

RESEARCH ARTICLE

Soil assessment for urban agriculture: a Vancouver case study

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Abstract

With the expansion of urban agriculture in many North American cities, there is a current need to evaluate the soil and urban environment to assess potential risks of metal contamination in urban grown food. In this study, a university farm, a community garden, and a brownfield located in Vancouver, BC were characterized with respect to soil metal concentrations, atmospheric deposition of metals, and bioaccumulation of metals in *Poa pratensis*. Wet and dry deposition were collected over five months. Aqua regia and HCl extractions were used to evaluate total and labile metal fractions of Zn, Pb, Ni, Mn, and Cu. Highest soil metal concentrations, atmospheric deposition flux, and bioaccumulation in *Poa* were found at the community garden, followed by the brownfield site, and the University of British Columbia Farm. Concentrations of Ni and Mn seem to be associated with soil parent material, while Zn, Pb, and Cu were indicators of industrial activity. Concentrations of metals in atmospheric deposition were not an immediate concern but their potential accumulation in the soil requires attention. The framework developed by the case study identified three factors meaningful for assessing metal contamination on an urban agriculture site: site history, atmospheric deposition trends, and parent material.

Keywords: Trace metals, urban agriculture, metal deposition

1. Introduction

1. 1. The challenges of urban agriculture

Urban agriculture currently raises public health and food safety concerns because of environmental pollution in cities. In Vancouver, as in other North American cities, industries are leaving the city core resulting in vacant lots potentially contaminated with metals and other chemical products. These sites are termed "brownfields" because they qualify as "abandoned, vacant, derelict or underutilized commercial and industrial properties where past actions have resulted in actual or perceived contamination and [there remains] an active potential for redevelopment"

(BC Ministry of Environment, 2013a). These sites are often converted to community gardens or urban farms for limited tenure and are managed by individual urban growers or non-profit organizations that may not be equipped to deal with on-site contamination.

Sites of urban agriculture are commonly located in areas of high traffic density, industrial activity, and air pollution. Lee *et al.* (2007) and Li *et al.* (2001) reported atmospheric deposition as a major contributor to metal contamination in urban soils. Lead has been the most prevalent heavy metal pollutant, as it was a significant component of petroleum products

in Canada until 1990 (Environment Canada, 2010). Historical resource-based land uses in the Fraser Valley of B.C. also led to recorded high emissions of Pb, Ni, and Zn during 1960-1966 (Pott and Turpin, 1996). Since plant uptake and groundwater leaching tend to be low, metals persist in soils for long periods of time causing unique environmental concerns (Dudka *et al.*, 1996). The variability of emission rates, metal bioavailability in soils, and plant uptake increases the complexity of addressing atmospheric deposition and limits comparability among studies. Few studies have investigated metals in the urban environment from the perspective of how long-term atmospheric deposition and contamination of soils can impact metal bioaccumulation in vegetation.

1.2. Sources and pathways of metal contamination in urban soils

Since metals of anthropogenic origin have been found to be more mobile and bioavailable than metals of lithogenic and pedogenic origin (Kabata-Pendias, 2001), accumulation of metals in urban dust and soils may be of particular concern. Metals may include Cd, Cu, Mn, Ni, Zn, As, and Pb originating from soil amendments such as commercial fertilizers, liming materials, agrochemicals, sewage sludge and irrigation water (He *et al.*, 2005). Past land uses such as recycling and disposal of metallurgical, municipal and industrial waste on-site can also result in the creation of waste dumps which promote the corrosion of metals and leaching of mobile constituents into the underlying soil (Alloway, 1995). Contamination of urban soils, most substantially from Zn, Pb, and Cu, have been found in industrialized cities across the world: Hong Kong (Li and Liu, 2001), New Delhi (Singh and Kumar, 2006), and Toronto (Wiseman *et al.*, 2013). Thus, it is likely that metal concentrations at brownfield sites in Vancouver will be enriched in comparison to background levels.

