ECOSYSTEM FUNCTIONS AND PLANT COMMUNITY STRUCTURE OF URBAN SPONTANEOUS VEGETATION

by

Sarah L. Robinson

Submitted in partial fulfillment of the requirements
for the degree of Master of Science.

at

Dalhousie University
Halifax, Nova Scotia
December 2009

DALHOUSIE UNIVERSITY

Department of Biology

The undersigned hereby certify that they have read and recommend to the Faculty of Graduate Studies for acceptance a thesis entitled "ECOSYSTEM FUNCTIONS AND PLANT COMMUNITY STRUCTURE OF URBAN SPONTANEOUS VEGETATION" by Sarah L. Robinson in partial fulfillment of the requirements for the degree of Master of Science

Dated: December 11, 2009

Supervisor: ______________________________

Readers: ______________________________

____

____

Departmental Representative: ______________________________

DALHOUSIE UNIVERSITY

DATE: December 11, 2009

AUTHOR: Sarah L. Robinson

TITLE: ECOSYSTEM FUNCTIONS AND PLANT COMMUNITY STRUCTURE OF URBAN SPONTANEOUS VEGETATION

DEPARTMENT OR SCHOOL: Department of Biology

DEGREE: MSc CONVOCATION: May YEAR: 2011

Permission is herewith granted to Dalhousie University to circulate and to have copied for non-commercial purposes, at its discretion, the above title upon the request of individuals or institutions. I understand that my thesis will be electronically available to the public.

The author reserves other publication rights, and neither the thesis nor extensive extracts from it may be printed or otherwise reproduced without the author's written permission.

The author attests that permission has been obtained for the use of any copyrighted material appearing in the thesis (other than the brief excerpts requiring only proper acknowledgement in scholarly writing), and that all such use is clearly acknowledged.

Signature of Author

TABLE OF CONTENTS

LIST OF TABLES

Chapter 2:

Chapter 3:

LIST OF FIGURES

Chapter 2 (located at the end of chapter 2):

ABSTRACT

This thesis set out to investigate the processes that determine the richness and composition of plant communities of spontaneously colonized derelict land in Metro Halifax, Nova Scotia. As urbanization rates continue to rise urban spontaneous vegetation (USV) communities are becoming more common. While typically considered to have no or negative economic value, USV contributes to a variety of ecosystem services not captured in current urban ecosystem models. Vascular plant composition and aboitic conditions of three urban communities (USV, forest and lawn) are described in Chapter 2. USV is diverse and unique, but the abiotic variables measured were not strong predictors of plant diversity. In Chapter 3, ecosystem services provided by the three urban habitats were quantified and compared, showing USV provides several ecosystem services that complement other urban habitats. Studies of urban biodiversity aid in the understanding of the effects of urbanization on biota and serve as a foundation for encouraging diverse communities of organisms within cities. Factors influencing the distribution and composition of USV communities could be vital for preserving native species by incorporating such knowledge into planning and urban development systems. USV should be considered an asset to urban greening initiatives, providing a low-cost, low maintenance approach to landscape planning, while providing a number of ecosystem benefits not provided by traditional elements of landscape design.

LIST OF ABBREVIATIONS AND SYMBOLS USED

AC CDC - Atlantic Canada Conservation Data Centre
AGS - Atlantic Geoscience Society
AIC - Akaike information criterion
ANOVA - Analysis of variance
CBCN - Canadian Botanical Conservation Network
CBIN - Canadian Biodiversity Information Network
CEC - Cation exchange capacity
COEC - Council Officers Executive Committee
HRM - Halifax Regional Municipality
IPCC - Intergovernmental Panel on Climate Change
LAI - Leaf area index
NDMS - Nonmetric-multidimensional scaling
PCA - Principal component analysis
PCs - Principal components
PI - Point intercept
USCB - United States Census Bureau
USDA - United States Department of Agriculture
UNEP - United Nations Environment Programme
US NPS - United States National Park Service
USV - Urban spontaneous vegetation
VOCs - Volatile organic compounds
WCA - Weed Control Act

ACKNOWLEDGEMENT

I am heartily thankful to my supervisor, Jeremy Lundholm, whose encouragement, guidance, patience and support from the initial to the final level enabled me to develop an understanding of the subject.

Lastly, I offer my regards and blessings to all of those who supported me in any respect during the completion of the project, especially those who assisted my fieldwork or tolerated insect sampling in their lawns.

