The challenges and opportunities of urban food production: A case study from Victoria, British Columbia

by
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Supervisory Committee

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Abstract

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Food production in urban areas has been conducted worldwide as a subsistence strategy and source of income. Recently, however, it is recognized that urban agriculture has the potential to contribute to the development of sustainable urban environments. This study examines the benefits of urban food production in North American cities, as well as focusing on some of the critical barriers to its widespread expansion and acceptance. It also explores the potential for contamination of produce from the ambient atmosphere in mid-sized urban centres.

Through interviewing nine urban farmers and one urban planner, in the city of Victoria, British Columbia, I documented each producer's knowledge of the benefits and limitations associated with urban food production. Each interviewee impressed upon me the numerous benefits that can be accrued through the practice of urban agriculture, but they also painted a picture of the struggles that urban farmers face. Issues identified included: a real and perceived risk of contamination, problems with land ownership and access, and lack of meaningful support for urban farmers. Although urban agriculture has been accepted in principle by the City of Victoria and other Canadian cities, there are many challenges that must be overcome for urban food production to truly produce a viable, sustained food system. A coordinated, comprehensive government policy for involvement in the urban food system is critical to effectively addressing urban food issues.

Investigations of heavy metal levels in lettuce (*Lactuca sativa*) grown in sampling sites across an urban/rural gradient showed that atmospheric contamination by heavy metals is greatest at urban sites, but also affects residential and rural sites. Sampling site types included: a control area (rural farms and properties outside of Victoria); residential sites (yards in residential neighbourhoods in the City of Victoria); and, industrial/business sites (heavily trafficked and industrialized areas in downtown Victoria). Site types were intended to reflect areas perceived as safe, probably safe, and probably not safe, and were selected based on expert opinion and land use. Results indicate that caution should be exercised in growing leafy greens at downtown sites, and that growing food in most residential neighbourhoods and green spaces is typically no worse than growing greens in rural Victoria. In fact, due to the proximity of urban agriculture to the market, growing food locally eliminates the need for transportation and extra processing; reducing the extra exposure crops otherwise might face during these phases.

Urban food production requires the support of communities and governments in order to contribute to both urban food security and urban sustainability. The City of Victoria has started on a path to ensuring that this food system receives the required support, but it requires concerted effort and action. Further research into urban food systems is necessary to ensure that urban food production is able to become a viable, sustained food system.

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Chapter 1

1.1 Introduction

Urban dwellers now represent the majority of the world's population (Clark, 1998; Donald and Blay-Palmer, 2006); in North America more than 80% of the population live in urban areas (McDonnell et al., 2009). Food currently reaches the majority of North Americans through the global industrialized food system, a system that today is widely acknowledged as unsustainable (Blay-Palmer, 2006; Delind, 2006; Kloppenburg et al., 1996). As a result of both the shift in demographics and the development of the system of industrial agriculture, cities are quickly becoming the focus for innovative food production and distribution systems. Urban food production has been identified as a means of increasing the local food supply and providing an effective alternative to the unsustainable model of industrialized agriculture (CRD Roundtable on the Environment, 2006; Mendes, 2006; Mullinix et al., 2009). Like many cities in North America, the City of Victoria, British Columbia is becoming engaged in urban food production to enhance sustainability and food security within its community (Bouris et al., 2009; CRD Roundtable on the Environment, 2006).

Urban environments, however, are deeply humanized landscapes; they are constantly impacted by anthropogenic factors, including transportation and industry, and the pollution these activities produce. The development of viable and sustainable forms of agriculture in urban areas must address the risks and challenges that are inherent in the opportunity of enhancing food production in the city. The current environment for growing food in the City of Victoria is not well understood (Bouris et al., 2009). One widespread concern is the potential for contamination of food products grown in urban areas by automotive and industrial emissions. This concern must be addressed if urban food production is to develop as a viable, sustainable alternative to the conventional food system in Victoria and vicinity.

To date, most of the research on urban food production has focused on regions of the world where urban agriculture is being implemented as a response to issues of subsistence and survival. Research in urban centres in Latin America and Africa has focused on this type of urban agriculture (Cole et al., 2008; Inoccencio et al., 2003; Mougeot, 2006; Nabulo, et al. 2006; Smit et al., 1996). However, there is also a need to understand urban food production as a strategy to increase sustainability in cities everywhere. This study seeks to investigate motivations for growing food in North American cities, barriers to these efforts and the risks of contamination. Victoria, B.C. represents an excellent case study to examine the barriers and opportunities associated with urban food production because it is similar to many other mid-sized North American cities in terms of the level of industrial activity and it has a growing population of urban farmers pushing the boundaries of existing by-laws and regulations.

Increases in industrialization and urbanization, along with associated air pollution (as well as soil and water pollution), threaten urban food production and the quality of the growing environment in cities throughout the world (Agrawal et al., 2003). Although these problems are not likely as acute in Victoria as they are in massive urban centres such as Toronto, Ontario or Vancouver, British Columbia, residents of Victoria have identified the potential for contamination as a possible barrier to the expansion of urban agriculture. Atmospheric pollution is not recognized as a widespread problem in cities like Victoria, making Victoria an excellent case study to examine the pervasiveness of atmospheric pollution and its effects on urban produce.

1.2 Thesis objectives

This research developed out of my interest in food production systems. I wanted to examine a relevant concern associated with urban food production in North America. In the process of determining a specific aspect of urban food production to study, I spoke with many urban and rural food producers in and around the City of Victoria. Their interest in the potential for crop contamination as well as other barriers to the widespread acceptance and expansion of urban food production helped guide the focus of my study. The overall goal of this research was to explore urban food production in the City of Victoria, focusing on two themes: 1) urban food producers' perceptions of the role urban food production has in efforts to increase urban sustainability and of the barriers that stand in the way of its widespread acceptance and expansion; and 2) the potential for atmospheric contamination of produce. The specific objectives of chapters two and three of this thesis are, respectively:

1. Gain insight into the perceptions and views of urban food producers regarding their assessment of the potential contributions urban food production can make to urban sustainability as well as the barriers preventing these contributions.

2. Evaluate the potential for heavy metal contamination of produce (lettuce, *Lactuca sativa L.*) grown at a range of locations throughout the City of Victoria

1.3 Thesis framework

The remainder of this chapter introduces the context and background of this research, situating it within the broader scope of food production systems and urban environments. This chapter explores general concepts such as the urban environment and food production systems before narrowing in on urban food production and the environmental toxicology associated with growing food in urban areas.

The second chapter presents the results of my qualitative study involving urban food producers within the City of Victoria. This study explores urban food production from the viewpoint of those engaged in it. Semi-structured interviews were conducted with nine urban food producers and one local planner. The objective of these interviews was to gain an understanding of the contributions of urban food production to urban sustainability and examine the barriers hindering its acceptance and expansion.

The third chapter presents the results of a quantitative study of heavy metal contamination of produce grown in the City of Victoria. Specifically, this study involved an analysis of lettuce (*Lactuca sativa* L.) grown in planter boxes positioned in various locations throughout the City of Victoria and surrounding area during the peak pollution season. The goal of this study was to compare heavy metal levels in produce grown in the City of Victoria, produce grown in surrounding rural areas, and produce available from local grocery stores. A multivariate analysis was also conducted to examine the potential drivers of urban food contamination.

The final chapter synthesizes the results of the qualitative and quantitative portions of my thesis research. It examines potential measures for reducing the risks associated with atmospheric deposition of contaminants, and discusses future initiatives to enhance urban food production. Data derived from this study can be used to establish criteria to determine acceptable growing spaces for leafy greens. These criteria can be informed by actual heavy metal concentrations in produce grown around the city, as well as by the knowledge, perceptions and opinions of urban food producers.

1.4 Study area

This study was conducted in Greater Victoria, British Columbia, Canada with a focus on the City of Victoria. Victoria is located in the Capital Regional District on the southern tip of Vancouver Island. This area has been the homeland to the Lekwungen Coast Salish peoples for millennia (Keddie, 2003). Fort Victoria was established by the Hudson's Bay Company in 1843 as a trading post and fort (City of Victoria, 2009). Incorporated as a City in 1862, Victoria was the first permanent coastal settlement in British Columbia, and it stands today as the oldest city in Western Canada (City of Victoria, 2009; McGillivray, 2000). Victoria remained the largest city in the west for most of the 19th century, until it was surpassed by Vancouver (McGillivray, 2000). Today, Victoria is known primarily as home of the Provincial Government, and as a retirement and tourism destination (City of Victoria, 2009). According to the 2001 census, the estimated population of the Capital Regional District was 330 000, and is expected to reach 400 000 by the year 2020. Victoria is located in a sub-Mediterranean climate zone and receives some of the most moderate weather across Canada (City of Victoria, 2009). For eight months of the year, it typically remains frost free, with a very low humidity ratio. Temperatures remain mild, ranging from 0-25 degrees Celsius, with the average annual temperature being 10.3 °C (Environment Canada, 2010). As such, winters rarely include snow, and summer time highs generally occur in the months of July and August (City of Victoria, 2009; Environment Canada, 2010). Victoria is situated in plant hardiness zone 8a; there are nine major zones, with 0 being the harshest and 8 the mildest (Government of Canada, 2010). This climate is ideal for agriculture and associated activities (MacNair, 2004). Victoria has a long history of local food production with the claim of supporting its own Island food community (Joint Commission, 2007; MacNair, 2004). In fact, the southern portion of Vancouver Island and the nearby Gulf Islands were known at one time as "Vancouver's Market Garden", as produce was exported to the mainland as well as supplying Victoria with 80% of its food supply (Bouris et al., 2009). At present, however, the City has become heavily dependent on imported foods, with 90% of its produce coming from outside sources (Cleverly, 2001).

The physical separation of Vancouver Island from the mainland, demands a complex transportation network. Victoria's proximity to US markets and its many sea and air links have facilitated the development of a food system dominated by imports (MacNair, 2004). Sea, air and road traffic all play critical roles within the City of Victoria. Ferries carrying passengers, cars, trucks and trailers, make more than 100 crossings to and from the mainland daily, linking Victoria to Vancouver, Seattle, Prince Rupert and Alaska. Float plants (private, charter and scheduled) transport tens of thousands of people annually, and more than 60 scheduled daily flights connect Victoria with mainland destinations (City of Victoria, 2009).

Victoria's reliance on this increasingly complex transportation system makes it very vulnerable should any disruption occur. Rising fuel prices and ferry fares could have immediate, adverse impacts, potentially delaying food imports and isolating Vancouver Island. Given this susceptibility, local and urban food production have been recognized as important strategies for dealing with sustainability and food security issues in the City of Victoria (CRD Roundtable on the Environment, 2006).

1.5 Research design

This project employed a mixed methods research approach, in which both quantitative and qualitative data were collected to provide a comprehensive understanding of the research problem (Casey and Murphy, 2009). Mixed methods research can be formally defined as "the class of research where the researcher mixes or combines quantitative and qualitative research techniques, methods, approaches, concepts or language into a single study" (Johnson and Onwuegbuzie, 2003, p. 17). A mixed methods approach allows the researcher to be inclusive, pluralistic and complementary in the design and execution of the research (Johnson and Onwuegbuzie, 2003). As a research paradigm, the mixed methods approach did not emerge until the 1990s when it established itself as a separate methodology with its own worldview, vocabulary and techniques (Denscombe, 2008). While there are a variety of reasons for using a mixed methods approach, I chose this design for its ability to establish a more holistic understanding by combining information from diverse data sources (Denscombe, 2008; Morrel and Jin Bee Tan, 2009; Tashakkori and Creswell, 2007). It was particularly appropriate for my research study because it enabled a more complete contextualization of urban food contamination. Working with local experts also yielded insight into local barriers to the expansion and acceptance of urban agriculture (Casey and Murphy, 2009).

1.6 The urban ecosystem

Urbanization is now recognized as a significant, global trend (Grove and Burch, 1997), one that is currently occurring at an unprecedented rate (Pickett et al., 2001). In industrial nations, land conversion for urban and suburban uses is proceeding even more rapidly than population growth in urban areas (Pickett et al., 2001). Cities are no longer compact, consolidated aggregations of houses and commercial centres; instead they sprawl out in all directions, growing around, and in many cases, taking over prime agricultural lands (Pickett et al., 2001; Ramankutty et al., 2002).

Home to the majority of the human population and associated anthropogenic activities, the cities of the 21st century will have enormous influence on the provisioning of global ecosystem services (McDonnell et al., 2009). It is critical that these cities transform themselves into self-regulating, sustainable systems (McDonnell et al., 2009). To this end, many argue that the linear and mechanistic approach to urban planning and city design must be replaced with one that emphasizes circular systems (Beatley, 2000). Likewise, the idea of attaining balance between city and nature is also promoted with regards to urban sustainability (Wheeler and Beatley, 2004). Focusing on the idea of inputs (eg. energy and food) and outputs (eg. waste and carbon emissions) and creating closed loop systems is a powerful framework for local sustainability (Beatley, 2000). In fact, Beatley (2000) argues that cities must

> "…strive to live within their ecological limits, fundamentally reduce their ecological footprints, and acknowledge their connections with and impacts on other cities and communities and the larger planet" (p. 6).

Urban food production has been identified as a critical component in efforts to transform cities to achieve greater sustainability, and the potential for urban food production has received considerable attention. The built and densely populated nature of the urban environment provides unique opportunities for agricultural activities, including the proximity to markets, growing demand for food, access to cheap resources (eg. urban organic wastes and wastewater) as well as generating a microclimate that can extend the growing period compared to the surrounding landscape (Alberti et al., 2003; van Veenhuizen and Danso, 2007). At the same time however, this "built nature" also contributes to health risks associated with agricultural activities in the urban environment. Contamination from traffic and industrial sources can significantly impact soil, air and water, with the potential to cause health and environment risks, including consumption of contaminated food produced in cities (Lee-Smith, 2006; Lock and van Veenhuizen, 2001; van Veenhuizen and Danso, 2007).

If urban food production is to contribute to urban sustainability, it is important to understand the processes and mechanisms that impact food production and are impacted by food production in the urban ecosystem. Several disciplines can contribute to this, but ultimately a multidisciplinary approach is required, involving agricultural science and ethnoecology that take into consideration the unique aspects of agriculture in the urban environment. Knowledge of the agricultural processes derived from rural areas cannot simply be transferred to urban areas, just as the study of urban ecology cannot be fully understood by applying principles and models developed in other ecosystems (Grove and Burch, 1997).

1.7 Food systems

Food systems can be defined a s the combined elements of food production, processing, distribution, preparation and consumption (Gregory et al., 2005). Food systems can be as simple as subsistence farming, where producers grow a diverse array of food for their personal consumption, or can be complex systems where farmers have to purchase food for their own family's consumption, while growing massive amounts of a single crop that will subsequently be exported (Gregory et al., 2005).

As little as 60 years ago, agriculture was the primary component of most food systems. Since that time, agriculture in Canada has evolved from simple, subsistence and commercial operations, to industrialized businesses that are the domain of corporations (MacRae et al., 1993; Magdoff et al., 2000). This widespread and now conventional form of food production is characterized by large-scale, highly industrialized and mechanized practices, with monocultures of crops and extensive use of chemical fertilizers, herbicides and pesticides, and large-scale irrigation (Beus and Dunlop, 1990). Industrial agriculture is dependent on large, capital intensive production units and technology, and external energy sources and inputs (Beus and Dunlop, 1990). Farmers are encouraged by government policy and the manufacturing industry to produce greater and greater surpluses of food with less and less labour (Magdoff et al., 2000). Coupled with increasing mechanization, this has effectively enabled the consolidation of land holdings and the shedding of the traditional labour force (Blay-Palmer, 2008; Lang, 2003). With changes in the scale of operations, the political and social factors influencing production have also shifted. Control has moved from farmer to retailer, from national legislative bodies to regional and global organizations, and from the state to multinational corporations (Gregory et al., 2005).

Today, food reaches the majority of North Americans through a complex global system that threatens both natural and social communities (Kloppenburg et al., 1996). Growing food has been reduced to one component in a multi-faceted industrialized food system. Since food products increasingly require more processing and transportation, ultimately this process has worked to distance producers from consumers (Blay-Palmer, 2008). This is compounded by a food system that demands the maintenance of a massive globalized transportation network (Barker, 2002; Blay-Palmer, 2008; Viljoen, 2005). Additionally, by replacing many real food ingredients with chemical additives, the food industry has reduced its reliance on specific raw materials, and further distanced itself from agricultural production (Wilkinson, 2002). As a result, consumers are able to access a year round fruit and vegetable market, where produce continuously arrives from distant locations in carefully planned intervals (Lang, 2003). This system of "cheap", "seasonless" food with its focus on quantity and short-term efficiency has become the norm for most consumers in the industrialized world (Blay-Palmer, 2008; Lang, 2003). The industrialization of agriculture has had many negative consequences, including widespread groundwater contamination, soil erosion and degradation, chemical residues in food, and the demise of the family farm and rural communities (Beus and Dunlop, 1990; Kimbrell, 2002). Massive expansions of global transportation infrastructure needed to support the industrialized food system have also caused global air quality problems including increasing emissions of carbon dioxide (Barker, 2002). Intensive tillage has caused soil erosion, substantive losses of fertility and nutrients, and declines in the world's supply of arable land, creating problems for the future of agriculture (Horrigan et al., 2002).

The industrial food system has been valorized as the world's most productive food system, however, the growing presence of food insecurity and hunger remains one of its defining characteristics (Allen, 1999; Kimbrell, 2002). In 2004, almost one in ten Canadian households experienced food insecurity (Kirkpatrick and Tarasuk, 2009). Additionally, the nutritional quality implications of shipping produce around the world, and health externalities associated with unmonitored growing conditions, inherent in the industrial food system must be recognized as important concerns (Lang, 2003).

As the limitations of this system are becoming more apparent, the exploration of alternative food systems has become critical. One response is the growing network of self-reliant, locally or regionally based food systems that are establishing themselves (Blay-Palmer, 2008; Kloppenburg et al., 1996). These alternatives to the global, industrial system consist of diversified farms that employ sustainable practices, and supply fresher, more nutritious foods to small-scale processors and consumers. These alternative food systems typically remain embedded in local communities and farm ecologies (Blay-Palmer, 2008; Beus and Dunlop, 1990; Kloppenburg et al., 1996). Often the overarching philosophy of producers engaged in these food systems is to redistribute value and bridge the gap between food producers and food consumers (Donald, 2008).

1.8 Urban food production

Urban food production can be defined as agriculture occurring in the city. In most cases it manifests itself as fruit and vegetable gardens, but it is not so limited (Viljoen, 2005). As a practice, it is opportunistic in nature, occurring anywhere and everywhere the space exists to plant a few seeds or raise a few chickens (Mougeot, 2006). It is characterized by proximity to markets, high competition for land, limited space, re-use of urban resources (organic solid waste and wastewater), low degree of farmer organization, production of mainly perishable products and a high degree of specialization (van Veenhuizen, 2006). The practice of producing food in urban areas is not a new idea by any means; as a strategy for improving livelihoods it has always been a part of urban life (Mougeot, 2006; van Veenhuizen, 2006).

The number of activities designed to promote urban food production at international, national and local levels has grown significantly, and it is currently gaining substantial recognition as a tool for sustainable urban development (van Veenhuizen, 2006). Not only does urban food production work to "green" the city, but it provides a means of utilizing organic waste products from the city, reduces pollution, helps minimize the urban heat island effect, and consequently improves air quality (Brown and Jameton, 2006; van Veenhuizen, 2006). When food is grown locally, the need for transportation and processing of food is also substantially reduced, contributing to a reduction of the ecological footprint of city dwellers (Mendes, 2006; Mougeot, 2006). Urban agriculture can also work to build community and social capital, creating local resilience and self sufficiency (Brown and Jameton, 2000; van Veenhuizen, 2006). It is not surprising therefore, that urban food production has consistently been identified as a key priority for a number of cities across North America (CRD Roundtable on the Environment, 2006; Mendes, 2006; Mullinix et al., 2009).

Currently, the industrial food system supplies the majority of food consumed in the City of Victoria. Unfortunately, the loss of agricultural lands to development and urbanization has significantly reduced the opportunities for local food production in Victoria as elsewhere (MacNair, 2004). Access to the remaining arable land is hindered by high rural property prices. The high value of real estate coupled with the insufficient income generated by farming, has directly contributed to the declining number of farmers on the Island (MacNair, 2004). Agriculture employs only 1% of the labour force in the Capital Region (MacNair, 2004; CRD Roundtable on the Environment, 2006). The physical separation of the City of Victoria from the BC mainland, coupled with the loss of arable land and the decline in the rural farms, has created a strong incentive for more urban food production. Health professionals, urban planners, environmental activists, community organizers and policy makers are recognizing the value of urban food production for economic development, food security, preservation of green space and community sustainability (Brown and Jameton, 2000; van Veenhuizen, 2006).

Currently, the City of Victoria is engaged in a variety of urban food production activities. Over 50 homes are estimated to keep backyard chickens and this number is growing (Bouris et al., 2009). There are thousands of home gardens, and food is currently being produced in backyards, on boulevards, balconies and rooftops. There are three Commons Gardens located in urban Victoria. Designed as permaculture sites with food and flower plants for public harvest, these gardens are maintained by communities for educational and recreational purposes. Victoria also has three urban food production demonstration sites, as well as a growing number of community allotment gardens. Initiatives such as edible landscaping, school gardens, and gleaning programs are also occurring. Two properties in the City of Victoria are licensed for home-based urban agriculture and several properties participate in small-plot intensive (SPIN) gardening (Bouris et al., 2009).

Despite this enormous potential, one aspect of urban food production that is poorly understood is the potential risk to human and environmental health from growing food in urban environments in terms of associated contaminants (Birley and Lock, 1998; Cole et al., 2008; Lee-Smith and Prain, 2006; van Veenhuizen and Danso, 2007). Just as for rural agriculture, urban agriculture may have negative consequences if associated risks are not considered and proper preventative and guiding measures are not taken (van Veenhuizen and Danso, 2007). Additional research to guide policy that can reduce and eliminate these risks is critical. As noted previously, contamination of urban grown food from airborne pollutants in particular is not well understood.

