An assessment of trace metals in the soil, vegetation and atmospheric deposition of urban areas in Vancouver

by

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ABSTRACT

Urbanization of recent decades has motivated the expansion of urban agriculture as a means to address growing concerns of food security, climate change mitigation and community building, especially in areas facing socio-economic challenges. Community gardens are often relegated to brownfield sites which may have contained some degree of soil contamination prior to remediation. The intrinsic placement of gardens in areas of high industrial exposure poses a concern for atmospheric deposition as another source of contaminants. Metals are of particular interest because they have large anthropogenic contributions and persist in soils for very long periods of time. This study investigates metal concentrations in the native soil and atmospheric deposition of three sites, which represent a range in crop production, site history and industrial exposure. Metal accumulation in the rhizosphere soil, root and shoot of Kentucky bluegrass was assessed. Study sites include the UBC Farm, the 16 Oaks community garden and a brownfield in the Strathcona neighbourhood. Field sampling of topsoil and vegetation took place in the fall. In addition, wet and dry deposition were collected over a period of five months. HCl and aqua regia extraction were performed to determine the labile and total fractions of metals in the soil, vegetation and deposition. During this time Zn, Pb, Ni, Mn and Cu were found at detectable concentrations at all sites. Total metal concentrations were highest at 16 Oaks and lowest at the Farm. Dry deposition was the main mechanism for atmospheric metal contributions and was largest at the Brownfield and lowest at the Farm. Ni and Mn seem to largely originate from parent material while Zn, Pb and Cu may be considerably influenced by atmospheric deposition. High mobility into root and shoot were observed for all metals with large variability at 16 Oaks and the Brownfield. This may be attributed to site heterogeneity, lack of plant preference for accumulation into vegetative parts and large variability in foliar uptake. Future siting of community gardens needs to address the potential additive effects of native soil contamination and atmospheric deposition, as parent material, site history and current deposition trends seem to be complementary to overall soil and vegetative health.

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1. INTRODUCTION

1.1 Community gardens and urban sources of metal contamination

Urbanization is a global phenomenon and one that often consumes valuable lands that constitutes the rural, agricultural and natural landscapes. In 2006, 80% of the national and 85% of the British Columbian population were reported to live in urban centres (Statistics Canada 2012). Population pressure increases the energy demands of the city often leading to increased resource consumption and waste production. Communities are not equally affected by this demand as those with lower socio-economic status are more vulnerable to food insecurity (Barbolet *et al.* 2005). An urban food strategy addresses concerns of growing poverty and food security by providing local and often organic alternatives for food production (Okvat and Zautra 2011) which reduces the fossil fuel load necessary to grow and transport food, indirectly reducing the amount of waste exported from the city (Nolasco da Silva 2007). The growth of community gardens has been particularly significant in Metro Vancouver due to the lack of access to fresh produce in vulnerable areas such as the Strathcona/DTES, Grandview-Woodlands and Renfrew-Collingwood neighbourhoods (Barbolet *et al.* 2005). Small, often vacant plots can be used as gardens to supplement diets or provide the primary source of fresh vegetables and fruit.

The practice of urban agriculture provides a sustainable use of green spaces; addresses the concerns associated with climate change; and, enhances the social wellbeing and economic value of the community. The creation of habitats for birds and other small animals enhances urban biodiversity, while absorption of air pollutants by plants and trees enhances urban health (US EPA 2011). Climate change mitigation is achieved both directly and indirectly through the uptake of greenhouse gases and through lifestyle change and education. Niinemets and Penuelas (2007) suggest that garden plants may exhibit a disproportionately large contribution to the earth's carbon balance because urban plants are usually grown with little to no natural predators, at naturally high temperatures, with high available CO_2 and nitrogen deposition. As such, urban-grown plants have been observed to have greater photosynthetic rates than rural-grown plants. From a social perspective gardens provide sites for daily interaction, celebration of special events, and educational tours for youth (Saldivar-Tanaka and Krasny 2001). Low-income and immigrant communities are

given the opportunity to grow culturally salient food and interact with nature in an accessible and affordable way. Economic benefits can range from costs saved from growing one's own vegetables to increasing the property value of a neighbourhood in close proximity to a garden (US EPA 2011).

In Metro Vancouver, access to land is a significant challenge because of high property values and growing populations (Kaethler 2006). Globally, urban agriculture occupies public land or land leased from a local landlord (Bryld 2003). The expansion of urban agriculture places intense pressure on the remaining available plots of land. As a result, gardens are often relegated to brownfield sites which prior to development may have contained industrial waste and/or exhibit some form of soil contamination (Devine 2007). Several garden sites in Vancouver have even been established on closed-down gasoline stations which have been capped and left standing for several years. Limited land tenure also constrains longer term site remediation. In Vancouver, land tenure is given for approximately five years (Kaethler 2006) which limits the incentive and capacity for gardeners, landowners or the municipal government to invest time and capital to remediate a potentially contaminated soil. As an alternative, raised beds of imported fill from the city or compost from local farms are often used as the growth media after the native soil has been extensively covered with nylon sheeting (pers. comm. Bouchard, Community Gardener 2011). Vegetation grown in raised beds currently dominate community gardens in urban Vancouver.

A prominent feature of community gardens is its proximity to urban centres, which often parallel regions of high traffic density, industrial activity, and air pollution. Sezgin *et al.* (2003) and Li *et al.* (2001) have reported atmospheric pollution to be a major contributor to heavy metal contamination. Lead often being the most important heavy metal pollutant as it was a significant component of petroleum products (Sezgin *et al.* 2003) prior to Gasoline Regulations made under the Canadian Environmental Protection Act in 1990 (Environment Canada 2010). In cases of point-source emissions Fakayode and Onianwa (2002) and Moseholm *et al.* (1992) found topsoil and vegetation to be meaningful sinks for dry and wet deposition of metals. Harrison and Chirgawi (1989a) propose that the extent of metal retention depends on the particle size distribution, weather conditions, plant surface characteristics, the solubility of the chemicals, and the chemicals present on the plant surface. The variability of emission rates and plant uptake (Moseholm *et al.* 1992) increases the

complexity of addressing atmospheric deposition and limits the level of comparability among studies.

Urban agriculture is valuable because it has the potential to address the intersection of environmental, social and economic needs within a growing urban population. However, the quality of community gardens as an urban artifact requires investigation into how metal concentrations in the soil and vegetation are affected by the atmosphere and native soil environment. Metals are of particular concern because they persist in soils for very long periods of time since leaching and uptake and removal by crops are generally low (Dudka and Miller 2008). Therefore contaminated sites have the potential to impact plants and humans for a long period of time. While actions can be taken to ameliorate the effects of contaminated native soil, atmospheric deposition of pollutants is largely affected by the intrinsic placement of gardens in or near urban centres. The effect of dry and wet deposition of metals from non-point sources in current and future sites of urban agriculture needs to be determined before claims can be made of the nutritional and ethical value of growing vegetation to support communities facing food insecurity.

1.2 Metal distribution and transport in the atmosphere and soil

Historically the term "heavy metals" has been used to describe metals which had a density greater than $3.5\text{-}7\text{g/cm}^3$ (Duffus 2002). The lack of consensus in establishing a definite threshold density resulted in a general abandonment of this definition. Density has been found to have little significance on the reactivity of a metal providing further support to develop a classification of metals based on their chemical properties. Currently the use of this term in the literature connotes that these metals (or their compounds) are toxic (Appenroth 2010). While some metals may be benign or even beneficial in small concentrations toxicity may occur when a threshold limit is exceeded (Tiller 1989). The term "trace metal" is also commonly used to describe the relative quantity of metal contaminants in the soil. Historically the term was used to describe elements that are ubiquitous but hard to detect (Tiller 1989). Currently, "trace metal" is defined as an element which is present at a concentration of less than 100 parts per million in a sample of soil (Banfalvi 2011). Trace metals are equivalent to micronutrients which are needed in minute quantities for proper growth, development, and physiology of an organism. Essential micronutrients for plant

growth include boron, chlorine, copper, iron, manganese, molybdenum and zinc (McKenzie 2001). Bowen (1979) suggests that when the rate of mining of a given element exceeds its natural rate of cycling by a factor of ten or more, the element must be considered a potential pollutant. According to this definition, the following metals may be considered most hazardous to the biosphere: Ag, Au, Cd, Cr, Hg, Mn, Pb, Sb, Sn, Te, W and Zn. However, elements that are considered to be of greatest risk to environmental health do not necessarily overlap; these include: Be, Cd, Cr, Cu, Hg, Ni, Pb, Se, V and Zn (Kabata-Pendias 2001).

Accumulation of metals in soil may arise from natural and anthropogenic sources (Figure 1). In igneous rocks, trace metals occur as trace constituents of primary minerals (Alloway 1995). They are incorporated in minerals through isomorphic substitution in the crystal lattice as governed by the ionic charge, ionic radius and electronegativity of the major element and the trace element substituting it. Because sedimentary rocks comprise 75% of the earth's rocks, secondary minerals may be more relevant for soil parent material. Generally clays and shales tend to have relatively higher element concentrations because of their capacity to adsorp metal ions.

Anthropogenic additions of soil amendments directly to a site may be a significant source of metals especially if accumulation has occurred after some years; these may include commercial fertilizers, liming materials, agrochemicals, sewage sludge and irrigation water (He et al.2005). Recycling and/or disposal of metallurgical, municipal and industrial waste can also result in the creation of waste dumps which promote the corrosion of metals and leaching into the underlying soil (Alloway 1995). In addition, urban sites often contain infill following remediation practices such as excavation. Infill results from the demolition of urban structures and may contain a high proportion of processed wood, glass, ceramics, plastic, asphalt, metal and building stone (Craul 1992). Chemically, anthropogenic artifacts may alter the composition of the soil (Bullock and Gregory 1991). These artifacts may release metals directly into the soil or create conditions that are favourable for their (im)mobilization.

Metals emitted into the atmosphere are transported through the movement of air masses and can migrate considerable distances from their source. They are deposited in soluble form in rainwater and as particulate matter in dry deposition. Natural emissions of metals include eroded soil particles which may account for approximately 20-30% of the Cu,

Pb, Ni, and Zn emitted from natural sources (Nriagu 1989) and only 6% for Cd (Nriagu 1979). The contribution of volcanic emission is enhanced for Cd, accounting for 40-50% of its natural emissions compared to 20-40 % for Pb, Cu, Zn, Ni, and Sb (Nriagu 1989). Nriagu suggests that vegetative exudates are only significant (20%) for the emission of Zn into the atmosphere. Other sources such as sea spray and forest fires represent only minor sources which comprise less than 10% of the total natural emissions (Nriagu 1989).

Anthropogenic emission of metals results from the combustion and processing of fossil fuels, metal ores, as well as industrial products (Pacyna and Pacyna 2001). Industrialization in recent decades has led to "mankind [becoming] the key agent in the global atmospheric cycle of toxic metals" (Nriagu 1989). Nriagu reports that anthropogenic emissions exceeded natural rates of Pb and Cd emission by more than an order of magnitude (1979). Cu, Ni, and Zn exhibited anthropogenic increases of approximately 300%, 200%, and 700% of their natural source emissions. The main source of anthropogenic emission of nonferrous heavy metals is primary metal production, with the exception of lead which originates mainly from vehicular pollution. Pacyna and Pacyna (2001) found that some metals enter the atmosphere with exhaust gases as they evaporate from raw material during high-temperature production of industrial goods, combustion of fuels, and incineration of municipal and industrial wastes. Accidental release from landfills or spills to water bodies may also result in volatilization and entrainment of metals.
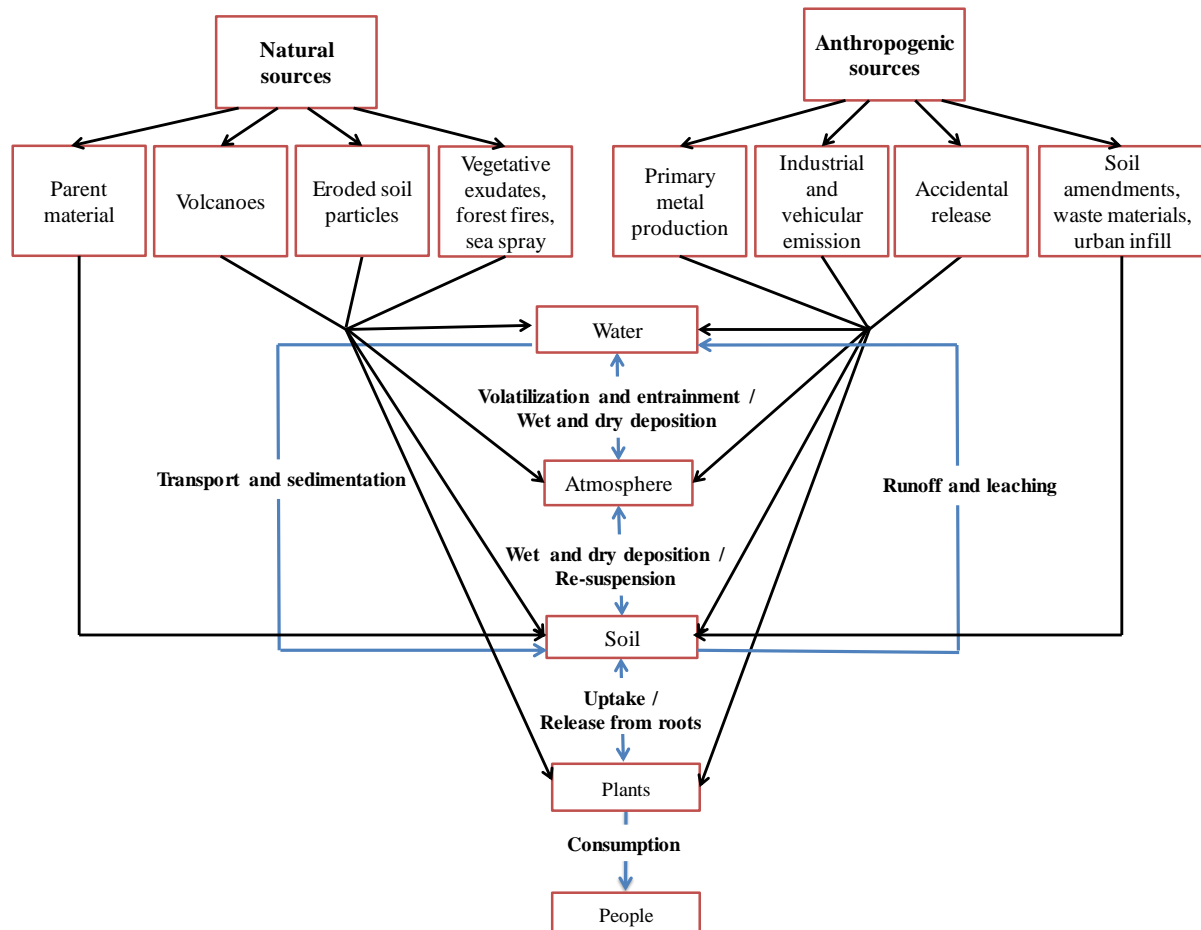
Figure 1. Pathways of metal transport to the human population.

During deposition, the particulate fraction released or produced in the atmosphere range from 0.005-500µm (Smith 1977). The fine fraction accounts for particles in the range of 0.01-1µm while the coarse fraction corresponds to particles greater than 10µm in diameter. Artinano *et al.* (2003) found that particles smaller than 2.5 µm correlate with the dominant particles size in vehicular emissions. The fine fraction consists of gases emitted from high temperature processes such as coal and waste incineration (Allen *et al.* 2001) which have condensed to form non-volatile products (Smith 1977). Particles in this fraction tend to have long residence times, deposit slowly and travel far distances from the source of emission (Witt *et al.* 2010). Soil particles, process dust, industrial combustion products, and marine salt particles account for the mid-size range of 1-10 µm (Smith 1977). Associated metals likely have mechanical and high-temperature sources and are transported through the

advection of air masses (Allen *et al.* 2001). The coarse fraction corresponds to particles that frequently result from mechanical processes such as the resuspension of soil or road dust (Galloway *et al.* 1982). These metals likely have short residence times and are quickly removed from the atmosphere (Witt *et al.* 2010). The size of the metal bearing particle may determine whether wet or dry deposition will dominate (Galloway *et al.* 1982). Fine particles and gases are transported high into the upper troposphere and can be incorporated into the formation of raindrops. Larger particles include resuspended soil and dust and do not reach high altitudes where rain forms; these particles are inefficiently carried by precipitation and are mainly deposited dry. Smith (1977) identified three main pathways for atmospheric deposition: i) sedimentation due to gravity which is significant for larger particles; ii) impaction due to release from eddy currents; and iii) deposition due to precipitation. In some regions, the atmospheric load of heavy metals, specifically Cd, Pb, V, and Zn is highest during the winter and lowest during the summer (Lee *et al.* 2007). The distribution of particles is influenced by anthropogenic forces; in regions of moderate to high traffic density fine particles were found to be a minimum in the summer as traffic density declined (Artinano *et al.* 2003).

