

Uptake and Translocation of Heavy Metals in Salt Marsh Sediments by *Spartina patens*

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The Hackensack Meadowlands is a coastal marsh system in northeastern New Jersey, located approximately 10 km west of New York City. Within the Meadowlands, twelve destructed or degraded estuarine wetland sites are currently part of ecological restoration projects that are in various phases of development from planning to completion (<http://www.meadowlands.state.nj.us/naturalresources/wetlands/Wetlands.cfm>). A completed restoration site is Harrier Meadow (North Arlington, NJ) where mitigation work included the creation of channels, impoundments, low marsh habitat and upland habitat islands. Important salt marsh plant species such as salt-meadow grass (*Spartina patens*), and spike grass (*Distichlis spicata*) dominate portions of the marsh. The sediments of Harrier Meadow contain heavy metals at concentrations that are below regulatory action limits (e.g., cadmium (Cd) 0–1 ppm; chromium (Cr) 10–18 ppm; copper (Cu) 13–60 ppm; nickel (Ni) 7–15 ppm; lead (Pb) 0–87 ppm; zinc (Zn) 28–94 ppm) (<http://www.meri.njmeadowlands.gov/ecorisk/>), but above those typically found in uncontaminated environments (van Driel et al. 1995; Swaileh et al. 2004).

Since *Spartina* species have been shown to take up heavy metals into roots and translocate them into above-

ground parts (see Weis and Weis (2004) for review), we had investigated the fate and the effects of selected heavy metals (i.e., Cd, Cr, Cu, Ni, Pb, and Zn) in sediment cores that were densely covered with *Spartina patens* in a recent short-term study (Suntornvongsagul et al. 2007). Since levels of metals taken up and translocated had been shown to vary depending on the metal concentration in the substrate (Vogel-Mikus et al. 2005), and to be affected by the presence of other metals (McKenna et al. 1993; Podar et al. 2004), half of these cores were artificially amended with Ni in order to increase its availability, and to assess potential effects on uptake of other metals. Ni was chosen since it was the most accumulated metal in shoots from a mixture containing Cd(II), Cu(II), Ni(II) and Zn(II) in identical concentrations (Peralta-Videa et al. 2002), and was assumed to persist in hydrated form in pore water. We demonstrated that Ni-amendment had no significant effect on the fate of other metals in sediments, however, observed increased root-uptake of certain metals. Although translocation of Ni into shoots reflected the 10-fold higher concentrations in sediments and roots in Ni-amended cores, metal translocation into shoots was generally small for all metals (Suntornvongsagul et al. 2007). The goal of the current study was to extend the observations beyond the first growing season, and to assess whether Ni-amendment had effects on metal uptake and translocation after three growing seasons.

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Materials and Methods

Sediment cores covered with *S. patens* plants (13 × 13 × 13 cm, $n = 10$) weighing approximately 2 kg fresh weight, were collected from Harrier Meadow at the

Table 1 Heavy metal concentration in soil (mg [kg {dry wt.}]⁻¹) in control and Ni-amended soil at the beginning of the first growing season ($n = 5$, $X \pm$ (SE))

	2.5 cm depth		5.0 cm depth		7.5 cm depth	
	Control	Amended	Control	Amended	Control	Amended
Ni	22.6 (6.3)	177.3 (35.5)	10.9 (2.4)	27.6 (5.1)	9.3 (2.8)	26.9 (3.5)
Cd	2.8 (0.5)	3.3 (1.1)	0.9 (0.1)	1.1 (0.4)	0.7 (0.2)	1.0 (0.2)
Cr	35.5 (11.5)	39.7 (5.0)	15.0 (3.7)	20.2 (6.6)	9.7 (1.3)	16.0 (2.1)
Cu	55.2 (15.0)	48.4 (7.7)	31.7 (10.0)	27.2 (5.7)	19.0 (8.5)	19.1 (2.5)
Pb	207.9 (46.1)	222.9 (34.7)	95.9 (18.4)	108.9 (20.0)	64.8 (12.0)	92.8 (12.6)
Zn	189.5 (10.7)	175.1 (25.4)	133.0 (49.3)	105.0 (46.0)	68.3 (21.9)	99.2 (26.3)

end of February 2000 similar to a previous study (Burke et al. 2002). Cores were fitted into plastic pots and placed in individual pails containing 5 ppt artificial seawater (Instant Ocean® Mentor, OH, USA) amended with 5 ppm NH_4^+ and PO_4^{3-} , respectively, so that standing water was present 5 cm below the top of the core, which correlated to observed water levels in the field. This level was roughly maintained during the experiment through daily adjustments with amended 5 ppt artificial seawater. Water in the pails was completely exchanged once a week to maintain this salinity.