1.9 Urban atmospheric pollution

Atmospheric pollution is a serious environmental problem in urban environments (Mayer, 1999; Molina and Molina, 2004). The large concentrations of people living in relatively small areas have created the opportunity for pollutants emitted from anthropogenic activities to build up in the air, water and soil, reaching levels that can significantly impact plant, animal and human health (Perkins, 1974). Air quality in cities is the result of a complex interaction between natural and anthropogenic environmental conditions (Mayer, 1999). Numerous studies have linked air pollution with premature mortality; indicating that the risks associated with poor air quality can be quite substantial

(Jerrett et al., 2009; Nel, 2005; Schlesinger et al., 2006). Photochemical smog in cities – created by traffic, industrial activities, power generation and solvents – has become the primary cause for concern about urban air quality (Molina and Molina, 2004).

The urban atmosphere includes photooxidants, gases, trace metals, inorganic substances and man-made organic chemicals (Bormann, 1982; Stern et al., 1973). Particulate matter, oxides of sulfur and nitrogen (SOx and NOx), and tropospheric ozone have all been recognized as important contaminants in the urban environment (Lovett, 1994; Schell and Denham, 2003). Particulate matter has been identified as a key component of polluted air, and is estimated to kill more than 500 000 people each year (Nel, 2005).

Many of these compounds are normally present in unpolluted air, but become pollutants when their concentrations are significantly increased in cities (Perkins, 1974). For example, heavy metals naturally occur from geochemical materials in the environment, and their presence in the atmosphere does not necessarily indicate heavy metal pollution. A problem exists only when concentrations become elevated, a phenomenon that often occurs in urban areas (Prasad, 2004). Urban areas typically have elevated levels of copper, cadmium, zinc, mercury, lead and tin (Birke and Rauch, 2000; Sezgin et al., 2004; Sterrett et al., 1996). Heavy metals remain in the atmosphere as aerosols, by association with solid particulate matter of diameter 0.6-1.0 um. The atmospheric residence time for heavy metal aerosols is approximately ten days (Simonetti et al., 2003). Heavy metals, such as lead, are of particular concern in urban areas, because they have an adverse effect on human health, are non-biodegradable in nature and can remain in the human body for long periods of time (Lee et al., 2006; Li et al., 2004). Previous studies have demonstrated that exposure to high concentrations of heavy metals can lead to a build up in the fatty tissue of the body, which in turn can affect the central nervous system. Heavy metals can also be deposited in the circulatory system and lead to disruptions in the normal functioning of internal organs (Lee et al., 2006).

The main sources of atmospheric contaminants are automotive emissions, road dust, industrial emissions, the burning of fossil fuels, and wastes from industrial and residential activities (Alexander et al., 2006; Biasoli et al., 2007; Sterrett et al., 1996). However, as noted previously, automotive related emissions are now recognized irrefutably as the primary contributors to the pollution load in urban areas (Ahmed, 2009; Biasoli et al., 2007; Gadsdon and Power, 2009; Honour et al., 2009; Lee et al., 2006; Mage et al., 1996; Molina and Molina, 2004; Mudd and Kozlowski, 1975; Nel, 2005; Peachy et al., 2009; Schell and Denham, 2003; Sterrett et al., 1996). Sources associated with transportation have been consistently identified as the primary sector for emissions in the City of Victoria. This category includes light-duty vehicles, heavy duty vehicles, aircraft, rail, marine, non-road and road dust (B.C. Ministry of Healthy Living and Sport, 2009; Levelton Engineering Ltd., 2001; Pott and Turpin, 1998).

Technological improvements to fuels and engines have undoubtedly resulted in substantial reductions in vehicular air pollution (National Roundtable on the Environment and Economy, 2003). However, in many cities these reductions are offset by increased numbers of vehicles and increased levels of vehicle use (Molina and Molina, 2004; National Roundtable on the Environment and Economy, 2003). Additionally, it has been noted that the combustion of low-leaded and unleaded gasoline is still a major source of atmospheric lead (Pacyna and Pacyna, 2001).

In the City of Victoria, atmospheric pollution tends to peak during the hottest months (July-September). During this period, roads are dry and dusty and vehicular traffic is at its highest volume (Levelton Engineering Ltd. 2001; Ministry of Transportation and Infrastructure, 2009). Collectively, high temperatures, dust levels, and vehicle use in the summer contribute to maximize aerosol levels, indicating that the heavy metal pollution load is probably also at its peak. Within the City, almost 80% of all trips are made via automobile and most are made by single occupant vehicles (Capital Regional District, 2009). While cycling has increased in popularity, walking has decreased (Capital Regional District, 2009). This increase in vehicle use is related to the overall decline in the number of homes within 400 m of a commercial centre, indicating that neighbourhood centres are generally no longer within walking distance. Travel by vehicle, therefore, remains the predominant mode of transportation and the trend towards increased vehicle use is likely to continue (Capital Regional District, 2009).

1.10 Environmental toxicology

Extensive studies conducted in North America and elsewhere in the world, have clearly demonstrated the adverse impacts of air pollution on vegetation (Agrawal et al., 2003; Ashmore et al., 1988; Emberson et al., 2001; Mukherjee et al., 2001; Voutsa et al., 1996). Dealing with environmental pollution is a major problem for food production, but air pollution is especially problematic because food producers have little opportunity to mitigate negative effects (Mukherjee et al., 2001). Atmospheric pollutants also represent a major threat to crop production, significantly impacting yield and nutritional quality, as well as increasing concentration of heavy metals and other contaminants in the produce itself. This could, therefore have important consequences for the livelihoods and well being of producers and consumers of crops grown in urban areas (Agrawal et al., 2003 Mudd and Kozlowski, 1975; Wahid, 2006).

Several mechanisms are responsible for the transfer of organic pollutants to plant tissues. They include: 1) uptake through transpiration stream, 2) volatilization and subsequent re-deposition on leaves, 3) adsorption from direct contact with soil particles, 4) aerial absorption of volatile compounds by leaves, 5) deposition and penetration of contaminated soil particles and dusts on leaves, and 6) soil-to-root transfer of contaminants followed by translocation via the transpiration stream (Khan et al., 2008). The soil-root pathway has often been considered the most important route for contaminants but, the air-leaf interface is likely of equal importance for exposed plant parts (Harrison and Chirgawi, 1989). In fact, atmospheric deposition is the predominant pathway by which heavy metals enter exposed plant tissues (Harrison and Chirgawi, 1998; Nabulo et al., 2006; Voutsa, 1996).

Atmospheric deposition of heavy metals to leaves occurs because of the chemical potential gradient between the atmosphere and sites of deposition (Heck et al., 1988). This deposition occurs through three separate processes; wet deposition of material contained in precipitation, dry deposition (direct deposition of atmospheric particles and gases to vegetation, soil or surface water) and cloud deposition (deposition through water in the form of clouds and fogs) (Lovett, 1994; Peachey et al., 2009).

Once deposition has occurred, the plant’s response is dependent on several variables. Important physical and chemical factors including light, temperature, humidity, and soil moisture, can all impact the interaction between the contaminant and the plant (Heck et al. 1988). Biological factors include the presence of insects and/or pathogens, stomata control, the presence and/or activity level of detoxification systems (for toxicants and their metabolites), and the cells' ability to repair and/or compensate for the injury. The structure of the exposure, including the independent effects and interactions of concentration and duration of exposure also need to be considered. In the leaf, heavy metals can be: non toxic; toxic but inaccessible (insoluble or rare); or toxic and accessible (Prasad, 2004). Heavy metals that are toxic and readily accessible will have the greatest impact on plant health.

Plants are exposed to heavy metals in the atmosphere during the growing season and are especially susceptible to heavy metals in their early growth phases (Mudd and Kozlowski, 1975). Leafy vegetables have a significantly greater capacity to bio-accumulate heavy metals compared to non-leafy vegetables (Kachenko and Sing, 2006; Voutsa et al., 1996; Zhuang et al., 2008). Heavy metals can also be deposited onto crop surfaces during the production, harvesting, transportation and marketing stages of the food system. In fact, it has been found that transportation and marketing systems can play a significant role in elevating the heavy metal concentrations in vegetables (Sharma et al., 2009). Once in the plant, heavy metal contamination does not only have adverse impacts for the health of the plant, but can also pose serious health risks to consumers (Kachenko and Singh, 2006; Khan et al., 2008).

1.11 Conclusion

Food production has always been a part of urban life. However, the impact of the urban environment on the growth of food plants is poorly understood. There are many benefits of urban food production, a number of which are currently being recognized as contributing to urban sustainability. Nevertheless, the role of airborne contaminants, such as heavy metals, requires additional investigation. There are many benefits of urban food production, a number of which are currently being recognized as contributing to urban sustainability. The City of Victoria, like other cities, has agreed to support urban agriculture. Nevertheless, if urban food production is to produce a viable alternative to the conventional food system of industrial agriculture, the barriers and risks associated with it must be examined. This research was designed to gain a better understanding of the barriers to the expansion of urban agriculture as well as the contributions it made towards urban sustainability in the City of Victoria and the potential impact atmospheric deposition of heavy metals had on produce growing in the City of Victoria.

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Chapter Two: Perceptions of urban farmers in Victoria: the potential for urban food production to contribute to urban sustainability and the barriers that stand in the way

2.1 Abstract:

Urban food production has been identified as both a means for enhancing local food supply and creating more sustainable cities (Mendes, 2006; Mullinix, 2009). The practice of producing food in urban areas is not a new idea, but the number of activities designed to promote urban food production at international, national and local levels has grown significantly (van Veenhuizen, 2006). This paper explores urban food production in the context of sustainability and food security by examining the perspectives and opinions of urban farmers. Semi-structured interviews were conducted with nine urban farmers and one city planner in the City of Victoria, British Columbia. Despite the substantial benefits of urban agriculture, including: improving food security, reducing urban ecological footprints, developing awareness and appreciation for the environment, strengthening communities and enhancing urban green space, a number of challenges inhibiting the wider expansion and acceptance of urban food production were identified by the interviewees. Challenges include a real and perceived risk of contamination, problems with land ownership, and lack of meaningful support for farmers engaged in urban food production. Several potential opportunities to facilitate acceptance and expansion of urban food production also emerged from the study, including increasing municipal and community support for urban agriculture and facilitation of the necessary supporting structures by updating and creating new by-laws and developing proper support facilities for urban farmers. Major requirements for expanding and enhancing urban agriculture include effective communication and coordinated action.

*Key words***:** community development; food systems; food security; risks; urban agriculture; urban farmers; urban sustainability; Victoria British Columbia

2.2 Introduction

Worldwide, cities are faced with the enormous challenge of providing basic services for expanding populations. These services include provision of food and drinking water, sanitation and waste management, health care and education, and providing employment and maintaining accessible green spaces (van Veenhuizen and Danso, 2007). Many cities lack the basic infrastructure to meet these requirements adequately, and continued urbanization will only intensify these inadequacies, increasing inequality, poverty, malnutrition and food insecurity, social segregation and environmental degradation (Ramankutty et al., 2002; van Veenhuizen and Danso, 2007).

Urban food production, or urban agriculture, has gained considerable attention recently for its potential contributions to urban sustainability (van Veenhuizen and Danso, 2007). Research on urban agriculture has largely focused on subsistence strategies in developing countries in Latin America and Africa (Cole et al., 2008; Inoccencio et al., 2003; Mougeot, 2006; Nabulo et al.. 2006; Smit et al., 1996), and studies of urban agriculture in developed countries like Canada are relatively uncommon. Yet, the potential benefits of urban agriculture for the developed world are immense and many North American cities, including Vancouver and Seattle, have undertaken a number of urban agriculture initiatives (Broadway and Broadway, 2011; Seattle City Council, 2010). Urban agriculture can increase food security and urban resilience, create employment opportunities, enhance green space, increase social cohesion, help reduce the urban waste stream and reduce the energy required to grow and transport food from outside the city

(Cole et al., 2008; van Veenhuizen and Danso, 2007). Nevertheless, there are substantial barriers to urban food production that must be considered. The aim of this paper is to highlight the potential for urban agriculture in a mid-sized western Canadian city, Victoria, British Columbia, and to identify possible obstacles to producing food in urban environments. It is based on the perspectives and experiences of local farmers who are already involved in urban agriculture, literature on urban agriculture, and existing policy in the Capital Regional District. This paper is intended to provide insights for individuals, communities and governments wishing to promote self sufficiency of urban populations in Canada and elsewhere in the world.

2.3 Methods

Semi-structured interviews were conducted with nine individuals working as full- or part-time farmers who had knowledge of urban food production in the City of Victoria[1]. Some of these individuals combined farming with other employment, including work in education, consulting, landscaping, and other jobs unrelated to food production. Interviews were designed to explore the experiences and perceptions of urban food producers and elicit their concerns regarding specific aspects of urban food production. Potential candidates were identified through word of mouth and discussion with the urban agriculture community in the City of Victoria. Some participants owned the properties on which they grew food. The rest rented or leased land or accessed it through temporary agreements. Interviews were digitally recorded and transcribed with Express Scribe (Burke et al., 2010). NVivo 8 software was used to code the text by key themes and subthemes, enabling the identification of emergent themes in the data (Bazeley, 2007).

[1] Approved by the University of Victoria's Human Research Ethics Board. Protocol number 10-155.

To gain insight into the policy directions the City of Victoria is taking with respect to urban agriculture, a telephone interview was conducted with city planner Kristina Bouris. Additionally, a thorough literature review was conducted to examine urban agriculture policy and practice in North America and other parts of the world.

2.4 Results

Several major themes emerged from the interviews. Participants identified a range of ways in which urban food production can contribute to urban sustainability (Theme 1: Benefits). Sub-themes in the "benefits" category included urban agriculture: 1) improves food security; 2) reduces a city's ecological footprint; 3) develops awareness and appreciation of the environment and food production; 4) strengthens communities, and; 5) enhances urban green space. Participants also described a number of substantial barriers that stand in the way of realizing these contributions (Theme 2: Barriers). In the "barriers" category respondents identified: 1) risk of food contamination; 2) perceived risks associated with agriculture in urban areas; 3) landownership, land availability, logistics and location issues, and; 4) need for more support for urban farmers. Each of the sub-themes in the benefits and barriers categories is presented in more detail in the following sections, with reference to the respondents' experiences and perspectives.

At an early stage in this research project, several participants identified the risk of food contamination as a common concern of urban food consumers.

To examine the potential risk of crop contamination, I also conducted research focused on the potential for heavy metal contamination by atmospheric deposition of produce grown in urban environments. Contamination by heavy metals has long been identified as a significant health concern associated with urban food production (van Veenhuizen and Danso, 2007; Lee-Smith, 2006; Lock and van Veenhuizen, 2001; see also Chapter 1). Therefore, I analyzed leaf lettuce (*Lactuca sativa*) samples grown at sites across an urban-rural gradient in Victoria, to quantify the potential for heavy metal contamination as a function of traffic and road density. The goal was to determine if there are areas where urban food production should be avoided (see Chapter 3).

2.4.1 Benefits of urban food production

Improves Food Security:

Interviewees were acutely aware of food security issues. Many made reference to the Cuban experience, describing how important it was to be prepared for the possibility of a similar situation occurring in a Canadian context. The 1960s US trade embargo of Cuba, and the 1991 collapse of the Soviet Union, isolated Cuba, and the country was left to rely on its own limited resources (Dominguez, 1997). It suddenly lost access to affordable fossil-fuels, food imports and the key components of industrialized agriculture (Novo and Murphy; 2008). One participant noted the vulnerability of Canadian cities to the cutting off of food imports in the face of imminent loss of oil reserves. About 60% of British Columbia’s imported food comes from the United States – primarily California (Lee et al., 2010; Ostry, 2010), and fuel shortages will severely limit the transportation of food (Kimbrell, 2002; Lee et al., 2010). Cities that do not produce their own food will be immediately impacted (Lee et al., 2010). A strong, reliable, base of food production close to a population centre such as Victoria will reduce this risk. The interviewee commented,

> "…the idea that urban dwellers have that our food will all sort of magically appear in the city, but won't be grown in the city, it will be grown somewhere out there, is really a luxury that we can't afford."

Despite these concerns, interviewees explained that the general public is much more conscious today than ten years ago of issues relating to food security and problems with the industrialized food system, noting that more and more people are becoming interested in learning how to grow food.

Reduces ecological footprint:

Producing significant quantities of food within urban areas reduces a city's ecological footprint. All those interviewed commented that since cities are 'the market', both producers and consumers have to travel shorter distances. An urban farmer can harvest produce in the morning and sell it immediately in a market that may only be a few hundred meters away. Likewise, most customers need only walk a few blocks to pick up fresh produce. Interviewees pointed out that inputs for urban food production (seeds, tools, equipment, etc.) also travel shorter distances, since urban farms are closer to centres of distribution.

They noted that the proximity to resources and the reduced scale of urban farming allows farmers to begin 'closing the loop' of material and energy use. Direct access to the urban waste stream also provides essential inputs that otherwise would need to be purchased and transported from elsewhere. One participant noted that proper management of urban waste and waste water can be an onerous task for cities, especially when population is expanding. However, the urban waste stream represents a huge resource for food production, much of which can be diverted. Several participants described receiving drop offs of organic matter, leaf mulch or wood chips from the city and local businesses – inputs that otherwise would have to be disposed of by the city's waste management group.

Water, a potential problem for urban planners, can also become a valuable resource if diverted and utilized in urban food production. The impermeable surfaces of every urban area create an opportunity for rainwater catchment and use. As one interviewee pointed out,

> "… [rainwater] will be sort of a possible source of resilience in the future, whereas in rural areas you don't have that huge catchment system to collect from."

In many alternative agricultural systems, labour represents a critical input. In rural settings, according to participants, this resource can be in short supply. In urban areas, however, there is typically no shortage of workers. Many participants described weekly work parties where volunteers helped with harvesting, weeding and planting. Using human power eliminates the need for fossil-fuel powered machinery. One of the key benefits of urban farming, mentioned by all interviewees, was the opportunity to be independent of vehicle ownership; public transport, accessible amenities and access to auto share programs make farmers in urban areas less dependent on vehicles. Conversely, food production in rural areas demands the continuous use of a vehicle as amenities are typically not within walking distance, produce must be transported to market, and inputs require direct transportation to and from the farm.

Develops awareness and appreciation of the environment and food production:

Urban food production happens where most people live. Interviewees were well aware that they worked in the public eye. Hundreds of people walk past urban food production sites on a daily basis. While acknowledging the burden of public exposure, participants' generally emphasized the benefits of ongoing public interaction. Since members of the public were able to view the daily activity of urban farmers, the participants believed the citizens would gain a deeper understanding of sustainable agricultural activities. Having a farmer in the neighbourhood also gives people the incentive to begin experimenting with food production themselves. Interviewees described activities such as volunteering, growing produce in planters on a porch or balcony, or starting a backyard garden, as ways individuals had begun engaging with food production. The proximity of urban agriculture to homes and workplaces creates a unique opportunity for people to become involved. Interviewees also noted that residents who were able to watch farmers at work were likely to talk about what was going on, ask for advice, or use the opportunity to educate their children. Education, according to participants, is a central tenet to urban food production. Taking the time to teach others about the importance of growing food and food security was something that all participants felt was critical and which they did daily. As one interviewee said,

> "…when I get high school groups in, they don't even recognize anything that's growing. This is the second generation that is removed and disconnected from growing food. So it's really important to start educating and getting people reconnected with where their food is coming from."

Having the opportunity to engage in or observe the entire process of growing food – from soil preparation to planting and tending to harvesting - reconnects people with the natural processes and environment around them. The participants believed that experience with urban agriculture will ultimately lead to a change in perspective and individual behaviours in a way that strengthens the health of both the environment and the community.

Strengthens community:

Food is one of the fundamental bonds connecting humans to their environment and each other. Participants were quick to illustrate how growing food strengthens local communities. One interviewee told me that engaging in food production, even if it is just “sticking your head over the fence to check out the neighbour’s food garden”, introduces people to the other people that make up their community. This participant believed that,

> “...a part of growing food is that it’s a basis for conversations with neighbours….”

Similarly, another interviewee described a personal experience with building community,

> “I’ve never had such a solid sense of connection to my community, and part of it is because we’re out there talking to people, but part of it is specific to gardening, and I think there’s something about growing things and particularly when it relates to food or native plants as we’ve got on the side here, that we crave.”

To create sustainable, resilient communities, people must be motivated to change their behaviours and lifestyles. This motivation must come from a “fun perspective” rather than a “fear perspective”, one participant told me. Urban food production can facilitate the transition, encouraging action without supplying a constant feeling of impending doom.

Maintains and enhances urban green space:

Urban agriculture enhances urban green space. One interviewee mentioned that because of greater plant diversity and 'bloom succession' in nicely landscaped urban yards, honey production is more viable than in the surrounding countryside. Healthy bee populations in the city can ensure pollination of certain plant and tree species.

Each participant mentioned that the urban microclimate was well suited for food production as warmer temperatures extend the growing period.

> "All the concrete and grey space has contributed to heating up the city and it's created a better microclimate than right outside the city, even though we are in the same farming zones", one respondent noted.

Additionally, extensive vertical spaces provide south-facing walls that are ideal for growing fruit trees and vegetables that need extra warmth. By taking advantage of the unique landscape present in urban environments, food production can add to the extent of urban green space.

2.4.2 Barriers to urban food production

In spite of the contributions urban food production can make towards the development of sustainable communities, the urban environment presents a number of specific barriers and challenges to the expansion of urban food agriculture.

Risk of contamination:

The potential for contamination is a widespread concern with regards to urban agriculture. However, participants expressed different views of the risk associated with the three main vectors through which food can become contaminated: air, soil and water. Although atmospheric pollution can be a serious environmental problem in urban environments (Mayer, 1999; Molina and Molina, 2004), generally, the interviewees did not feel that the potential for contamination from aerial sources was a major problem. As one respondent declared,

> "I'm not as concerned about air quality… especially in Victoria where we have a lot of wind, it's not really stagnant. Probably the air quality is better in some ways than the Fraser Valley [a region known for agriculture] in the summer time."

Another participant explained that when he thinks about atmospheric contamination and toxicity of air, he tends to think on a global level, rather than on a local level. His concerns with atmospheric pollution focused on carbon dioxide and other greenhouse gases. Other participants acknowledged the risk of aerial contamination but said that it wasn't a major concern in the City of Victoria.