1.3 Metal availability in soil

While long-distance transport of metals occurs as particulate matter, movement of metals within the soil mass occurs mainly in the aqueous phase. Plants accumulate metals within their roots and shoots through water uptake (Robinson *et al.* 2006). Metal solubility ultimately determines its availability to be taken up or bio-accumulated by plants. Factors which determine this uptake include pH, redox conditions, adsorption/desorption, the presence of other ions, metal complexation (solution/precipitation), and the type of soil and vegetation present. Not all processes are equally important for each element but all processes are affected by soil pH/redox potential and biological processes (He *et al.* 2005). Since many metals form cations or oxycations in solubilized forms, they are more likely to be adsorbed to particle surfaces at high pH; in contrast, metals that have high charge and form oxyanions are more likely to be adsorbed to particle surfaces at low pH. Redox conditions can indirectly affect metal availability by determining which oxidation state is most stable (Robinson *et al.* 2006). Reddy and Chinthamreddy (1999) found that at low pH and under oxidizing

conditions Cr(VI) is more stable than Cr(III); however, most Cr(III) compounds are sparingly soluble at the normal range of pH in soil while some Cr(VI) compounds are very soluble (US EPA 2012).

In the soil matrix, ion composition can impact metal mobility. Competing ions can affect the capacity for metals to adsorp to particle surfaces as replacement usually occurs for ions with similar radii (Robinson *et al.* 2006). Luo and Rimmer (1995) observed in the zinc-copper interaction that the addition of copper increased the amount of readily available zinc to plants; this occurs because copper adsorption replaced sites once occupied by zinc. Precipitation of metals with phosphates or sulfides decreases mobility, while the presence of dissolved organic matter from root exudates increases mobility through chelation by functional groups (Robinson *et al.* 2006). Metals may also be associated with specific soil minerals which range in their capacity to weather, dissolve, and release metals in solution (Gibson and Farmer 1984). Desboeufs *et al.* (2005) found that metals dissolved from carbonaceous species often adsorbed impurities or salts that were highly soluble with dissolution having little pH dependence. Metals dissolved from the aluminosilicates, specifically bound to Fe/Mn oxides were less soluble with dissolution having high pH dependence.

Plants also exhibit preference in associating with metals as some may act as metal excluders or non-excluders (i.e. indicators and hyperaccumulators of metals) (Raskin 1994, Chaudhry *et al.* 1998). Metal excluders can effectively prevent metals from entering their aerial parts, though accumulation may still occur in the roots. Indicators reflect metal levels in the soil, while hyperaccumulators concentrate metals in their above ground tissues to levels exceeding those present in soil.

1.4 Atmospheric deposition onto vegetation

Initially foliar contamination was considered to be preventable by washing vegetation prior to consumption (Motto *et al.* 1970); however, studies have shown that deposited metals may enter inner plant tissues (Ernst and Cramer 1980). In a laboratory experiment, Harrison and Chirgawi (1989a) and Azimi *et al.* (2003) discovered that in many cases dry deposition is the dominant mechanism of particle transfer since the net effect of wet deposition is often to

cleanse the plant. An exception may apply during particularly rainy periods for the more soluble metals (e.g. Cd, Zn and V).

The rate of uptake and accumulation of metals by plants is usually associated with their concentrations in the soil (Harrison and Chirgawi 1989a). Vegetation nurtured in a growth chamber had relative atmospheric contribution of Cd, Cr, Ni, and Pb which ranged from 8-96%. Lower atmospheric contributions indicated greater ease of metal uptake from the soil which was observed for Cd and Zn. Harrison and Chirgawi (1989a and 1989b) found that metals behaved differently in their translocation to unexposed parts of the vegetation. Cd and Pb were found to accumulate preferentially in the leaves as compared to the storage roots while all plant parts efficiently accumulated Zn. Edible portions (i.e. fruiting bodies or storage tissues) of crops tend to accumulate less metals and display lower sensitivity to increases in metal concentrations than vegetative tissues (Motto *et al.* 1970). Harrison and Chirgawi (1989a) found that the efficiency of uptake was high for Zn and Cd, low for Pb and moderate for Ni and Cr. Urban areas of India demonstrated corresponding trends with maximal uptake for Zn followed by Cu, Cd and Pb (Sharma *et al.* 2008).

Results from field studies of metal uptake were comparable to those in the growth chamber: Cd was excluded from accumulation in the pea fruit; Cr accumulated in the pea leaves but not in the pods or fruit; and Pb demonstrated minimal translocation in the roots and within the plant system. Higher metal concentrations were consistently found in exposed parts as compared to non-exposed parts of the plant. Accumulation of heavy metals in plants may affect absorption and transportation of essential elements, damage plant structure, affect physiological and biological activities and decrease the overall functions of the plant (Cheng 2003). Different vegetative species tend to accumulate different metals, possibly due to differences in leaf surface-to-volume ratios and in surface and uptake characteristics (Harrison and Chirgawi 1989a, Chaudhry *et al.* 1998). On a short time scale, atmospheric deposition contributes directly to foliar contamination and on a long time scale it contributes to metal contamination in soils.

1.5 Study objectives

      This study investigates the significance of metal contributions from the native soil and atmospheric deposition for accumulation of metals in the root and shoot of Kentucky bluegrass. Three sites were selected which exhibit a range of exposure to industrial activity, native soil metal contamination, level of management and production of food crops. Study sites include the UBC Farm at the University, the 16 Oaks community garden in the Shaughnessy neighbourhood, and a brownfield on Hastings Street and Glen Drive in the Strathcona neighbourhood (Figure 2). The main objectives of this study are to provide a preliminary assessment of:

- the bulk (wet and dry) atmospheric contribution of metals to the three sites and how they compare with the soil contribution of trace metals;
- the preferred pathway for metal accumulation (i.e. in the soil, roots or foliage);
- the relationship between pH, organic matter and the accumulation of easily extractable and total metal concentrations in the soil at each site; and
- the potential implications of the findings for the future siting of community gardens.

      The UBC Farm is expected to exhibit the lowest atmospheric deposition of metals and the lowest metal contamination to its native soil as it is located in the sparsely populated South Campus of UBC which has only in recent years experienced large scale development of residence buildings and shopping malls. The soil has been managed in varying degrees for the past 40 years (UBC Farm 2011) thus it is likely that a large proportion of the trace metals would be stably bound in humus, immobilized in solid forms, or leached from the ecosystem. The 16 Oaks community garden is expected to exhibit an intermediate range of metal deposition and native soil contamination. Oak Street and 16th Avenue is a moderately high trafficked intersection; it serves as a major bus route and borders a predominantly residential area. Previous to development of the community garden the site was occupied by a restaurant and a parking lot. During development, discovery of an oil tank and car battery in the soil suggested that some form of metal contamination may persist on the site (Iverson 2006). The Hastings brownfield on the northeast corner of the Georgia Street viaduct is expected to exhibit the highest deposition of metals and the highest metal contamination to its native soil. The viaduct is 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 (pers. comm. Florko, City of Vancouver 2011). Following this period the native soil was overlain with various layers of construction fill, however no other attempt has been made to remediate the soil.
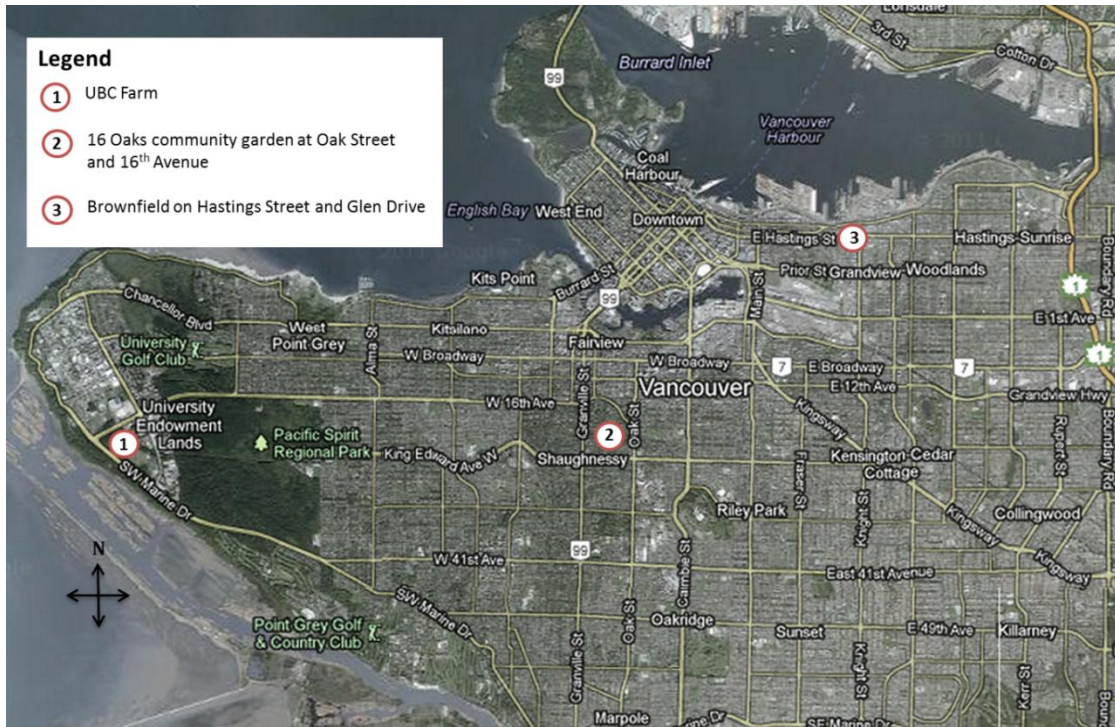
Figure 2. Map of Vancouver with locations of study sites (Google Maps 2012).

2. METHODOLOGY

2.1 Site and soil information

     The UBC Farm is a 24ha university research site which integrates cultivated field areas with hedgerows, orchards, and maturing successional forest stands (UBC Farm 2011). The soils are well-drained and sandy and the southern-facing slope along with the moderate maritime climate favours the cultivation of a wide variety of crops all year long. Edible crops produced include vegetables, fruits, berries, and herbs. The 16 Oaks community garden was established approximately three years ago; prior to that, the site was vacant for approximately ten years (pers. comm. Bouchard, Community Gardener 2011). It is a mostly level site which measures 1336 m^2 in area (Iverson 2006). Potentially contaminated soil was excavated and piled in the far southeast corner of the site. Most gardeners have opted to use imported soil from various compost sources as the growth media for their food crops. No edible vegetation is grown in the native soil; various species of flowers and vegetables such as kale, lettuce and squash are grown on raised bed plots. The Brownfield site is 2134 m^2 in area and has been vacant for the past forty years (pers. comm. Florko, City of Vancouver 2011). It has a northern aspect and a relief of 2-3 metres from east to west. The top layer of fill contains medium green sand and gravel which overlays a metal-containing sand fill. Below these two layers of fill, the native soil is approximately 1-2.5 metres below the surface. Site observations revealed that the soil is quite heterogeneous and compacted in most areas. The western site is susceptible to flooding during high rainfall periods. The whole site is occupied mainly by grasses (e.g. Scotch broom) and a few trees, with dense, well established blackberry bushes bordering the eastern and northern edge.

2.2 Field sampling: soil, vegetation and atmospheric deposition

     A stratified-random sampling design was applied to this study because little is known about the distribution of metals within each site and the scope of this study cannot account for the range of extraneous environmental and anthropogenic factors (e.g. local climate and traffic density) that may affect the deposition of metals. The first round of field sampling was conducted on October 4, 2011. Each site was stratified on the basis of differences in

vegetative cover. Within each vegetation stratified site, soil samples were collected using a hand trowel. The subsoil (20cm below from the surface), topsoil (top 20cm of the surface) and three composite samples, each compiled from five randomly selected areas were collected. A second round of sampling was conducted on February 14, 2012. On each site, five samples of native topsoil and grass and one sample of subsoil were collected. At the UBC Farm sampling took place adjacent to the orchard and the chicken coup; at the 16 Oaks garden it took place on the southeast corner for native soil sampling and throughout the site for raised bed sampling; and at the Brownfield sampling was completed in the eastern section of the site. For the 16 Oaks garden the three composite samples were taken from three different raised bed plots. Vegetation samples included native grass and berries found on the site. Kentucky Bluegrass (*Poa Prantesis*), a hardy lawn grass common to cool moist climates in North America, was collected from all sites. At the UBC Farm and the Brownfield site blackberries were selected; the 16 Oaks site contained only strawberries grown on one of the raised bed plots. Sampling took place in the fall and few berries could be collected from all sites.

An atmospheric deposition filter and rainwater collector was placed on each of the sites near the location of soil and vegetation sampling. The system included a funnel, which contained a 2µm filter (Whatman, 42) housed in a wire chamber; the funnel was attached to a hose and a four-litre collection bottle (Figure 3). For the purposes of this study, "soluble" elements were classified as those being less than 2µm in diameter. Collection of dry and wet deposition resumed for nearly five months ending at the beginning of March 2012.
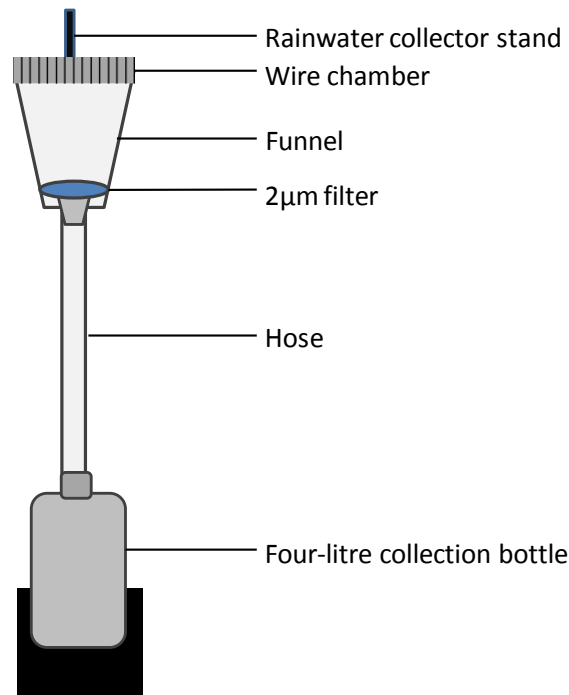
Figure 3. Diagram of deposition collector system.

2.3 Sample processing, pH, electrical conductivity and loss on ignition

Soil, vegetation and worms found in the samples were air-dried over a period of two days prior to processing. Sampling of worms was opportunistic by collecting individuals that were discovered during the collection of roots. At the 16 Oaks site moss was interspersed in the grass samples thus roots could not be differentiated between moss and Kentucky bluegrass. During extraction of the roots soil attached to surfaces was washed with distilled water and collected. This sample was used as an approximate measure of rhizosphere soil conditions. Soils were sieved through a 2mm stainless steel sieve and tested for pH, electrical conductivity (EC) and organic matter content. The soil pH was initially measured in water at a 1:2 or 1:5 ratio since many of the soils contained a large fraction of fine particles. Soil pH was measured a second time in a 0.01M $CaCl_2$ solution as described by Hendershot *et al.* (1993). This method is less sensitive to a range of soil-to-solution ratios and allows for a fair approximation of the field pH for agricultural soils. EC measurements were conducted in distilled water for soil (Rayment and Higinson 1992). Rainwater was collected from sites every 2-3 weeks depending on the amount of rainfall observed; pH of the water was

determined for each collection. Loss on ignition was measured at three temperature intervals (Atkinson *et al.* 1958): losses from ambient to 105°C; losses from 105°C to 350°C; and losses from 350°C to 550°C. Vegetation and worms were also analyzed for loss on ignition; samples were initially dried at 70°C to ensure no losses of organic matter prior to heating the samples to 350°C and 550°C.