After a one-week acclimation period, the concentration of Ni was increased in half of the cores ($n = 5$) through amendments with NiSO_4 (50 mg kg^{-1} core material) dissolved in water and poured onto the surface of the core. The second half of the cores received NaSO_4 (50 mg kg^{-1} core material) dissolved in water, and served as controls for heavy metal contaminated cores. Pots of all treatments were placed at random on a greenhouse bench and moved once a week during the growth period for 6 months (March to September) under ambient light (750 $\mu\text{mol m}^{-2} \text{s}^{-1}$) and temperature conditions (22–25°C) to minimize bench effects. After the first growing season (March 2 to August 28, 2000), each core and treatment was sampled with a cork corer (2 cm diameter) (Burke et al. 2002). Between October and March, plants from which all senescent above-ground biomass was harvested, were kept at 4°C in a cold room. In March, seawater was renewed and plants transported back into the greenhouse for the next growing season. This procedure was repeated for three years until cores were sampled destructively at the end of the third growing season (September 2003).

Samples ($n = 3$) were collected between 1.5–3.5 cm (further referred to as 2.5 cm depth), 4.0–6.0 cm (5.0 cm depth), and 6.5–8.5 cm (7.5 cm depth) below the surface of each core as in a previous study where these samples demarcated significant changes in redox potential and sulfate/sulfide profiles (Burke et al. 2002). Each of these samples was divided into five 1-g portions. From each of

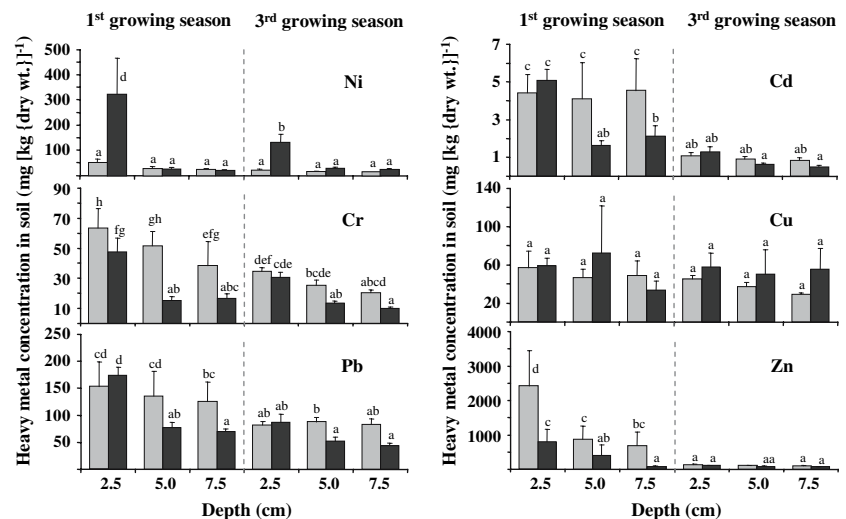
the samples one portion was retained for root and sediment dry-weight determination. The other four portions were evaluated for heavy metal concentrations in plant roots, and associated sediment. For heavy metal analyses, shoots, and separated roots and soil were dried at 80°C, ground by using a mortar and a pestle, and sieved (<74 μm , 200 mesh). 0.5 g of each ground sample was digested by using the OI Analytical Microwave Digestion System including OI Analytical PFA Teflon® vessels (CMS Field Products Group, Pelham, AL). Soil samples were digested in 10 mL HNO_3 (70%), while plant material was digested in 5 mL HNO_3 (70%) and 2 mL H_2O_2 (30%) based on the United States Environmental Protection Agency (US EPA) Method 3051 (EPA 1983). Heavy metal concentrations for Cd, Cr, Cu, Ni, Pb and Zn in plant leaves, roots, and associated soil was determined after digestion by Atomic Absorption Spectrometry (Varian SpectrAA 220FS, Walnut Creek, CA) using flame or graphite tube atomizer detection, depending on the concentration of the metals in the samples (EPA 1983).

All data are presented as means \pm standard error ($X \pm$ SE) and analyzed by analysis of variance (ANOVA) followed by Duncan's multiple range tests (Duncan 1995) using SPSS 11.0.1 (LEAD Technologies Inc., Chicago, IL).