Soil contamination, was a much larger concern for all participants. The interviewees who farmed cooperatively recounted a situation where they were forced to abandon one garden site due to soil contamination. The source of the contamination was unknown and there were no obvious signs of contamination. However, a child of the property owner experienced health problems that were traced back to lead-contaminated soil in the yard. The group tested the soil in their garden. Although, lead levels were below US standards for agricultural soil, they decided to destroy the crops and abandon the site.

The interviewees felt that testing urban soil for contaminants prior to growing food is the best course of action, but expressed that the costs of lab analysis can be prohibitive. As a cheaper alternative, they described conducting site history reviews by “going to the archives” to determine the potential for contamination based on past land use of a site. While not a substitute for testing, the interviewees felt that it was an affordable and important step.

Participants also spoke about the potential for soil contamination from pesticides, fertilizers or herbicides. They suggested that homeowners in some areas may have used chemical fertilizers and pesticides on their lawns that could be mobilized in run-off. Nevertheless, the overall consensus was that even if urban homeowners were applying these chemicals, rural agricultural land would probably have a greater concentration of these chemical compounds from years of heavy application.

The potential for crop contamination via water was not considered a serious concern. Only one participant even mentioned the possibility for contamination via water used for crop irrigation, noting:

> “…I’d like to know how much contamination is involved there [in run-off entering his rain barrels], and if I found out there is then I’d probably want to replace my roof material a bit quicker, you know?”

This participant also constructed a wetland system in his backyard to clean his grey water for irrigating perennial food crops. A similar system, he said, could be used to filter rainwater so that it could be stored and used for irrigation.

The interviewees noted that site location could affect the risk of contamination. Boulevard gardening, or gardening on the median between the side walk and the road, was frequently mentioned as potentially problematic in this regard. Despite concerns, participants agreed that boulevard gardening for personal consumption was a better choice than buying imported produce, primarily because of the environmental impacts and health risks associated with conventional agriculture. Most participants indicated they would grow food on a boulevard, but the location would dictate what they would grow.

> "…I would avoid growing greens or any leafy above ground vegetable… [in reference to boulevard gardening]."

Perceived risks associated only with agriculture in urban areas:

Although the potential for contamination is a serious concern, one of the most important challenges identified by interview participants was situating the risks of urban food production in the context of the hazards associated with other methods of food production, including industrial scale agriculture. Interviewees noted that people eat produce from the grocery store without questioning its origin or growing conditions. Interviewees believed that people exaggerate the risks associated with urban agriculture because they are familiar with the potential for contamination in the urban environment and are ignorant of the risks associated with conventional agriculture.

Interviewees expressed concern that misperceptions of the risk of contamination could dissuade individuals from supporting urban food production. One participant felt that eating produce grown on boulevards in the City of Victoria is preferable to eating imported produce, where the potential for contamination is magnified by the growing conditions and transport process. This participant observed that while people prefer not to live in places with massive amounts of air pollution it would seem that they have no problem buying produce grown in these areas.

The idea that people would be reluctant to eat produce grown in the city because of potential contamination was also described as "worrying about things on the wrong end". If contamination was a problem, people should be attempting reduce the levels of contaminants in the environment – not ignoring the problem by refusing to eat urban grown produce. Another participant told me that most people know that many of the conveniences and luxuries of modern life are damaging to human health but are reluctant to give them up. Overall, interviewees felt that the major drivers of contamination (improper waste management, and transportation (cars, buses, planes, boats etc.)) should be the focus of concern. Ultimately, participants acknowledged that if food is contaminated from atmospheric deposition, then it doesn't matter where it is grown because this risk is pervasive.

> "… and I mean, we live in the city, we're breathing it. It's okay to breathe it but not eat it?"
>
> "I'm sure that there's toxins in the soil and I'm sure that they are on this side too [in reference to her yard versus the boulevard], and I'm sure they are on the organic farm, you know, on whatever road, because it's everywhere now. There's no escaping it."

Landownership, land availability, logistics and location issues:

Participants also described the challenge of getting access to adequate space for food production as one of the major barriers facing urban agriculture. They recognized the challenge of finding land for people with low incomes. In urban areas, land prices can be much higher than in rural areas. Consequently, many of the participants lease or rent plots. These temporary arrangements can be superseded by other land uses, such as development. This lack of security of tenure means that farmers are under the constant threat of losing their investment in the land (fertile soil/infrastructure) and having to start all over again elsewhere. One of the participants leases the land she grows food on for a nominal amount, but opportunities like that are rare. A number of the participants are involved in an urban farming cooperative that has agreements with various homeowners to utilize their backyard space for a minimum period of three years, but circumstances can change and agreements can be broken. The cost and effort of enforcing land use agreements tends to be prohibitive. Essentially, farmers who rent land are at the mercy of the landowner.

The lack of long-term access to land is a huge barrier to the development of agricultural systems in urban areas. The interviewees stressed that barriers to land access also mean that urban farmers do not have the luxury of optimizing growing sites based on light levels and size. The challenge is to find land, any land – not the best piece of land. The soil quality in urban areas also presents a substantial barrier to urban food production. Soil quality can vary greatly from property to property. During the construction of residential housing, one participant told me, most of the topsoil is removed and the lot is back filled with rubble. This means that a lot of work is required to rebuild the soil for agriculture.

> "… I've gardened in places where I've found things like drywall and concrete and all sorts of strange things in the soil from just being in an urban environment and not having really good topsoil."

With land security, it is possible to invest in infrastructure to increase efficiency and sustainability – to rebuild soil quality. One participant was lucky enough to be in a rental situation where he has the opportunity to invest in the property, without having to worry about losing it.

The participants who operated a number of garden plots noted the additional difficulty of travelling and moving equipment from site to site. This is especially difficult when most of the travel is done by bicycle. Having multiple sites also means increased set up costs because each site needs its own irrigation system, compost bins, soil amendments, deer fencing, seeds, water, as well as harvest and tool sheds. Likewise, the interviewees mentioned that multiple sites introduce more planning variables. Each site is likely to have different soil, pests, and wildlife issues, and ultimately each requires a unique management plan. To meet this challenge, urban food producers must work to a very efficient schedule.

A few interviewees noted that finding land is particularly challenging for young people. They said that land access is associated with class and income, and young people interested in farming typically do not have the necessary means to achieve this. However, as the interest in urban food production grows, one participant predicted that the boundaries of ownership and public spaces will increasingly be tested. Initiatives like the Haultain Common, a boulevard garden in Victoria, have sparked numerous projects of a similar nature, creating friction around the idea of 'the commons'.

> "… I find myself being very puzzled about how it came to be that the corporate entity behaves as if they actually own the land… when people talk about the City, they don't mean the populous, they mean City Hall, they mean the corporation,

and they say, 'Oh doesn't the city own that?' And I say 'Actually we own that, the City of Victoria, the corporation, holds it in trust for the common good'… We own that land collectively and, and now we're beginning to behave as though we had some say in how it will be, what our relationship to that land will be."

This participant also noted that gardening in boulevards indicates that citizens are taking control over how they want to live their lives and reclaiming public spaces as part of a growing movement of what she deemed "city repair".

Need for more support for urban farmers:

Finally, the lack of support for urban farmers was mentioned as another large barrier to the expansion of urban food production. As one of the participants explained, farming requires a huge amount of work with very little profit, regardless of where it is practiced. It takes time and dedication to build up the soil, to understand specific site conditions and to discover by trial and error what works and what does not at a given site.

One interviewee described how the labour intensive nature of farming left little time to develop solutions to problems or research new techniques. Unlike rural farmers, urban producers do not generally benefit from research and extension activities of federal or provincial agricultural agencies.

> "…I'd like to know the answers to those things [how effective and safe new growing techniques are], I'd like to experiment with that and see, I think it would be some really important research, because a lot of people around the world are getting more into growing food in the cities… and maybe there are those studies out there but, as a farmer I don't have a whole lot of time to go reading science papers."

One participant noted how urban farm sites can be extremely variable. This heterogeneity requires that each site be managed differently, but, without the proper support, urban farming will remain largely a trial-and-error process.

2.5 Discussion: Enhancing urban food production

2.5.1 Benefits of urban food production

Urban agriculture has the potential to make an important contribution to the sustainability of North American cities: improving urban food security, reducing the urban ecological footprint, developing an awareness and appreciation of the environment, strengthening communities, enhancing urban green space and increasing sustainable food production (Cole et al., 2008; van Veenhuizen and Danso, 2007).

As participants described, the urban microclimate offers a unique growing environment for food production. Cities in the northern hemisphere have higher air temperatures, increased annual rainfall and decreased wind speeds in comparison to rural counterparts; extending the potential growing season (Alberti et al., 2003; Bolund and Hunhammar, 1999; Taha, 1997). The novel combinations of organisms, both native and introduced, present in urban areas, interact in complex, anthropogenically driven successions enabling urban areas to facilitate excellent growing conditions for food crops (Alberti et al., 2003). Urban food production can help diversify agricultural systems, providing an extra buffer against the risk of crop failures. As one interviewee told me, this is a hard time for farmers. The weather is unpredictable and uncontrollable. Models suggest that changes in precipitation patterns, higher temperatures, periodic extreme weather events, disease and insect infestation are likely to occur more frequently. These changes will negatively impact crop yields (Lee et al., 2010). Food production in the city will strengthen food security for urban areas, buffering against these risks.

As indicated by participants, urban food production can contribute to increasing food security for urban dwellers. In urban areas, accessing nutritious, safe food is a problem for many people (Larsen and Gilliland, 2008; Rose et al., 2009). Research suggests that the recent suburbanization of food retailers in North America has resulted in urban food "deserts"; disadvantaged areas with inadequate access to retail outlets (Larsen and Gilliland, 2008; Rose et al., 2009). By providing direct access to nutritious, good food, urban food production can increase food security in those neighbourhoods (Brown and Carter, 2003; CRD Roundtable on the Environment, 2006; MacNair, 2004 Mendes, 2006 Mullinix et al., 2008).

Furthermore, as interviewees stressed, urban food production allows direct access to the market, reducing the negative impacts associated with the transportation network required for industrial agriculture. When cities import their food from distant places, or even from adjacent rural areas, the associated carbon footprint can be enormous. Most food consumed within cities in North America is shipped from places outside the continent, typically travelling between 2 400 and 4 000 kilometers and spending as many as seven to fourteen days in transit (Brown and Carter, 2003). Just as the interviewees pointed out, producing food within the city boundaries connects the places of production with markets, reducing energy use for transport, packaging and cooling, and subsequently reducing emissions of CO_2 and other polluting greenhouse gases (Deelstra and Giradet, 2000; van Veenhuizen and Danso, 2007).

Urban food production has been shown to be an essential tool for community development (Saldivar-Tanaka and Krasny, 2004). The observations of the study participants on the social nature of food production reflects previous research that demonstrates how the intensely social nature of urban agriculture facilitates the inclusion of groups that are often marginalized in society, including women, children, the poor, the homeless and the elderly (Smit and Bailkey, 2006; van Veenhuizen and Danso, 2007).

Not only is education recognized by the urban farmers of Victoria as an important aspect of urban agriculture, its importance has been recognized by gardeners across North America. In a study of community gardens in a Latino community in New York City, researchers found that senior citizens were the most active gardeners and children under 13 years of age were the most frequent visitors. Gardeners at the sites investigated were teaching young people and had geared the garden activities towards children (Saldivar-Tanaka and Krasny, 2004). In a more direct fashion, the Food Project in the Roxbury and Dorchester sections of Boston has been designed around education, giving young people the skills and confidence to become agents of change in their troubled neighbourhoods (Smit and Bailkey, 2006).

Not only does urban agriculture help develop awareness of the process of food production and the environment (Baker, 2004; Delind, 2002), it also provides opportunities to cultivate democratic food practices by raising awareness of where food comes from, encouraging commensality and the consumption of locally grown food(Baker, 2004). The participant's observations of how the public nature of urban agriculture can enable the public to gain a deeper understanding of sustainable agriculture, are reinforced by the findings of other studies which confirm that the proximity of urban agricultural activities to homes and workplaces allows more people to become "food citizens", thereby facilitating the shift towards ecologically sound, economically viable and socially just food systems (Baker, 2004; Delind, 2002).

As the interviewees indicated in this research, there is a two way relationship between urban agriculture and urban green space. Both work to enhance each other. Contrary to popular belief, urban areas offer excellent growing conditions for many plants. Urban food production is able to take advantage of this, enhancing both the amount of green space in a city and contributing to the green space that already exists. The concentration of people and the built up landscape has created a different microclimate from that of the surrounding countryside. Cities in the northern hemisphere can have higher air temperatures, increased annual rainfall, and decreased wind speeds in comparison to their rural counterparts (Alberti et al., 2003; Bolund and Hunhammar, 1999; Taha, 1997). Many of the interviewees mentioned that the urban microclimate resulted in enhanced food production as warmer temperatures extend the growing period. The extensive vertical spaces in the city provide south walls that are ideal for growing fruit trees and vegetables that need the extra warmth. By taking advantage of the unique landscape present in urban environments, food production is able to add to the amount of green space in a city.

Food production also contributes to enhancing the quality of green space that already exists in urban areas. The added diversity of plants creates a range of habitats and resources for insects, birds and other urban wildlife (Angold et al., 2006), and makes as one participant explained, honey production in the city a viable business. This is also evidenced by higher honey production in cities in the United Kingdom and Germany, compared to the surrounding countryside (Deelstra and Giradet, 2000).

2.5.2 Barriers to urban food production

Despite the potential contributions urban agriculture can make to urban areas, in order to strengthen and expand current and future urban agricultural initiatives, a number of barriers must be overcome. Impediments identified by participants included the risk and perceived risk of food contamination; landownership, location and logistical issues; and the need for support.

The potential for crop contamination was a concern for all interviewees, who indicated the real and perceived risks of contamination through three main vectors – air, soil, and water – must be addressed. Atmospheric pollution can be a serious environmental problem in urban areas (Mayer, 1999; Molina and Molina, 2004). Although atmospheric contamination was not a major concern of the interviewees of this study, research has demonstrated that a phenomenon known as a 'neighbourhood halo effect' means that people are generally reluctant to attribute high-level air pollution to their home area (Bickerstaff and Walker, 2001). Although Victoria is not home to extensive industrial activity, airborne pollutants can still be a substantial concern. The results of the observational study of the potential for heavy metal contamination of lettuce demonstrate that during the peak of the tourist season, traffic emissions can have significant impacts on the levels of heavy metals that leafy greens contain. At this time, the ambient atmosphere in rural Victoria can also lead to elevated heavy metal concentrations in leafy greens grown at peri-urban market farms (*see Chapter 3*). Site location within the City can play an important role in mitigating the exposure level of produce to contaminants, as produce grown in low traffic residential neighbourhoods can be comparable to produce grown on rural properties. For example, boulevard gardening can be problematic due to the proximity of produce to traffic emissions. The interviewees were right to let the location dictate what should be grown. The results of the observational study demonstrated that lettuce grown in residential backyards had significantly lower cadmium, zinc and manganese levels than lettuce grown in the downtown core of Victoria (*see Chapter 3*).

Soil contamination was a greater concern to the interviewees. In recent years there has been a push to address the problem of urban soil contamination due to rapid industrialization and urbanization (Grasmuck and Scholz, 2005). Soils serve both as a sink and as a source for trace metal contaminants, and the accumulation of heavy metals in urban soils can result in heavy metal contamination of urban grown produce and, increased exposure to heavy metals due to their proximity to human activities (Sun et al., 2010). Like air, water was not a vector that concerned interviewees. However, untreated water can introduce contaminants to the food system, including both heavy metals and bacteria. This can obviously have negative consequences for human health (Mougeot, 2006).

Understanding the intricate connections between food production and pollution is an important step towards minimizing and mitigating the risks to urban agriculture. However, it is important to keep in mind the reality that all of the participants in this study shared with me; ‘pristine’ environments simply do not exist anymore. Participants stressed that the risks associated with urban food production must be evaluated in the broader context of global food systems. Most

North Americans do not hesitate to buy from the grocery store, without considering the safety of the produce. For example, agriculture in the Fraser Valley Regional District in southwestern British Columbia generates over a billion dollars of revenue annually (FVFDMA, 2010). Although there are no large communities or industrial uses in the region, ozone, particulate matter, nitrogen oxides and volatile organic compounds have all been listed as concerns in this area (FVRD, 2006). Similarly, the results of the observational study on heavy metals in lettuce grown across an urban-rural gradient in Victoria demonstrate that rural produce is not safe from atmospheric contamination. Although produce grown in rural sites has significantly lower lead, cadmium, zinc and manganese concentrations than produce grown in downtown Victoria, heavy metal levels were still elevated above the Food and Agriculture and the World Health Organizations' recommended safe limits. These findings highlight the fact that atmospheric deposition of heavy metals is problematic worldwide, in both rural and urban areas (*see Chapter 3*).

As participants in this study were quick to point out, it is ironic that the health concerns linked with food contamination are only associated with urban grown produce, because all forms of agriculture face similar issues (Binns and Lynch, 1998). Furthermore, although areas like boulevards may be at higher risk for contamination, if someone who typically buys imported produce decided to start a boulevard garden, it would be a step towards urban sustainability. By reducing the need for transportation these actions would ultimately decrease the levels of contaminants entering the environment, subsequently reducing the potential for crop contamination in both rural and urban areas.

Understanding and addressing the potential health hazards associated with urban food production would not only reassure consumers, it would help secure the support of municipal authorities that remain critical of urban agriculture because of such concerns (Smit et al., 1996).

Many participants identified a lack of support as a substantial barrier to the acceptance and expansion of urban agriculture. Proper supporting structures for urban agriculture have been facilitated in the past in Victoria. As early as 1918, Victoria's City Council convinced the provincial government to pass the innovative "Greater Food Production Act" which essentially enabled cities to take over unused land to grow food, without having to compensate the property owner (Tracey, 2009). This program lasted only a short time, until the risk of food insecurity was believed to be gone. However, in the 1930s, the reality of the Great Depression brought hunger and the government acted by supporting relief gardening to help citizens survive the hard times (Tracey, 2009).

Today, the pervasiveness of industrial agriculture and the seeming stability of the food importation system create a false sense of local food security for the majority. The reality is that in 2004, one in ten Canadian households experienced food insecurity (Kirkpatrick and Tarasuk, 2009). The physical separation of Vancouver Island from the rest of the country makes it increasingly vulnerable should a food crisis occur. Victoria is reliant on food imports, with 90% of its produce coming from outside sources (MacNair, 2004). If transportation were cut off, the Island would only have an estimated three-day supply of food (Bouris et al., 2009).

Several existing by-laws and regulations directly impact the urban food system in counterproductive ways, including the animal control bylaw which allows the keeping of poultry, but not farm animals, in the city; zoning bylaws which restrict commercial greenhouses and nurseries in most residential zones; and, the zoning bylaw schedule D definition of "home occupation" which permits urban agriculture, but limits the number of people involved to two per site, and restricts parking and other home occupations on site (Bouris et al., 2009). The municipal tax schedule for agricultural lands has also been amended to prevent urban farmers from claiming provincial farm status (lower tax rate). Access to land continues to be problematic, as multi-dwelling units account for 84% of Victoria's housing stock, 60% of residents are renters, and there is currently a shortage of community allotment garden plots. As the City's properties become increasingly dense, multi-family housing will increase, forfeiting yard space (Bouris et al., 2009). Victoria has some of the highest property values in the country, making it impossible for urban agriculture to generate economic returns that would compete with commercial or residential (re)development. Finally, because of the regulations preventing greenhouses and nurseries from being located in residential zones, home gardeners are reliant on seedlings imported from outside the city and region and the lack of covered growing space limits the type of crops that can be grown and consumed (Bouris et al., 2009). It is vital that these by-laws be revisited in order for urban agriculture to develop in a positive manner in the City of Victoria.

2.5.3 Existing and future initiatives

In response to the growing awareness of the threat to food security, the City of Victoria has taken some steps to enhancing urban food production. In 2009 the City of Victoria conducted a food systems assessment (Bouris et al., 2009), an important first step in working towards a sustained urban food system (Allen, 1999; Brown and Carter, 2003).

In addition, the City has engaged in a number of other initiatives related to food; for example, the animal control by-law permits an unspecified number of chickens and is one of the most permissive in North America. Additionally, Victoria has supported an innovative model of edible community commons gardens in parks, where the food is available for anyone to harvest. The City also funds an annual operating grant to the nonprofit Compost Education Centre, an urban agriculture hotline and an urban agriculture workshop series. It has set up a demonstration vegetable garden at the front door of City Hall, and engaged in active promotion of public markets through a City-produced promotional brochure, website links, operating agreements with market operators and ongoing support from City staff. The municipal government has also adopted quite a number of policies and guidelines that affect the different aspects of the urban food system. One such policy, The Community Gardens Policy (2005), encourages the development and retention of community gardens in partnership with nonprofit groups on public and private lands. Additionally, the Urban Agriculture Resolution (2007) has pledged municipal support in principle for urban agriculture and promotes collaboration between stakeholders.

The City is also in the process of producing plans such as the Urban Forest Master Plan and the Parks Master Plan which contain specific references to urban agricultural activities. More specifically, the Urban Forest Master Plan contains a section that calls for the planting of fruit and nut bearing trees in public spaces and allows for the delegation of responsibility of maintenance (Gye and Cullington, 2009). The Parks Master Plan will address the issue of existing urban agricultural activities in parks (City of Victoria, 2011). These plans, however, are still in draft form. Urban agriculture also features prominently in the re-visiting and drafting of The Official Community Plan (OCP) (Bouris, K. City Planner, Victoria, BC. Pers. comm., 17 February, 2011). The OCP serves as the guiding document for future policy and planning. It reflects the directions that the community as a whole feel the city should take. Once it is implemented, all future by-laws must conform to the planning principles set out in the OCP, suggesting that the updated OCP could be a vehicle for the acceptance and expansion of urban agriculture in Victoria. Kristina Bouris, a city planner responsible for food issues, reports that an updated OCP has been submitted to City Hall for an internal review, but it will remain in draft form until September 2011. Food issues are at the top of the agenda in terms of community interest and the OCP draft is faithful to the people's vision for Victoria (Bouris, K., City Planner, Victoria, BC. Pers. comm., 17 February, 2011). The suggestions outlined in the draft framework include: designating food responsibilities with a staff position; exploring options for increased number of allotment gardens and plots and concerns with allotment gardens in parks; facilitating broad discussion regarding suitability of food system activities on public lands; and exploring information needs to support urban food systems, including the creation of an inventory of potential food-producing lands, and the possibility of food production for personal use on public lands. The draft also recommends investigating options and models for securing a year-round farmers' market and identification of food supply and food access needs as part of emergency preparedness (Scott, 2010). This draft clearly contains a number of positive steps that will begin to address food systems issues in the City of Victoria.