2.4 Aqua regia and HCl extraction

Aqua regia extraction was completed on all soil and vegetation samples as described by Cheng and Ma (2001). Following loss on ignition approximately 0.500 g of soil and 0.250g (or the maximum possible weight) of vegetation was weighed out, mixed with 15mL of aqua regia solution (1 HNO_3: 3HCl) and boiled to dryness. Samples were washed with approximately 20mL 0.1M HCl through a 2 µm filter and made up to 100mL with 10% HNO_3. This extraction process approximates the total amount of recoverable elements within the samples with the exception of those bound in aluminosilicate compounds. The elements included in this analysis were Zn, Pb, Ni, Mn, Cu, Cd, Co, Cr, Fe, Al, Mg, Ca, Na, K, and P. HCl extraction was applied to soil, wet and dry deposition, and rhizosphere soil samples. 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 matrix to determine the proportion of metals available for plant uptake. The residual fraction is considered immobile under natural soil conditions. Approximately 5 g of fresh soil were weighed out and equilibriated for 24 hours to 25mL of 0.1M HCl. Rainwater and rhizopshere soil samples were concentrated by boiling the residue dissolved and washing with 1M HCl to ensure that residue remaining in the glassware was minimized. Filters containing dry deposition and a blank filter were dried at 110°C and digested at 550°C. All sediment remaining after digestion was weighed for HCl extraction; the weight of the blank filter was subtracted from the samples. All samples undergoing HCl extraction were washed with approximately 25mL of 0.1M HCl through a 2µm filter and made up to 50mL with 10% HNO_3. Hydrogen peroxide (30%) was added in small volumes (1-5mL) to oxidize samples containing high dissolved organic matter. If precipitate formed, samples were re-filtered and made to the appropriate volumes. All samples were analyzed using an inductively coupled

plasma atomic emission spectrometer (ICP-OES) to determine the relative concentrations of the elements of interest.

3. RESULTS

3.1 Caveats to the data

Five metals were considered for comparison among the three study sites: Zn, Pb, Ni, Mn and Cu; Co, Cd and Cr were not considered as values obtained in the soil, vegetation, and deposition (with the exception of Cr) were below detection limits. Figures and tables in the Results section present data relevant to these five metals. Complete datasets and analysis pertaining to all elements that were included in the ICP analysis can be found in the Appendix. A small number of soil and wet deposition samples contained high Zn and Mn concentrations above the standards set for the ICP measurements. These values may be subject to a range of variation. Soil and rhizosphere soil samples from all three sites exhibited high iron content; oxidation during the aqua regia extraction may result in an underestimation of Fe concentration values. However, Fe is not a metal of concern and the proportion available to plants is sufficiently low. Limited statistical analysis could be performed on the data because of the small sample sizes and the large difference in standard deviations among sites. Data from the two sampling events were compiled as no obvious differences in metal concentrations were observed. Values for the composite samples completed in the first round of sampling were incorporated into measurement of topsoil mean for every site except 16 Oaks. For statistical analysis, data collected for a Land and Food Systems Master's Theses (Thomas 2012) was included into the calculation of mean and standard deviation values for soil metal concentrations at 16 Oaks and the Hastings brownfield.

3.2 Soil Properties

The general soil characteristics of the Farm, Garden and Brownfield are comparable with low variability within sites (Table 1). EC values are very low and pH is near neutral at 16 Oaks and slightly acidic at the other two sites. Loss on ignition was most significant at the

Farm where values doubled the organic matter content of the other two sites. Raised bed samples also contained high organic matter content with high variability likely due to limited sampling and the wide range of compost sources.

Table 1. Soil properties of the study sites.

Site	Sample	Sample Size	pH in water	pH in 0.01M CaCl₂	EC (dS/m)	LOI at 350°C (%)
			SD	SD	SD	SD
UBC Farm	Topsoil	9	5.80	5.16	0.0506	11.7
			0.358	0.597	0.0121	2.61
16 Oaks community garden	Topsoil	9	6.20	5.90	0.163	6.92
			0.505	0.457	0.111	3.64
	Raised bed	3	7.18	6.74	0.227	20.2
			0.201	0.0702	0.135	15.1
Hastings brownfield	Topsoil	14	5.84	5.14	0.0556	4.95
			0.504	0.507	0.0646	1.56

3.3 Metal concentrations in the soil and atmospheric deposition

Total and available metal concentrations in the subsoil and topsoil were proportional among all sites: 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 converged among all sites; and Cu was only sizable at the Hastings brownfield and the raised bed composite samples (Table 2). Across all sites the order of available metal concentrations was Mn>Zn>Pb>Cu>Ni. Metal availability (%) was approximated by dividing metal concentrations obtained from HCl extraction by values from aqua regia extraction. Values above 100% were eliminated as they may have resulted from random sampling of aluminosilicate particles which were not dissolved by aqua regia, in which case total metal concentrations would be underestimated. Values for availability were similar among sites for Zn, Ni and Mn while Pb and Cu availability was considerably higher at 16 Oaks and the Hastings brownfield. Metal availability ranged from 1-59% for Zn, 2-85% for Pb, 2-45% for Ni; 18-93% for Mn and 1-87% for Cu.

Wet deposition metal concentrations were found to be low for all three sites with a relative order of Zn>Cu>Pb>Mn>Ni (Table 2). Differences among sites were minimal and fluxes ranged from 5.2 mg/kg/m^2/day for Zn to 0.002 mg/kg/m^2/day for Mn. These values are

several orders of magnitude smaller than fluxes achieved for dry deposition affirming past studies which found dry deposition to be the dominant factor in atmospheric metal contributions (Harrison and Chirgawi 1989a, Azimi *et al.* 2003). The order of metal concentrations found in dry deposition is the same as in wet deposition. The Hastings brownfield exhibits the highest flux for all metals followed by the Farm (with the exception of Zn) and the 16 Oaks community garden. The difference in flux between each site is approximately two-fold for Pb, Ni and Mn; it is also two-fold for Zn with metal contributions at 16 Oaks surpassing those at the Farm. The large flux of Cu at the Hastings site suggests that a local source is contributing this particular metal. Dry deposition fluxes ranged from 37, 300 mg/kg/m^2/day for Zn to 27 mg/kg/m^2/day for Ni. Bulk metal deposition collected over the entire study period showed concentrations ranging from 15 to 15,000 times greater than total metal concentrations found in the soil (Figure 4). The greatest difference between metal concentrations found in soil compared to deposition is observed at the UBC Farm followed by the Hastings brownfield and 16 Oaks.
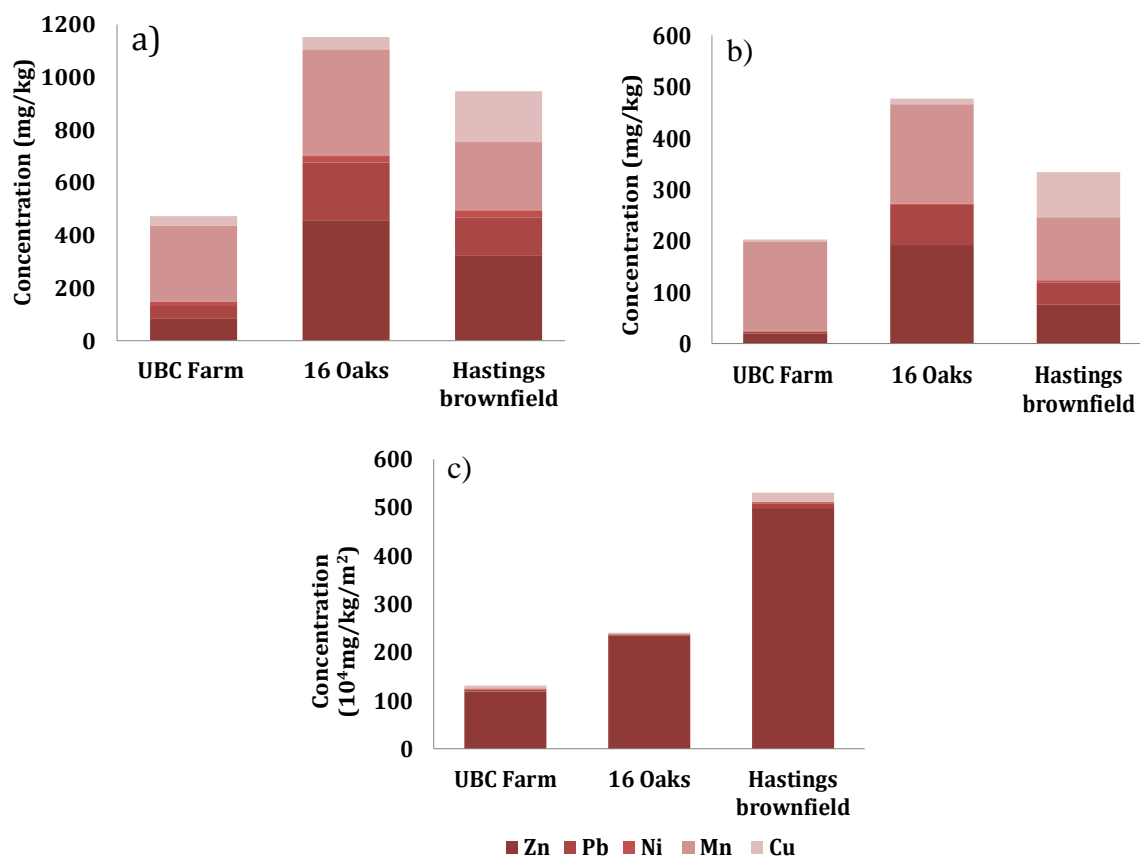
Figure 3. a) Total soil metal concentrations; b) available soil metal concentrations; and c) bulk metal contributions from atmospheric deposition.

Table 2. Mean and standard deviation values for total and available metals in soil, vegetation and atmospheric deposition.

Site	Sample	Sample Size	mg/kg dry matter				
			Zn	Pb	Ni	Mn	Cu
			SD	SD	SD	SD	SD
UBC Farm	Topsoil (aqua regia)	9	85.1	44.9	16.4	291	35.4
			27.1	16.1	11.4	223	10.5
	Topsoil (HCl extraction)	9	20.1	3.01	1.76	175	3.16
			19.9	1.30	1.20	41.0	1.84
	Rhizosphere soil	5	36.3	49.5	3.64	262	18.7
			15.5	17.6	2.55	123	8.33
	Root	5	174	53.0	15.0	427	72.4
			59.2	12.3	11.8	125	17.5
	Shoot	6	738	82.2	36.0	1350	150
			768	21.3	32.2	841	70.6
	Wet deposition (mg/kg/m^2/day)	1	2.95	0.00860	0.00853	0.00231	0.0128
	Dry deposition (mg/kg/m^2/day)	1	8460	327	101	71.2	367
	Strawberries	1	234	-	47.1	357	103
	Worms	1	2810	157	-	290	307
16 Oaks community garden	Raised bed (aqua regia)	3	2630	212	38.9	362	254
			4020	183	33.9	98.4	272
	Raised bed (HCl extraction)	3	70.1	14.9	2.09	121	3.56
			18.8	20.0	2.27	51.0	3.25
	Topsoil (aqua regia)	9	456	219	24.3	407	45.0
			356	196	13.6	361	10.3
	Topsoil (HCl extraction)	9	191	78.1	2.93	193	11.2
			153	71.2	1.32	178	9.94
	Rhizosphere soil	5	607	436	9.26	376	39.1
			633	409	13.6	392	49.8
	Root	5	1360	455	35.8	399	106
			969	397	18.5	279	43.3
	Shoot	6	1330	387	53.3	506	148
			989	315	38.2	323	54.9
	Wet deposition (mg/kg/m^2/day)	1	5.22	0.0140	0.00400	0.00420	0.0407
	Dry deposition (mg/kg/m^2/day)	1	17600	160	27.0	46.1	169
	Strawberries	1	652	-	34.1	7360	128
	Worms	1	3570	485	12.7	297	91.0
Hastings brownfield	Raised bed (aqua regia)	14	324	143	26.1	260	193
			344	134	23.7	147	924
	Topsoil (HCl extraction)	14	76.8	41.6	4.65	122	87.9
			160	75.0	9.25	23.5	51.2
	Rhizosphere soil	5	347	164	22.6	585	193
			260	95.1	20.1	440	140
	Root	5	843	172	46.0	403	448
			219	39.6	11.9	181	133
	Shoot	6	905	253	63.7	814	290
			570	227	44.5	590	192
	Wet deposition (mg/kg/m^2/day)	1	5.99	0.0135	0.00337	0.00484	0.0303
	Dry deposition (mg/kg/m^2/day)	1	37500	782	192	120	1310
	Blackberries	1	373	24.2	258	716	220
	Worms	1	2210	245	-	513	383

3.4 Metal accumulation in the rhizosphere soil, root and shoot

The density of vegetation found on the sites was variable: Kentucky bluegrass was distributed extensively on the Garden and the Farm but was sparse and patchy on the Brownfield site. Rhizosphere soil, root and shoot metal concentrations exhibit similar trends to those found in the soil. Mean concentrations at 16 Oaks and the Hastings brownfield are higher than those at the UBC Farm for Zn and Pb with 16 Oaks exhibiting a larger range of variability; metal concentrations converge for Ni and Mn; and Cu concentration are highest at the Hastings brownfield. Greater variability overall is observed in the grass samples, notably for the UBC Farm which shows the largest mean concentration for Mn. The order of metal concentrations is very similar to available metals in the soil with either Zn or Mn being the most abundant. At all sites, mean metal concentrations in the root and shoot are higher than those found in soil. The variability of rhizosphere soil metal concentrations at 16 Oaks and Hastings closely resembles those of root and shoot; at the UBC Farm, this measure aligns more closely with topsoil metal measurements. Accumulation of Zn, Mn, and Cu at the Farm tends to occur in the shoot while the range of concentrations for Pb and Ni overlap among shoot, root and rhizosphere soil (Figure 5). At the 16 Oaks site all three vegetation measurements overlap with large variability for all metals (Figure 6). Mean metal concentrations in the root and shoot are comparable at the Hastings brownfield with rhizosphere soil metal concentrations tending to be lower (Figure 7).

Bioconcentration factor (BCF) of root (*Croots/Csoil (available) = ratio of root concentration to soil concentration*) and shoot (*Cshoots/Csoil (available) = ratio of shoot concentration to soil concentration*) and Translocation Factor (*TF = Cshoots/Croots = ratio of shoot concentration to root concentration*) were calculated (Padmavathiamma 2009) (Table 3). For the UBC Farm BCF values for each metal tended to be higher in the shoots compared to the roots suggesting that at this site accumulation largely occurs in the above-ground exposed parts of the plant. This relationship is not evident at the other two sites where the range of BCF values for root and shoot largely overlap. Mn and Ni show a convergence in BCF of root and shoot among all sites which reflects the convergence in both soil and vegetation concentrations for these two metals. For all sites the BCF for root and shoot of Mn is consistently low while values for Pb and Zn are comparable. The TF did not show any qualitative differences in range among sites or metals which may be an effect of the small

sample size of this study. It may infer that for this species of grass metals are not preferentially taken up into the shoots as compared to the roots.