Results and Discussion

A relative accumulation of heavy metals was observed in the upper part of the cores (Table 1), which is often encountered in marsh sediments (Otero and Macias 2003). Except for Ni in Ni-amended cores, which was applied to the surface of the sediment cores, this accumulation most likely reflects atmospheric deposition in this urbanized area, or plant effects that resulted in metal translocation and release on the surface, e.g., through salt glands or decaying plant material (Weis and Weis 2004). Surface amendment through sediment deposition seems unlikely, since Harrier Meadow is infrequently flooded.

Fig. 1 Heavy metal concentrations in soil taken at different depths (2.5, 5.0 and 7.5 cm) in soil cores vegetated with *S. patens*, and either non-amended (light bars) or Ni-amended (dark bars) after one or three growing seasons. Bars and error bars represent mean and standard error values. The “identical letters” represent “no significant” differences between treatments ($p > 0.05$) as determined by Duncan’s multiple range test



At the soil surface, overall concentrations of metals were slightly higher than those obtained from other sites at Harrier Meadow, but still within the range of values observed at sites from other industrialized areas (Otte et al. 1991). The basic distribution profile of heavy metals in sediments could still be observed at the end of the first growing season (Fig. 1). Ni amendment significantly lowered concentrations of Cd, Cr, Pb, and Zn in the more anoxic portions of the cores (i.e., at depths of 5.0 and 7.5 cm) as compared to non-amended cores (Fig. 1). This effect was not obtained for Cu and Ni. After the third growing season, soil concentrations of all heavy metals decreased from the first growing season except for Cu, where concentrations remained relatively consistent. The effects of Ni-amendment after the first growing season in the more anoxic parts of the core could be a consequence of competition of heavy metals for soil binding sites, where Ni amendment increased metal mobilization. For example, Cd tends to adsorb to a high degree to complex compounds with natural organic ligands (Linnik 2003). At the depth of 2.5 cm, about 5-times higher total organic carbon (TOC) was found than in the lower parts of the cores (12% versus 2%). Consequently, competition between added Ni and other metals for soil-binding sites at the 2.5-cm depth may not have been as pronounced as compared to lower depths. High concentrations of added Ni therefore would have caused a release and leaching of other metals in the deeper portions of the cores where there are fewer potential metal binding sites, resulting in a decrease in concentration of other metals as compared to non-amended cores. This effect would be reduced in time since Ni would also gradually leach out into the lower depths or out of the system.

All metals were taken up by plant roots, but no significant effects of Ni-amendments were observed after both the first and the third growing season. Except for Cr, which showed higher concentrations in roots after the third sea-

son, no significant differences in root metal concentrations were obtained between seasons (Fig. 2). In our concurrent short-term study, we found that Ni-amendment increased root uptake of other heavy metals, including Cr, Cu and Zn, but these effects were transitory and differences were not detected at the end of the growing season. Ni added to the soil cores is initially free and soluble, and competition between free Ni and other metals for soil binding sites may increase the solubility of other metals. This would result in 1) a decrease in metal concentration at depths where soil binding sites are limited, and 2) an increase in root uptake of some metals as a consequence of their increased solubility. Although Ni-amendment increased root uptake of metals over the short term, we could not detect any effect of Ni on root uptake of other heavy metals after the completion of the first growing season, although altered soil concentrations could still be observed in the more anoxic portions of the soil cores.

Shoot concentrations of metals were affected by season, however, as concentrations for Cd and Pb decreased in time, while concentrations of Cu and Ni (the latter after Ni-amendment only) increased. Values for Cr remained unchanged (Fig. 3). Values in shoots were generally one to two orders of magnitude lower than in roots, depending on the metal (Fig. 3). These results are in agreement with those proposed for other monocotyledonous plant species that were found to concentrate metals primarily in their roots (Otte et al. 1991; Weis and Weis 2004). All metal concentrations in plant tissues fell between critical deficiency and toxicity values, and were thus in a range typically found for many agricultural plants (Marschner 1995).