Examination of urban agriculture in cities across North America revealed that a number of cities in the Pacific Northwest have formed Food Policy Councils and created staff positions to address food systems issues (Bouris et al., 2009). Two nearby cities (Seattle and Vancouver), provide excellent examples of progressive policy to promote urban agricultural development. (Broadway and Broadway, 2011; Erickson et al., 2009) In 2010, Seattle began the “2010: The Year of Urban Agriculture” campaign to promote urban agriculture efforts. The City Council approved Council Bill 116907 that supports the rapidly growing local food movement. The ordinance updates the City’s Land Use Code allowing ‘urban farms’ and ‘community gardens’ in all zones, with some limitations in industrial zones. It increases the number of chickens allowed per lot from three to eight, with additional chickens allowed for large lots associated with community gardens and urban farms. Notably, residents are also now allowed to sell food grown on their properties – a substantial barrier still facing the urban farmers of Victoria. Additionally, legislation has been introduced that formally recognizes farmers’ markets, allowing them in more areas of Seattle, as well as allowing dedicated food production on rooftop greenhouses with a 15 foot exemption to height limits in a variety of higher density zones (Seattle City Council, 2010).

Another leader in urban agriculture, the City of Vancouver, become involved with food related issues in the early 1990s. City Council established a sustainable food system, approved a Food Action Plan and formed a Food Policy Council to advise the city on food-related issues. In 2005, Vancouver conducted an urban agriculture inventory that documented existing city activities and policies supportive of urban agriculture, as well as obstacles to food production in the city. The 2005 report found that the biggest impediment to urban agriculture was rising Vancouver property values. Victoria is also faced with high property values, although it does not have the same population density to support. Due to its growing population density, Vancouver has little vacant land for food production (Broadway and Broadway, 2011). Nevertheless, as a 2010 Winter Olympics legacy project, the Vancouver City Council unanimously passed a motion requiring the city to work with the Vancouver Food Policy Council to create 2010 garden plots by January 2010. This goal was met, and currently there exist approximately 1600 community garden plots and 900 community shared plots, integrated in various development projects around the city. The City has also modified local bylaws to allow hobby beekeeping.

In 2010, Vancouver adopted the new action plan, *Vancouver 2020: A bright green future*. Vancouver plans on becoming a global leader in urban food systems, reducing the city's food carbon footprint by a third by 2020. This plan builds on the Food Charter the City adopted in 2007, and outlines strategies to increase food production in the city, including the use of social marketing programs to promote the conversion of lawns into gardens, requiring green roofs on some new developments that can be used to grow food, adopting an edible landscaping policy and promoting small plot intensive farming for food cultivation on underutilized land (Broadway and Broadway, 2011). Vancouver and Seattle face similar issues as Victoria but have made great advancements towards achieving sustainable urban food systems by implementing integrated strategies to address any issues. The City of Victoria is in an excellent position to learn from the experiences of these cities.

2.5.4 Need for integrated effort

Although the City Council of Victoria appears to be very supportive of urban agriculture and hands out a large amount of funding to organizations involved in urban agriculture, because Victoria lacks a coordinated institutional approach to food system issues, the initiatives taken are often piecemeal and disconnected from a coordinated strategy of significantly improving urban food security (Bouris et al., 2009). For example, implementation of the Parks Master Plan and the Urban Forest Master Plan will be delayed until the OCP has been enacted – to ensure that there is no conflict between planning documents. This means a delay in moving forward on parks and forestry proposals of at least a year, if not longer (Bouris, K. Pers. comm., 17 February, 2011). The Parks Department appears to support the concept of allotment gardens, but due to the small size of green spaces and the presence of a number of competing uses (dog parks, sports fields), creating community gardens in parks continues to be a challenge (Bouris, K. Pers. comm., 17 February, 2011). Furthermore, the creation of a new staff position to support urban food production is unlikely due to current budget constraints. Instead, relevant activities will continue to be carried out by a staff member, in addition to their regular activities (Bouris, K. Pers. comm., 17 February, 2011). These piecemeal approaches to dealing with urban agriculture do not ensure effective support. A coordinated, comprehensive government policy for involvement in the urban food system is critical to effectively address urban food issues.

By creating a space to develop a community wide strategy, encouraging synergistic joint efforts and producing much larger effects than the efforts of any one sector, Food Policy Councils are able to evaluate problems and bring in the appropriate policy makers more effectively than single groups can (Brown and Carter, 2003). The formation of a Food Policy Council to coordinate policy initiatives, conduct research, and provide education and events to promote community food security (Brown and Carter, 2003) would help enhance urban agriculture in the City of Victoria. Adopting an official mandate for municipal food policy with specific mechanisms to support the development of an urban food system, strengthened by the support of City Council, community stakeholders and at least one dedicated City staff position would facilitate the proper establishment of a coordinated, comprehensive set of municipal government policies, creating regulations, programs and services that aim to enhance the urban food system (Bouris et al., 2009).

2.6 Conclusion

In North America, 80% of the population resides in urban areas, and the trend of growing urbanization is not expected to change (Human Resources and Skills Development Canada, 2010). To meet the essential needs for jobs, food, energy, water and sanitation, while conserving and enhancing the resource base that supports them, cities need to grow in a sustainable manner (van Veenhuizen and Danso, 2007; WCED, 1997). The knowledge of urban farmers interviewed and literature reviewed in this study show that urban agriculture can contribute to urban resilience, sustainability and ecosystem function.

Nevertheless, there are a number of substantive barriers that stand in the way of the widespread acceptance and expansion of urban agriculture. There are many critical by-laws that must be revisited including the animal control bylaw and a number of zoning bylaws which restrict urban agricultural development. While there are environmental and health risks associated with urban food production there are also numerous benefits and efforts to expanded urban food production; and planners should seek to maximize these positive contributions while minimizing the potential risks (van Veenhuizen and Danso, 2007). It is important to keep the risks of crop contamination contextualized – all forms of agriculture face similar threats (Binns and Lynch, 1998), a conclusion also supported by the observational field work to assess contamination issues associated with this study (*see Chapter Three*). Understanding that urban food production can play a vital role in rebuilding our cities is just one step – it is our job to discover the risks and barriers and to work collectively to minimize and overcome them. Enhancing and expanding urban food production will be a critical component in the creation of sustainable, resilient communities. However, the piecemeal approaches that are currently being implemented in the City of Victoria will not allow for the realization of the full potential of urban food production. The establishment of a comprehensive food strategy, capable of responding to the difficulties the future may hold is required to effectively address food issues. As the interviewees in this study stressed, the key is to act now. Strong, effective relationships must be forged between farmers and consumers and meaningful communication must occur between governments and citizens. Seeds must be planted now, so that when the need arises, the trees are already bearing fruit. Cities are home to the majority of the world's population, which makes them a hub for innovative thinking and collective action where people can make changes to their quality of life and environment.

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Chapter Three: Heavy metal contamination from atmospheric deposition in produce grown in urban environments: a case study in Victoria, British Columbia

3.1 Abstract:

Anthropogenic activities, inherent in urban environments have resulted in elevated levels of potentially toxic elements. Motor vehicles are the primary source of air pollution in most urban areas. As a result, farmers and consumers have expressed concerns with contaminant levels in produce grown in urban areas. Exposure to ambient atmospheric pollution is an important pathway for contamination of produce grown in urban localities. In this study, lettuce (*Lactuca sativa* L) was grown in a uniform medium in three treatment areas – downtown industrial/business, residential and rural locations – in and around the City of Victoria, British Columbia. Atmospherically deposited lead, zinc, manganese and cadmium concentrations in the lettuce leaf tissue were determined by microwave digestion and inductively coupled plasma analysis. In addition, samples of purchased lettuce, from five local grocery stores, were also analyzed. Soil probes were used to determine the extent of metal deposition in soil from atmospheric sources. Elevated levels of lead, cadmium and zinc existed in lettuce grown at all site types – urban and rural – as compared to the Commission of the European Communities (2001), the Food and Agriculture Organization (FAO) and the World Health Organization (WHO) (FAO/WHO-CAC, 2001) guidelines for safe heavy metal levels in leafy greens. Although all site types were contaminated, concentrations of lead, cadmium, zinc and manganese were highest in the industrial/business sites, with the lead concentration being substantially higher. Correlations were found to exist between the higher traffic and commercial building density and the heavy metal levels found in these locations.

Therefore growing sites should be selected based on road and commercial building density in order to minimize the potential for heavy metal contamination of produce. However, by comparison to levels of lead and cadmium in produce grown worldwide, Victoria presents one of the better urban growing environments. Due to the unusually high zinc and manganese concentrations in Victoria samples further research is required to locate emission sources and consequences. Consumers cannot avoid contamination by purchasing commercial lettuce; purchased samples also contained elevated heavy metal levels.

Keywords: atmospheric pollution; contamination; heavy metals; health risks; urban agriculture; Victoria British Columbia

3.2 Introduction:

The explosion of interest in local food production has lead to a dramatic increase in urban agricultural activity (van Veenhuizen and Danso, 2007). Although urban agriculture is promoted for its potential contributions to urban sustainability and food security (van Veenhuizen and Danso, 2007), the health risks of urban food production are not well understood. Atmospheric pollution is one of the most serious environmental problems in urban areas where the concentration of anthropogenic activities has lead to the accumulation of contaminants (Mayer, 1999; Molina and Molina, 2004; Wang, et al., 2005). The potential contamination of food products by automotive and industrial emissions represents a significant health concern (Bouris et al., 2009). In most urban areas, automotive emissions are the primary source of air pollution (Frumkin, 2002; Gadsdon and Power, 2009; Honour et al., 2009; Nel, 2005). Lead, zinc and manganese are emitted into the atmosphere from a number of traffic related sources, including vehicle exhaust, brake dust, tires, and road dust (road paint and road construction materials) (Adachi and Tainosho, 2004; Aschner, 2000; Councell et al., 2004; Lough et al., 2005). Although significant improvements have been made to reduce vehicle emissions in recent decades, these advancements have been offset by an increased number of vehicles (Duzgoren-Aydin, 2007; Frumkin, 2002). Contamination from cadmium is associated primarily with industrial emissions (Hovmand et al., 1983). Humans can be exposed to heavy metals through the ingestion of contaminated produce and leaves present an important pathway for the transport of heavy metals into food plants (Harrison and Chirgawi, 1989). Metals found as contaminants in vegetables can pose a serious health threat to humans when found in concentrations exceeding the amounts required by the body (Agbenin et al., 2008; Ascher, 2000; Duzgoren-Aydin, 2007; Jarrup and Akesson, 2009; Kachenko and Singh, 2006; Walsh et al., 1994). Human exposure to high concentrations of heavy metals including lead, cadmium, manganese and zinc can result in a buildup in the fatty tissues of the body which in turn can affect the central nervous and circulatory system (Nriagu, 1988). Organizations such as the Commission of the European Communities (2001), the Food and Agriculture Organization (FAO) and the World Health Organization (WHO) (FAO/WHO-CAC, 2001), have guidelines for safe levels of heavy metal contamination in vegetables and crops (Maleki and Zarasvand, 2008; Nabulo et al., 2006). Research in Iran, Uganda, Poland and Greece has shown that produce grown in urban areas can frequently exceed safe heavy metal concentrations (Cole et al., 2008; Maleki and Zarasvand, 2008; Nabulo et al., 2006; Voutsa et al, 1996). While some research has been done to examine the potential hazards of urban agriculture in developing countries, little work has been done on contamination of urban food production in North American cities. If urban food production is to become a viable, sustainable food system these risks must be addressed. The objective of this research was to quantify the potential for heavy metal contamination of food grown in mid-sized North American cities as a function of peak traffic flow and building density.

3.3 Methods

My goal was to characterize variability in metal contamination across an urban-rural gradient in the peak pollution period in the city of Victoria. As such, research was conducted in the mid-summer when the potential for atmospheric contamination was greatest (CRD, 2010; SENES, 2010). Lettuce (*Lactuca sativa* L.; Asteraceae), a commonly grown leafy green, was selected as a bio-indicator species. It is sensitive to the common contaminants of the urban environment, and is a known accumulator of heavy metals (Sterrett et al., 1996). Many urban gardeners clip salad leaves for consumption without washing them, therefore, unwashed lettuce samples were analyzed to provide an indication of the heavy metal concentrations that produce can contain.

3.3.1 Sampling

Sampling sites were located across an urban-rural gradient in Victoria, BC. This region is located on the southern tip of Vancouver Island. Victoria is a mid-sized Canadian city with a population of approximately 330 000 (City of Victoria, 2009). Called the “City of Gardens”, Victoria is known as a clean, attractive city and is a popular tourist and retirement destination (City of Victoria, 2009). Victoria is situated in the mildest plant hardiness zone in Canada (Zone 8a) and is ideal for agricultural activities (Government of

Canada, 2010; MacNair, 2004). Due to its sub-Mediterranean climate zone, Victoria receives some of the most moderate weather in Canada (City of Victoria, 2009). Temperatures remain mild year-round, typically ranging from 0-25°C, with an average annual temperature of 10.3 °C (Environment Canada, 2010). Winters frequently do not include snow and summer time highs generally occur in the months of July and August (City of Victoria, 2009; Environment Canada, 2010).

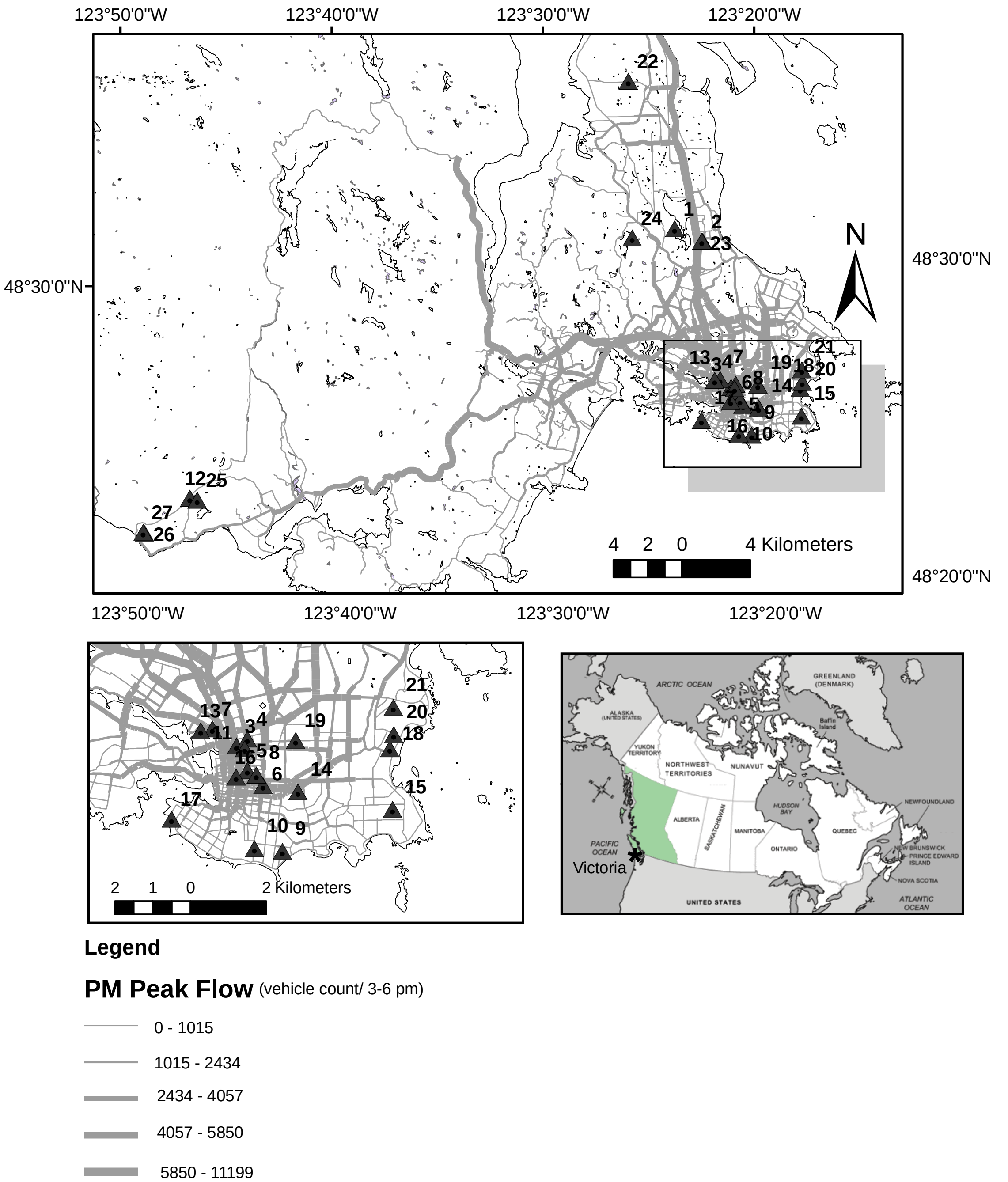

Figure 1: Map of sampling locations and peak traffic density in the Greater Victoria Area (grey lines correspond to volume of cars from 3-6 pm). The numbers on the map correspond to the sites listed in Table 1. The inset map on the left shows the locations of sampling sites in urban Victoria. The map (at right) shows the province of British Columbia (highlighted in green) and the City of Victoria (marked with a star) (map retrieved from www.bcpl8s.ca/map.htm).

Lettuce planting boxes were established across Greater Victoria, but the majority of sites were located in the City of Victoria (Figure 1). Three site types were selected: (1) rural (control); (2) residential; and (3) industrial/business (Figure 1). Control sites were located on commercial farms or rural properties around the City of Victoria, residential sites were established in the yards of residential homes and industrial/business sites were located in the downtown core where there was greater traffic and industrial activity (see Photo 1, 2 and 3). Site types were selected to reflect areas perceived as safe (rural), impacted but safe (residential) and impacted and not safe (industrial business). Sites were selected based on expert opinion and land use (see Chapter 2) (Table 1) (*See Appendix A, map 1*).

Table 1: Site description and environmental variables associated with each of the 27 sampling locations. Industrial/Business site locations referred to as I/B.

Treatment	Site #	Afternoon peak flow (traffic volume)	Road density (m/km^2)	Building Density (building area/km^2)	Site description
Control	1	4083.0	36671	39.4	Isolated rural property north of Victoria
Control	2	8211.0	10067	27.4	Market farm on outskirts of Victoria
Control	12	47.0	3723	17.6	Market farm in rural area west of Victoria
Control	22	585.0	7143	29.2	Market farm near Saanichton
Control	23	8149.0	10067	27.4	Market farm on outskirts of Victoria
Control	24	1272.0	5173	36.0	Market farm north of Victoria
Control	25	49.0	4733	18.0	Market farm in rural area west of Victoria
Control	26	502.0	3723	15.3	Rural property west of Victoria
Control	27	385.0	3723	12.8	Rural property west of Victoria
I/B	3	24726.0	473664	49.5	Next to parking lot in downtown core

I/B	4	23519.0	306194	45.9	Next to busy road way in downtown core
I/B	5	23813.0	473664	46.6	Next to busy road way in downtown core
I/B	6	20177.0	416635	42.5	Next to busy road way in downtown core
I/B	7	22817.0	473664	45.1	Next to auto mechanic shop
I/B	13	21098.0	473664	46.5	Next to recycling plant in industrial area
I/B	16	22775.0	416635	46.7	Next to busy road way in downtown core
I/B	17	1388.0	14310	39.9	Next to ferry harbour and Helijet landing
I/B	19	15004.0	306194	36.4	Boulevard next to road
Residential	8	22520.5	473664	46.3	Side yard, residential neighbourhood
Residential	9	2293.0	14310	23.9	Back yard in a residential neighbourhood
Residential	10	3962.0	10067	28.4	Side deck in a residential neighbourhood
Residential	11	24619.0	473664	47.3	Back deck in a residential neighbourhood
Residential	14	11603.0	416635	34.9	Back yard in a residential neighbourhood
Residential	15	985.0	7143	11.3	Back yard in a residential neighbourhood
Residential	18	3258.0	14310	13.4	Back yard in a residential neighbourhood
Residential	20	3298.0	14310	11.6	Back yard in a residential neighbourhood
Residential	21	3703.0	36671	12.5	Back yard in a residential neighbourhood

Picture 1: Industrial/business sampling site located next to busy roadway (Site # 5)

Picture 2: Control sampling site on rural market farm property north of Victoria (Site # 22)

Picture 3: Industrial/Business sampling location next to auto mechanic and busy roadway (Site #7)

To estimate the minimum sample size required for each treatment, I conducted a power analysis using data from a study of heavy metal contamination of urban vegetation in Africa (Nabulo et al., 2006). Although the sites in Kampala City, Uganda, examined by Nabulo et al. (2006), are not completely analogous to urban Victoria, this data provided some useful estimates of within group and between group variations in heavy metal levels. Based on this analysis I established nine replicate planters in each site type. Seeds of the loose leaf lettuce cultivar, Simpson Elite Lettuce, purchased from West Coast Seeds, were germinated in a greenhouse in late June of 2010 using certified organic

Sea Soil™ container mix. This medium is approved by the Organic Materials Review Institute and is regularly tested for heavy metals. It contains no detectable lead or cadmium concentrations (personal communication Sea soil representative, 2010). After 17 days in the greenhouse, plants were transplanted into cedar planter boxes filled with the same growing medium. Each planter box (65x20x15cm) received four plants. On July 15th, planter boxes were distributed to the locations shown in Figure 1. Each box was placed on the ground surface and received approximately 1L of water/ day in order to keep the soil moist. Planter boxes remained outside for approximately 18 days. The weather during this period was sunny and warm with an average temperature of 20.3°C (range of 17-24°C). It did not rain during the course of the experiment (Environment Canada, n.d.).