Metal concentrations for worms and berries found on the sites must be considered with caution as the sample size is very small. Collection of berries was limited by the period of sampling for this study; approximately 0.100g from all sites were analyzed. Sampling of worms was opportunistic and depended on whatever was present in the topsoil samples.16 Oaks contained the largest number of worms followed by the UBC Farm and the Hastings brownfield. Bioconcentration of all metals seems to be evident in berries and worms. Metal concentrations for berries tend to be lower or to overlap with those found in the shoots; most sizable concentrations are found for Zn, Mn (notably at the 16 Oaks garden) and Cu. This must be considered in future studies as fruiting bodies are generally of greatest interest for human consumption and has been expected to have some capacity for excluding metals (Motto *et al.*1970). Metal concentrations found in worms is also comparable to those found in the shoots; across all sites Zn concentrations were high and above those found in the shoots.
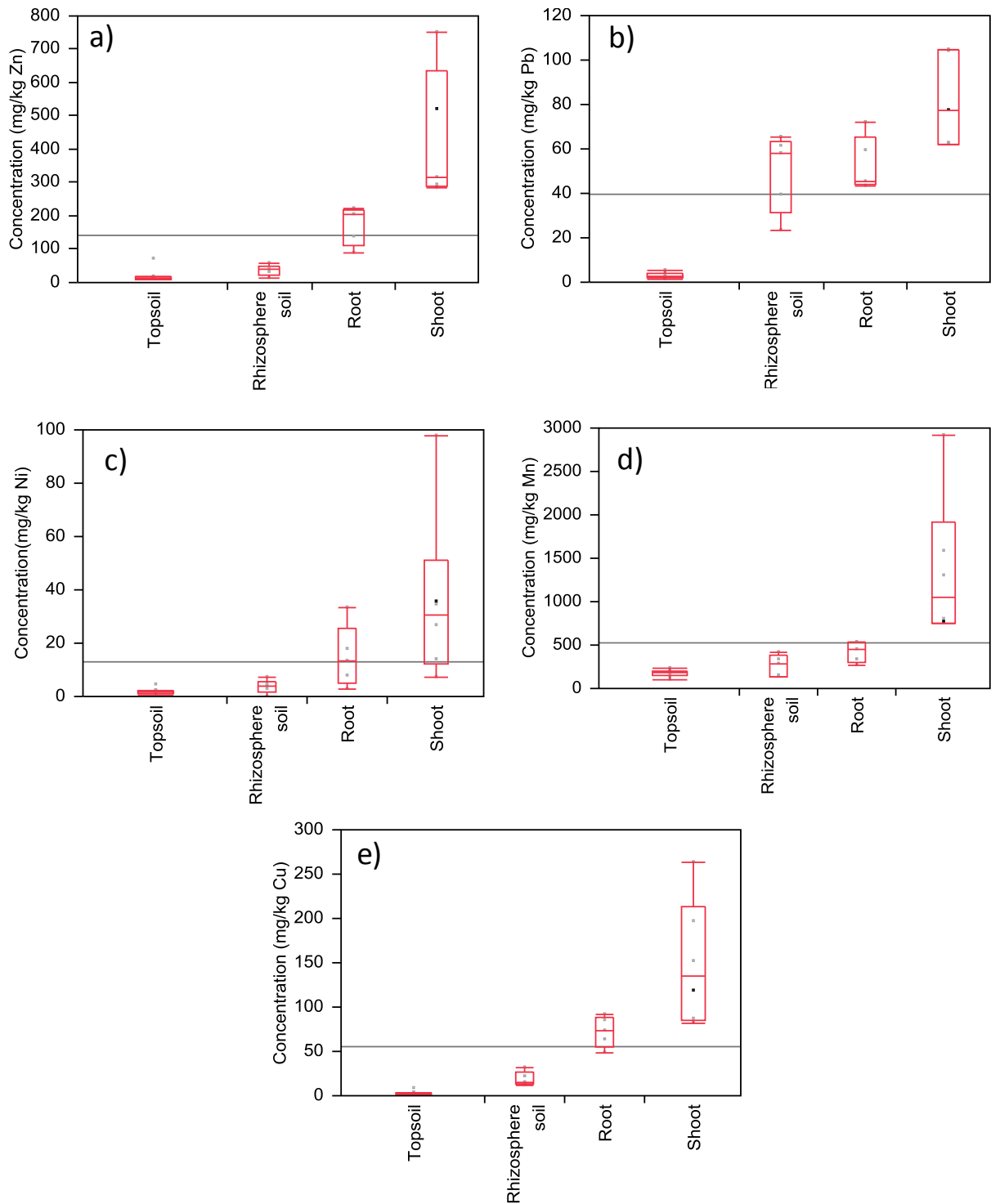
Figure 4. Boxplot of metal concentrations in soil and vegetation at the UBC Farm for a) Zn, b) Pb, c) Ni, d) Mn and e) Cu.

*Note: Two outlier points were removed for Zn and Pb from a grass sample from the first round of sampling.
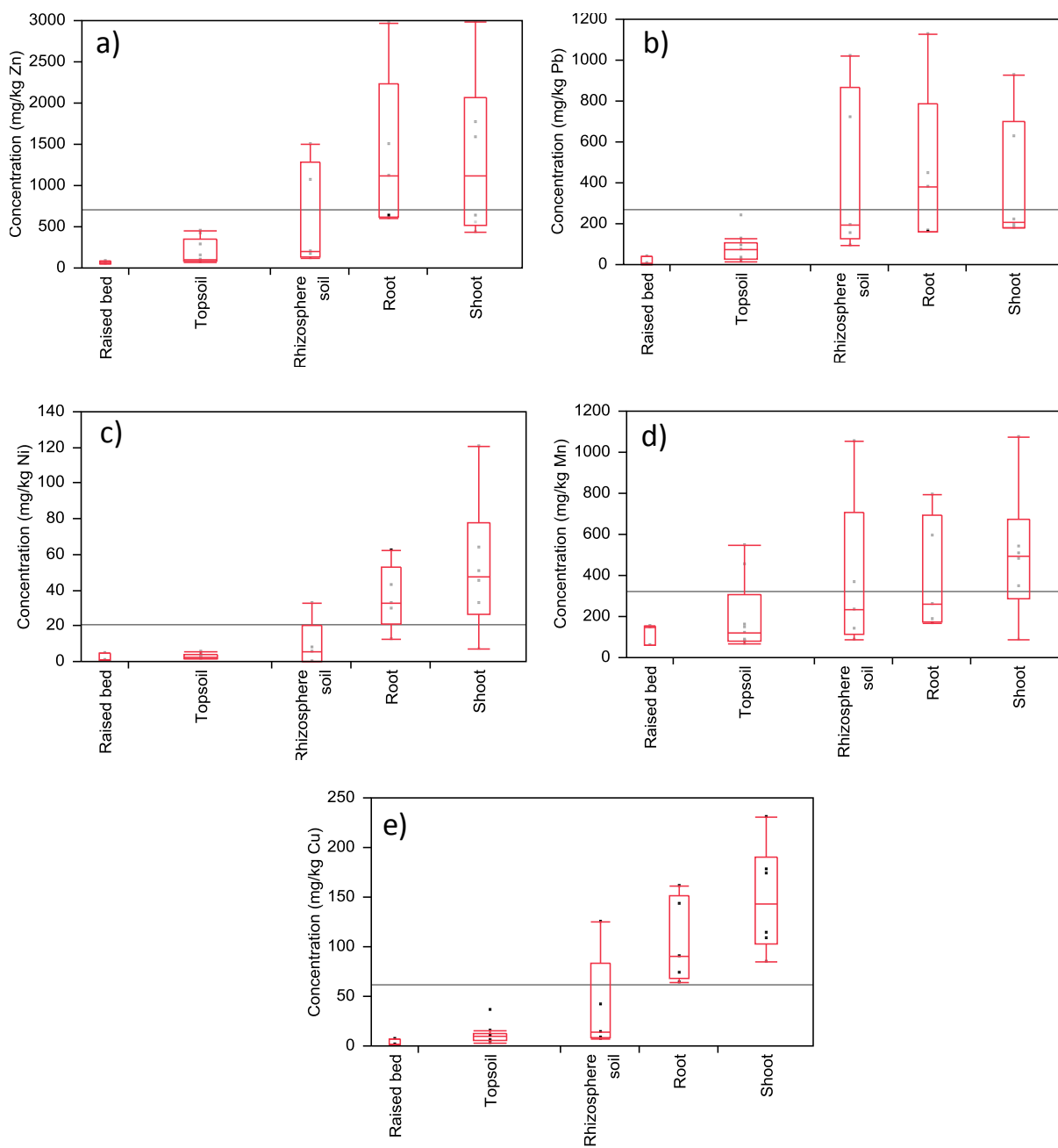
Figure 5. Boxplot of metal concentrations in the soil and vegetation at the 16 Oaks community garden for a) Zn, b) Pb, c) Ni, d) Mn and e) Cu.
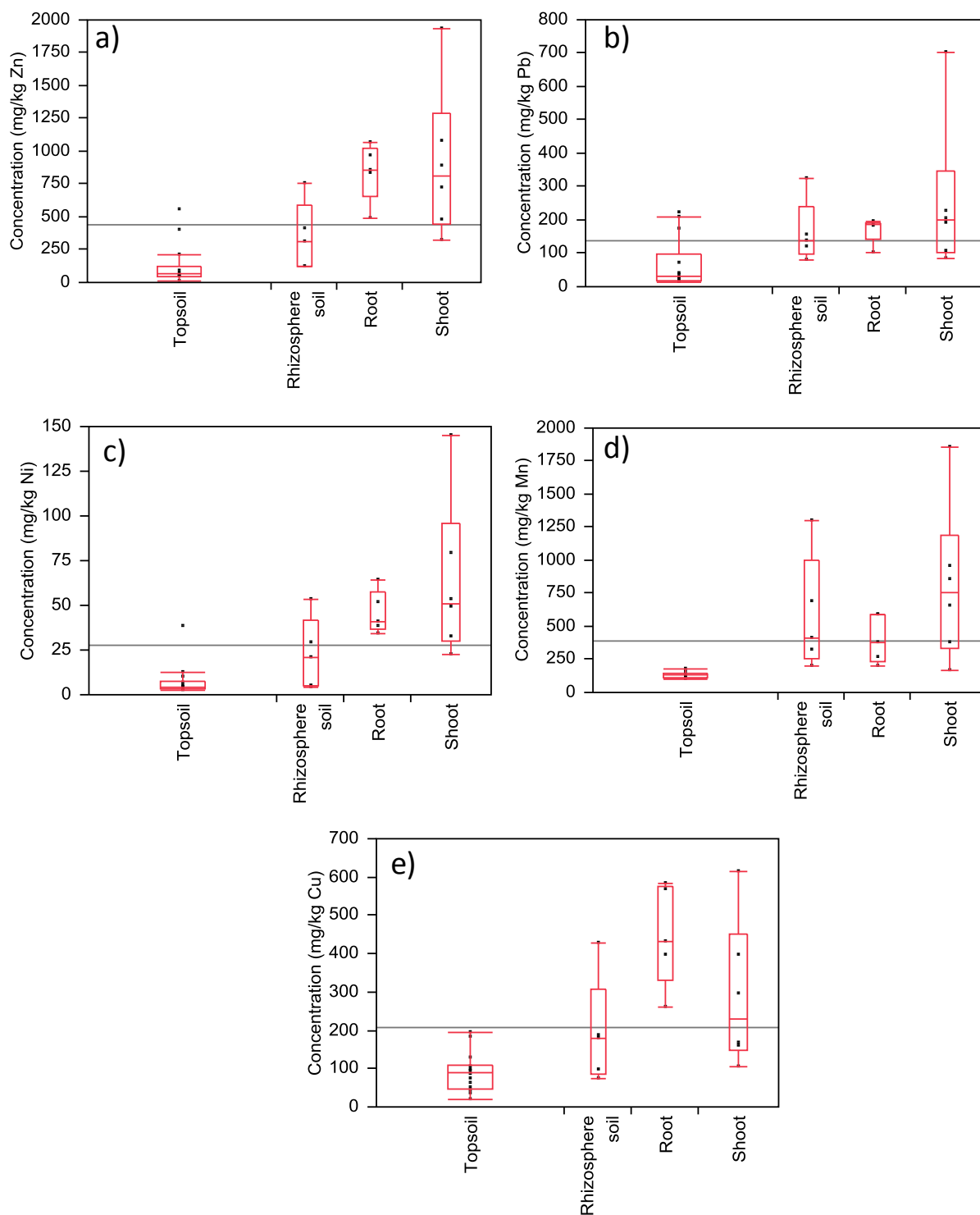
Figure 6. Boxplot of metal concentrations in soil and vegetation samples at the Hastings brownfield for a) Zn, b) Pb, c) Ni, d) Mn and e) Cu.

Table 3. Mean and standard deviation values for BCF of root and shoot and TF.

Site	Factor	Sample Size	Zn	Pb	Ni	Mn	Cu
UBC Farm	BCF root		14.3	26.7	10.8	2.50	28.4
	SD		5.21	10.7	10.5	0.568	12.9
	BCF shoot	5	34.4	39.6	21.6	8.52	44.1
	SD		10.8	8.84	21.2	4.64	17.2
	TF		2.58	1.59	5.83	3.35	1.84
	SD		0.917	0.467	6.55	1.40	0.838
16 Oaks community garden	BCF root		6.92	5.88	19.7	4.70	12.5
	SD		2.35	1.65	15.5	3.33	3.42
	BCF shoot	5	5.84	6.63	23.9	6.26	19.3
	SD		2.70	4.10	18.3	4.87	13.0
	TF		1.06	1.19	2.66	2.21	1.62
	SD		6.92	5.88	19.7	4.70	12.5
Hastings brownfield	BCF root		15.8	8.33	12.1	3.66	7.23
	SD		4.40	2.04	3.03	1.80	0.552
	BCF shoot	5	19.2	15.2	13.3	7.28	5.58
	SD		9.06	12.9	8.91	6.23	3.23
	TF		1.32	1.67	1.15	3.05	0.793
	SD		0.829	1.17	0.687	3.62	0.486

3.5 Relationships among soil properties and metals in the soil and vegetation

A correlation matrix was developed for pH, EC, LOI, and metal concentrations in the soil, rhizosphere soil, roots and shoots. A t-test was performed to determine statistically significant correlations. pH and EC values varied within a small range across all sites which limited the capacity to observe their effect on metal availability in soils. Loss on ignition (LOI) was not found to correlate with any metals, which may again reflect the limited range among the sites. The co-occurrence of metals was mainly observed for total Zn and Pb: a significant positive correlation ($p < 0.05$, $t > 3.182$) was found in soil ($r=0.93$, $t=4.32$), rhizosphere soil ($r=0.89$, $t=3.43$), roots ($r=0.97$, $t=6.74$) and shoots ($r=0.96$, $t=6.14$). As expected available Zn, Pb and Cu in the soil correlated with corresponding metals in the roots ($r=0.88$, $t=3.24$; $r=0.94$, $t=4.77$; $r=0.99$, $t=10.4$). In the rhizosphere soil, Ni was found to correlate with Mn ($r=0.95$, $t=5.16$) and Cu ($r=0.92$, $t=4.23$); associations with Mn may be related to metal affinity for Mn oxides in the soil.

4. DISCUSSION

4.1 Metal concentrations in the soil and atmospheric deposition

Natural concentrations of elements in soil can be expected to vary depending on parent material, organic matter, mineralization and soil processes (Dudka and Miller 2008). Nair and Cottenie (1971) found that the total concentrations of Zn, Cu, Ni, Mn and Pb are closely related to their total contents in the parent material from which they are derived. According to a City of Vancouver parent material classification map developed by Iverson (2006) the three sites originate from three different parent materials: glacial till at the UBC Farm; glacial marine at the 16 Oaks garden; and marine at the Hastings brownfield. The main difference between the three classifications is particle size distribution and drainage capacity with soils ranging from sandy and well-drained in glacial till to fine-textured and poorly-drained with increasing marine influence (Iverson 2006). Baker (1950) found that soils of the Lower Fraser Valley had higher Mn concentrations than soils in other areas of the province which likely explains the high concentration of Mn at all sites. This has been attributed to the presence of marine parent materials. The relatively low Ni concentrations may be a result of the extraction process applied as over 50% of Ni in soils may be associated with the residual fraction (HF and $HClO_4$ soluble) remaining after aqua regia extraction (McGrath 1995). The results of this study suggest that different parent material reflect similar total metal concentrations for Ni and Mn. Ni and Mn tend to be associated with accumulations of translocated clays and hydrous oxides in the subsoil (Alloway 1995). Since metal concentrations in the topsoil and subsoil were similar within sites, this suggests that redistribution may have occurred in the soil profiles. As such it is likely that pedogenic processes and metal content in the parent material do not vary significantly across sites and are the main factors determining soil concentrations of metals with low atmospheric or anthropogenic contributions.

The divergence in values for Zn, Pb and Cu may be attributed to specific site history and local urban-industrial conditions at the 16 Oaks and Hastings site. While natural emissions of Zn, Ni, Cu and Pb are comparable, worldwide anthropogenic contributions of Zn and Pb are 15-20 times greater than that of Ni and Cu (Nriagu 1979). Within the soil

profile, Zn, Pb and Cu are often found concentrated at the soil surface as a result of cycling through vegetation, atmospheric deposition and adsorption by soil organic matter (Alloway 1995). This may be of concern as recent findings suggest that regardless of metal forms and under similar soil conditions, metals of anthropogenic origin will be more mobile and bioavailable than metals of lithogenic and pedogenic origin (Kabata-Pendias 2001). Since pH is one of the main factors determining metal mobility, the close agreement of near neutral to slightly acidic pH values (>5.5) at all three sites indicates that current soil conditions are generally not conducive to increasing metal availability to plants. Most metals are increasingly soluble as soils become more acidic and hydrogen ions displace cations adsorbed to soil colloids; any net positive charge on the soil colloid acts to repel metal cations (He *et al.* 2008). It is likely that metal speciation across sites may be quite comparable and may explain the overlaps in range of metal availability (%) for all metal except for Pb and Cu. Cu is specifically adsorbed in soils making it one of the least mobile trace metals (Baker and Senft 1995) as well Pb is reported to be the least mobile trace metal (Kabata-Pendias 2001). Therefore if metals are not in available forms they are likely to persist in soils for long periods of time. The residence time of Zn, Ni, Cu and Pb in temperate soils are 1000 to 3000 years (Bowen 1979).