The geochemistry of soils reflects the influences of both natural soil formation processes and human additions on the existing parent material. Parent materials rich

in clay tend to have relatively high natural metal concentrations due to their high adsorption capacity (Alloway 1995). The parent material of the podzolic soils, in the Vancouver area, originated from coarse textured glacial, marine, or glacial-marine till and contain appreciable amounts of Al, Fe, and Mn (Iverson, 2012). These oxides and hydroxides form strong bonds with metals that may function to limit the mobility of metal contaminants. Soil age may also play a role; in fresh soils that have not been exposed to leaching or with limited organic matter amendments, metals may be more bioavailable to plants because they are not tightly held in the mineral matrix or in stable humic compounds (Wiseman *et al.*, 2013).

Humans can be exposed to metals in soils through direct dermal contact with and/or ingestion of contaminated soils, as well as through inhalation of contaminated soil in the form of dust (Dudka *et al.*, 1996). Humans may also consume metals in the form of contaminated crop plants. Contamination of surface layers occurs as a result of atmospheric contributions of metal-containing exhaust deposits, often onto the leaf surface; while intrinsic contamination occurs through uptake of soil contaminants and storage in edible plant parts. Translocation and bio-accumulation of metals from soil to aboveground plant parts is variable by plant species and genotype (Peijnenburg *et al.*, 2006). Singh and Kumar (2006) found Pb and Cd to be mainly taken up through foliar deposition, while Cu and Zn through uptake from the soil. As such, leafy vegetation were found to predominantly accumulate metals from atmospheric deposition, while fruit or root-based vegetation accumulate metals from the soil.

1.3. Atmospheric deposition trends

Metal emissions may be moderated by seasonal trends; Lee *et al.* (2007) found the atmospheric load of Cd, Pb, V, and Zn to be highest during the winter and lowest during the summer. On a regional scale, Pott and Turpin (1998) noted a decline of metal deposition along a west-east gradient in Metro Vancouver, reflecting higher population densities along the coast.

Contrasting south-east/north-west winds and a thermal sea breeze pattern circulates atmospheric metals within this region. However, limited studies have been done on the magnitude of metal deposition in Metro Vancouver. Gelinas and Schmit (1998) observed that enrichment of metals from major roads decreased with distance and approached background levels at ~100m from a major road. Alternatively, Toronto Public Health (2011) has suggested that a 30m threshold distance is sufficient for reducing metal contamination concern.

1.4. Study Objectives

The purpose of this study is to provide an initial assessment of metal contamination of established and potential food-growing sites in Vancouver's urban soils. The assessment addresses the metal contents and accumulation in atmospheric deposition, soil, and subsequent bio-concentration in vegetation. Three sites were selected which exhibit a range of exposure to industrial activity, and soil metal contamination.

2. Methodology

2.1. Site history and sampling

Trace metal concentrations were assessed at three urban sites in Vancouver. Site history was investigated prior to sampling via information from the City of Vancouver and firsthand accounts from community members in each neighbourhood. Site assessment included an evaluation of topography, soil compaction, evidence of possible contamination (i.e. odours, oil slicks, anthropogenic debris), and type/presence of vegetation. Soil samples were taken from the top 0-30 cm of soil (the depth of rooting of most annual plants). Particular areas of interest included areas slated to be garden beds or play areas, and areas where contamination was suspected. Study sites included the UBC Farm at the University of British Columbia, the 16 Oaks community garden in the Shaughnessy neighbourhood, and a brownfield site

on Hastings Street and Glen Drive in the Strathcona neighbourhood (Figure 1).

The UBC Farm is a 24 ha university research site which integrates cultivated field areas with hedgerows, orchards, and maturing successional forest stands (UBC Farm, 2009). It is located in the sparsely populated South Campus of UBC which has experienced large scale development of residence buildings and shopping malls only within the last decade. The soil originates from glacial till parent material and is well-drained and sandy. It has been managed for the past 40 years with incorporation of organic matter into the topsoil (UBC Farm, 2009).