Picture 4: Lettuce seedlings in greenhouse

Lettuce heads were harvested by cutting the base of the plant when samples began exhibiting signs of bolting after 18 days. Prior to harvesting, an injury survey was completed for each plant by counting the number of injured leaves per plant and estimating the percentage of injured leaf area. Following the methodology of Ghosh (1998), an injury score was calculated by multiplying the number of injured leaves by the percent damage. Injury categories included necrosis, chlorosis, insect damage, signs of disease, discoloration, loss of colour, early senescence, misshapen leaf and other. After harvest, the fresh weight of each plant was determined using an Ohaus Scout *Pro* electronic scale with an accuracy of ± 0.1 g and a precision of ± 0.1 g.

To compare lettuce grown across the urban-rural gradient in Victoria with commercially grown lettuce, I purchased nine samples of lettuce from five local grocery stores. Looseleaf (*Lactuca sativa* var. *crispa*), romaine (*Lactuca sativa* var. *romana*) and butterhead lettuce (*Lactuca sativa* var. *capitata*) were selected from each of the five locations; different samples were taken at each store. Store-bought lettuce samples were purchased on the day that the planter box lettuce was harvested (See Table 2). The growing conditions, soil types and processing procedures associated with these samples are unknown. Regardless, these samples provide a useful comparison with lettuce grown across the urban-rural gradient in Greater Victoria. It can be assumed that purchased lettuce samples were exposed to water at some point prior to analysis; either through misting during marketing or rinsing post-harvest to remove dirt and debris and preserve freshness (4 samples were labeled as pre-washed; 2 samples were subject to in store misting; and all samples were clean of dirt and debris).

Table 2: Description of lettuce purchased on the same day from five grocery stores within the City of Victoria

Variety	Sample ID #	Store	Region	Packaging	Package Information
Bay romaine	33	Fairways	California	Sealed plastic	Organic, pre-washed, no preservatives
Spring mix	34	Fairways	California	Sealed plastic bag	Thoroughly washed and ready to eat
Butter lettuce	35	Market on Yates	BC	Plastic container	Greenhouse grown, store in water at room temperature for 7-14 days
Green artisan lettuce	36	Market on Yates	California	Plastic container	Wash before use
Green lettuce	38	China town market	No info	Open air	None
Green leaf singles	41	Safeway's	California	Plastic container	Thoroughly washed and hand packed
Green Leaf lettuce	43	Safeway's	BC	None	None
Romaine lettuce	48	Thrifty's	California	Sealed plastic bag	Organic, pre-washed, no preservatives
Green leaf lettuce	47	Thrifty's	BC	None	None

Three unpackaged purchased samples (#38, #43, #47) were separated into two treatments: washed and unwashed. The washed samples were rinsed with deionized water for 30 seconds. A lack of plant material prevented the analysis of washed and unwashed experimentally grown lettuce. Once they were weighed the individual lettuce plants in each planter were combined into composite samples. This was required to provide sufficient dry weight for triplicate metal analysis. All samples were dried at 60°C for three days and then kept at 30°C until they could be processed for analysis.

3.3.2 Chemical Analysis

To determine the heavy metal content of all lettuce samples I used microwave digestion and inductively coupled plasma-optical emission spectrometry (ICP).

Dried samples were ground in a Wiley® Mill and microwave digestion was used to prepare ground tissue for metal analysis (Photo 5). Samples were prepared for digestion by adding 0.250 grams of tissue to 4 ml of digestion solution, consisting of 15 ml of 10 000ppm scandium, and 30 ml of 30% concentrated hydrochloric acid diluted to 1L with 70% concentrated nitric acid. A carousel containing up to eight samples took about 40 minutes for microwave digestion. After the samples cooled, they were diluted with 10 ml of 10% hydrochloric acid to 15 ml. Digests were decanted into fresh tubes for analysis.

Picture 5: Ground lettuce samples for ICP analysis

Scandium was used as an internal standard in each digest. Two NIST certified reference standards, Spinach Leaves (SRM 1570a) and Bush Branches and Leaves (NCS DC73349) were used in each digestion carousel in order to verify accuracy of analytical procedure. Both standards were needed because Bush Branches and Leaves could not give an accurate concentration of cadmium while Spinach Leaves could not give an accurate concentration of lead. Each digestion carousel included both standards.

ICP analysis was conducted using a Prodigy High Dispersion ICP (Teledyne Instruments) located at the B.C. Ministry of Forests and Range Research Branch. The ICP was calibrated using six internal standards prior to analysis according to the Laboratory's standard procedure. The concentrations of standards chosen corresponded to the estimated concentrations of the metals of interest. To ensure accuracy of the ICP instrument each row included nine lettuce samples, a Bush Branches and Leaves standard, a Spinach Leaves standard and a stock standard. The percent theoretical value should ideally be between ± 5% of 100.

Plant Root Simulator™ probes were used to estimate metal deposition in the growing medium of each planter box. Plant Root Simulator™ probes contain ion exchange surfaces that exhibit the characteristics and nutrient adsorption phenomena of plant roots, enabling them to act as ion sinks. The probes adsorb similarly charged ions from the soil solution and labile nutrient pools (Western Ag Innovations, 2007). The probes provide a dynamic measure of ion flux over time that measures the actual bioavailable nutrients in the soil (Qian and Schoenau, 2002). Probes supply rates are better correlated to plant uptake than traditional chemical extraction values (Western Ag Innovations, 2007). Both anion and cation probes were placed in eight planters from each treatment. Eight additional planters were filled with fresh Sea Soil™ as a control. All boxes were kept in a greenhouse and watered daily. After two weeks, the probes were removed and rinsed in deionized water and shipped to the laboratory for analysis using inductively-coupled plasma spectrometry and atomic absorption spectrometry (Western Ag Innovations, 2007).

3.3.3 Characterizing Sample Sites

To explore differences in the degree of urbanization among site types, I compared three indicators obtained from GIS data: road density, building density and afternoon peak traffic flow (Capital Regional District, 2010) (*See Appendix A map 2, 3, and 4*). Road density (meters of road/square kilometer) was calculated using the line density function in the spatial analyst toolbox in ARC GIS 10. Building density (building area/square kilometer) was calculated by converting the polygon coverage of commercial buildings to a point file and using the point density function weighted according to building area (square kilometer). Afternoon peak flow was obtained from government data that combined estimates of vehicle volume during the afternoon peak period (3-6 pm) with traffic models (TRANSCAD). These files were exported into shape files from the regional transportation model (Capital Regional District, 2010). The line thickness on Figure 1 corresponds to total flow volume: thick lines have greater volume than thin lines. The mean value for each variable (peak flow, road density and building density) was calculated in a 100 m^2 buffer surrounding each site using the zonal statistics tool in ARC GIS 10.

3.3.4 Statistical analysis

To test the hypothesis that the three site types (control, residential and industrial/business) differed from each other in terms of site and lettuce sample characteristics, I used several non-parametric statistical tests. Non-parametric approaches were used because a number of the response variables of interest violated the assumption of normality. Data normality was assessed with the Shapiro-Wilk normality test using the shapiro.test function in R as well as by examining the distribution of the data by generating quantile-quantile plots of each variable (R Development Core Team, 2009a). To test for differences among site types with respect to each response variable, univariate non-parametric analyses of variance (non parametric ANOVAs) were performed. The

Kruskal-Wallis test was employed to determine whether or not significant differences existed among site type means for each heavy metal (lead, cadmium, zinc and manganese), site characteristics (peak flow, road density and building density) and sample characteristic (fresh weight and injury score). Kruskal-Wallis testing ranks the data of a specified group and then conducts an analysis of variance on the ranks (McDonald, 2009). Tests were conducted in R using the 'kruskal.test' function. If significant differences existed, post-hoc testing was conducted to determine which treatments were significantly different. Post-hoc Kruskal-Wallis testing was applied in R using the Wilcoxon rank sum test (pairwise.wilcox.test), a nonparametric test for equality of two samples that are non-normal. P-values were corrected for multiple testing using the Bonferroni correction (p.adj="bonferroni") (Troyanskaya et al., 2002; Whitlock and Schluter, 2009). Univariate non-parametric ANOVAs and post-hoc testing with the Bonferroni correction were also conducted to determine if there were significant differences between soil treatments and heavy metal concentrations using data derived from the soil probe experiment.

Washed and unwashed portions of the same purchased lettuce samples were analyzed using paired t-tests. These tests explore the hypothesis that the difference between metal concentrations in washed and unwashed samples is zero (Whitlock and Schluter, 2009). Paired t-tests are used for repeated measurements of the same samples – which are non-independent (washed and unwashed) (McDonald, 2009). Paired t-tests were conducted using the t.test function with the paired specification in R (R Core Development Team, 2009a). A post-hoc power analysis was conducted to determine if the power was great enough for any results from this portion of the experiment to be substantive. These tests were conducted in R using the function pwr.t.test (R Development Core Team 2009a).

To assess the hypothesis that the median heavy metal concentration in Victoria lettuce samples is equal to the FAO/WHO recommended maximum level of each heavy metal (FAO/WHO-CAC, 2001), I conducted Wilcoxon signed rank sum tests. This non-parametric test estimates the median and 95% confidence interval of each heavy metal (Shier, 2004; Whitlock and Schluter, 2009). These tests were conducted in R using the wilcox.test function(R Development Core Team, 2009b). P-values were adjusted for multiple tests using the Bonferroni correction in R (p.adj="bonferroni") (Troyanskaya et al., 2002).

To examine the relationship among heavy metal concentrations, yield, injury and site characteristics derived from GIS software, I performed a principal component analysis using the 'prcomp' function in R (R Development Core Team, 2009c). This analysis employed a correlation matrix (McGarigal et al., 2000) of the following variables: road density, building density, afternoon peak traffic flow, lead, cadmium, manganese and zinc concentrations, yield and injury score. In order to make interpretation easier, the dimdesc() function from the package 'FactoMineR' was used to describe the dimensions given by the variables. The dimdesc() function calculates the correlation coefficients and the p-values of the variables which are significantly correlated to the principal dimensions (Husson et al., 2010).

3.4 Results:

3.4.1 Accuracy of Results

To ensure accurate results, samples were digested three times and each digest was run through the ICP machine twice. The raw data was carefully examined to ensure consistency among stock standards and triplicate samples. Ideally, the percent theoretical value of stock standards should be within ± 5% of 100. The stock standard theoretical values remained within 3% of 100. The standard errors for the values for each metal in the stock standard were very low ranging from 2-4%. The percent theoretical value for all metals remained between 95-105% with the exception of the Spinach standard percent theoretical value for manganese which was at 90%.

For cadmium the standard errors of the multiple runs of the triplicate samples means ranged from 0.03-0.09 with two outliers of 0.29 and 0.50 (mean of 0.07). For lead the standard error of the multiple runs of the triplicate sample means ranged from 0.08-0.44 with one outlier at 1.16 (mean of 0.24). For manganese, the standard errors of the multiple runs of the triplicate sample means ranged from 0.18-4.39 (mean of 1.66) and for zinc the standard error of the multiple runs of the triplicate sample means ranged from 0.33-2.19 with one outlier at 4.30 (mean of 1.12). Two digestion carousels were found to display inaccurate results for the two standards (Bush Branches and Leaves and Spinach). These digests were discarded and new ones were prepared and used.

3.4.2 Heavy Metal Concentrations in Lettuce Tissue

Analysis of heavy metal data indicated that there were significant differences in lead, cadmium, manganese and zinc concentrations among site types (Table 3).

Industrial/business sites had significantly higher lead (p=0.019), cadmium (p=0.031), zinc (p=0.019) and manganese (p = 0.006) concentrations than residential site types (Figure 2). Similarly, industrial business sites had significantly higher lead (p=0.0012), manganese (p=0.0012) and zinc (p=0.0033) concentrations than control sites (Figure 2). Lead concentrations in samples from residential sites were significantly greater than the control sites (p=0.04), but cadmium, zinc and manganese concentrations did not differ between the residential and control sites types (p=0.34; p=0.28; p=0.75 respectively) (Figure 2) (*See Appendix B, Table 12*).

Table 3: Kruskal-Wallis analysis of heavy metal concentrations, site characteristics and sample characteristics among site types. Significant differences shown in italics.

	Kruskal-Wallis X^2	Degrees of Freedom	P-value
Lead	17.6	2	*0.00015*
Cadmium	9.1	2	*0.0108*
Zinc	14.4	2	*0.00075*
Manganese	16.2	2	*0.00031*
Fresh Weight	2.2	2	0.330
Injury Score	0.6	2	0.753
Peak Flow	12.5	2	*0.00194*
Building Density	11.9	2	*0.00262*
Road Density	19.1	2	*7.19E-05*

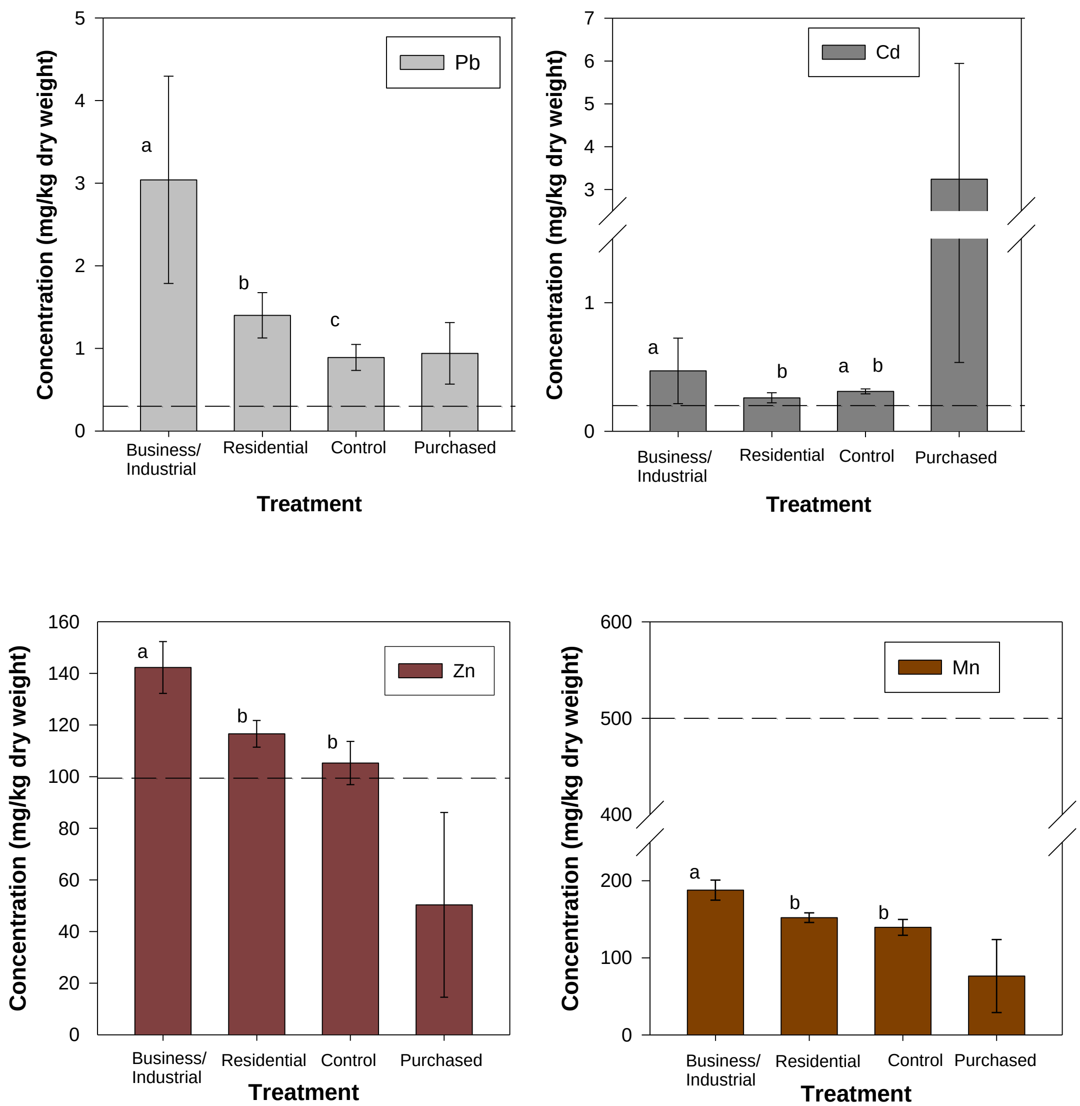

Figure 2: Heavy metal concentrations in lettuce tissue from the three site types and purchased lettuce samples. Bars show means (mg/kg dry weight) of each site type and error bars show 95% confidence interval. Means with different letters are significantly different (determined by non-parametric post-hoc ANOVA testing). Dashed lines show FAO/WHO (2001) recommended safe levels of each heavy metal.

Purchased lettuce samples had notably different metal concentrations than samples grown in Victoria. Lead levels were similar to control lead levels, while cadmium levels were much higher than all Victoria samples. Zinc and manganese concentrations were lower in purchased samples than the samples grown in Victoria (Figure 2).

Comparisons of the FAO/WHO recommended safe limits with lettuce samples showed that lead concentrations in lettuce from industrial business, residential and control sites, and purchased samples (W=45, p=0.0039) were significantly greater than the safe limit of 0.3 mg of Pb/kg (Figure 2). Cadmium concentrations in industrial/business (W=45, p=0.0039), residential (W=41, p=0.027), control (W=45, p=0.0039), and purchased (W=45, p=0.0039) samples were also greater than the recommended guideline of 0.2 mg of Cd/kg (Figure 2). Zinc concentrations in industrial/business (W=45, p=0.039) and residential (W=44, p=0.0078) samples were greater than the recommended guideline of 99.4 mg of Zn/kg (Figure 2). Zinc concentrations in control (W=32, p=0.3) and purchased samples (W=9, p=0.13) were not significantly different than the recommended level. Manganese concentrations in industrial/business, residential, control and purchased samples (W=0, p=0.0039) were significantly lower than the recommended level of 500 mg of Mn/kg (Figure 2).

Table 4: Median and 95% confidence interval for heavy metals (mg/kg dry weight) by treatment estimated using the Wilcoxon signed rank sum test. Treatments greater than the recommended max limit (p<0.05) are shown in italics.

	Lead	Cadmium	Zinc	Manganese
Industrial/Business	*2.51 (1.82-4.75)*	*0.35 (0.31-0.91)*	*144.43 (130.07-152.94)*	191.71 (168.83-215.19)
Residential	*1.39 (1.06-1.82)*	*0.25 (0.21-0.31)*	*115.84 (104.83-128.24)*	150.40 (143.37-163.22)
Control	*0.88 (0.67-1.09)*	*0.30 (0.28-0.35)*	102.08 (95.98-115.57)	139.71 (121.06-156.38)
Purchased	*0.80 (0.58-1.50)*	*2.58 (0.52-6.76)*	35.34 (21.23-109.85)	59.50 (37.70-160.31)
Recommended Max. Limit*	0.3	0.2	99.4	500

*FAO/WHO recommended guidelines

Heavy metal concentrations varied considerably in washed and unwashed samples (Table 5). Although an attempt was made to examine the effect of washing, the results were uninformative as the sample size was too small for adequate statistical power.

Table 5: **Mean Cd, Mn, Pb, and Zn contents (mg/kg dry weight) in washed (W) and unwashed (UW) purchased samples.**

	Pb-W	Pb-UW	Cd-W	Cd-UW	Zn-W	Zn-UW	Mn-W	Mn-UW
Purchased Sample #38	0.40	2.36	10.56	12.84	161.29	191.66	195.87	253.86
Purchased Sample #43	0.48	0.96	0.95	0.84	81.73	65.00	87.20	68.44
Purchased Sample #47	0.52	0.50	0.46	0.63	39.82	47.39	11.43	18.17

3.4.3 Visual Survey

Results from the visual survey of individual lettuce heads at each sample site indicated that no significant differences existed among treatments for either fresh weight or injury score (Table 3). Injury type consisted mainly of herbivory (as indicated by missing parts of the plant leaf) followed by chlorosis, necrosis and leaf deformation. The industrial business sites contained the highest injury score and the lowest injury score of all sites with a mean of 801.53. Lettuce samples in the residential sampling sites had a mean of 603.07 and samples in the control sites had a mean of 717.95. Overall, the level of injury sustained by the majority of the samples was comparable to that sustained by market produce. Only a few heads were not suitable for market due to massive herbivory, including eight heads from industrial/business sites (two sampling sites in total) and one head from a control site.

Industrial/business sites also contained both the highest fresh weight and lowest fresh weight out of all lettuce samples with a mean fresh weight of 56.91 g. Lettuce samples in the residential sampling sites had a mean of 53.33 g while samples from control sites had a mean of 40.9 g.

Picture 6: Example of lettuce heads at an industrial/business site prior to harvest (Site #17)

Table 6: **Mean and 95% confidence interval of fresh weight and injury score by site type.**

	Fresh Weight	Injury Score
Industrial/Business	56.91 (28.72 -85.10)	801.53 (462.32-1140.74)
Residential	53.33(41.03 - 65.64)	603.07 (398.89 -807.25)
Control	40.9 (28.56 -53.24)	717.95 (510.29 - 925.61)

3.4.4 Root Uptake of Atmospheric Deposition

Although soil probe data showed a pattern similar to metal concentrations in lettuce tissue (industrial>residential>control), non parametric ANOVAs found no significant differences between lead, cadmium or zinc concentrations and soil treatments (Table 8). Both lead and cadmium levels were below the minimum detection limits (0.2 micrograms/10cm^2/burial length) for all soil treatments (Table 7). Mean zinc and manganese concentrations were higher in industrial/business sites than in the residential treatment and the control. Manganese concentrations showed the potential for significant differences to exist between soil treatments, post-hoc testing with adjusted p-values revealed no significant differences between fresh and control soil (p=0.16), industrial and control soil (p=1), industrial and fresh soil (p=0.14), residential and control (p=1), residential and fresh soil (p=0.24) or residential and industrial soil (p=1) (*See Appendix B, Figure 4*).

Table 7: Mean plant available metal concentrations and 95% confidence interval per soil treatment (micrograms/10cm^2/burial length).

	Pb	Cd	Zn	Mn
Minimum Detection Limits	*0.2*	*0.2*	*0.2*	*0.2*
Industrial/Business Soil	0.05 (0-0.1)	0 (0-0)	4.45 (3.1-5.8)	8.7 (6.5-10.8)
Residential Soil	0.03 (0-0.07)	0 (0-0)	3.38 (1.7-5.0)	7.87 (5.9-9.9)
Control Soil	0 (0-0)	0 (0-0)	2.8 (1.8-3.5)	7.26 (5.1-8.8)
Fresh Soil	0 (0- 0)	0(0-0)	2.7 (2.2-3.2)	5.35 (4.2-6.4)

Table 8: Kruskal-Wallis analysis of soil treatment and plant available heavy metal levels. No significant differences found to exist between soil treatment and lead, cadmium or zinc.