The presence of compost at the UBC Farm and at 16 Oaks may influence the bioavailability of metals depending on its properties. Zinati *et al* (2001) found that MSW-compost was able to supply larger amounts of plant available Cu and Zn compared to composted sewage sludge because in the former Cu and Zn were bound to organic forms and in the latter they were bound to Fe-Mn oxides. Zn and Pb comprise the largest fraction of metals present in compost. As such, the application of compost at these sites may have contributed to the total metal concentrations in the topsoil. The source of compost and the rate of application at the two sites are not known but may be meaningful to consider at a later time. The consensus in the literature suggests that organic matter has the potential to bind metals in stable organic forms limiting their solubility and bioavailability (Smith 2009). Pb is the most strongly bound and Ni the weakest with Zn and Cu showing intermediate sorption capacities. In addition to organic matter, Pb has been observed to have high affinity to Mn oxides, Fe-Al hydroxides and clay mineral (Kabata-Pendias 2001). The interaction of Pb and Mn may suggest that over time as Mn oxides develop, Pb availability at these sites may

decline. Pb and Cu were observed to have low % availability at the UBC Farm indicating that the influence of organic matter on metal mobility requires a long period time to take effect and may be evident for only some metals.

Calculated enrichment factors for total deposition at various non-urban and urban locations in Europe and North America reported the following sequence Pb>Zn=Cu>Ni >Mn (Cawse 1976). A higher enrichment factor indicates greater importance of atmospheric deposition as a source of these metals in soils and plants. This ordering generally approximates what was observed in wet and dry deposition in this study except that Pb concentrations were less than Zn and Cu concentrations. This may be attributed to the discontinued use of Pb in gasoline products post 1970s as vehicle emissions was the largest atmospheric contribution of Pb. High Zn and Cu contributions may reflect the industrial nature of the areas, as these metals are indicators of contamination from street dust; they are found in gasoline, oil lubricants, and industrial and incinerator emissions (Li *et al.* 2001). Metals in street dust have been found to have higher concentrations (Wei and Yang 2010) and mobility than metals in urban soils because of their adsorption to coarse-sized, feasibly weathered calcite minerals (Li *et al.* 2001). The UBC site unexpectedly had the second highest metal concentrations with the exception of Zn even though it has the lowest traffic density of the three sites. This may be due to the fact that large scale construction was occurring in close proximity (~200m) from the sampling area. In this study, measurement of dry deposition corresponds to particles larger than 2µm and may include re-suspended soil particles, road dust and industrial combustion products which due to their relatively large size tend to deposit close to the emission source. This may suggest that close-range anthropogenic actions may be more meaningful for the deposition of all metals, other than Zn, even when traffic and industrial activity is relatively low. The low concentrations observed for wet deposition may reflect the distribution of metals in the fine-sized fraction which may suggest that high temperature emissions do not contribute significantly to deposition in these areas.

The different order of metal concentrations in soil and deposition may indicate 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 atmospheric deposition in addition to specific soil conditions. While Mn availability is sizable in soils, atmospheric contribution of this metal is

relatively small. Ni concentrations are low in both soils and deposition which suggests that it is not a metal of concern at these three sites. Cu concentrations in the soil and deposition are mainly meaningful at the Hastings brownfield and may demonstrate the integration of site history and the current deposition trends in the area.

4.2 Metal accumulation in the rhizosphere soil, root and shoot

Rhizosphere soil conditions are mainly relevant for the purposes of chelation to increase metal mobility and uptake (Laurie and Manthey 1994). At the interface of roots and soil, exudates are excreted which release amino acids containing many functional groups to bind available metals. While metals dissolved in soil solution in ionic, chelated or complexed forms are preferred, uptake of available ions is largely dependent on total ion concentrations in the soil (Kabata-Pendias 2001). This may explain why rhizosphere metal concentrations are approximately between soil and root metal concentrations: in the rhizosphere metal mobility is enhanced but bioconcentration has not occurred. Since the level of management on the three sites differs significantly it is likely that exudate content may vary among sites depending on microorganism associations and the conditions of plant growth. Thus mobilization of metals for uptake is subject to heterogeneity within and among sites resulting in sizable ranges of metal concentrations for rhizosphere soil and roots. Translocation of metals from roots into shoots depends on the mobility of the metal as well as the preference of the plant. Foliar uptake of metal deposition is influenced largely by the morphology of the leaves which is again affected by conditions of plant growth (Laurie and Manthey 1994). Furthermore, shoots may translocate metals to roots if excesses are present. The complexity of the root-shoot interaction limits the capacity to fully understand the factors that are significant at each study site even when examining a single species of grass. The large range for shoot metal concentrations at all sites is likely a consequence of the many variables involved in metal uptake. With increasing soil heterogeneity at a site the variability in root and shoot will be increasingly magnified. The relative accumulation of metals in roots and shoots are largely a reflection of soil metal concentrations which may indicate limited plant preference for accumulation in specific vegetative parts. Higher concentrations tend to occur in the shoots, although this is not evident at all sites. As a consequence of the limited sample size, it cannot be determined whether there are meaningful differences in uptake between

metals. 16 Oaks showed the largest variability in root and shoot concentrations which may suggest that this site is highly heterogeneous in both soil and atmospheric metal contribution.

The bioaccumulation of trace metals in green plants is generally as follows Zn>Cu>Pb>Mn>Ni (Kabata-Pendias 2001). This trend was not observed in measurements of BFC of root and shoot with the exception of Mn. This may simply indicate that Kentucky bluegrass takes up Mn according to its physiological needs and does not tend to accumulate it. Despite the relative immobility of Pb it was found to have BCF of root and shoot values comparable to Zn which is known to accumulate efficiently in all plant parts (Davies 1995). Koeppe (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 Kentucky bluegrass during what may be its senescent stages. The strong positive correlation between Zn and Pb in soils, rhizosphere soil, roots and shoots may simply reflect the parallel mobility of Pb to Zn in these sites. At the UBC Farm the high BCF of shoot relative to root may be attributed to the combination of very low soil metal concentrations in coordination with relatively high atmospheric deposition on the site. This was not evident at the other sites where trends for soil metal concentrations closely aligned with trends for atmospheric deposition of metals.

4.3 Considerations for future siting of community gardens

None of the soil metal concentrations found at the Farm were above the metal standards for agricultural land (the most stringent soil standards) set by the B.C. Ministry of Environment (2012) under the Environmental Management Act for Contaminated Sites Regulation. These generic or matrix numerical standards are based on a standard measurement protocol which is likely an assessment of total instead of available metals (Table 4). Matrix numerical standards were found for Zn, Pb and Cu and selected for human health protection, since this study focuses on sites of urban agriculture for human consumption. Mean values for total Pb and Zn concentrations at the 16 Oaks garden and the Hastings brownfield were above these standards but are subject to a large range of variability. The main complication with urban soils is determining the background soil

quality. Often the lack of detailed site history confounds what can be considered anthropogenic contributions. For the Lower Mainland, the B.C. Ministry of Environment developed regional background soil quality estimates, based on aqua regia extraction, which can be used as a reference point for the metal concentrations found on the three study sites (Table 4). Based on these estimates metal concentrations at the UBC Farm can be considered at or below soil background levels while 16 Oaks and the Hastings brownfield exhibit elevated levels for Zn and Pb and Zn, Pb and Cu respectively. The lack of standards set for Mn may indicate that it has not been a metal of interest or concern in the past. Current atmospheric quality standards are designed for human respiratory health and not for the assessment of contaminant deposition onto soil or vegetation. No standards have been set for metal concentrations in vegetation grown on potentially contaminated sites.

Table 4. Standards for comparison with total metal concentrations at the study sites (adapted from B.C. Ministry of Environment 2012).

	mg/kg dry matter	
Metal	**Contaminated site standards for agricultural land**	**Background soil estimates for the Lower Mainland**
Zn	300	200
Pb	100	60
Ni	150	80
Mn	N/A	N/A
Cu	1500	45

Future siting of community gardens must address some of the concerns that arise in integrating food production with an urban environment. While not all metal are relevant to all sites the importance of parent material, site history and current deposition trends are complementary in determining soil and vegetative health. In this study, a current Garden had the highest cumulative soil metal concentrations even in comparison to a current Brownfield. While atmospheric deposition at this site was lower than at the Brownfield, the additive load may be significant for metals that are already abundant in these soils. Even if raised beds are used, it is not clear whether bioconcentration in shoots result mainly from metal translocation from the roots or from absorption at the foliar surface; this is likely subject to the metal(s) of

concern and the type of vegetation considered. The level of complexity involved in metal uptake and the long residence time of metals should not be underestimated. Therefore environmental standards that are in place need to be considered in the light of local context.

5. CONCLUSIONS

The preliminary assessment of three urban sites of current or future agricultural production in Vancouver revealed the significance of parent material, site history and current deposition trends to overall soil and vegetative health. Total soil metal concentrations were highest at 16 Oaks followed by the Hasting brownfield and the UBC Farm. Bulk deposition was highest at the Brownfield followed by the Farm and the Garden. Ni and Mn concentrations seemed to originate from the parent material while Zn, Pb and Cu were likely elevated due to anthropogenic contributions which were only evident at 16 Oaks and the Hastings brownfield. Atmospheric deposition collected over the five month period was up to four orders of magnitude greater than the total metal concentrations in soil. Zn concentrations seem to be most related to high traffic density while local anthropogenic actions may be more important for the other metals. Accumulation of metals tended to be higher in the shoots with large variability in general. Metal concentrations in the rhizosphere soil were intermediate between those found in topsoil and the roots. Zn and Pb was correlated in soils, rhizosphere soil, roots and shoots which may reflect the high level of mobility for Pb in Kentucky bluegrass. In comparison to local background soil metal standards, Zn and Pb seem to be elevated at 16 Oaks and Zn, Pb and Cu seem to be elevated at the Hastings brownfield. An integrative approach needs to be taken to address the potential additive effects of soil and deposition on metals in vegetation. Future work should include investigation of metal accumulation in fruit-bearing vegetation, an assessment of seasonal variations in metal deposition and the development of regional standards for atmospheric deposition of metals.

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APPENDIX: COMPLETE DATASETS AND STATISTICAL ANALYSIS RESULTS

Table A1. Soil properties of individual samples from the study sites.

First sampling event: 5 November 2011

Site	Sample	EC (dS/m)	pH in water	pH in 0.01M CaCl$_2$	Organic Matter (%)
UBC Farm	Topsoil	0.040	5.23	6.63	11.6
UBC Farm	Composite 1	0.055	5.52	5.27	8.57
UBC Farm	Composite 2	0.070	5.71	4.83	7.73
UBC Farm	Composite 3	0.065	6.09	4.99	15.6
UBC Farm	Subsoil	0.050	5.59	4.72	7.33
16 Oaks	Topsoil	0.060	5.24	5.54	4.90
16 Oaks	Raised bed composite 1	0.120	7.12	6.73	29.1
16 Oaks	Raised bed composite 2	0.180	7.01	6.67	28.8
16 Oaks	Raised bed composite 3	0.380	7.40	6.81	2.73
16 Oaks	Subsoil	0.045	6.00	5.79	2.73
Hastings brownfield	Topsoil	0.040	5.75	4.72	4.22
Hastings brownfield	Composite 1	0.055	5.95	5.96	4.63
Hastings brownfield	Composite 2	0.070	5.49	4.90	4.32
Hastings brownfield	Composite 3	0.045	5.43	4.68	6.54
Hastings brownfield	Subsoil	0.025	5.69	4.65	3.59

Second sampling event: 14 February 2012

Site	Sample	EC (dS/m)	pH in water	pH in 0.01M CaCl$_2$	Organic Matter (%)
UBC Farm	Topsoil 1	0.030	5.51	4.63	13.0
UBC Farm	Topsoil 2	0.050	5.70	4.75	11.7
UBC Farm	Topsoil 3	0.050	6.12	4.98	10.1
UBC Farm	Topsoil 4	0.045	6.01	4.99	14.6
UBC Farm	Topsoil 5	0.050	6.34	5.34	12.6
UBC Farm	Subsoil	0.030	5.97	5.21	7.14
16 Oaks	Topsoil 1	0.075	6.14	5.89	3.30
16 Oaks	Topsoil 2	0.130	6.23	5.71	4.52
16 Oaks	Topsoil 3	0.170	6.22	5.86	5.13
16 Oaks	Topsoil 4	0.150	6.09	6.10	7.19
16 Oaks	Topsoil 5	0.075	6.25	5.50	5.07
16 Oaks	Subsoil	0.050	6.53	5.81	2.73
Hastings brownfield	Topsoil 1	0.075	6.2	5.36	4.87
Hastings brownfield	Topsoil 2	0.030	6.22	5.05	5.89
Hastings brownfield	Topsoil 3	0.070	6.25	5.07	4.12
Hastings brownfield	Topsoil 4	0.055	5.35	5.04	5.74
Hastings brownfield	Topsoil 5	0.060	5.88	5.47	4.22
Hastings brownfield	Subsoil	0.025	6.12	5.22	1.75

Table A2. Mean and standard deviation values of soil properties.

Site	Sample	Sample Size	EC (dS/m)	pH in water	pH in 0.01M CaCl$_2$	Organic Matter (%)
			SD	SD	SD	SD
UBC Farm	Topsoil and composite	9	0.0506	5.80	5.16	11.7
			0.0121	0.358	0.597	2.60
UBC Farm	Subsoil	2	0.0400	5.78	4.96	7.24
			0.0141	0.269	0.346	0.134
16 Oaks	Topsoil	6	0.110	6.03	5.77	5.02
			0.0459	0.391	0.228	1.26
16 Oaks	Raised bed composite	3	0.227	7.18	6.74	20.2
			0.136	0.201	0.0702	15.1
16 Oaks	Subsoil	2	0.0475	6.26	5.80	2.73
			0.00350	0.375	0.014	0.00
Hastings brownfield	Topsoil and composite	9	0.0556	5.84	5.14	4.95
			0.0151	0.352	0.403	0.887
Hastings brownfield	Subsoil	2	0.0250	5.90	4.94	2.67
			0.00	0.304	0.403	1.30

Table A3. Element concentrations from aqua regia extraction of individual soil samples from the study sites.

First sampling event: 5 November 2011

Site	Sample	Zn	Pb	Ni	Mn	Cu	Fe	Al	Mg	Ca	Na	K	P
								(mg/kg dry matter)					
UBC Farm	Topsoil	122	42.6	9.01	141	32.2	13800	16600	3230	3080	273	972	1090
UBC Farm	Composite 1	70.4	35.0	6.12	144	47.2	13000	15400	2820	2990	185	768	1540
UBC Farm	Composite 2	50.7	21.8	7.88	110	23.0	12700	15500	2640	3590	305	740	926
UBC Farm	Composite 3	85.4	45.1	14.8	230	37.9	17100	18500	3310	3360	183	1000	1550
UBC Farm	Subsoil	66.9	42.0	17.9	393	28.0	19600	17300	3790	3500	63.3	803	882
16 Oaks	Topsoil	335	170	11.3	182	40.9	13500	14400	3960	8510	732	711	612
16 Oaks	Raised bed composite 1	318	110	21.1	475	102	21800	16600	7880	34200	691	3460	3480
16 Oaks	Raised bed composite 2	295	103	17.6	297	92.8	18300	15600	6690	36500	621	2260	2560
16 Oaks	Raised bed composite 3	7270	424	78.0	313	568	43000	13800	8880	2070	672	892	286
16 Oaks	Subsoil	383	109	25.0	463	135	26600	18000	3500	46600	1230	5400	5660
Hastings brownfield	Topsoil	1010	499	72.6	446	381	72600	10200	3410	3300	399	847	325
Hastings brownfield	Composite 1	571	202	36.6	185	303	23900	12500	3590	3700	316	1020	453
Hastings brownfield	Composite 2	227	92.7	15.9	122	163	18400	14500	4630	3200	353	1010	452
Hastings brownfield	Composite 3	148	55.3	23.2	160	120	14000	14200	3550	2640	117	1190	405
Hastings brownfield	Subsoil	124	45.5	9.54	258	118	15600	11900	3150	2140	337	940	363
Second sampling event: 14 February 2012													
UBC Farm	Topsoil 1	90.4	40.7	37.4	147	27.1	18100	20500	2730	3780	72.1	862	1340
UBC Farm	Topsoil 2	63.8	50.8	9.24	207	31.9	14700	18200	2730	3120	38.9	704	1250
UBC Farm	Topsoil 3	67.4	39.9	9.57	370	38.2	16700	17500	2730	3030	79.2	813	875
UBC Farm	Topsoil 4	133	81.8	21.6	785	55.2	27000	34300	5180	7000	348	1580	2630
UBC Farm	Topsoil 5	83.1	46.1	31.6	488	26.0	17600	20900	3150	5970	133	968	1740
UBC Farm	Subsoil	80.2	40.3	26.4	341	26.5	21000	26100	4250	3740	158	1210	1370
16 Oaks	Topsoil 1	339	130	18.9	191	35.7	25300	24400	4960	3950	354	1580	400
16 Oaks	Topsoil 2	558	184	25.6	335	40.8	23800	23800	4650	4300	569	1480	563
16 Oaks	Topsoil 3	606	229	13.7	186	35.8	16400	19300	3990	4980	389	1320	526
16 Oaks	Topsoil 4	1320	734	56.7	217	62.8	24300	25900	4560	9940	1210	1360	975
16 Oaks	Topsoil 5	314	123	16.5	113	38.0	26200	28400	5410	5480	325	1830	499
16 Oaks	Subsoil	262	108	18.6	219	31.6	17800	20000	4090	3090	70.8	1080	439
Hastings brownfield	Topsoil 1	160	83.7	24.9	196	164	17200	15700	3240	3210	107	1070	412
Hastings brownfield	Topsoil 2	321	136	26.3	593	258	28600	26000	5710	5380	493	1910	670
Hastings brownfield	Topsoil 3	133	59.8	14.4	287	93.2	17900	16000	3180	2850	122	1090	362
Hastings brownfield	Topsoil 4	182	81.4	9.23	196	156	17500	19900	4860	3520	214	1450	381
Hastings brownfield	Topsoil 5	170	79.0	11.9	157	100	13000	16400	4090	4400	224	1250	370
Hastings brownfield	Subsoil	419	170	49.6	312	170	25500	15700	3700	3270	130	935	362

Table A4. Mean and standard deviation values for element concentrations from aqua regia extraction of soil.