The 16 Oaks community garden was established in 2008; prior to that, the site was vacant for approximately ten years following the removal of a restaurant and parking lot. Oak Street and 16th Avenue is a moderately high traffic intersection; it serves as a major bus route and borders a predominantly residential area. The site is level and measures 1340 m² in area with soils originating from glacial marine parent material. No edible vegetation is grown in the native soil; various species of flowers and vegetables are grown on raised bed plots.

The Hastings site, 2130 m² in area, has been vacant for the past forty years (City of Vancouver, personal communication, January 15, 2012). It has a northern aspect and a relief of 2-3 metres from east to west. The Hastings brownfield is located on the northeast corner of the Georgia Street viaduct. The viaduct serves as a high traffic roadway and the Strathcona neighbourhood is populated by various industries. From 1955 to 1970, the site was used as a scrap metal yard. Attempts to remediate the soil included the addition of various layers of construction fill including medium sand and gravel for topsoil which overlays a metal-containing sand fill. The native soil, originating from marine parent material is deposited 1-2.5 metres below the surface. Site observations revealed that the soil is spatially heterogeneous and compacted in areas, with remnants of metal parts present within 30cm of the soil surface. The whole site is occupied by grasses, and regionally invasive shrubs and vines.

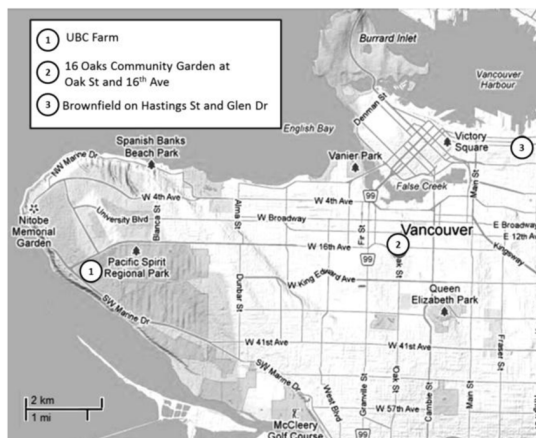


Figure 1. Locations of the study sites in Vancouver, British Columbia.

2.3. Testing for metals in soil, Kentucky bluegrass, and atmospheric deposition

Laboratory analysis included pH, organic matter content, and total and labile fraction extraction of metal contaminants of interest. In addition to soil sampling, native vegetation and atmospheric deposition were collected to determine an empirical relationship between traffic density and metal deposition. A stratified-random sampling design was applied to this study since limited information was available about the metal distribution at these sites. Two sampling events took place over October 2011 to February 2012 for the collection of individual and composite topsoil (0-20cm) samples, and root and shoot samples of Kentucky bluegrass (*Poa pratensis*), a hardy lawn grass common to all three sites. Wet and dry deposition was collected using an atmospheric deposition filter and rainwater collector that was placed at each of the sites near the location of soil and vegetation sampling. The system included a funnel which contained a 2.5µm filter (Whatman 42) housed in a wire chamber; the funnel was attached to a hose and a four-litre collection bottle. For the purposes of this study, “soluble” elements were categorized as those being less than 2.5µm in diameter. Collection of dry and wet deposition was carried out during the wet

season, starting from October and continuing for five months until March 2012.