CHAPTER 1 - INTRODUCTION

1.1 URBAN SPONTANEOUS VEGETATION: SPECIES DIVERSITY, COMMUNITY STRUCTURE AND ECOSYSTEM FUNCTIONING

1.1.1 URBANIZATION AND URBAN ENVIRONMENTS

The world's population is becoming increasingly urban. In 2008, the global urban population equaled the global rural population for the first time in history (United Nations 2007). In Canada and other developed nations, urbanization rates are currently around 80% and continuing to rise. Over the next four decades, cities are expected to absorb all of the world's projected population growth as well as a proportion of the global rural population growth (United Nations 2007). The rise in the size of cities results in greater areas of land being altered by human activities. Built-up or urban area accounts for two to three percent of land area globally, but human infrastructure impacts close to 50% (UNEP 2002). In Canada, cities and towns make up approximately 0.2% of total land area (CBIN 2005) and in the United States over 5% of the land is urbanized (USCB 2001).

Urban areas are highly modified and environmental conditions are often vastly different from the surrounding countryside (McDonnell and Pickett 1990, Vitousek *et al*. 1997). Cities are characterized by a range of constructed and paved elements, serving housing, business, industry, recreation and transportation needs. Urban development (and other human activity) influences local and global ecological processes, causing shifts in biogeochemical cycles, reducing biodiversity and altering drainage and watercourses (Vitousek *et al.* 1997). Built structures, paved surfaces and other urban landscape modifications are a major threat to global biodiversity (McKinney 2002). Natural habitats are removed and replaced with impermeable surfaces like roads, parking lots and buildings. The substitute of vegetation with dark impermeable surfaces produces an urban heat island effect, where air temperatures increase by several degrees compared to the surrounding countryside. The dark surfaces have lower albedo (surface reflectivity of solar radiation) and higher heat capacity than surrounding natural areas, causing more heat to be absorbed and stored. Impermeability and lack of vegetation also limits evaporation and transpiration that usually function to cool the air. Additionally, vehicles, factories, and domestic heating and cooling units give off heat further enhancing the urban heat island effect.

Pollution is ubiquitous in urban centers. Elevated concentrations of noxious contaminants (CO_2, NO_X, SO_2, O_3, VOCs) and particulate matter associated with human activities are common above urban areas. These pollutants coupled with higher air temperatures in cities accelerate the formation of smog (Akbari *et al.* 2001). Excessive summer temperatures coupled with reduced air quality has severe health implications for urban inhabitants (Heath Canada 2006). Other climate parameters are also altered by urban conditions including wind speed, humidity, cloud cover and ultraviolet radiation (Hu *et al.* 1995). In addition, local precipitation can be increased in cities (by 5-10%) due to more particles (dust) in the air for condensation (Botkin and Keller 1995).

Hydrology is often highly modified by development causing water management problems in cities (Paul and Meyer 2001). Paved surfaces and building surfaces prevent water infiltration to the ground below and most precipitation is diverted directly to storm-sewer systems. Urban runoff increases flooding risks and often transports urban pollution, which can cause problems downstream. Soils and substrates not covered by impermeable surfaces are often highly compacted, which can reduce infiltration of water (Pitt *et al.* 2001) and lowers the capacity to support vegetation and soil microorganisms.

Urban soils commonly have very complex compositions because materials often originate from various natural and synthetic sources. In addition, pollutants from industry (i.e. acid deposition) and municipal waste (i.e. de-icing salt, motor oil and heavy metals) are commonly present in urban soils. These disturbances affect urban soil quality by disrupting natural pedogenic processes, changing the rate and extent of soil development (Effland and Pouyat 1997). Some of the pollutants mentioned above may also be persistent and have long-term consequences for ecosystem health (Edwards 2002).

Despite the harsh environmental conditions in urban centers, urban biodiversity is often quite high (Gilbert 1989, Sukopp *et al*. 1979, Balmford *et al*. 2001, Araujo 2003, Hope *et al*. 2003, Kuhn *et al*. 2004). Studying the biodiversity and diverse communities of cities can help to understand the effects of urbanization and serve as a foundation for encouraging diverse communities of organisms to enhance quality of life for city inhabitants. Such knowledge could be incorporated into planning and urban development schemes to increase sustainability on local and global levels.

1.1.2 HISTORY OF URBAN ECOLOGY AND THE STUDY OF URBAN SPONTANEOUS VEGETATION

Academic interest in the flora of urban areas dates back to the early 1800s (see, Lund 1974) although the flora associated with walls, castles and ruins have been documented in Europe for centuries (Sukopp 2008). The study of cities as ecosystems, however, is a relatively new pursuit in ecology dating to the early 1970s (see Stearns 1970, Sukopp 2008). Presently, urban ecological studies are becoming more common especially in Europe and several summaries of urban ecological communities have been produced; in the UK (Gilbert 1989) and Germany (Sukopp 2008), see Sukopp 2008 for a more comprehensive review of historical urban ecology. In North America, ecologists seem more reluctant to study urban environments, instead evaluating urban ecosystem characteristics in relation to urban-to-rural gradients (see, McDonnell *et al.* 1997). The research has typically focused on remnant natural areas in cities rather than uniquely urban plant communities (Hope *et al.* 2003). Despite this, interest in urban ecology in North America has gained some interest due to collaborations between the natural and social sciences (Grimm *et al.* 2008). Locally, characteristics of urban vegetation in the Halifax area have been investigated, including forests (Freedman *et al.* 1996; Turner *et al.* 2005) and spontaneous vegetation (Lundholm and Marlin 2006).