Site	Sample	Sample Size	(mg/kg dry matter)											
			Zn SD	Pb SD	Ni SD	Mn SD	Cu SD	Fe SD	Al SD	Mg SD	Ca SD	Na SD	K SD	P SD
UBC Farm	Topsoil and composite	9	85.1	44.9	16.4	291	35.4	16700	19700	3170	3990	180	934	1440
			27.0	16.1	11.4	223	10.5	4350	5800	794	1460	110	265	534
UBC Farm	Subsoil	2	73.6	41.2	22.2	367	27.3	20300	21700	4020	3620	111	1010	1130
			9.40	1.20	6.01	36.8	1.06	990	6220	325	170	67.0	288	345
16 Oaks	Topsoil	6	579	262	23.8	204	42.3	21600	22700	4590	6190	596	1380	596
			384	234	16.9	72.9	10.3	5280	5040	560	2450	338	375	199
16 Oaks	Raised bed composite	3	2630	212	38.9	362	254	27700	15300	7820	24200	661	2200	2110
			4020	183	33.9	98.5	272	13400	1420	1100	19200	36.2	1280	1640
16 Oaks	Subsoil	2	323	109	21.8	341	83.3	22200	19000	3800	24800	650	3240	3050
			85.6	0.710	4.53	173	73.1	6220	1410	417	30800	820	3050	3690
Hastings brownfield	Topsoil and composite	9	325	143	26.1	260	193	24800	16200	4030	3580	260	1200	426
			291	141	19.4	158	99.2	18600	4560	868	845	138	314	101
Hastings brownfield	Subsoil	2	272	108	29.6	285	144	20600	13800	3420	2710	234	938	363
			208	88.0	28.3	38.2	36.8	7000	2690	389	799	146	3.54	0.707

Table A5. Element concentrations from HCl extraction of individual soil samples from the study sites.

First sampling event: 5 November 2011

													(mg/kg dry matter)
Site	Sample	Zn	Pb	Ni	Mn	Cu	Fe	Al	Mg	Ca	Na	K	P
UBC Farm	Topsoil	72.2	5.47	1.44	176	2.32	172	4130	141	1670	34.7	227	71.3
UBC Farm	Composite 1	17.3	4.13	1.21	234	3.49	238	4170	159	2450	31.3	231	183
UBC Farm	Composite 2	10.6	2.81	0.730	97.7	1.99	142	4000	137	2210	34.9	199	116
UBC Farm	Composite 3	18.7	4.08	0.960	214	3.42	161	3870	186	1870	36.8	163	124
UBC Farm	Subsoil	7.69	3.88	0.830	183	3.19	300	4100	143	2140	34.8	93.6	56.2
16 Oaks	Topsoil	456	240	5.14	147	35.6	979	2580	629	5020	553	186	119
16 Oaks	Raised bed composite 1	53.8	3.69	0.780	149	1.82	207	321	1100	11600	296	1170	356
16 Oaks	Raised bed composite 2	65.8	2.93	0.780	153	1.55	240	453	1200	12800	56.5	563	195
16 Oaks	Raised bed composite 3	90.6	38.0	4.71	62.6	7.31	1020	1360	299	2240	119	53.9	64.1
16 Oaks	Subsoil	42.1	2.51	0.630	124	2.37	108	211	1400	12500	87.7	1650	279
Hastings brownfield	Topsoil	56.6	28.0	3.54	136	104	736	1300	376	1330	41.3	108	93.4
Hastings brownfield	Composite 1	215	172	9.65	122	183	786	1880	247	1700	80.6	87	38.5
Hastings brownfield	Composite 2	84.7	35.3	4.79	134	97.9	589	1910	311	1900	43.6	129	71.8
Hastings brownfield	Composite 3	63.1	28.8	4.28	143	95.1	573	1650	334	1630	37.0	130	73.4
Hastings brownfield	Subsoil	241	233	22.3	226	276	1180	1920	211	889	46.1	48.9	21.3

Second sampling event: 14 February 2012

Site	Sample	Zn	Pb	Ni	Mn	Cu	Fe	Al	Mg	Ca	Na	K	P
UBC Farm	Topsoil 1	9.49	1.40	2.00	133	2.30	16.8	2240	68.4	1190	17.0	55.2	22.4
UBC Farm	Topsoil 2	11.6	2.52	1.83	163	1.60	67.3	3020	95.2	1590	26.2	97.8	57.3
UBC Farm	Topsoil 3	9.45	2.70	2.40	195	7.76	64.4	3150	109	1670	38.9	116	35.5
UBC Farm	Topsoil 4	14.2	2.24	0.700	186	2.98	32.7	2720	133	1450	22.3	79.9	45.3
UBC Farm	Topsoil 5	17.1	1.78	4.55	172	2.56	38.3	2420	160	1300	36.7	141	74.1
UBC Farm	Subsoil	5.25	1.83	2.19	108	3.19	4.62	2440	47.8	1270	11.0	42.4	11.0
16 Oaks	Topsoil 1	102	34.7	1.40	69.1	9.85	1030	1400	412	732	93.4	74.4	10.2
16 Oaks	Topsoil 2	144	90.0	1.93	85.3	9.29	595	1520	310	802	94.5	163	9.95
16 Oaks	Topsoil 3	289	70.3	2.37	77.8	6.17	319	1360	242	717	148	120	8.17
16 Oaks	Topsoil 4	409	129	3.88	82.0	11.0	172	1400	209	742	222	141	13.9
16 Oaks	Topsoil 5	88.0	28.8	1.63	117	6.03	776	1630	172	872	67.6	138	0.520
16 Oaks	Subsoil	132	44.5	1.34	65.8	9.09	406	1890	180	979	106	68.5	30.9
Hastings brownfield	Topsoil 1	63.6	35.8	4.42	110	75.8	457	1230	320	672	30.4	122	58.7
Hastings brownfield	Topsoil 2	64.4	19.3	3.95	109	63.4	308	981	271	545	26.6	87.9	30.4
Hastings brownfield	Topsoil 3	43.2	19.1	5.05	107	50.5	534	1360	314	736	40.6	92.9	63.8
Hastings brownfield	Topsoil 4	59.5	24.2	3.35	142	85.5	569	1540	359	843	35.8	116	39.3
Hastings brownfield	Topsoil 5	40.6	11.8	2.84	99.5	36.4	323	1090	253	594	24.1	61.8	31.6
Hastings brownfield	Subsoil	94.2	52.9	10.7	78.3	51.8	332	1730	154	902	29.6	45.5	31.7

Table A6. Mean and standard deviation values for element concentrations from HCl extraction of soil.

Site	Sample	Sample Size	Zn SD	Pb SD	Ni SD	Mn SD	Cu SD	Fe SD	Al SD	Mg SD	Ca SD	Na SD	K SD	P SD
								(mg/kg dry matter)						
UBC Farm	Topsoil and composite	9	20.1	3.01	1.76	174	3.16	104	3300	132	1710	31.0	146	81.0
			19.9	1.30	1.20	40.9	1.84	76.8	758	36.2	410	7.52	64.0	51.2
UBC Farm	Subsoil	2	6.47	2.86	1.51	146	3.19	152	3270	95.4	1700	22.9	68.0	33.6
			1.72	1.45	0.960	53.0	0.00	209	1170	67.3	615	16.8	36.2	32
16 Oaks	Topsoil	6	248	98.8	2.72	96.4	13.0	645	1650	329	1480	196	137	27.0
			160	78.4	1.48	29.7	11.2	349	467	170	1730	183	38.2	45.3
16 Oaks	Raised bed composite	3	70.1	14.9	2.09	122	3.56	489	711	866	8880	157	596	205
			18.8	20.0	2.27	51.1	3.25	460	566	494	5780	124	559	146
16 Oaks	Subsoil	2	132	44.5	1.34	65.8	9.09	406	1890	180	979	106	68.5	30.9
			63.6	29.7	0.500	41.2	4.75	211	1190	863	8150	12.9	1120	175
Hastings brownfield	Topsoil and composite	9	76.7	41.6	4.65	123	88.0	542	1440	309	1100	40.0	104	55.6
			53.4	49.5	2.00	16.7	42.2	162	330	45.0	534	16.6	23.0	21.9
Hastings brownfield	Subsoil	2	168	143	16.5	152	164	756	1820	183	896	37.8	47.2	26.5
			104	127	8.20	104	158	600	134	40.3	9.19	11.7	2.40	7.35

Table A7. Proportion of elements extracted using HCl as compared to aqua regia in individual soil samples from the study sites.

First sampling event: 5 November 2011

						Percent Available (%)							
Site	Sample	Zn	Pb	Ni	Mn	Cu	Fe	Al	Mg	Ca	Na	K	P
UBC Farm	Topsoil	59.3	12.8	16.0	-	7.18	1.25	24.9	4.36	54.3	12.7	23.3	6.53
UBC Farm	Composite 1	24.5	11.8	19.8	-	7.40	1.84	27.0	5.62	82.0	16.9	30.1	11.9
UBC Farm	Composite 2	20.9	12.9	9.22	89.0	8.66	1.12	25.8	5.19	61.7	11.4	26.9	12.5
UBC Farm	Composite 3	21.9	9.04	6.47	93.2	9.01	0.940	20.9	5.62	55.5	20.1	16.3	8.03
UBC Farm	Subsoil	11.5	9.24	4.66	46.6	11.4	1.53	23.6	3.78	61.2	54.9	11.6	6.37
16 Oaks	Topsoil	-	-	45.4	80.4	87.0	7.24	17.9	15.9	59.0	75.6	26.2	19.5
16 Oaks	Raised bed composite 1	16.9	3.35	3.68	31.4	1.79	0.950	1.93	13.9	34.0	42.9	33.9	10.2
16 Oaks	Raised bed composite 2	22.3	2.84	4.42	51.3	1.67	1.31	2.89	17.9	35.1	9.09	24.9	7.61
16 Oaks	Raised bed composite 3	1.25	8.98	6.04	20.0	1.29	2.39	9.83	3.37	-	17.7	6.04	22.4
16 Oaks	Subsoil	11.0	2.31	2.52	26.6	1.76	0.410	1.17	40.0	26.9	7.10	30.5	4.93
Hastings brownfield	Topsoil	5.61	5.61	4.87	30.5	27.2	1.01	12.7	11.0	40.2	10.3	12.7	28.7
Hastings brownfield	Composite 1	37.7	85.2	26.4	66.0	60.4	3.29	15.0	6.87	45.9	25.5	8.54	8.51
Hastings brownfield	Composite 2	37.3	38.0	30.1	-	59.9	3.20	13.1	6.71	59.5	12.3	12.7	15.9
Hastings brownfield	Composite 3	42.5	52.0	18.4	88.9	79.5	4.08	11.6	9.38	61.6	31.6	10.9	18.1
Hastings brownfield	Subsoil	-	-	-	87.6	-	7.59	16.2	6.69	41.4	13.7	5.20	5.88
Second sampling event: 14 February 2012													
UBC Farm	Topsoil 1	10.5	3.45	5.35	90.5	8.50	0.0900	10.9	2.50	31.4	23.6	6.40	1.67
UBC Farm	Topsoil 2	18.2	4.97	19.8	79.0	5.00	0.460	16.6	3.48	51.0	67.4	13.9	4.56
UBC Farm	Topsoil 3	14.0	6.78	25.1	52.6	20.3	0.390	18.0	3.99	55.2	49.2	14.3	4.05
UBC Farm	Topsoil 4	10.6	2.74	3.26	23.7	5.39	0.120	7.92	2.56	20.7	6.42	5.05	1.72
UBC Farm	Topsoil 5	20.6	3.87	14.4	35.4	9.83	0.220	11.6	5.09	21.7	27.7	14.6	4.26
UBC Farm	Subsoil	6.55	4.55	8.29	31.6	12.1	0.0200	9.35	1.12	34.1	6.96	3.50	0.800
16 Oaks	Topsoil 1	30.0	26.6	7.40	36.3	27.6	4.07	5.73	8.31	18.5	26.4	4.71	2.55
16 Oaks	Topsoil 2	25.9	49.0	7.55	25.4	22.8	2.50	6.38	6.67	18.6	16.6	11.0	1.77
16 Oaks	Topsoil 3	47.7	30.6	17.20	41.7	17.2	1.94	7.02	6.07	14.4	38.0	9.09	1.55
16 Oaks	Topsoil 4	31.0	17.6	6.83	37.8	17.5	0.710	5.41	4.57	7.46	18.4	10.4	1.43
16 Oaks	Topsoil 5	28.0	23.4	9.85	-	15.9	2.96	5.73	3.18	15.9	20.8	7.54	0.100
16 Oaks	Subsoil	50.5	41.2	7.19	30.0	28.8	2.28	9.46	4.41	31.7	-	6.34	7.04
Hastings brownfield	Topsoil 1	39.9	42.8	17.8	56.3	46.3	2.65	7.85	9.86	20.9	28.6	11.4	14.2
Hastings brownfield	Topsoil 2	20.1	14.2	15.0	18.4	24.6	1.07	3.78	4.74	10.1	5.39	4.60	4.53
Hastings brownfield	Topsoil 3	32.5	31.9	35.2	37.2	54.1	2.98	8.54	9.88	25.8	33.4	8.51	17.6
Hastings brownfield	Topsoil 4	32.7	29.7	36.3	72.3	55.0	3.26	7.76	7.38	23.9	16.8	8.05	10.3
Hastings brownfield	Topsoil 5	23.9	14.9	23.8	63.4	36.3	2.48	6.66	6.18	13.5	10.7	4.96	8.53
Hastings brownfield	Subsoil	22.5	31.0	21.6	25.1	30.6	1.30	11.0	4.18	27.6	22.8	4.86	8.74

[1] All values greater than 100% eliminated from statisitcal analysis.

Table A8. Mean and standard deviation values for proportion of available elements in soil.