Soil samples were air-dried for 48 hours prior to analysis. Vegetation samples (leaves and roots) were thoroughly rinsed with deionized water and dried, prior to being analyzed. Soils were sieved through a 2mm stainless steel sieve and soil pH was measured at 1:2 or 1:5 ratio in water and 1:3 in a 0.01M CaCl₂ solution (Hendershot *et al.*, 1993). An estimate of organic matter was determined for soil samples initially dried at 105°C and vegetation samples at 70°C prior to measurement by loss on ignition at 350°C and 550°C (Atkinson *et al.*, 1958). Five metals were selected for consideration, Zn, Pb, Ni, Mn, and Cu, as indicators of contamination. Two types of extractions were completed for comparative purposes to assess total and labile soil metal concentrations. Aqua regia extraction was applied to all soil and vegetation samples as described by Cheng and Ma (2001). HCl (at 0.1M dilution) was used to extract soil, and wet and dry deposition. This extraction method (Snape *et al.*, 2004) approximates the labile or mobile phases of metals (eg. water soluble and exchangeable fractions) in the soil or sediment as the proportion of metals available for plant uptake. All samples were analyzed using an inductively coupled plasma atomic emission spectrometer (ICP-AES).

3. Results

Data from the two sampling events were combined as no obvious differences in metal concentrations were observed. Soil properties of the farm, garden and

brownfield are given in Table 1. pH at the farm and brownfield were slightly acidic, while pH at the garden was closer to neutral. Loss on ignition estimates of organic matter were highest at the farm where values were doubled that of the other two sites.

Table 1. Mean values for pH and loss on ignition for topsoil at the three study sites.

Site	Sample Type (0-20cm)	Sample Size	pH in Water	pH in 0.01M CaCl ₂	LOI at 350°C (%)
UBC Farm	Native soil	9	5.80	5.16	11.7
16 Oaks Community Garden	Surface material	9	6.20	5.90	6.92
Hastings Brownfield	Surface material	14	5.84	5.14	4.95

Total metal concentrations were highest at the 16 Oaks community garden and lowest at the UBC Farm (Figure 2), which may be reflective of the more rural location of the farm, in contrast to the high traffic volume of the urban setting at the 16th Avenue and Oak Street intersection. The disparity in urban-rural soil metal concentrations have been observed by Li *et al.* (2001) and Salonen and Korkka-Niemi (2007).

Metal contributions via atmospheric deposition were also lowest at the farm and higher at the Hastings site, where the influence of shipping traffic at the ocean inlet may impact the metal concentrations meaningfully. Table 2 provides data on the variability of metal contents both within and among the sampled sites. A result of the various disturbances characteristic of urban sites is the greater variation in metal contents at 16 Oaks and the Hastings brownfield, as expressed by the range of values around the mean. Across all sites the order of available metal concentrations was Mn>Zn>Pb>Cu>Ni. Zn concentrations were very low at the UBC Farm and 4-5 times higher at 16

Oaks and the Hastings brownfield; Pb was highest at 16 Oaks and lowest at the UBC Farm; Ni and Mn concentrations were similar among all sites; and Cu was only sizable at the Hastings brownfield. Site history may be especially relevant to account for the enrichment of Zn, Pb, and Cu at the Hastings brownfield, which was previously a dumping-ground for metallurgical materials. The relatively high Mn concentration at the UBC Farm can be attributed in part to naturally high concentrations of metals found in parent material rich in clays (Salonen and Korkka-Niemi, 2007).

Topsoil (native soil or surface material) metal concentrations extracted by Aqua regia and 0.1M HCl were similar in their relative proportions. The ratio between total and labile metal concentrations ranged from 2 to 4 for Zn; approximately 3 for Pb to as high as 15 (for the UBC Farm); 5 to 8 for Ni; approximately 2 for Mn; with greatest variability for Cu, ranging from 2-12. This suggests that with the possible exception of Cu, HCl extraction, a much simpler laboratory protocol than Aqua regia, may be used as a proxy for an initial assessment