Uptake and translocation of metals were not significantly affected by Ni-amendment after the first and third growing season, except for Ni itself, where 10-fold higher concentrations in cores resulted in corresponding increases in root uptake and translocation into shoots (Fig. 3). These

Fig. 2 Heavy metal concentrations in roots taken at different depths (2.5, 5.0 and 7.5 cm) in soil cores vegetated with *S. patens*, and left non-amended (light bars) or Ni-amended (dark bars) after one or three growing seasons. Bars and error bars represent mean and standard error values. The “identical letters” represent “no significant” differences between treatments ($p > 0.05$) as determined by Duncan’s multiple range test

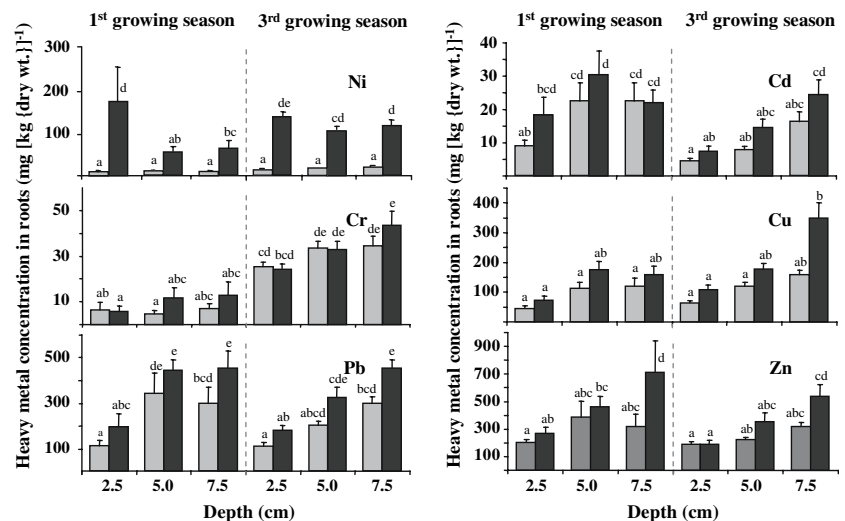
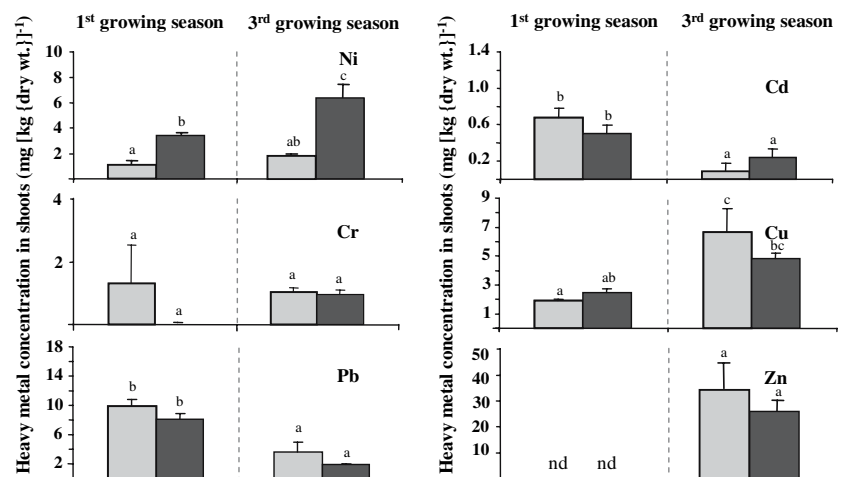


Fig. 3 Heavy metal concentrations in shoots of *S. patens* grown on non-amended (light bars) or Ni-amended (dark bars) soil cores after one or three growing seasons. Bars and error bars represent mean and standard error values. The “identical letters” represent “no significant” differences between treatments ($p > 0.05$) as determined by Duncan’s multiple range test



results corroborate observations on highly contaminated environments where no antagonistic effects of heavy metals on plant uptake were observed (McKenna et al. 1993; Podar et al. 2004). However, they are in contrast to results of the same studies that reported on the inhibition of Cd uptake when heavy-metal-contaminated soils were amended with low and moderate concentrations of Zn (McKenna et al. 1993; Podar et al. 2004), or on reduction of leaf concentrations of Zn in *Phragmites australis* after Cu-amendment (Weis et al. 2004).

Although considerable uptake of all heavy metals into, or adsorption to, roots was encountered in this study, translocation from below- into above-ground parts of *S. patens* was not significant with values in shoots remaining within normal limits for plant tissue even in treatments with Ni-amendment (Marschner 1995; van Driel et al. 1995; Swaileh et al. 2004). Levels were always well below those encountered in plants from more industrial areas and highly contaminated soils (Deram et al. 2006). Thus, our

results do not indicate any potential of *S. patens* to act as a conduit for the movement of toxic metals into the food web when this plant species is used for the restoration of moderately contaminated salt marshes like Harrier Meadow.

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