	Kruskal-Wallis X^2	Degrees of Freedom	P-value
Lead	3.705	3	0.295
Cadmium	NaN	3	NA
Zinc	5.183	3	0.159
Manganese	8.374	3	0.0389

3.4.5 Analysis of Site Zones

Site types selected using expert opinion and land use patterns showed significant differences in mean afternoon peak traffic flow, building density and road density. The mean for each variable was greatest in the industrial/business site type and lowest in the control site type (Table 9). Non-parametric ANOVAs revealed significant differences between individual site characteristics: peak flow, building density and road density and site type (Table 3). Post-hoc Wilcoxon rank sum tests with Boniferroni corrections showed significant differences between site types with respect to all site characteristics. As expected, industrial site types had higher afternoon peak traffic flow ($p = 0.0033$), building density ($p = 0.0017$) and road density ($p = 0.0011$) than control site types. The residential site type had a significantly greater road density than in the control areas ($p = 0.0023$). No other significant differences were found between industrial and residential site types and residential and control site types.

Table 9: Mean and 95% confidence interval of site characteristic by site type.

	Peak Flow (vehicle count at 3-6pm)	Road density (m of road/km^2)	Building Density (building area/km^2)
Industrial/ Business	19479.7 (14661.7-24297.6)	391344 (14310-473664)	44.3 (41.7-47.0)
Residential	8471.3 (2540.8-14401.7)	116015 (7143-473664)	25.5 (15.9-35.1)
Control	2587 (363.9-4810.1)	94147 (3723-10067)	24.8 (18.7-30.9)

Principal component analysis of experimental response variables and site variables revealed that the first three principal components explained 80% (cumulative) of the total variation in the data. Principal component one (PC1) and two (PC2) explain 70% (cumulative) of the total variation in the data. Although the rule of thumb is to present the first *k* axes that explain 80% (cumulative) of the total variation (Zuur et al., 2007), only the biplot of PC1 and PC2 was of interest (Zuur et al., 2007) (Figure 3).

The relationship between variables and PC 1 and PC2 is depicted in Figure 3 and Table 10. Figure 3 revealed that site types are divided into two major groups, industrial/business sites and residential and control sites. The variables manganese, lead, zinc, peak flow, road density and building density were significantly correlated with PC1. Sampling sites with negative values for PC1 had high lead, manganese and zinc concentrations and high peak flow, and road and building density. Control and residential site types are grouped to the right side of the figure indicating that they had below average values for building density, road density, peak flow, manganese, lead and zinc concentrations. There are two residential sites with intermediate values of PC1. Cadmium concentrations, fresh weight and injury score are unrelated to peak flow, building density and road density and the other three heavy metal concentrations, but are significantly correlated with PC2. Fresh weight is inversely related to injury score – indicating that the greater the injury the lower the weight.

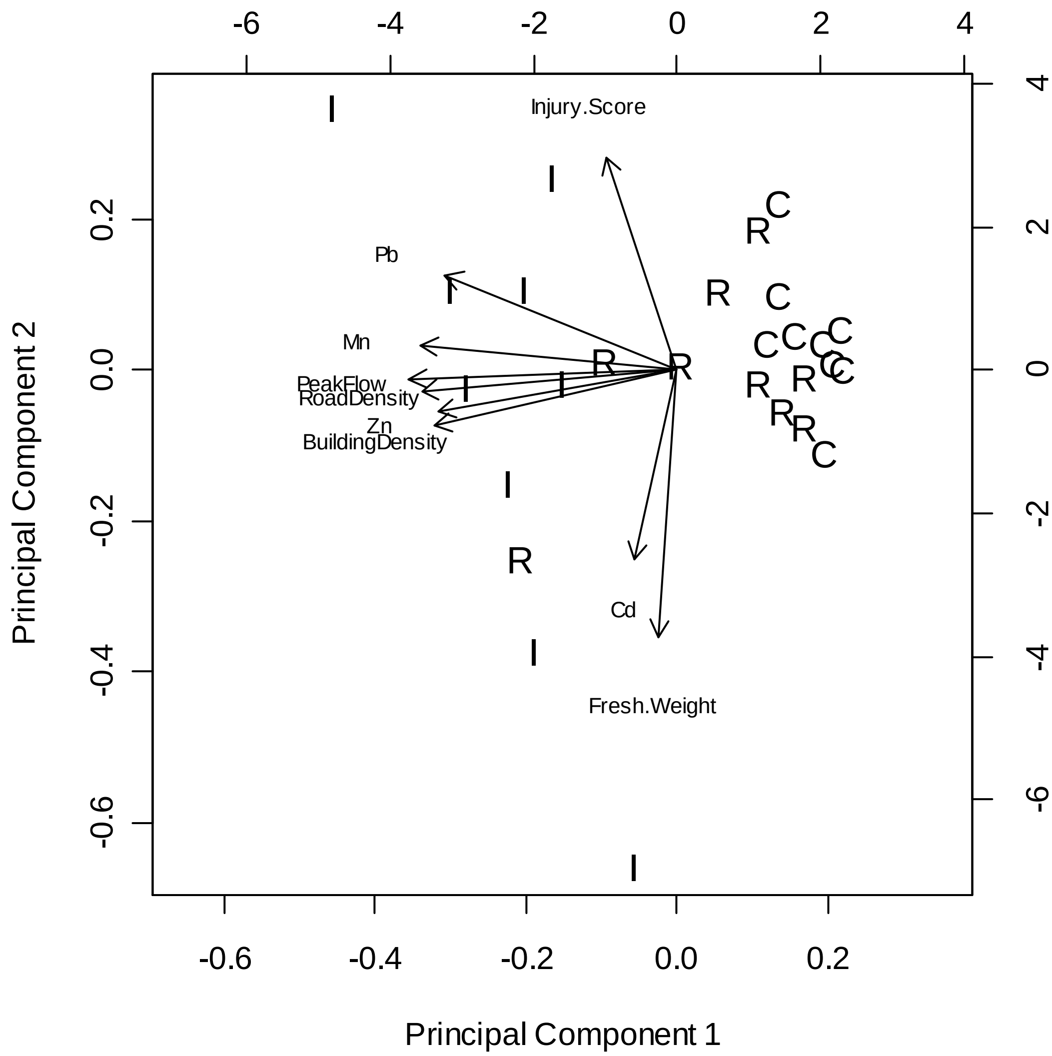

Figure 3: Correlation biplot of principal component scores for samples in each site type: R= residential; C=control; I = industrial/business. Arrows show the variable loadings on each PC axis. Pb = lead, Zn = zinc, Cd= cadmium and Mn = manganese concentrations.

Table 10: Loadings of principal components that explain the majority of the variation in the data. Variables whose p-values are smaller than 0.05 are significantly correlated to either principal component one or two indicated with an asterisk.

	Principal Component 1	Principal Component 2
Manganese	-0.42*	0.06
Cadmium	-0.06	-0.47*
Lead	-0.38*	0.23
Zinc	-0.30*	-0.11
Fresh weight	-0.03	-0.66*
Injury score	-0.12	0.52*
Peak flow	-0.43*	-0.02
Road density	-0.41*	-0.05
Building density	-0.39*	-0.13

3.5 Discussion:

3.5.1 Potential for atmospheric contamination of produce grown in Victoria

The results of this study show that some sites are more susceptible to heavy metal contamination than others. Industrial business areas yielded samples that had significantly higher heavy metal concentrations than samples from residential or control sites. Control sites had the least contaminated samples, but they were only moderately less so than the residential sites. The principal component analysis of experimental response variables and site variables suggests that lead, zinc and manganese concentrations are linked to increased traffic and building density at industrial and residential sites. Higher traffic density in more urban areas means greater traffic emissions, higher levels of atmospheric pollution and ultimately greater heavy metal deposition. These findings are consistent with a 2006 study which demonstrated that lead contamination of plant leaves mediated by atmospheric deposition was a function of traffic density (Nabulo et al., 2006).

Although leaded gasoline was banned in Canada as fuel for on-road vehicles in 1990, leaded wheel weights – small pieces of pure lead attached to the rim of vehicle tires – drop from vehicle wheels where they are pulverized by traffic (Duzgoren-Aydin, 2007; Lough et al., 2005; Merchant, 2009). The re-suspension of lead contaminated road dust has subsequently become one of the predominant sources of leaded emissions into the environment (Duzgoren-Aydin, 2007). Additionally, leaded fuel is still used for off-road and marine engines. In coastal regions such as Victoria, marine traffic can be a substantial contributor to lead emissions (Duzgoren-Aydin, 2007).

Unlike lead, manganese and zinc, cadmium contamination does not appear linked to increased traffic and building density. Cadmium concentrations in the samples grown in Victoria were not correlated with traffic density or lead, zinc or manganese concentrations (Figure 3). This is also consistent with Nabulo et al.'s study which showed that cadmium concentrations were not significantly related to traffic density (2006). The primary sources of cadmium to the atmosphere are non-ferrous and ferrous metal production, coal combustion and waste incineration (Hovmand et al., 1983). Only one sampling site had lettuce with considerably higher levels of cadmium (cadmium concentrations were below detection limits in the growing medium). This site is located in James Bay next to a Cruise ship docking site. It is possible that waste incineration on cruise ships contributed to the elevated levels at this sampling site (Environmental Protection Agency, 2008).

Elevated levels of zinc and manganese found in the lettuce samples grown in rural and urban Victoria were not expected based on the findings of similar studies on heavy metal contamination. Additional research must be conducted in order to determine possible reason for the anomalously high concentrations of these elements. Possible explanations for the zinc and manganese concentrations include point sources such as smelters (Simonetti et al., 2003) and metal plating facilities. Additionally, the location of Vancouver Island along the mixing line between Canada-USA, subjects Victoria to both atmospheric emissions from both the major urban centres of Vancouver and Seattle (Simonetti et al., 2003). Municipal wastewater discharge into the ocean from the two sewage handling facilities that service Victoria (Sierra Legal Defence Fund, 2004) and the subsequent ocean spray may also be contributing to the high concentrations of manganese in the ambient atmosphere. However, these explanations remain purely speculative in nature and further investigation is required to determine the sources of zinc and manganese to the atmosphere.

3.5.2 Potential for contamination in a global context:

As there are human health implications associated with ingesting heavy metals, the FAO/WHO has set recommended guidelines for the maximum limit of metal concentrations in leafy greens (Table 11). Average lead concentrations were elevated above these guidelines for all lettuce samples grown in rural and urban Victoria (FAO/WHO-CAC, 2001). Cadmium and zinc concentrations are also elevated, but not to the same extent as lead concentrations (Figure 2).

The findings of this study are consistent with the findings of previous studies that have shown that heavy metals are higher in urban areas with increased road density. Table 11 compares the levels of atmospheric contamination in leafy greens grown in rural and urban Victoria with the heavy metal concentrations found in leaf greens grown worldwide (Nabulo et al., 2006; Nali et al., 2009; Voutsa et al., 1996).

Table 11: **Mean element concentrations in lettuce grown in areas worldwide (mg/kg dry weight). Asterisk marks the values from Thessaloniki Greece as medians. [a] Voutsa et al. (1996). [b]Compiled by Voutsa et al. (1996).[c] Nali et al. (2009). [d]Nabulo et al. (2006) . [e]McLeod (2010). [f] FAO/WHO recommended guideline (2001)**

	Pb	Cd	Zn	Mn	N
Thessaloniki, N.Greece[a]	11.2*	0.58*	39.2*	33.3*	8
Rural Greece[b]	28	1.1	58	6.8	N/A
Castelfiorentio, Tuscany, Italy [c]	1.59	0.59	85	75	11
Kampala City, Uganda[d]	7.74	0.89	56.03	N/A	6
Industrial Victoria [e]	3.0	0.5	186.2	142.3	9
Residential Victoria [e]	1.4	0.3	150.8	116.6	9
Rural Victoria [e]	0.9	0.30	138.1	105.1	9
Recommended Max. Limit[f]	0.3	0.2	99.4	500	

A certain degree of atmospheric contamination is pervasive. It has adverse impacts in both urban and rural areas. These comparisons show that contamination levels of lead and cadmium, even during peak pollution periods in Victoria, are moderate compared to rural and urban areas worldwide. Although use of leaded gasoline may be contributing to the lead concentrations found in some of these areas, leaded gasoline has been phased out in Italy. Zinc and manganese levels however are considerably higher in the lettuce samples from rural and urban Victoria. Manganese concentrations do not exceed the FAO/WHO recommended levels however. Contamination is obviously unavoidable due to global levels of atmospheric pollution, and it would appear that the FAO/WHO recommended maximum limits for heavy metals are generally surpassed.

The analysis of store bought lettuce samples indicated that cadmium contamination is higher in comparison to the Victoria samples. Additionally these store bought lettuce samples still had higher lead and cadmium concentrations than the safe limit recommended by the FAO/WHO (2001) (Figure 2). Imported lettuce does, however, have much lower zinc and manganese levels than lettuce grown on Vancouver Island. These findings reinforce the notion that Vancouver Island is subject to elevated levels of zinc and manganese in the atmosphere, however more research is necessary.

3.5.3 Washing as a mitigation strategy:

Previous studies have demonstrated that superficial atmospheric deposition of heavy metals can be removed by washing depending on the function of the element and its metabolic association (Nabulo et al., 2006; Sharma et al., 2008; Voutsa et al., 1996). Nabulo et al. (2010) discovered that washing leaf greens reduced the lead concentrations on average by 35% relative to unwashed material. Likewise, Adekunle et al. (2009) demonstrated that while lead concentrations in all unwashed leafy green samples ranged from 6.35-20.85 mg/kg, washing the vegetables with water reduced lead concentrations by 11.36-43.52% (although it did not bring the values below the FAO/WHO recommended limit). Applying these results to the lettuce samples grown in Victoria suggests that although washing can reduce the lead concentrations in lettuce samples, it does not eliminate the risk (as a reduction of 44% of lead concentrations results in the lowest lead concentration of only 0.5 mg/kg). Moreover, in a study to examine the effects of rinsing produce under tap water, researchers found that it was the mechanical action of rubbing produce under tap water for at least 30 seconds that was likely responsible for removing residues of lead (Krol et al., 2000). Due to the fragile nature of lettuce tissue, any rubbing action of this kind could damage the produce, while simple rinsing is unlikely to result in a significant reduction of contaminant levels.

The results of this study also suggest that all lettuce grown in urban and peri-urban environments should be washed prior to consumption. Lettuce grown at sites across greater Victoria had higher lead concentrations than commercially produced lettuce samples. One possible explanation for lower lead concentrations in purchased lettuce samples is that they were subject to some form of rinsing or washing before or during the marketing stage. Cadmium concentrations in the purchased lettuce samples, however, were considerably greater than the samples grown in Victoria. Unlike lead, cadmium has been known to exhibit greater leaf penetration, and is not likely to be removed by rinsing (Nabulo et al., 2008; Voutsa et al., 1996).

Zinc and manganese levels in purchased lettuce samples were much lower than the concentrations found in samples grown in Victoria. However, this is probably a result of the growing conditions and not post-harvest rinsing procedures. None of the purchased produce was grown on Vancouver Island and therefore was not subject to the same ambient atmospheric conditions as the lettuce grown in urban and rural Victoria.

3.5.4 Importance of site selection:

Due to the levels of contamination discovered through this research, it appears there are some areas in urban Victoria that are best avoided – at least with respect to lettuce production. Samples grown at industrial business sites were generally far more contaminated than those grown in rural and residential Victoria. In some cases, the metal concentrations in samples grown in industrial business sites were more than double those found in residential or rural samples. The high variability in responses variables at industrial business sites can be linked to the variation in sampling sites associated with this category. Victoria is a mid-sized city with no major industrial activity. Sampling sites ranged from the few industrial areas to high traffic areas dominated by businesses. The principal component analysis also suggests that there are areas in Victoria that should be avoided for leafy greens production. Residential neighbourhoods varied in terms of road and building density and peak traffic flow. Similar loadings of lead, manganese and zinc concentrations with peak traffic flow, road and building density suggest that levels of these heavy metals are related to traffic emissions. Therefore caution should be taken when growing leafy greens in neighbourhoods near high traffic areas or in growing locations next to roadways (front yards or boulevards). As the principal component analysis indicates, a few of the residential sampling sites were similar to industrial sites. This implies that although the mean values for heavy metal contamination suggest that it is acceptable to grow produce in residential areas – this doesn't apply to all residential areas.

Likewise, caution should be exercised when growing food crops at industrial business sites and some residential sites. The lettuce samples grown in these areas had far greater concentrations of heavy metals than lettuce grown in residential or rural areas. Site characteristics, including greater traffic flow, road and building density likely created areas that are not suited for leafy green production. Although other food plants may be safely grown at these sites, care should be taken to mitigate exposure to the ambient atmosphere. Additional research is required.

These findings indicate that the urban farmers interviewed in the Chapter 2 were correct in their assessment of acceptable growing spaces and their perception that "pristine places simply do not exist anymore". As participants indicated, areas where the air is easy to breathe; where traffic is not heavy; and where the gardening experience is pleasurable; are safer than areas in the industrial or downtown core. Similarly, they were right to assume that consumers would not be avoiding contamination by purchasing imported lettuce – atmospheric pollution is a problem worldwide. The uncharacteristically high zinc and manganese concentrations present in produce grown in Victoria, however, was not predicted. It seems that these high concentrations are localized to Vancouver Island and that further investigations are needed. Nevertheless, with regards to the potential for lead and cadmium contamination of urban grown produce, it can be surmised that urban agriculture occurring in low traffic residential neighbourhoods will ensure the integrity of Victoria's food system will stay intact.

This work could be expanded to generate guidelines regarding safe sites for leafy greens (and other crops) in the City of Victoria. Appropriate zones and best practices for leafy produce can be developed and promoted to minimize the amount of contamination found in produce. Additionally, air quality studies could be conducted to better understand the risk posed by atmospheric contamination to produce.

3.6 Research Limitations

This study provides an estimate of the potential for crop contamination in the Greater Victoria Area. Due to the large scale of exposure and the complex mixture of polluting substances, pollution studies often use observations of intact real-world systems (Eberhardt and Thomas, 1991). Examination of actual communities has demonstrated that no two examples are quite alike – there exist many small but potentially significant differences between similar communities due to chance and inconsistencies in weather, climate and substrate (Eberhardt and Thomas, 1991). Each experiment can only reflect the net results of that specific pollutant regime and the prevailing environmental conditions during the period of the experiment. This study was conducted during the peak pollution period; during a period of no rainfall, and the lettuce was unwashed. Consequently the results are likely not indicative of the contamination risk present in all portions of the growing season (Ashmore et al., 1988; Bell and Marshal, 2000).

Less than ideal conditions for lettuce growth meant that there was not enough dry lettuce tissue to do triplicate analysis of washed and unwashed samples. Washing has been demonstrated to reduce heavy metal concentrations in lettuce tissue, particularly lead (Nabulo et al., 2006; Sharma, 2008; Voutsa et al., 1996). However, comparisons with other studies conducted in Victoria or elsewhere, cannot provide precise estimates of the levels likely to be removed by washing due to the large variation heavy metal levels in harvested produce show from year to year, even at the same location in the field (Voutsa et al., 1996). Further study is needed to examine the effects of washing on the contaminant levels present in Victoria.

3.7 Conclusions

The potential for crop contamination by heavy metals is one of the major health risks associated with urban food production (van Veenhuizen and Danso, 2007; Lee-Smith, 2006; Lock and van Veenhuizen, 2001). Crop contamination poses a barrier to the expansion and acceptance of urban agriculture, preventing urban food production from contributing to urban food security and sustainability. However, the results of this study suggest that all areas are subject to contamination. Although lead and cadmium levels in produce grown in Victoria were well above the FAO/WHO recommended maximum level, the risk was present across all treatments urban and rural and included store-bought commercial lettuce samples.

Nevertheless, growing produce in certain areas should be avoided due to the greater potential for contamination to occur. Areas with high traffic and/or industrial activity should be avoided. As a certain level of atmospheric contamination is pervasive, quiet residential neighbourhoods where found to be comparable to rural areas with regards to heavy metal contamination.

One of the more unexpected outcomes of this research was the discovery of elevated levels of manganese and zinc in produce grown in rural and urban Victoria. The concentrations of those two metals are considerably higher than the concentrations found in produce grown elsewhere in the world. Further research must be done to determine the cause as well as the consequences of these high heavy metal levels.

Atmospheric contamination is an issue for all food systems and strategies to mitigate contamination must include reducing atmospheric exposure. The potential for contamination can be mitigated through site selection, growing crops under cover and taking necessary precautions to shield produce from exposure post-harvest. Best practices for consumers should include thorough washing procedures. Ultimately, however, strategies to reduce heavy metal emissions to the atmosphere must be put in place.

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Chapter Four: Farm cities

4.1 Introduction

With more than 80% of North Americans living in urban areas, cities are now our primary habitat. Most cities require extensive areas of land to sustain their food systems – more often than not cities depend primarily on imports from increasingly distant regions (Deelstra and Giradet, 2005). Food reaches the majority of North Americans through the industrialized, global system of food exports and imports. The province of British Columbia as a whole imports 45% of its food, with 70% of its vegetable imports coming from the United States, about 20% from Mexico, and just under 10% from China (Lee et al., 2010; Ostry, 2010). This dependency on imported food makes cities like Victoria vulnerable should a disruption occur in transportation or supply network. In the event of such a disruption the communities on Vancouver Island, including Victoria, would only have an estimated three-day supply of food (Bouris et al., 2009). Fuel shortages or increases in gas prices would also have an immediate impact on the City's food supply (Kimbrell, 2002; Lee et al., 2010). The challenge for Victoria, as for cities worldwide, is to create its own self-regulating, self-sustaining food system (Deelstra and Giradet, 2005).

One strategy to significantly increase the resilience and self-sufficiency of cities like Victoria is the enhancement of urban food production. This is a cost effective way to augment food security, to address the negative aspects inherent in the present model of industrialized agriculture, and to improve our collective relationships to food production and distribution (van Veenhuizen, 2006). The City of Victoria has recognized the role that urban food production can play in creating a sustainable urban environment, however, there are many barriers that stand in the way of its acceptance and expansion.