of potentially contaminated soil. Table 3 presents the mean and range of concentrations for metals in grass samples collected at the study sites. With few exceptions, a greater concentration of metals was found in the shoots than roots of Kentucky bluegrass, consistent with findings by Padmavathiamma and Li (2009). Zn and Pb concentrations are high at 16 Oaks and the Hastings brownfield and considerably lower at the UBC Farm, while Cu concentrations were only elevated at the Hastings brownfield. In contrast, Ni and Mn concentrations are similar across all sites. Greater variability overall is observed in the grass samples, notably for the UBC Farm where the highest mean concentration for Mn was found, perhaps as a result of the parent material of soil Mn (Luttmerding, 1981). The order of abundance for metals is similar to available metals in the soil with either Zn or Mn being most abundant. The ratio of metals in the roots and shoot ranged from 0.3 to 1 for Zn; 0.7 to 1 for Pb; 0.4 to 0.7 for Ni and approximately 0.4 to 1.2 for Mn and Cu. Results are consistent with Padmavathiamma and Li (2009) for Zn, Pb, Mn, and Cu. These results suggest that concerns regarding toxic effects of consuming plants on such sites extend beyond metal concentrations in soil and plant roots as the effect of bioaccumulation and translocation to edible plant parts may be substantial. Clearly, advocating for an expansion of urban agriculture warrants additional work for individual plant species as well as site conditions.

Although the data is limited and preliminary, atmospheric metal inputs into the study sites were predominantly in the form of dry deposition, affirming findings by Harrison and Chirgawi (1989). Differences in metal concentrations of up to five orders of magnitude were found. Metal concentrations in wet deposition were consistent with the range observed in snowpack in eastern Canada by Barrie and Vet (1984). Evaporated deposition samples were not weighed, thus flux calculations in Table 4 approximate contributions from dry deposition only. The relative order of

abundance of metals is $\text{Zn} > \text{Cu} \approx \text{Pb} > \text{Ni} > \text{Mn}$. Dry deposition fluxes ranged from nearly $1600 \mu\text{g}/\text{m}^2/\text{day}$ for Zn to less than $2 \mu\text{g}/\text{m}^2/\text{day}$ for Mn. Metal concentrations for Mn and Pb are within the low range observed by Brewer and Belzer (2001) at Burnaby Lake. The 16 Oaks Community Garden exhibited the highest flux for all metals followed by the Hastings Brownfield and the UBC Farm. The difference in flux between each site is approximately three-fold for Zn, and two-fold for Pb and Cu between the UBC Farm and the Hastings Brownfield.

These findings are consistent with deposition patterns of metals in urban and rural settings in eastern Canada where Zn and Cu, metals commonly associated with transportation sources, were found to accumulate in industrial areas (Barrie and Vet, 1984). Since Zn is commonly emitted from vehicular traffic and tire wear, the notably high Zn flux at 16 Oaks may be largely attributed to road dust and the high traffic density observed at this site. The large flux of Pb and Cu at the 16 Oaks and Hastings site suggests that a local source is contributing to these metal concentrations; this may be attributed to the proximity of the 16 Oaks site to shipping routes for the Canadian National Railway and the Burlington Northern-Santa Fe Railway, and the proximity of the Hastings site to the Vancouver Wharves Terminal (i.e. aviation float planes and helicopters) and to the shipping route for the British Columbia Railway (Port Metro Vancouver, 2010). Although Pb is no longer used as a gasoline additive, higher concentrations appear to be associated with high traffic areas consistent with Brewer and Belzer's (2001) findings for the persistence of residual Pb in particulate metal concentrations measured at Burnaby Lake.

The results demonstrate the need to address atmospheric contributions as well as soil metal concentrations in making a true assessment of metal contents in urban soils and plants that are grown for human consumption.