Site	Sample	Sample Size	Percent Available (%)											
			Zn SD	Pb SD	Ni SD	Mn SD	Cu SD	Fe SD	Al SD	Mg SD	Ca SD	Na SD	K SD	P SD
UBC Farm	Topsoil and composite	9	22.3	7.59	13.3	66.2	9.03	0.714	18.2	4.27	48.2	26.2	16.8	6.14
			14.8	4.14	7.58	28.7	4.52	0.605	7.00	1.22	20.0	19.8	8.57	3.99
UBC Farm	Subsoil	2	9.02	6.90	6.48	39.1	11.8	0.775	16.5	2.45	47.6	30.9	7.55	3.58
			3.50	3.32	2.57	10.6	0.494	1.07	10.1	1.88	19.2	33.9	5.73	3.94
16 Oaks	Topsoil	6	32.5	29.4	15.7	44.3	31.3	3.24	8.03	7.45	22.3	32.6	11.5	4.48
			8.71	11.9	15.0	21.0	27.6	2.25	4.87	4.50	18.4	22.4	7.55	7.40
16 Oaks	Raised bed composite	3	13.5	5.06	4.71	34.2	1.58	1.55	4.88	11.7	34.6	23.2	21.6	13.4
			10.9	3.41	1.21	15.8	0.261	0.749	4.31	7.50	0.778	17.6	14.2	7.90
16 Oaks	Subsoil	2	30.8	21.8	4.86	28.3	15.3	1.34	5.32	22.2	29.3	7.10	18.4	5.98
			27.9	27.5	3.30	2.40	19.1	1.32	5.86	25.2	3.39	-	17.1	1.49
Hastings brownfield	Topsoil and composite	9	30.2	34.9	23.1	54.1	49.2	2.67	9.66	8.00	33.5	19.4	9.15	14.0
			11.8	24.0	10.2	23.6	17.6	1.03	3.62	2.10	19.1	10.5	3.03	7.18
Hastings brownfield	Subsoil	2	22.5	31.0	21.6	56.4	30.6	4.44	13.6	5.44	34.5	18.2	5.03	7.31
			-	-	-	44.2	-	4.45	3.68	1.77	9.76	6.43	0.240	2.02

Table A9. Soil properties of individual samples from two of the study sites (Thomas 2012).

Site	Sample	EC (dS/m)	pH in water	pH in 0.01M CaCl$_2$	Organic Matter (%)
16 Oaks	Topsoil 1	0.050	5.63	5.31	2.77
16 Oaks	Topsoil 2	0.125	5.20	4.70	2.26
16 Oaks	Topsoil 3	0.055	5.90	5.34	4.38
Hastings brownfield	Topsoil 1	0.120	6.88	6.46	8.32
Hastings brownfield	Topsoil 2	0.285	4.94	4.81	3.28
Hastings brownfield	Topsoil 3	-	5.98	5.42	7.17
Hastings brownfield	Topsoil 4	0.390	7.19	6.90	9.85
Hastings brownfield	Topsoil 5	0.255	6.47	6.17	15.2

Table A10. Mean and standard deviation values for soil properties (Thomas 2012),

Site	Sample	EC (dS/m)	pH in water	pH in 0.01M CaCl$_2$	Organic Matter (%)
		SD	SD	SD	SD
16 Oaks	Topsoil	0.077	5.58	5.12	3.14
		0.042	0.353	0.361	1.11
Hastings brownfield	Topsoil	0.263	6.29	5.95	8.76
		0.111	0.882	0.835	4.33

Table A11. Element concentrations from aqua regia extraction of individual soil samples from two of the study sites (Thomas 2012).

Site	Sample	(mg/kg dry matter)											
		Zn	Pb	Ni	Mn	Cu	Fe	Al	Mg	Ca	Na	K	P
16 Oaks	Topsoil 1	160	125	20.0	700	41.1	24200	19000	3950	4120	114	573	584
16 Oaks	Topsoil 2	266	136	24.3	513	60.5	26100	23100	5530	16300	559	1460	1220
16 Oaks	Topsoil 3	209	135	31.3	1230	49.0	24500	19300	3170	8750	170	1230	1260
Hastings brownfield	Topsoil 1	803	296	43.6	468	249	42100	14500	4870	4080	1080	913	770
Hastings brownfield	Topsoil 2	270	138	29.7	400	181	34600	12300	3440	2990	833	894	268
Hastings brownfield	Topsoil 3	1080	371	90.1	470	3610	46100	12300	3550	3930	582	981	410
Hastings brownfield	Topsoil 4	62.5	180	21.7	318	45.8	17800	15400	3400	4570	121	669	222
Hastings brownfield	Topsoil 5	158	64.5	13.2	347	71.0	19300	15200	4020	4610	995	1050	167

Table A12. Mean and standard deviation values of element concentrations from aqua regia extraction of soil (Thomas 2012).

Site	Sample	Sample Size	(mg/kg dry matter)											
			Zn	Pb	Ni	Mn	Cu	Fe	Al	Mg	Ca	Na	K	P
16 Oaks	Topsoil	3	212	132	25.2	813	50.2	24900	20500	4220	9720	281	1090	1020
			53.2	6.22	5.67	371	9.73	1060	2310	1200	6140	243	461	380
Hastings brownfield	Topsoil	5	475	210	39.6	401	832	32000	13900	3860	4040	723	901	367
			444	123	30.3	68.7	1560	13000	1510	621	655	387	143	242

Table A13. Element concentrations from HCl extraction of individual soil samples from two of the study sites (Thomas 2012).

Site	Sample	(mg/kg dry matter)											
		Zn	Pb	Ni	Mn	Cu	Fe	Al	Mg	Ca	Na	K	P
16 Oaks	Topsoil 1	88.4	70.9	4.52	453	15.3	528	2670	448	1370	173	615	42.8
16 Oaks	Topsoil 2	60.1	22.0	3.05	162	5.02	428	1990	571	1000	174	351	120
16 Oaks	Topsoil 3		16.1	2.41	547	2.19	132	1580	659	800	121	438	93.6
Hastings brownfield	Topsoil 1	404	208	12.2	171	193	1460	1840	351	1030	113	2900	39.9
Hastings brownfield	Topsoil 2	82.4	71.1	6.39	146	103	1020	1310	374	692	61.6	387	69.5
Hastings brownfield	Topsoil 3	561	224	38.2	179	130	1540	1890	455	1060	98.2	4060	52.1
Hastings brownfield	Topsoil 4	15.9	17.7	3.08	137	17.6	730	2040	459	1030	48.1	88.7	50.7
Hastings brownfield	Topsoil 5	48.7	39.6	2.91	118	42.7	765	2040	371	1040	63.4	292	85.6

Table A14. Mean and standard deviation values of element concentrations from HCl extraction of soil (Thomas 2012).

Site	Sample	Sample Size	(mg/kg dry matter)											
			Zn	Pb	Ni	Mn	Cu	Fe	Al	Mg	Ca	Na	K	P
16 Oaks	Topsoil	3	78.1	36.3	3.33	387	7.51	362	2080	559	1060	156	468	85.5
			15.7	30.1	1.08	201	6.91	206	548	106	288	30.2	134	39.3
Hastings brownfield	Topsoil	5	222	112	12.6	150	97.2	1100	1820	402	968	76.9	1550	59.6
			245	96.7	14.8	24.8	69.9	380	299	50.9	155	27.4	1820	18.0

Table A15. Proportion of elements extracted using HCl as compared to aqua regia in individual soil samples from two of the study sites (Thomas 2012).

Site	Sample	Percent Available (%)											
		Zn	**Pb**	**Ni**	**Mn**	**Cu**	**Fe**	**Al**	**Mg**	**Ca**	**Na**	**K**	**P**
16 Oaks	Topsoil 1	55.3	56.7	22.5	64.8	37.2	2.18	14.0	11.3	33.2	-	-	7.32
16 Oaks	Topsoil 2	22.6	16.1	12.6	31.6	8.29	1.64	8.58	10.3	6.16	31.2	24.0	9.87
16 Oaks	Topsoil 3	41.2	11.9	7.70	44.5	4.48	0.538	8.22	20.8	9.14	71.6	35.6	7.40
Hastings brownfield	Topsoil 1	50.3	70.2	28.0	36.5	77.5	3.47	12.7	7.20	25.1	10.4	-	5.19
Hastings brownfield	Topsoil 2	30.5	51.6	21.5	36.5	56.8	2.94	10.6	10.9	23.1	7.40	43.3	25.9
Hastings brownfield	Topsoil 3	51.8	60.3	42.4	38.1	3.59	3.34	15.3	12.8	26.8	16.9	-	12.7
Hastings brownfield	Topsoil 4	25.5	9.86	14.2	43.0	38.6	4.11	13.3	13.5	22.5	39.9	13.3	22.8
Hastings brownfield	Topsoil 5	30.8	61.4	22.1	34.0	60.2	3.97	13.4	9.24	22.5	6.37	27.9	51.3

Table A16. Mean and standard deviation values for proportion of available elements in soil (Thomas 2012).

Site	Sample	Sample Size	Percent Available (%)											
			Zn	**Pb**	**Ni**	**Mn**	**Cu**	**Fe**	**Al**	**Mg**	**Ca**	**Na**	**K**	**P**
16 Oaks	Topsoil	3	39.7	28.2	14.3	47.0	16.7	1.45	10.3	14.1	16.2	51.4	29.8	8.20
			16.4	24.7	7.57	16.7	17.9	0.839	3.25	5.75	14.8	28.6	8.21	1.45
Hastings brownfield	Topsoil	5	37.8	50.7	25.6	37.6	47.3	3.56	13.1	10.7	24.0	16.2	28.2	23.6
			12.3	23.7	10.6	3.34	28.1	0.477	1.67	2.58	1.90	13.9	15.0	17.6

Table A17. Element concentrations from aqua regia extraction of individual root and shoot samples from the study sites.

First sampling event: 5 November 2011

Site	Sample	Organic Matter (%)	Zn	Pb	Ni	Mn	Cu	Fe	Al	Mg	Ca	Na	K	P
								(mg/kg dry matter)						
UBC Farm	Shoot 1	82.3	2260	-	26.8	802	264	1260	698	40700	64200	703	301000	47300
16 Oaks	Shoot 2	89.0	1760	178	63.8	508	177	5230	4510	10000	70700	2400	113000	9190
Hastings brownfield	Shoot 3	82.5	326	83.3	145	858	104	13000	7720	11500	39000	8180	162000	32300

Second sampling event: 14 February 2012

Site	Sample	Organic Matter (%)	Zn	Pb	Ni	Mn	Cu	Fe	Al	Mg	Ca	Na	K	P
UBC Farm	Shoot 1	81.5	315	62.6	14.1	1300	87.0	7620	7670	10200	19800	1440	200000	27700
UBC Farm	Shoot 2	88.1	285	62.0	7.24	748	81.2	10400	9830	15800	41500	1820	226000	36000
UBC Farm	Shoot 3	94.0	294	105	97.7	1580	152	9610	7100	14000	46100	2770	257000	31200
UBC Farm	Shoot 4	71.8	751	104	34.2	2920	197	19600	15600	29700	61000	3170	413000	61800
UBC Farm	Shoot 5	80.9	520	77.2	35.8	762	118	16000	16300	13100	26900	1520	234000	40500
16 Oaks	Shoot 1	67.2	641	221	44.9	480	113	33000	36700	8240	17300	1280	49000	8460
16 Oaks	Shoot 2	66.9	550	181	7.19	88.5	85.3	7630	25800	6720	15200	1240	65900	9270
16 Oaks	Shoot 3	67.1	2990	924	121	1070	230	62000	60800	14400	33400	3040	34200	11500
16 Oaks	Shoot 4	61.6	1590	625	50.7	539	108	29500	30100	7680	18300	2220	82900	12900
16 Oaks	Shoot 5	91.4	430	196	32.4	349	174	14400	9780	4460	29800	1170	189000	23700
Hastings brownfield	Shoot 1	73.3	482	108	22.7	380	160	18600	16000	5290	14800	1160	55500	7630
Hastings brownfield	Shoot 2	90.9	1930	702	32.1	1860	616	51400	25400	8250	47400	-	226000	18500
Hastings brownfield	Shoot 3	87.8	726	192	53.3	172	166	4560	13600	3420	20700	935	97600	10700
Hastings brownfield	Shoot 4	85.7	892	228	49.1	656	397	17200	19100	5700	25300	1880	136000	11400
Hastings brownfield	Shoot 5	79.5	1080	204	79.5	958	297	24800	17700	8290	37200	1940	220000	21400
UBC Farm	Roots in topsoil 1	63.3	218	59.2	13.5	334	73.2	21700	27400	3540	11800	581	7530	4920
UBC Farm	Roots in topsoil 2	55.8	137	43.4	33.4	456	63.3	14800	18600	2710	8470	388	5790	3510
UBC Farm	Roots in topsoil 3	49.1	87.4	45.3	7.66	541	48.0	21800	22300	3060	9320	251	2090	1920
UBC Farm	Roots in topsoil 4	56.6	206	71.9	17.7	540	92.0	23700	26300	3630	11200	426	4630	4440
UBC Farm	Roots in topsoil 5	60.5	221	45.3	2.72	262	85.3	22200	26000	3590	16000	584	7110	5080
UBC Farm	Roots in subsoil	51.4	131	61.7	12.4	574	65.9	28100	30800	4160	9340	360	4090	3070
16 Oaks	Roots in topsoil 1	35.8	631	157	62.5	165	73.2	25000	25300	4270	6680	436	3890	1320
16 Oaks	Roots in topsoil 2	58.8	1500	445	42.7	791	142	53200	50000	10900	19300	1680	20200	5790
16 Oaks	Roots in topsoil 3	28.6	1120	380	12.4	185	89.9	25500	29000	4790	8590	795	3040	1240
16 Oaks	Roots in topsoil 4	64.0	2970	1130	32.4	593	161	36400	34300	5440	17900	2190	10600	4720
16 Oaks	Roots in topsoil 5	44.0	607	167	29.3	260	63.5	34400	32400	4270	9320	511	6130	1830
Hastings brownfield	Roots in topsoil 1	54.7	828	184	63.8	584	583	30600	20100	3870	11400	424	6390	2220
Hastings brownfield	Roots in topsoil 2	43.1	856	198	52.0	201	431	37800	22600	4090	10800	478	6200	1520
Hastings brownfield	Roots in topsoil 3	59.9	971	188	34.4	594	398	29900	26200	5420	13300	596	9960	2510
Hastings brownfield	Roots in topsoil 4	75.5	1070	188	41.1	261	567	35200	32900	6690	14400	716	12400	2910
Hastings brownfield	Roots in topsoil 5	53.1	491	102	38.7	374	259	26400	23700	4340	11400	353	5720	1530
Hastings brownfield	Roots in subsoil	42.3	396	200	26.0	395	175	118000	15000	2580	4710	1.20	1280	515

Table A18. Element concentrations from HCl extraction of individual rhizosphere soil samples from the study sites.

Second sampling event: 14 February 2012

Site	Sample	Zn	Pb	Ni	Mn	Cu	Fe	Al	Mg	Ca	Na	K	P
							(mg/kg dry matter)						
UBC Farm	Rhizosphere soil in topsoil 1	40.0	61.6	2.63	418	31.8	4380	9770	186	3480	162	682	1560
UBC Farm	Rhizosphere soil in topsoil 2	57.1	65.2	7.26	282	22.3	8060	7960	1270	2640	210	1240	985
UBC Farm	Rhizosphere soil in topsoil 3	38.7	57.7	4.33	333	12.9	4860	7950	717	2560	168	579	1020
UBC Farm	Rhizosphere soil in topsoil 4	31.4	39.1	3.70	147	12.1	4280	4140	630	1180	130	363	465
UBC Farm	Rhizosphere soil in topsoil 5	14.3	23.6	0.260	131	14.6	1490	3080	105	2300	79.9	460	778
UBC Farm	Rhizosphere soil in subsoil	20.0	48.6	5.07	468	61.7	5340	20600	83.9	5740	271	866	1860
16 Oaks	Rhizosphere soil in topsoil 1	1490	717	32.8	1050	125	51500	24400	8100	24200	1630	2240	3840
16 Oaks	Rhizosphere soil in topsoil 2	112	193	0.0700	139	13.6	5320	2610	167	4350	266	897	717
16 Oaks	Rhizosphere soil in topsoil 3	169	156	0.260	86.9	8.81	1420	1160	135	2740	106	367	323
16 Oaks	Rhizosphere soil in topsoil 4	1070	1020	5.54	366	41.7	7890	5370	423	8460	520	1520	1520
16 Oaks	Rhizosphere soil in topsoil 5	195	96.5	7.57	236	6.8	6930	7580	2320	2980	203	689	452
Hastings brownfield	Rhizosphere soil in topsoil 1	312	121	20.9	412	186	15800	10100	4460	4980	594	1380	531
Hastings brownfield	Rhizosphere soil in topsoil 2	126	78.8	5.34	196	72.6	1800	1510	210	2420	142	692	433
Hastings brownfield	Rhizosphere soil in topsoil 3	127	137	4.34	326	96.8	2730	2250	343	5060	352	1420	846
Hastings brownfield	Rhizosphere soil in topsoil 4	758	326	53.3	1300	427	41500	26400	13100	13800	1480	3930	1220
Hastings brownfield	Rhizosphere soil in topsoil 5	410	157	29.4	688	180	22900	16700	7160	8830	814	1990	902
Hastings brownfield	Rhizosphere soil in subsoil	1180	2470	143	1510	567	32000	45400	1510	34500	2320	2350	7500

Table A19. Mean and standard deviation values of element concentrations in vegetative samples.