One of the key impediments to food production in urban environments is the potential for food contamination. There are also many institutional barriers including, perceived risks associated with agriculture in urban areas, landownership, land availability, logistics and location issues, and the need for more support for urban farmers. In this thesis, I have explored these issues using qualitative and quantitative approaches. Semi-structured interviews, conducted with nine of Victoria's urban farmers and one urban planner were designed to explore the experiences and perceptions of urban food producers and elicit their concerns regarding specific aspects of urban food production. To examine the potential risk of crop contamination, I also conducted a field experiment focused on the potential for heavy metal contamination by atmospheric deposition of leafy greens grown across a rural-to-urban gradient in Victoria. Based on this work, I conclude that the advantages to urban food production – with some caveats around heavy metal contamination – outweigh the disadvantages. This chapter provides a synthesis of major conclusions and considers future directions for urban farming in light of the results of my research.

4.2 Risk of contamination

Food quality is a critical determinant of health, and one of the barriers to developing urban agriculture is the issue of food contamination (Ostry, 2010). Urban areas are seen as pollution hotspots: places where concentrated anthropogenic activities have lead to environmental degradation including contamination of the air, water and soil. For the urban farmers in the City of Victoria, soil contamination was the most pressing concern. The soil-root pathway has often been considered the most important route for contaminants (Harrison and Chirgawi, 1989). As the interviewees in my study mentioned, obtaining an accurate site history is a crucial step towards mitigating the potential for contamination through soil. A number of mitigation strategies, including removing the top 3-5 cm of soil in raised beds and replacing it with compost each year to remove any atmospheric deposition, have been demonstrated to reduce some of the risk (Clark et al., 2008). Additionally, amending the soil can limit metal availability. For example, application of lime increases soil pH and decreases heavy metal availability (Gray et al., 2006). Water contamination was not a great concern in Victoria, because the urban farmers are able to draw from the municipal water supply, which is tested and treated for contaminants. Atmospheric pollution was not considered to be a major concern in the City of Victoria either, largely because the City has comparatively small industrial areas. Vehicular emissions were mentioned as a concern particularly on busy roads or near automotive repair shops. Nevertheless, as discussed in Chapter 3 atmospheric pollution should be understood as a pervasive source of contamination for food crops.

In order to assess the potential impact of atmospheric pollution on leafy greens produced in the City of Victoria, I conducted an observational field experiment in the summer of 2010. Samples of leaf lettuce (*Lactuca sativa* L.) grown in selected sites across an urban-rural gradient were analyzed to quantify the potential for heavy metal contamination as a function of traffic and industrial emissions. The results of this study suggested that the atmospheric pathway is an important route for heavy metals to contaminate leafy greens (see Chapter 3). Leafy greens grown in industrial areas of urban Victoria have significantly greater heavy metal concentrations than in residential or rural Victoria. Leafy greens in residential Victoria contained similar levels of heavy metals (cadmium, zinc and manganese) as produce grown in rural Victoria. Although there are increased lead concentrations in samples from residential sites, it is still almost half the amount found in industrial sites. All areas had lead and cadmium concentrations greater than the recommended safe levels, but in comparison to rural and urban produce grown worldwide (Nabulo et al., 2006; Nali, 2009; Voutsa et al., 1996), urban Victoria presents one of the better growing environments. Anomalous zinc and manganese concentrations were discovered to exist in produce grown on Vancouver Island in comparison to other areas, however manganese concentrations remained below the recommended safe levels and zinc concentrations only exceeded recommendations in the industrial/business areas and residential areas. Additionally, no significant differences were found between all three site types and leaf injury level and sample fresh weight – indicating that urban agriculture can produce market quality lettuce.

This study reinforces the findings of previous studies that demonstrate that produce grown in rural areas can be subject to elevated levels of heavy metals that exceed the safe limits recommended by the Commission of the European Communities (2001), the Food and Agriculture Organization (FAO) and the World Health Organization (WHO), for heavy metals in vegetables and crops (Nali et al., 2009; Voutsa et al., 1996). Although these findings indicate that heavy metal concentrations are elevated in produce grown in the City of Victoria and that some areas are best avoided for greens production, this does not in any way suggest that urban food production, at least of some species, should not continue. First of all, this experiment was conducted at the peak pollution period when the potential for atmospheric deposition of heavy metal particles was greatest, which suggests that contaminant levels may not be as elevated during the rest of the growing season. Secondly, this experiment involved lettuce (*Lactuca sativa*) a leafy green known to have high heavy metal absorption ratios and therefore is not representative of all food plant species. Thirdly, as indicated, atmospheric pollution is a widespread problem and rural areas are not exempt. Viewed in a broader context, the heavy metal levels detected in this study are moderate. Furthermore, studies have demonstrated that atmospheric deposition during marketing and transportation can elevate heavy metal levels in produce, creating a potential health hazard for consumers that may not have existed pre-harvest (Sharma et al., 2008). Therefore, since urban agriculture by its very nature reduces the exposure length post-harvest, it could substantially reduce the potential for contamination of produce that may be present for rural agriculture. Based on the findings of my research, I conclude that with mitigation strategies, urban agriculture can be conducted in Victoria without increasing the risk to of heavy metal contamination faced by consumers.

4.3 Future Directions

Urban food production has been identified as a critical component of efforts to make cities more sustainable. In the City of Victoria, the increasing recognition of the need for food security and sustainability has led to a great interest in local food production (CRD Roundtable on the Environment, 2006). Interview participants were quick to point out that the general public is much more conscious of issues relating to food security and problems with the industrialized food system than they were even ten years ago. More and more people are becoming interested in locally grown produce and learning how to grow their *own* food. Although the City of Victoria has made an effort to support urban agricultural activities, the urban farmers interviewed felt there is still much progress to be made. This section discusses strategies designed to mitigate the potential for contamination, as well as to deal with the principal source of atmospheric pollution – traffic emissions.

4.3.1 Mitigating the level of contaminants in urban grown produce

Site Selection:

The pervasiveness of atmospheric pollution means it is not easily managed by individuals, but there are some measures that can be taken to mitigate its effects. Results from the field study (Chapter 3) confirmed the perceptions of urban farmers (Chapter 2) that some areas of the city are safe for food production, but other areas are not appropriate for this activity.

The results presented in Chapter 3 suggest that site selection for greens production is critical. My experiments showed that produce grown in the downtown core, near heavy traffic and industrial activities had much higher concentrations of heavy metals than produce grown in residential or rural areas. In my interviews urban farmers pointed out that growing food in these heavily trafficked downtown and industrial areas would not be desirable because conditions in these areas are not suitable for gardening. One of the interviewees noted that you wouldn't want to garden where "…it is difficult to breathe and where you wouldn't want your kids to play". Thus, the importance of considering growing conditions from the perspective of the gardening experience should not be dismissed: if gardening in an area is not a pleasurable experience because of traffic noise and air pollution, it is likely that the produce from that site will not be safe. Municipalities would be wise to consider this when selecting locations for community gardens. Although there may be vacant lots of land available, if they are situated near dense traffic, it may jeopardize the health and safety of citizens to grow food there. For example, in Vancouver, the recent 2010 Winter Olympics Legacy Project required the creation of 2010 garden plots by January 2010 (Broadway and Broadway, 2011). This goal was met; but placement of a number of these gardens likely increases the risk of heavy metal contamination. Common sense, it seems, can be used to achieve a fairly accurate assessment of the potential for contamination.

These conclusions are reinforced by studies conducted in other urban areas worldwide. Produce grown in sites close to roadways and heavy traffic have demonstrated higher heavy metal levels than produce grown at distance to these areas (Atayese et al., 2010; Nabulo et a., 2006; Preer et al., 1980). Nabulo et al. (2006) demonstrated that lead concentration in *Amaranthus dubius* leaves decreased with increasing distance from the road edge. Based on their findings they recommend that leafy vegetables should be grown 30 m from roads in high-traffic urban areas (Nabulo et al., 2006).

Other Strategies:

Despite known dangers, the practice of urban agriculture continues in many high risk areas around the world. The lessons learned from the experiences in these areas can provide valuable knowledge of ways to reduce the risk of contaminating food grown in cities like Victoria, where the existing pollution levels are much lower. In 1997, Poland celebrated 100 years of urban allotment agriculture. This is a country plagued by high prices and widespread unemployment – which makes it difficult for people to access the food supply. Local food production has provided a measure of autonomy for the Polish people and an alternative to the conventional system of food production and distribution (Bellows, 1999). However, there are a number of problems associated with urban agriculture in Poland. Silesia, Poland, is located inside the “sulfur triangle” – an area that spans four countries; Poland, the Czech and Slovak Republics, and (the former East) Germany.

The World Health Organization and Polish researchers have demonstrated that 60-80% of heavy metal toxins found in the people living in these densely industrial urban areas are ingested from food. The most severe threat is food contaminated with lead, cadmium and excessive concentrations of nitrogen compounds (Bellows, 1999). Silesian communities have experienced devastating rates of cancers, tumors and respiratory illnesses (Bellows, 1996). Although most local residents acknowledge the dangers of contamination of locally grown food, they remain suspicious of 'safe food', which is imported from outside the area, not least because it is commonly regarded as overpriced. A 1994, a survey demonstrated that most people were aware that locally grown food was not safe, but they continued to grow and consume this food for three major reasons: they 'knew what they were doing'; they distrusted nonlocal food sources and production procedures; and they desired to maintain distance from problems with market cost or supply (Bellows, 1999).

One of the lessons demonstrated by areas like Silesia, and echoed by the results of this research, is that not all urban agricultural practices are sustainable, secure or safe. While urban agriculture can address local issues of capacity building and food security, planners and decision-makers also must consider issues of environmental and human health and the possible complications of site-specific food contamination (Bellows, 1999). In Silesia, the local people attempted to maintain local production and achieve sustainability by implementing practical strategies to minimize or even eliminate the risk of contamination. Faced with the realities that: 1) Silesians would continue to grow food and; 2) soil remediation is ineffective when emissions remain constant, it became clear that alternative strategies had to be implemented (Bellows, 1999). One response to this situation was to select plants for cultivation based on their heavy metal absorption ratios – fruits and seeds absorbing ten times less heavy metals than leaves and roots (Bellows 1999; Bellows et al., 2000). People in Silesia were discouraged from growing plants susceptible to contamination: celery, parsley, leeks, lettuce, spinach, carrots, beets and radishes. Instead, they were encouraged to grow plants that would not absorb as many contaminants: legumes, gourds, onions, garlic, tomatoes and fruit trees and shrubs. Another response was to implement garden practices that reduce the risk of heavy metal contamination. These included: improving soil stability through crop planting and amending soil to reduce wind-born dust (Bellows, 1999; Bellows et al., 2000). Additionally, selective cropping – where highly absorptive plants are cultivated to take up heavy metals, was adopted as a way to provide protective cover and remediate soils. The practice of selective cropping is also known as phytoremediation, and has been used in many other heavily polluted areas to lower the concentration or bioavailability of pollutants in soil, water and air. Certain plants can help mitigate the effects of highly polluted environments in urban and semi-urban areas. Plants used in phytoremediation are able to intercept particulate matter and aerosols on their foliar surface (Upadhyay and Kobayashi, 2007; Kulshreshtha et al., 2009), adsorb or absorb these pollutants and transform or degrade them, acting as a sink for pollutants (Kulshreshtha et al., 2009; Morikawa and Erkin, 2003; Singh and Verma, 2007; Upadhyay and Kobayashi, 2007). The appropriateness of a plant to act as a pollutant sink depends on how quickly it can absorb pollutants from the atmosphere and metabolize or detoxify them at the cellular level (Singh and Verma, 2007). Plant leaves are continuously exposed to the ambient atmosphere and are therefore the primary receptors of particulate pollutants. There are genetically modified plants now commercially available that serve as sinks for air pollutants. These species include *Arabidopsi* (Takahashi et al., 2001), *Pittosporum tobira* (Kondo et al., 2002), and *Raphiolepis umbellate* (Erkin et al., 2003) (Singh and Verma, 2007; Morikawa and Erkin, 2003).

The strategies and techniques developed in highly industrialized and obviously polluted areas like Silesia can be applied to all urban areas to mitigate the risk of air pollution caused by vehicle traffic. Ultimately, however, these are only partial solutions that do not address the fundamental problem. Atmospheric pollution will continue to impact human health unless measures are put in place to prevent emissions of contamination.

4.3.2 Car-free cities

Throughout the interview process, many interviewees mentioned traffic emissions as a potential source for contamination and the benefits of creating car-free areas. One interviewee remarked that if a few of the streets were primarily for pedestrian and bicycle traffic that it could be safe for boulevard gardening, children would be able to play freely and the quality of life in this area would improve. Research has shown that lead contamination of plant leaves is a function of traffic density and distance from roadways (Nabulo et al., 2006). Reducing the number of cars allowed in urban areas or eliminating them altogether from selected areas would lower the potential from contamination of food grown in those areas. Additionally, atmospheric pollution in urban areas represents a major health concern, regardless of the degree to which it contaminates local agriculture. It is estimated that atmospheric particulate matter contributes to between 20 and 200 deaths daily in the large cities of North America (Chakre, 2006). Canadian studies have shown that chronic exposure to traffic-related air pollution may be associated with premature mortality; those living close to major roadways had a mortality rate advancement of 2.5 years and a significant increase in all-cause mortality of 18% (Jerrett et al., 2009). In addition, Dutch researchers have shown that the risk of cardiopulmonary mortality is doubled for subjects living near a major road (Jerrett et al., 2009). These health effects can be attributed to the higher intake fractions of traffic emissions and subsequent dose people receive when they reside near roadways, or to the higher toxicity of traffic pollutants compared with other sources (Jerrett et al., 2009). One of the critical problems is that cities were designed for vehicles. In the 1920s, most American urban planners thought of the automobile as one of the positive forces in society (Bottles, 1987). The modernist design which gave priority to cars and fast movement across the urban landscape continues to dominate 20th century urban planning and has an enormous influence on contemporary cities (Madanipour, 2003). This has not only compromised our ability to grow food but also to *live* in urban areas. Reducing traffic in urban areas will begin to minimize contaminant emissions – providing a much safer environment for both humans and plants. Increasing public transport while narrowing streets and widening sidewalks would be positive first steps towards reducing our vehicle-dependence. With rising fuel prices it is likely that more people will be willing to adjust their lifestyles by reducing vehicle use. Fewer vehicles on the roads mean less contamination in the air; which helps to eliminate one of the major sources of food contamination. It should be noted however, that this is a strategy that can only be effective in cities, because the people spread across rural areas are too dependent on existing transportation networks and the use of motor vehicles to support their lifestyle. Many cities have already established permanent or temporary car-free zones. In Toronto on the last Sunday of every month, from May to October, a busy downtown neighbourhood, Kensington Market, becomes car-free. The roads close and musicians and performers come out to help people reclaim the streets. Although the streets aren't car-free permanently, it has helped change the way people perceive the neighbourhood during the rest of the year (PS Kensington, 2010). Annual car-free days have also become common place in cities around the world. In 2008, the first annual Car-Free Vancouver day was held, where four communities presented their own car-free festivals (Car-Free Vancouver, 2010). New York City has also engaged in similar initiatives. Since 2006, the city has created over 200 miles of bicycle lanes, launched the city's first bus rapid transit route and successfully piloted pedestrian plazas in Times and Herald Squares. Pedestrian plazas have formed as a result of collaboration between non-profit groups, the City, and the Department of Transportation. At select sites, streets are redesigned to become car-free neighbourhood plazas. Currently the site has 35 different sites throughout the city in either completed, planning or construction phases. These sites have increased pedestrian safety, created new public spaces and enabled New Yorkers to re-imagine what their public spaces can look like (City of New York, 2010). During the summer months, the streets of downtown Victoria are packed with tourists and locals. This would be an ideal time to keep the downtown harbour front car-free; reducing the additional emissions associated with tourist season and ensuring a more pedestrian/bicycle friendly environment suited for human habitation.

4.3.3 Creating a livable city

The interview process detailed in Chapter 2 revealed one of the stark truths about urban living; as a space for human habitation, cities are often far from ideal. However, the expansion of agriculture in urban areas can actively work to remake urban areas. As outlined by the interviewees, urban agriculture not only improves food security for urbanites, but it reduces the city's ecological footprint, works to develop greater awareness of the environment, strengthens communities and enhances urban green space. The diverse range of people involved in urban food production helps build inclusive communities, provides employment and increases social interactions (Brow and Carter, 2003; Tidball and Krasny, 2007). Urban food production also works to close the accessibility gap for marginally housed and homeless population, enabling people to purchase healthy, nutritious food in their immediate vicinity. Due to the proximity of services, including accessible and efficient utilities and public transport, as well as having the population density necessary to support inherently more energy-efficient residential structures like apartment buildings, urban living has the potential to be more sustainable than rural living (Hemenway, 2004; Owen 2004). However, throughout the course of this research, I spoke with many urban farmers, permaculturalists, food activists and advocates and gardeners all of which spoke of the attractions of rural life.

Some of the factors encouraging people to make the move to rural areas include the environment, lifestyle and, in some cases, improved employment opportunities (Woods, 2005). Rural life and rural places are considered by many to be more attractive in terms of physical and social quality of the environment; as well as offering greater privacy, leisure potential and familiarity with the area. Rural areas are seen as quieter and calmer, allowing for a slower pace of life in a more pleasant community atmosphere, with less traffic, more nature, and easily accessible outdoor activities (Halfacree, 1994).

In spite of the attractions offered by rural life, the participants in this research have not left the city and probably never will. Undoubtedly there are social and financial constraints as well as personal obstacles that prevent people from packing up and moving to the countryside, but the urban farmers interviewed had other reasons for remaining in the city. They agreed that the small scale and access to resources and markets allows urban farmers to close the loop when farming; giving them independence from fossil fuels. One farmer reasoned that growing organic produce in the city is easier than growing it in rural areas where cross-field contamination can occur from genetically modified seeds and the large scale spraying of pesticides or herbicides. Finally, one of the main reasons why these farmers chose to stay in urban areas was the opportunity to inspire others. The high profile of urban farming enabled the public to see the sustainable initiatives and practices they were using on a daily basis. In rural areas, the only people that would see these same initiatives are those that drive out there. However, as Chapter two explains, there are many barriers currently standing in the way of the realization of these benefits and opportunities that we must work to overcome.

Many of the by-laws in Victoria hamper or prohibit sustainable activities such as urban food production, and the difficulties of land availability and access make rural living very attractive. In the City of Victoria the animal control by-law allows the keeping of poultry, but not farm animals, zoning bylaws restrict the commercial use of greenhouses and nurseries in most residential zones, and the zoning bylaw schedule D "home occupation" permits urban agriculture as a home occupation but limits the number of people involved to two per site and restricts parking and other home occupations on site (Bouris et al., 2009). Additionally, the municipal tax schedule prevents urban farmers from claiming provincial farm status subsequently blocking their access to a lower tax rate (Bouris et al., 2009).

In order that we may capitalize on the advantages of urban agriculture, it is critical that cities acquire the attractive elements of rural life that can be adapted to the urban environment. The increased self-sufficiency that accompanies food production in urban areas and the opportunity for income generation can allow those who want it to have a slower pace of life, even in the city. However, collective action must be taken to break down the barriers that stand in the way of achieving widespread acceptance and expansion of urban agriculture. Municipalities must work with farmers and consumer to understand the benefits and opportunities involved with urban agriculture as well as the risks and barriers and work to minimize and mitigate the latter.

4.3.4 Importance of Understanding Local Context

Strategies for mitigating the potential for contamination and creating livable urban areas cannot be implemented without knowledge of local realities. Many urbanites recognize the need for acquiring knowledge. They want to understand the environment of which they are part. The experience of people living in Silesia emphasizes that urban food production is not just about growing food, it’s about involving people in the process of growing food and drawing on and building their collective knowledge and experience. This conclusion is echoed in the responses of the urban farmers I interviewed in this research (Chapter 2).

Urban sustainability initiatives are dependent on the ecological limits of a specific place and will ultimately be influenced by local culture and attitudes (Rajaram and Das, 2010). As such, it is not something that can be deployed in a standardized version – one size fits all. Involving people in food production cultivates place-based knowledge and the understanding of site specific relationships between the human and the natural necessary for sustainable development (Rajaram and Das, 201).

The pathways for knowledge sharing are often non-existent or inaccessible in North American cities. Encouraging urban food production is one strategy for enhancing the access to and exchange of knowledge. Throughout the course of this research I interacted with many people, from a variety of backgrounds. The process of determining locations for the planter boxes led me to talk to many business owners, residents, and interested bystanders – of whom, a surprising number were quite interested in the results of my research. I found that people were curious about my research and they used it as a gateway to ask many more questions about the urban environment as a growing environment. It was clear from my interviews that most of the gardeners were concerned about the potential for contamination of their produce. However, they also clearly expressed that the benefits of producing food in the urban environment far outweigh the possible risks. Rather than choosing not to grow food in cities, the individuals I talked with sought knowledge that they could use to change local environment in order to mitigate any adverse effects. Therefore, it is critically important to include communities in the development of new knowledge and to enable any knowledge created to pass through appropriate channels in order to reach the greatest number of people. Not only will this enable suitable growing techniques to be utilized to mitigate contamination, but it will contribute to building community capacity towards creating a sustainable, livable cities.

4.4 Conclusion

Urban areas offer a unique opportunity for food production. The urban microclimate offers a warmer and longer growing season than adjacent rural areas (Berry, 1990), and urban food producers are able to take advantage of unique elements of urban environments including, access to resources and labour, and proximity to markets. In return, urban agriculture provides cities with employment and education opportunities, increased food security, diversion of urban waste products, and a means of facilitating social networking (Azapagic et al., 2007, van Veenhuizen and Danso, 2007). As the interviewees and the data from the observational experiment suggested, there are risks involved with the production of food in urban environments, not all agricultural practices are safe in urban areas. However, taken into the greater context of our current food systems, the benefits far outweigh these risks. Furthermore, actions can be taken to mitigate these risks, including strategies to reduce the potential for contamination of foodstuffs.

