites australis* ($n = 1$), *Solidago virgaurea* ($n = 1$), and *Polygonum cuspidatum* ($n = 1$). These plant samples were collected randomly from the dominant species at each sampling site to investigate plant metal uptake efficiencies and the relationship between soil and plant tissue samples. Roots were visually traced from the bole and excavated using a hand spade. Root fibers were collected, loose soil was removed with distilled water, and 10–15 g (wet weight) samples were stored in clean polypropylene containers. Woody tissue was collected by cutting a cross-sectional 'cookie' at approximately 1 m height, from which a wedge representing all growth years and of at least 25 g (wet weight) was taken from the specimen. Representative leaf samples were also collected from each specimen. With woody species, 5 g (wet weight) leaf samples were collected from the upper, middle, and lower sections of the plant to ensure that the samples were representative of the entire plant. Herbaceous plants were clipped above the ground and the entire plant was collected. Soil samples were also collected at the same stations in triplicate at 1 m spacing according to the depth of the greatest root penetration determined by visual examination and ranged from 4 cm to 15 cm with a mean of 9.2 cm. Gravel and visible plant material (roots and leaves) were removed from soil samples in the field. These soil samples were then placed in clean, new polypropylene containers, and stored at 4 °C. A LaMotte field soil pH meter was used for *in situ* soil pH measurement. Sample analyses for metal concentrations were transferred to the Environmental Toxicology Laboratory at the University of Medicine and Dentistry of New Jersey (UMDNJ) with accompanying Chain-of-Custody sheets on the day of collection for further analysis.

2.3. Metal analysis

The analytical methods for metals were more fully described and explained in Gallagher et al. (2008). Briefly, after removal of organic detritus (twigs, roots, etc.), each soil sub-sample was mixed thoroughly in sufficient double-distilled water to create a slurry and sieved through nylon mesh to <125 μm, with the screen washed with additional distilled water to aid passage. The biological and soil sub-samples for metal analysis were oven-dried at 60 °C for ~48 h to constant weights. An aliquot of ~0.5 g dried soil sample was weighed to the nearest milligram, treated with 10 ml trace-metal grade HNO_3, and acid extracted in Teflon bombs in a MARS-5 (CEM Corp.) programmed microwave instrument at >170 °C for 30 min. These acid extracts were reduced to a minimum volume on hot-plates and re-diluted with 1% HNO_3 for analysis by atomic absorption spectroscopy (AAS). A method blank and a National Institute of Standards and Technology (NIST) Standard Reference Material (SRM) 1944 were analyzed simultaneously with each set of 12 soil samples. These samples were analyzed for Cr, Cu, and Zn by Perkin–Elmer Model 603 flame AAS. Arsenic concentration was determined in the presence of a $Mg(NO_3)_2/Pd(NO_3)_2$

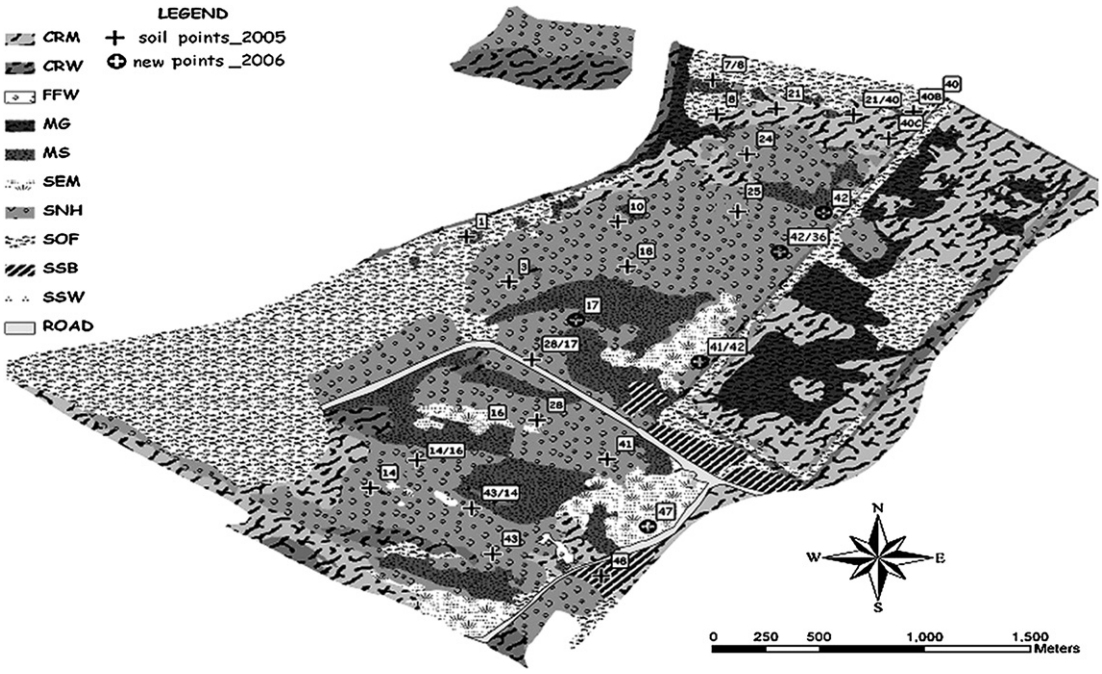

Fig. 1. Map of Liberty State Park, New Jersey with the vegetation assembling patterns for each sampling site. SNH, successional northern hardwood; SSB, successional shrub land; SOF, successional old field; MS, maritime shrub land; MG, maritime grasslands; CRM, common reed/mugwort; FFW, floodplain forested wetlands; SSW, shrub swamp wetland; SEM, shallow emergent marsh; CRW, common-reed-dominated wetland.