Site	Sample	Sample Size	Organic Matter (%)	Zn SD	Pb SD	Ni SD	Mn SD	Cu SD	Fe SD	Al SD	Mg SD	Ca SD	Na SD	K SD	P SD
									(mg/kg dry matter)						
UBC Farm	Shoot	6	83.1	738	82.2	36.0	1350	150	10700	9530	20600	43200	1900	272000	40800
			7.48	768	21.3	32.2	840	70.6	6440	5830	12000	17800	913	77000	12400
UBC Farm	Roots in topsoil	5	57.1	174	53.0	15.0	427	72.4	20800	24100	3310	11400	446	5430	3970
			5.38	59.2	12.3	11.8	125	17.5	3470	3630	405	2930	141	2190	1300
UBC Farm	Rhizosphere soil in topsoil	6	-	36.3	49.4	3.64	262	18.7	4610	6580	582	2430	150	665	962
			-	15.5	17.6	2.55	123	8.35	2340	2840	469	828	48.4	343	401
16 Oaks	Shoot	6	73.9	1330	388	53.3	506	148	25300	27900	8580	30800	1890	89000	12500
			12.8	990	315	38.3	322	54.8	21200	20200	3380	20900	775	56100	5730
16 Oaks	Roots in topsoil	5	46.2	1370	456	35.9	399	106	34900	34200	5930	12400	1120	8770	2980
			15.0	971	398	18.5	279	43.2	11400	9480	2820	5800	775	7030	2120
Hastings brownfield	Rhizosphere soil in topsoil	6	-	607	437	9.25	376	39.2	14600	8220	2230	8550	545	1140	1370
			-	633	410	13.6	392	50.0	20800	9380	3400	9050	626	744	1460
UBC Farm	Shoot	6	83.3	906	253	63.6	814	290	21600	16600	7080	30700	2820	150000	17000
			6.31	570	227	44.4	590	192	16100	5880	2860	12400	3030	67400	9100
UBC Farm	Roots in topsoil	5	57.3	843	172	46.0	403	448	32000	25100	4880	12300	513	8130	2140
			11.9	219	39.5	11.9	181	133	4520	4880	1170	1520	144	2920	611
UBC Farm	Rhizosphere soil in topsoil	6	-	347	164	22.7	584	192	16900	11400	5050	7020	676	1880	786
			-	260	95.0	20.1	439	140	16400	10400	5370	4430	515	1230	314

Table A20. Element concentrations from HCl extraction of wet deposition collections from the three sites.

								(mg/kg dry matter)						
Site	Date collected	pH	Zn	Pb	Ni	Mn	Cu	Fe	Al	Mg	Ca	Na	K	P
UBC Farm	21-Nov-2011	5.58	2.19	0.00532	0.00599	0.00575	0.0112	0.0466	0.0815	0.092	0.235	0.527	0.136	0.0217
UBC Farm	14-Dec-2011	5.44	1.32	0.00562	0.00367	0.000812	0.00900	0.00736	0.0573	0.182	0.269	1.40	0.105	0.0138
UBC Farm	4-Jan-2011	5.25	1.46	0.00334	0.00106	0.000233	0.00258	-	0.0166	0.0506	0.166	0.544	0.0438	0.0234
UBC Farm	13-Jan-2012	5.43	1.41	0.00432	0.01571	0.000901	0.0115	-	0.215	0.683	0.197	0.674	0.0675	0.0255
UBC Farm	3-Feb-2012	4.45	1.96	0.00651	0.00327	0.000250	0.00665	-	0.0694	0.132	0.256	1.26	0.0966	0.0213
UBC Farm	14-Feb-2012	4.95	0.597	0.00338	0.000260	-	0.00665	-	0.0560	-	0.272	0.103	0.0154	0.0101
UBC Farm	2-Mar-2012	-	4.31	0.0101	0.00831	0.00240	0.00992	0.0854	0.296	0.154	0.441	1.79	0.181	0.0315
16 Oaks	19-Nov-2011	5.69	2.2	0.00554	0.00341	0.00691	0.0149	0.0312	0.0484	0.0351	0.358	0.550	0.187	0.0163
16 Oaks	10-Dec-2011	5.6	1.4	0.00507	0.00529	0.00400	0.0927	0.0256	0.0856	0.109	0.475	1.25	0.176	0.0239
16 Oaks	29-Dec-2011	5.22	2.00	0.00405	0.00101	0.00188	0.00584	-	0.0368	0.0688	0.491	0.910	0.0881	0.0128
16 Oaks	13-Jan-2012	5.74	1.54	0.00497	-	-	0.00957	-	0.0547	0.0932	0.208	0.796	0.0731	0.0164
16 Oaks	3-Feb-2012	5.55	5.79	0.0112	0.00330	0.001900	0.0136	-	0.269	0.281	0.510	3.76	0.203	0.127
16 Oaks	14-Feb-2012	5.19	3.94	0.113	0.000400	0.00173	0.0171	0.0262	0.280	0.101	0.391	1.41	0.273	0.0414
16 Oaks	2-Mar-2012	-	5.36	0.0175	0.00356	0.001500	0.0196	-	0.180	0.134	0.353	1.87	0.169	0.0497
Hastings brownfield	19-Nov-2011	5.49	4.46	0.0076	-	-	0.0300	-	0.128	0.00611	0.343	1.46	0.0946	0.0426
Hastings brownfield	10-Dec-2011	5.3	5.17	0.01065	0.00935	0.0129	0.0371	0.0265	0.0701	0.0985	0.631	0.900	0.249	0.0211
Hastings brownfield	29-Dec-2011	4.85	2.59	0.00499	0.00215	0.00223	0.0157	-	0.0321	0.180	0.384	1.84	0.145	0.0152
Hastings brownfield	13-Jan-2012	5.23	3.09	0.00546	0.000440	0.00163	0.00639	-	0.0212	0.0500	0.200	0.813	0.0572	0.00722
Hastings brownfield	3-Feb-2012	4.85	6.53	0.0127	0.000930	0.00305	0.0158	0.202	0.557	0.299	0.439	4.51	0.259	0.0419
Hastings brownfield	14-Feb-2012	4.66	2.35	0.00545	0.000220	0.0008	0.0129	0.0613	0.216	0.0335	0.420	0.319	0.0376	0.0104
Hastings brownfield	2-Mar-2012	-	1.33	0.0109	0.00128	-	0.0111	-	0.124	-	0.454	0.297	0.0294	0.0352

Table A21. Total element concentrations in wet deposition over the entire collection period.

	Average pH					(mg/kg in dry matter)								
Site	SD	Zn	Pb	Ni	Mn	Cu	Fe	Al	Mg	Ca	Na	K	P
UBC Farm	5.18 / 0.420	13.2	0.0386	0.0382	0.0103	0.0576	0.139	0.793	1.29	1.74	6.30	0.645	0.147
16 Oaks	5.50 / 0.237	22.2	0.0596	0.0170	0.0179	0.173	0.0830	0.955	0.823	2.79	10.5	1.17	0.287
Hastings brownfield	5.06 / 0.322	25.5	0.0577	0.0144	0.0206	0.129	0.289	1.15	0.667	2.87	10.1	0.872	0.174

Table A22. Total and average flux of elements in wet deposition per unit area at the study sites.

	Total Flux (mg/kg dry matter/m^2)											
	Average Flux (mg/kg dry matter/m^2/day)											
Site	Zn	Pb	Ni	Mn	Cu	Fe	Al	Mg	Ca	Na	K	P
UBC Farm	413	1.20	1.19	0.323	1.80	4.35	24.7	40.4	54.2	197	20.1	4.60
	2.95	0.00860	0.00853	0.00231	0.0128	0.0310	0.177	0.288	0.387	1.40	0.144	0.0328
16 Oaks	694	1.86	0.529	0.559	5.41	2.59	29.8	25.7	86.9	329	36.5	8.97
	5.22	0.0140	0.00400	0.00420	0.0407	0.0195	0.224	0.193	0.654	2.47	0.274	0.0674
Hastings brownfield	797	1.80	0.448	0.643	4.02	9.03	35.8	20.8	89.7	316	27.2	5.41
	5.99	0.0135	0.00337	0.00484	0.0303	0.0679	0.269	0.156	0.674	2.38	0.204	0.0407

[1.] Area of funnel: 0.0320m^2

Table A23. Total element concentrations from HCl extraction of dry deposition for the entire collection period.

	(mg/kg dry matter)												
Site	Zn	Pb	Ni	Mn	Cu	Cr	Fe	Al	Mg	Ca	Na	K	P
UBC Farm	37900	1460	452	319	1650	-	14100	21900	3440	12400	5390	6510	6970
16 Oaks	75200	683	115	196	719	207	5780	7280	2140	18000	1550	1820	2390
Hastings brownfield	160000	3330	819	512	5600	757	17800	30400	4040	35600	10500	7100	5290

Table A24. Total and average flux of elements in dry deposition per unit area at the study sites.

Site	Total Flux (mg/kg dry matter/m^2) Average Flux (mg/kg dry matter/m^2/day)												
	Zn	**Pb**	**Ni**	**Mn**	**Cu**	**Cr**	**Fe**	**Al**	**Mg**	**Ca**	**Na**	**K**	**P**
UBC Farm	1180000	45700	14100	9960	51400	-	441000	684000	107000	386000	168000	203000	218000
	8460	327	101	71.2	367	-	3150	4880	767	2760	1200	1450	1550
16 Oaks	2340000	21300	3590	6130	22400	6460	180000	227000	66800	563000	48400	56600	74700
	17600	160	27.0	46.1	169	48.5	1360	1710	502	4230	364	426	562
Hastings brownfield	4980000	104000	25600	16000	175000	23600	555000	947000	126000	1110000	327000	222000	165000
	37500	782	192	120	1310	178	4170	7120	949	8360	2460	1660	1240

[1.] Area of funnel: 0.0320m^2

Table A25. Total and average flux of elements in bulk (wet and dry) deposition per unit area at the study sites.

Sample	Total Flux (mg/kg dry matter) Average Flux(mg/kg dry matter/m^2/day)												
	Zn	**Pb**	**Ni**	**Mn**	**Cu**	**Cr**	**Fe**	**Al**	**Mg**	**Ca**	**Na**	**K**	**P**
UBC Farm	1180000	45700	14100	9960	51400	-	441000	684000	107000	387000	168000	203000	218000
	8460	327	101	71.2	367	-	3150	4880	767	2760	1200	1450	1550
16 Oaks	2350000	21300	3590	6130	22500	6460	180000	227000	66800	563000	48800	56700	74700
	17600	160	27.0	46.1	169	48.5	1360	1710	502	4230	366	426	562
Hastings brownfield	4980000	104000	25600	16000	175000	23600	555000	947000	126000	1110000	327000	222000	165000
	37500	782	192	120	1310	178	4170	7120	949	8360	2460	1670	1240

Table A26. Element concentrations from aqua regia extraction of bulk berry sampling from the study sites.

Site	Sample	Organic Matter (%)	(mg/kg dry matter)											
			Zn	Pb	Ni	Mn	Cu	Fe	Al	Mg	Ca	Na	K	P
UBC Farm	Blackberries	84.3	234	19.9	47.1	357	103	2060	1900	20000	35700	637	275000	35500
16 Oaks	Strawberries	87.6	652	-	34.1	7360	128	1240	2860	17100	69000	1240	176000	27400
Hastings brownfield	Blackberries	85.9	373	24.2	258	716	220	1820	747	36600	59600	1710	290000	46800

Table A27. Element concentrations from aqua regia extraction of bulk worm sampling from the study sites.

Site	Organic Matter (%)	(mg/kg dry matter)												
		Zn	Pb	Ni	Mn	Cu	Cd	Fe	Al	Mg	Ca	Na	K	P
UBC Farm	56.5	3570	485	12.6	297	91.0	43.4	26300	23200	5100	11900	9240	17600	19300
16 Oaks	62.5	2210	245	-	513	383	-	30400	25500	5850	20600	12400	71000	45300
Hastings brownfield	51.2	2810	157	-	290	307	31.6	21600	15800	2690	10800	12400	21800	23000

Table A28. Significant correlations for Zn, Pb, Ni, Mn and Cu in soil and vegetative samples.

df=3; p<0.05 for two-tailed test: t>3.182 or t< -3.182				
Significant associations for metals		**Correlation**	**r**	**t**
Zn in soil (AR)	Pb in soil (AR)	+	0.974	7.40
	Na in soil (AR)	+	0.952	5.40
	Na in soil (HCl)	+	0.949	5.21
	Zn in roots	+	0.927	4.27
	Pb in roots	+	0.976	7.77
	Na in roots	+	0.882	3.24
Zn in rhizosphere soil	Pb in rhizosphere soil	+	0.892	3.43
	Ca in rhizosphere soil	+	0.919	4.03
Zn in roots	Na in soil (AR)	+	0.881	3.24
	Pb in roots	+	0.968	6.74
	Na in roots	+	0.902	3.62
Zn in shoots	Pb in shoots	+	0.962	6.14
	Fe in shoots	+	0.904	3.66
Pb in soil (AR)	Na in soil (AR)	+	0.939	4.72
	Na in soil (HCl)	+	0.907	3.73
	Zn in roots	+	0.908	3.76
	Pb in roots	+	0.977	7.88
Pb in soil (HCl)	EC in soil	+	0.888	3.34
	Zn in soil (AR)	+	0.945	5.04
	Na in soil (HCl)	+	0.914	3.92
	Zn in roots	+	0.877	4.52
	Pb in roots	+	0.934	4.77
	Na in roots	+	0.909	3.78
Pb in roots	Na in soil (AR)	+	0.926	4.24
	Na in soil (HCl)	+	0.904	3.67
	Na in roots	+	0.885	4.05
Pb in shoots	Fe in shoots	+	0.920	3.30
Ni in rhizosphere soil	Mn in rhizosphere soil	+	0.948	5.16
	Cu in rhizosphere soil	+	0.926	4.23
	Cu in rhizosphere soil	+	0.932	4.45
	Fe in rhizosphere soil	+	0.908	3.74
	Mg in rhizosphere soil	+	0.994	15.5
	Na in rhizosphere soil	+	0.917	3.97
	K in rhizosphere soil	+	0.929	4.36
Mn in rhizosphere soil	Fe in rhizosphere soil	+	0.936	4.61
	Al in rhizosphere soil	+	0.966	6.42
	Mg in rhizosphere soil	+	0.939	4.72
	Na in rhizosphere soil	+	0.950	5.26
	K in rhizosphere soil	+	0.928	4.32
Cu in soil (HCl)	Cu in roots	+	0.986	10.4
Cu in rhizosphere soil	Mg in rhizosphere soil	+	0.902	3.61
	K in rhizosphere soil	+	0.915	3.94

[1.] AR- aqua regia extraction

[2.] HCl- HCl extraction

Table A29. Significant correlations for other elements in soil and vegetative samples.

df=3; p<0.05 for two-tailed test: t>3.182 or t< -3.182				
Significant associations for other elements		**Correlation**	**r**	**t**
LOI in soil	P in soil (AR)	+	0.915	3.92
Fe in rhizosphere soil	Al in rhizosphere soil	+	0.947	5.14
	Ca in rhizosphere soil	+	0.937	4.64
	Na in rhizosphere soil	+	0.981	8.74
Al in soil (HCl)	Ca in soil (HCl)	+	1.00	62.6
Al in rhizosphere soil	Na in rhizosphere soil	+	0.918	4.00
Ca in rhizosphere soil	Na in rhizosphere soil	+	0.946	5.07
Mg in soil (AR)	K in soil (AR)	+	0.978	8.12
Mg in roots	Al in roots	+	0.909	3.78
	K in roots	+	0.899	3.55
Mg in rhizosphere soil	Fe in rhizosphere soil	+	0.913	3.88
	Al in rhizosphere soil	+	0.938	4.71
	Na in rhizosphere soil	+	0.911	3.84
	K in rhizosphere soil	+	0.910	3.81
Na in soil (HCl)	EC in soil	+	0.910	3.28
Na in rhizosphere soil	K in rhizosphere soil	+	0.896	3.49
P in soil (AR)	P in shoots	+	0.912	3.85
P in shoots	K in shoots	+	0.922	4.12

[1.] AR- aqua regia extraction

[2.] HCl- HCl extraction