Urban areas must become sustainable and self-sufficient. Our fundamental relationship to agriculture and food, as well as our common agricultural ancestries, facilitates direct and comprehensible forums and contexts to inform and educate people about ecosystems, ecology and sustainability. This means that urban food production can serve as a vehicle for the development of sustainable communities (Mullinix et al., 2008; Hinrichs, 2000). We know exactly what lies ahead of us – change. We know the earth will not continue to support our current levels of consumption and waste. Living sustainably may very well be the greatest challenge facing modern humankind, and our lives depend on achieving it. Problems of increasing global hunger and poverty, and the continued migration to urban centres, highlight the importance of expanding food production in urban areas (Cole et al., 2008). Enhancing urban food production will undoubtedly contribute to the sustainability of urban areas, but it requires cooperation from individuals, communities and governments. The change we need will require resilience, cooperation, innovation and collective action, as well as a better understanding of the risks and benefits and how to avoid the former and take advantage of the latter. It is my hope that this research has helped to inform both these aspects, and will assist Victoria and other urban centres in Canada move towards a more sustainable future.

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Appendix A:
Site maps of sampling locations and environmental characteristics

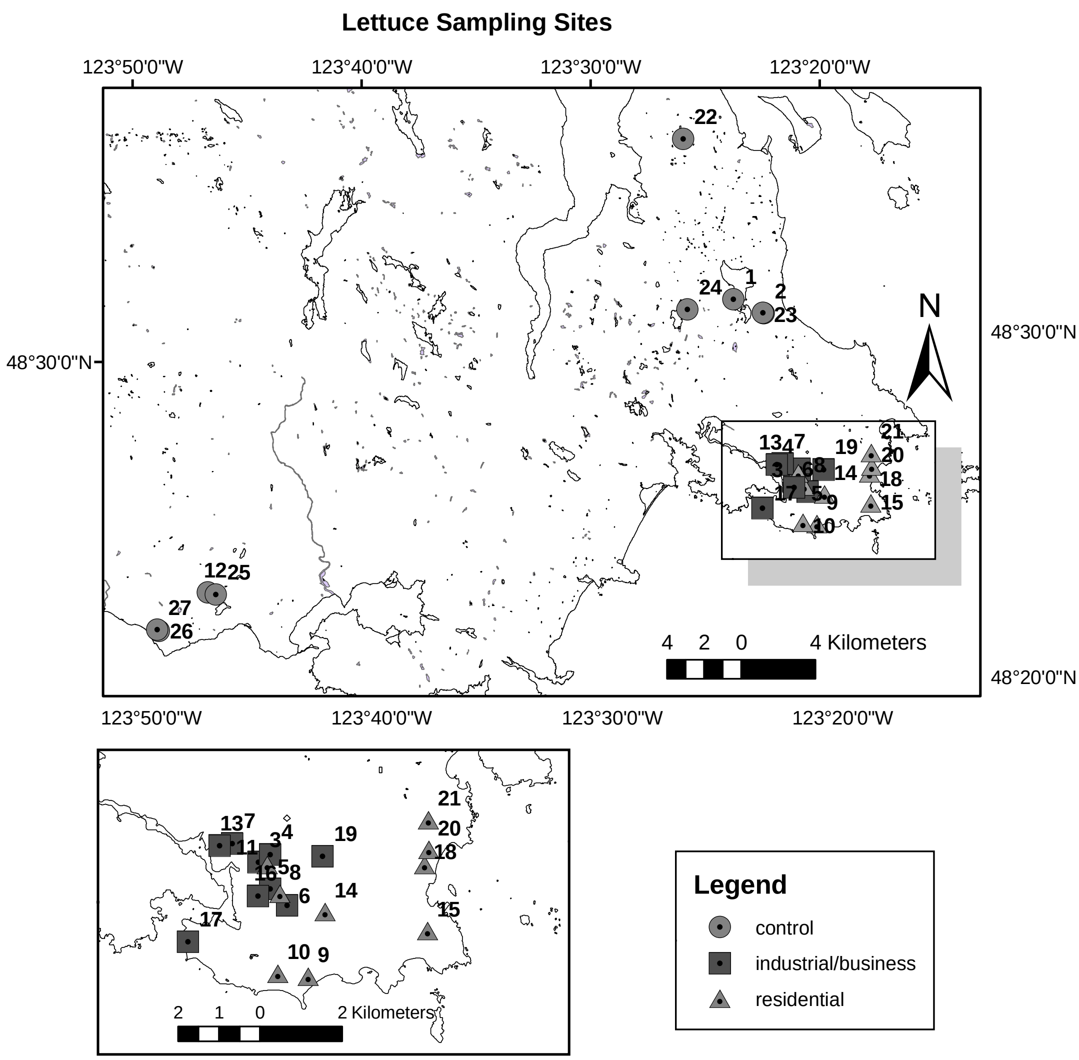

Figure 4: Map of sampling sites for lettuce grown in Greater Victoria

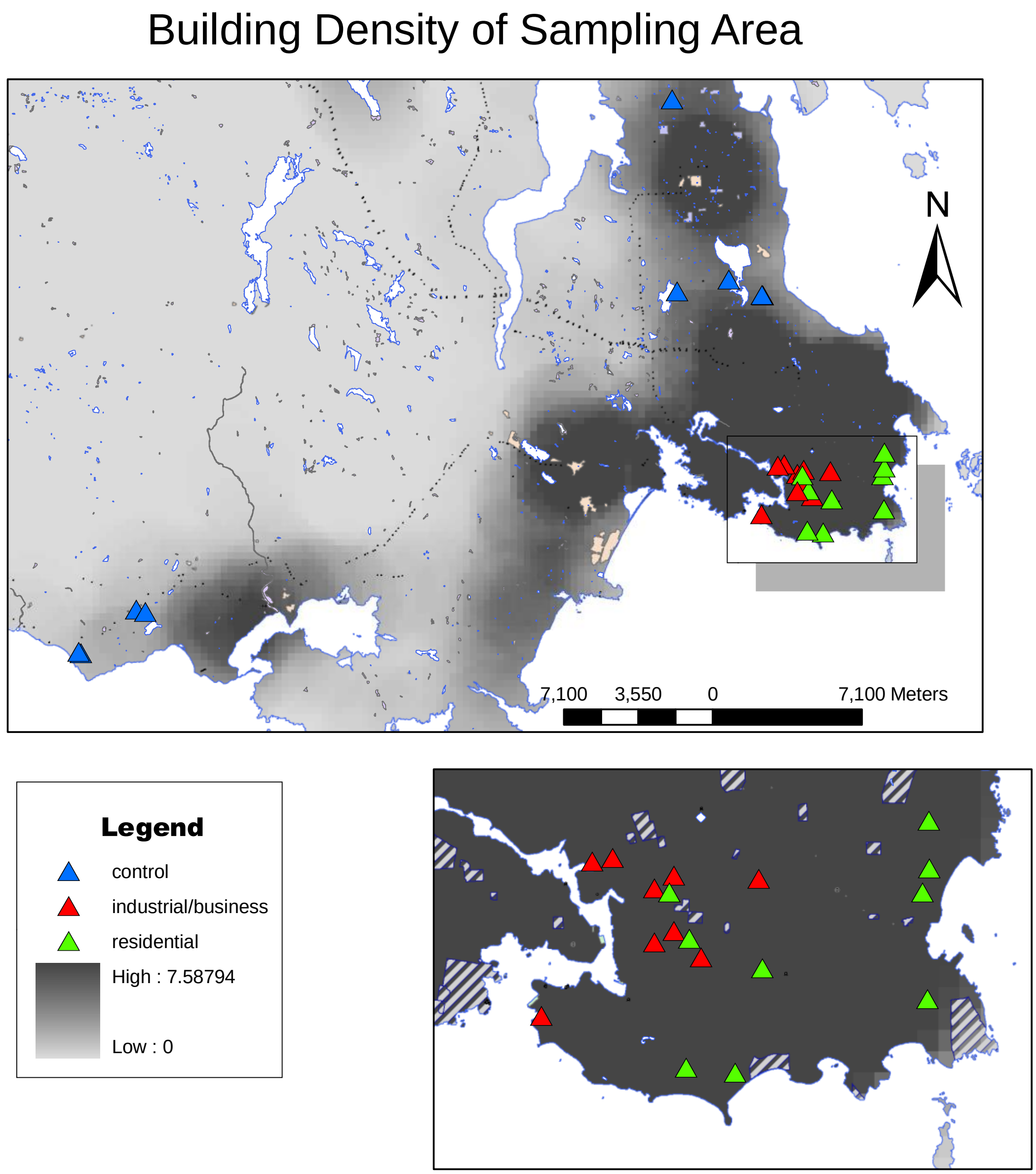

Figure 5: Building density of Greater Victoria.

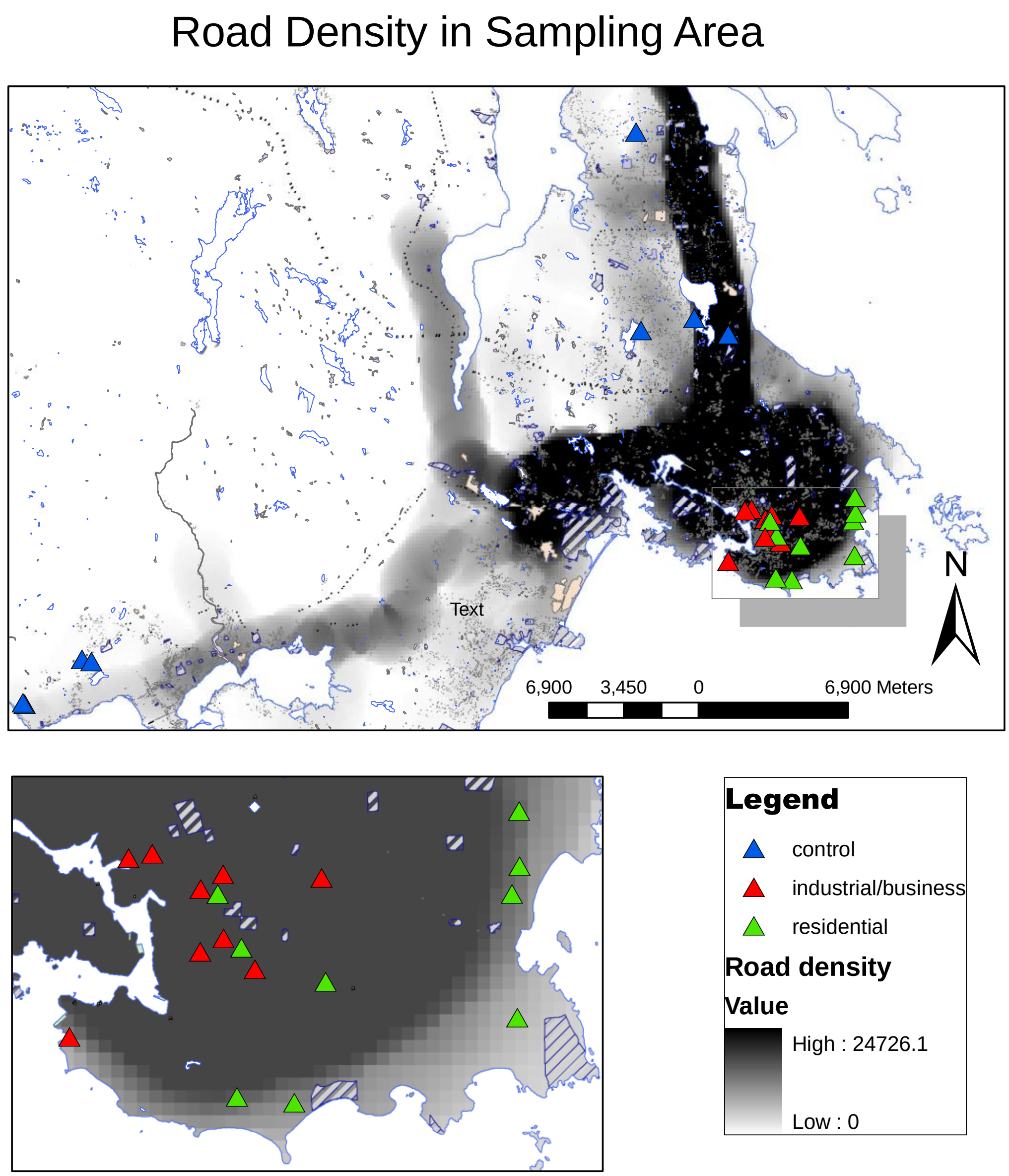

Figure 6: Road density present in Greater Victoria

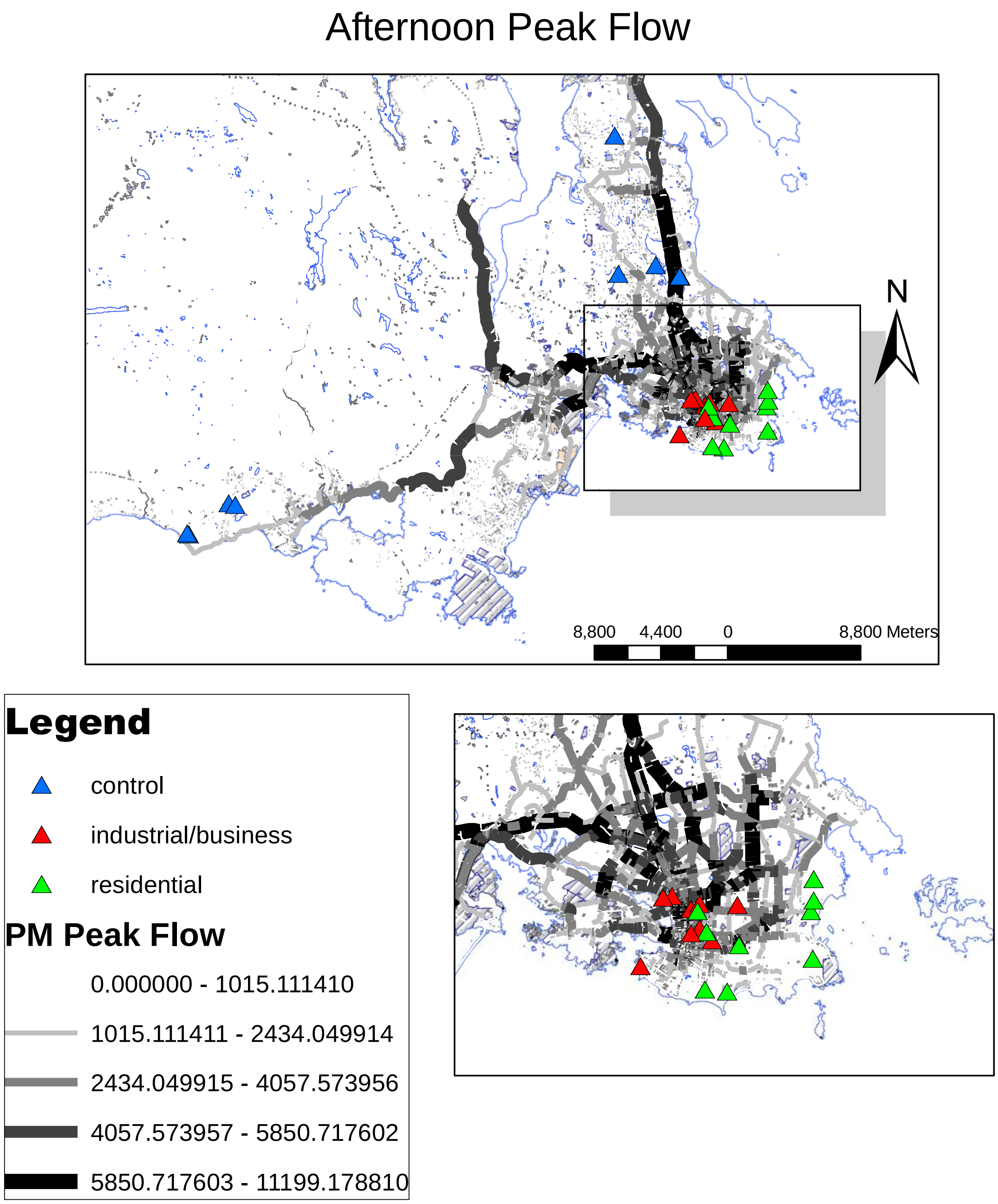

Figure 7: Afternoon peak traffic flow (3-6pm) present in Greater Victoria.

Appendix B:
Tables and figures of heavy metal concentrations in lettuce tissue and soil from each sampling site

Table 12: Metal concentrations by sampling location (mg/kg dry weight) as determined by ICP analysis

Treatment	Site #	Pb	Cd	Mn	Zn
Residential	8	1.45	0.18	157.61	110.33
Residential	10	1.82	0.20	154.56	119.57
Residential	9	1.95	0.25	148.03	97.55
Residential	15	0.82	0.24	146.23	126.76
Residential	18	1.51	0.27	138.50	129.73
Residential	21	1.32	0.21	154.53	103.45
Residential	20	0.83	0.37	140.51	108.50
Residential	14	1.06	0.26	150.29	112.11
Residential	11	1.86	0.32	178.41	141.54
Industrial/business	7	2.97	0.33	221.85	146.54
Industrial/business	13	7.45	0.42	223.96	165.05
Industrial/business	17	1.84	1.49	168.22	140.83
Industrial/business	5	2.91	0.30	215.19	148.04
Industrial/business	3	1.82	0.35	182.67	149.31
Industrial/business	4	2.17	0.30	166.77	113.60
Industrial/business	6	4.63	0.32	170.57	124.29
Industrial/business	16	1.47	0.36	170.01	152.47
Industrial/business	19	2.05	0.36	170.89	140.34
Control	23	1.35	0.26	142.15	94.25
Control	2	0.71	0.27	121.06	98.22
Control	26	1.16	0.40	161.77	130.29
Control	27	1.00	0.30	140.88	120.04
Control	25	0.98	0.29	166.52	102.08
Control	12	0.83	0.37	156.38	109.46
Control	1	0.56	0.29	134.06	100.34
Control	22	0.79	0.29	117.66	91.12
Control	24	0.61	0.31	114.44	100.86
Store	N/A	0.87	4.52	34.21	14.42
Store	N/A	0.54	5.32	75.95	14.83
Store	N/A	1.00	0.21	58.01	35.34
Store	N/A	1.01	3.71	60.98	26.32
Store	N/A	2.36	12.82	262.61	191.66
Store	N/A	0.64	0.70	71.27	28.04
Store	N/A	0.93	0.84	69.26	65.00
Store	N/A	0.52	0.64	18.43	47.39
Store	N/A	0.61	14.64	37.70	30.87

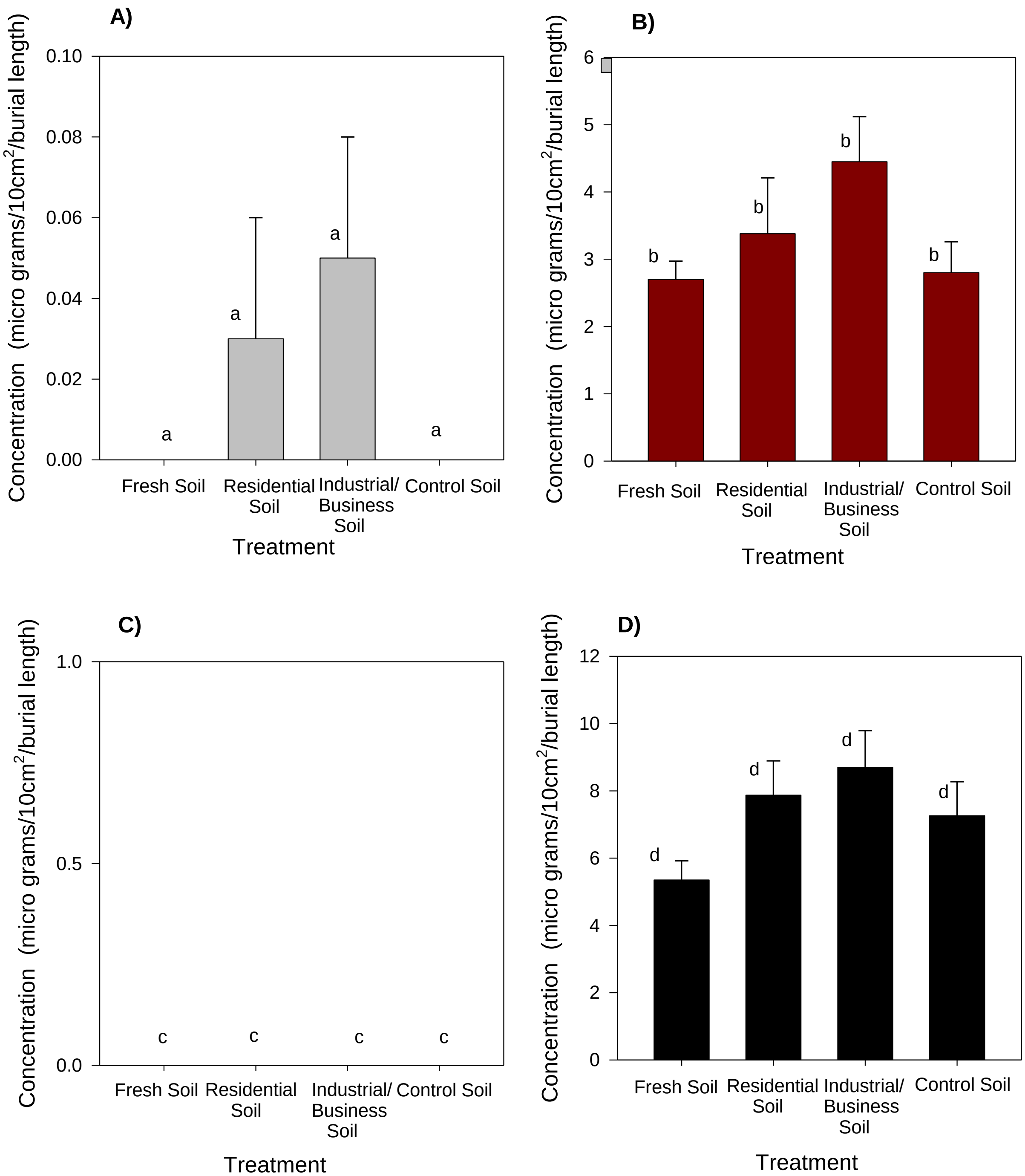

Figure 8: Heavy metal concentrations in soil as determined by Plant Root Simulator ™ probes. A) Lead; B) Zinc; C) Cadmium; and D) Manganese. Means with different letters are significantly different ($p<0.05$)