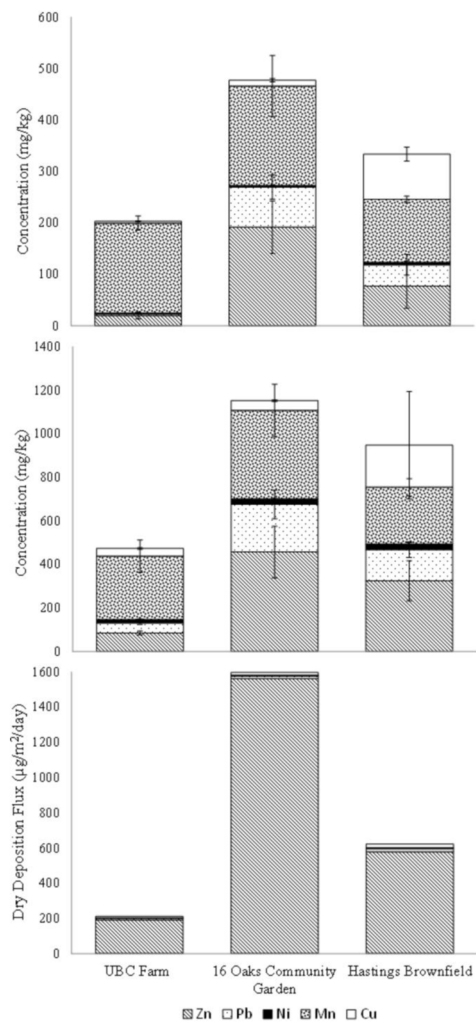


Figure 2. a) Total (Aqua regia extraction) soil metal concentrations; b) labile (0.1M HCl extraction) soil metal concentrations; and c) dry deposition metal flux at the three study sites. Standard error bars are shown.

Table 2. Maximum, mean, and minimum concentrations of Zn, Pb, Ni, Mn and Cu in topsoil at the three study sites, extracted using Aqua regia and 0.1M HCl.

Site	Extraction type for topsoil (0-20cm)	Sample Size		Zn	Pb	Ni	Mn	Cu	
(mg/kg)									
UBC Farm	Aqua regia	9	Max	133	81.8	37.4	785	55.2	
			Mean	85.1	44.9	16.4	291	35.4	
			Min	50.7	21.8	6.1	110	23	
	0.1M HCl		Max	72.2	5.5	4.5	234	7.7	
			Mean	20.1	3	1.8	175	3.2	
			Min	7.7	1.4	0.7	97.7	1.6	
16 Oaks Community Garden	Aqua regia	9	Max	1320	234	56.7	1230	62.8	
			Mean	456	219	24.3	407	45	
			Min	160	110	13.7	113	35.7	
	0.1M HCl		Max	456	240	5.1	547	35.6	
			Mean	191	78.1	2.9	193	11.2	
			Min	60	15	1.4	69.1	2.2	
Hastings Brownfield	Aqua regia	14	Max	1080	499	90	593	3610	
			Mean	324	143	26.1	260	193	
			Min	63	46	9.2	122	45.8	
	0.1M HCl		Max	561	224	38.2	179	193	
			Mean	76.8	41.6	4.7	122	87.9	
			Min	15.9	11.8	2.8	99.5	17.7	

Table 3. Maximum, mean, and minimum concentrations of Zn, Pb, Ni, Mn and Cu in root and shoot of *Poa pratensis* at the three study sites.

Site	Kentucky Bluegrass (<i>Poa pratensis</i>)	Sample Size		Zn	Pb	Ni	Mn	Cu
(mg/kg dry matter)								
UBC Farm	Root	5	Max	221	71.9	33.4	541	92
			Mean	174	53	15	427	72.4
			Min	87.4	43.4	2.7	262	48
	Shoot	6	Max	2260	105	97.7	2920	264
			Mean	738	82.2	36	1350	150
			Min	285	62	7.2	748	81.2
16 Oaks Community Garden	Root	5	Max	2970	1130	62.5	790	161
			Mean	1360	455	35.8	399	106
			Min	607	157	12.4	165	63.5
	Shoot	6	Max	2990	923	121	1070	230
			Mean	1330	387	53.3	506	148
			Min	430	178	7.2	88.5	85.3
Hastings Brownfield	Root	5	Max	1070	198	63.8	594	583
			Mean	843	172	46	403	448
			Min	491	102	34.4	201	259
	Shoot	6	Max	1930	702	145	1860	616
			Mean	905	253	63.7	814	290
			Min	326	83.3	22.7	172	104

Table 4. Mean dry deposition flux of Zn, Pb, Ni, Mn, and Cu at the three study sites.

Site	Zn	Pb	Ni	Mn	Cu
Flux ($\mu\text{g}/\text{m}^2/\text{day}$)					
UBC Farm	191	7.40	2.28	1.61	8.31
16 Oaks Community Garden	1560	14.2	2.39	4.07	14.9
Hastings Brownfield	578	16.7	3.48	2.58	21.5

4. Discussion

4.1. Soil factors impacting metal accumulation and availability

The similar concentrations of Ni and Mn metals across the topsoil and subsoil within each site suggests that for immature soils the influence of the original parent material is larger than the atmospheric load (Salonen and Korkka-Niemi, 2007). The divergence in values for Zn, Pb and Cu may be attributed to specific site history and local deposition trends at the 16 Oaks and Hastings sites. Total metal concentrations in soils and parent materials in the Lower Fraser Valley range from 50 to 150 ppm for Zn, 20 to over 920 ppm for Mn, and 20 to 50 ppm for Cu (Luttmerding, 1981). Background soil metal concentrations found for Pb and Ni are 60 ppm and 80 ppm, respectively (B.C. Ministry of Environment, 2013b). Based on these estimates metal concentrations at the UBC Farm can be considered near background levels, while 16 Oaks and the Hastings brownfield exhibit elevated levels for Zn and Pb and Zn, Pb and Cu, respectively. The elevated metal concentrations in sites with greater industrial activity are consistent with anthropogenic inputs of metals.

Since pH is one of the main factors determining metal mobility, the close agreement of slightly acidic pH values (>5.5) at all three sites indicates that current soil conditions may be limiting the bioavailability of trace metals to plants. Cu is specifically adsorbed in soils decreasing its potential as a mobile trace metal,

while Pb is reported to be the least mobile trace metal (Kabata-Pendias, 2001).

Translocation of metals from roots to shoots depends on both the metal and the variety of plant. Plant uptake of metal contaminants is influenced by the morphology of the leaves as determined by conditions of plant growth (Peijnenburg *et al.*, 2006). Through regression analysis, Padmavathiamma and Li (2009) found that root length, shoot length and the number of branches/root are the main factors influencing metal concentrations in plants. Heterogeneous growth conditions were observed within and among the sites, thus the degree of foliar uptake could not be accounted for in this study. Padmavathiamma and Li (2009) found *Poa* to have phytostabilization capacity (i.e. higher accumulation in the roots as compared to shoots) in highways soils for Zn, Pb, Mn, and Cu with highest accumulation for Mn. In this study, higher concentrations tended to occur in shoots with inconsistency among sites, which may be attributed to the method of passive metal uptake observed for this plant (Peijnenburg *et al.*, 2006). The degree of plant metal bio-accumulation was found to reflect soil metal concentrations suggesting that *Poa* has limited preference for accumulation in specific vegetative parts. As a consequence of the limited sampling size, it is inconclusive if meaningful differences in uptake exist among metals. Despite the relative immobility of Pb, it was observed to bio-accumulate in similar proportions to Zn, which tends to efficiently translocate to all plant parts (Davies, 1995).

Koepe (1977) proposes that uptake of Pb is highly dependent on physiological status. Under conditions of optimal growth Pb precipitates on the root cell wall and does not accumulate in the shoots. There is also a seasonal component by which Pb content in grass shoots increases during autumn and winter when plants are not in their period of active growth (Mitchell and Reith, 1966). This study examined *Poa* during what may be its senescent stages.

4.2. Measured deposition trends

Calculated enrichment factors for total deposition at various non-urban and urban locations in Europe and North America is sequenced as $Pb > Zn = Cu > Ni > Mn$ (Kabata-Pendias, 2001). A higher enrichment factor indicates greater importance of deposition as a source of these metals in soils and plants. This ordering generally approximates what was observed in bulk deposition in this study, with the exception of Pb concentrations being much lower than Zn concentrations. This may be attributed to the declining use of Pb in gasoline products post 1975 as vehicle emissions were the largest atmospheric contribution of Pb. Metals in street dust have been found to have higher concentrations and mobility than metals in urban soils because of their adsorption to coarse-sized, easily weathered calcite minerals (Li *et al.*, 2001). While Zn, Pb and Cu seem to be associated to anthropogenic activities Ni and Mn may be within background concentrations across all sites. This study has not been able to evaluate micro-climate effects on deposition of metals or the range of impact of emissions sources. From observation, the high flux of metals in dry deposition largely correspond to re-suspended soil particles, road dust, and industrial combustion products that due to their relatively large size tend to deposit close to the emission source. The low concentrations observed in wet deposition (particulate fraction $< 2.5 \mu m$ in diameter) suggest that high temperature emissions typically responsible for the emission of the fine fraction, do not contribute significantly to metal loading in these areas.

The different order of abundance of metals in soil and deposition indicates that atmospheric contributions is most meaningful for Zn and Pb which are already abundant in the soils at 16 Oaks and the Hastings brownfield. Enrichment of these metals in the soil may have occurred through long term deposition in addition to specific soil conditions. While Mn is relatively abundant in soils, atmospheric contribution of this metal is relatively small. This is unexpected as several Canadian studies (Simonetti *et al.*, 2010) have found high Mn contributions and attribute it to the use of MMT as an anti-knock replacement for tetra-ethyl lead. Cu enrichment may be of concern only at the Hastings brownfield.

4.3. Interpreting results within the context of provincial standards for metal contamination

The B.C. Ministry of Environment's (2013b) total metal standards for agricultural land use according to the Contaminated Sites Regulation is 150 ppm for Ni using a generic numerical soil standard; 450 ppm for Zn, 1000 ppm for Pb, and 150 ppm for Cu using a matrix numerical soil standard for toxicity to soil invertebrates and plants. No standards were provided for Mn, suggesting that it is not a metal of concern for soil contamination. None of soils sampled from the UBC Farm contained trace metals in excess of these standards. Mean values for total Zn at 16 Oaks and total Cu at the Hastings brownfield were above these standards, but exhibited wide variability among samples. The additive load of atmospheric deposition may be significant for metals that are already abundant in these soils. It is not conclusive whether bio-concentration in shoots results from metal translocation or from absorption at the foliar surface. As such, the level of complexity involved in metal uptake and the long residence time of metals in soil should not be underestimated.

4.4. Assessing metal contamination in urban soils

This study revealed three factors to be relevant for urban soil metal assessment: site history, deposition

trends, and parent material. Preliminary evaluation involved collecting site-specific information from city archives and community members, as well as observing site conditions and estimating the level of industrial activity in its proximity. Guidelines for assessing site history have been created by other Canadian cities such as Toronto (Toronto Public Health, 2011) and Montreal to determine the potential level of concern posed by a site. Secondary evaluation can be completed for sites posing medium to high levels of concern; this includes the physical testing of specific soil factors, total metal concentrations, and if feasible, deposition trends. Metal concentrations should then be evaluated according to the relevant standards under provincial or municipal regulations.

5. Conclusion

Three sites of interest to urban agriculture in Vancouver were investigated to determine metal accumulation from native soils/ surface material and atmospheric deposition, and the potential for subsequent bioaccumulation in *Poa pratensis*. Current industrial activity and historical metal contamination were found to impact metal accumulation of Zn, Pb, and Cu in soils at the 16 Oaks community garden and Hastings brownfield. Soil metal concentrations at the UBC Farm were within provincial standards for agricultural land. The proposed framework for urban soil metal assessment intends to provide a holistic strategy to address the complexity of metal accumulation in urban soils. While there remain limitations to its applicability, the outcomes of this framework can guide future management practices that minimize concerns of food safety on an urban growing site.

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