Knowledge of urban flora and fauna is crucial in understanding how urban ecosystems interact with other systems and may help understand and enhance ecosystem functioning in cities. Both natural and semi-natural ecosystems (like those found in cities) perform vital regulation, habitat and production functions such as climate regulation, biomass production, nutrient recycling, and habitat provision, supplying clean drinking water, food, and waste decomposition services (de Groot *et al.* 2002). Although ecosystem functioning may be altered in cities due to the overall lack of vegetation, the presence of pollutants and other human-induced stressors, green patches within the city landscape can provide beneficial ecosystem services. Traditional landscape features like parks and gardens reduce urban energy use, decrease pollution, and enhance biodiversity and habitat functioning (Pickett *et al*. 2001, Thompson *et al*. 2003, and Gaston *et al*. 2005). Other vegetated areas within cities can contribute positively to urban living, such as planted areas along transportation right-of-ways and community gardens. Ecosystem functioning and services of other vegetated urban landscape elements have been studied including remnant natural areas (Freedman *et al*. 1996), urban forests (McDonnell *et al*. 1997, McPherson *et al*. 1997), residential areas (Turner et al. 2005), riparian zones (Paul and Meyer 2001) and lawns (Falk 1979, Broll and Keplin 1995).

Increasing interest in wasteland, brownfield, and other uncultivated vegetation is emerging in urban ecology. Many derelict, underused and abandoned spaces support vegetation that can be classified as ‘spontaneous’ - plant propagules that colonize naturally without cultivation. These patches of urban spontaneous vegetation (USV) has also been referred to as ‘urban commons’ or ‘urban wastelands’ (Gilbert 1989), and ruderal vegetation (McKinney 2002). A variety of spontaneously colonized habitats (vacant lots, abandoned industrial areas, edges of parking lots, along rail lines, highways and other right-of-ways) frequently support a surprisingly high diversity of plant and animal species. In Europe, many USV habitats have been given considerable attention, including refuse tips (Darlington 1969), railway sites (Jehlík 1986 in: Sukopp 2008), road verges (Klimes 1987), wasteland (Sukopp *et al*. 1979), and old town centers (Brandes 1995) among others.

While USV is typically considered to have no or negative economic value, increasing research is providing insight into a variety of ecosystem services not captured in current urban ecosystem models (especially in North America). For example, brownfield land in Britain supports an estimated 12–15% of nationally scarce and rare invertebrates (Small *et al.* 2004). Findings like this stress the need to study areas of spontaneous vegetation colonization in and around cities.

1.1.3 RESEARCH OBJECTIVES

Understanding of the breadth of flora of cities and the associated ecosystem services provided by USV habitats will be important in the future planning and management of human-dominated urban ecosystems. Uncovering the factors that allow USV to survive (and thrive) in built environments will benefit urban ecological systems by improving our understanding of an increasingly dominant yet under-studied landscape feature. This type of research may have implications for public environmental policy, urban planning including green roofs, pollution reduction programs, nature conservation, and plant invasion ecology.

This study focuses on USV habitats in Metro Halifax, Nova Scotia and is divided into two themes (chapters): one describing spontaneous vegetation community composition and one examining the ecosystem functioning and services of USV habitats. The role of spontaneous vegetation in the urban landscape is investigated by addressing the following questions:

Chapter 2:

1. What is the species composition of USV in Metro Halifax? How do communities differ among site types (forest, lawn, USV)? Within urban spontaneous vegetation, how variable are the communities?
2. What abiotic variables influence USV species compositions?
3. Which abiotic variables influence selected plant species diversity?

Chapter 3:

1. How do urban habitats vary in levels of ecosystem functions?
2. What abiotic variables are associated/correlated with which ecosystem functions?

CHAPTER 2 - PLANT COMMUNITY COMPOSITION, SPECIES RICHNESS AND CORRELATES OF DIVERSITY IN THREE URBAN HABITATS

2.1 INTRODUCTION

2.1.1 BIODIVERSITY IN CITIES

Every city develops a distinctive assemblage of plant species, reflecting its unique climate, soil and anthropogenic conditions (Gilbert 1992). Both planted and spontaneously occurring species contribute to the urban flora, which can often be surprisingly diverse. Clemants and Moore (2003) recorded a total of 4,159 species in an extensive floral survey of eight cities in the northeastern United States, while roughly 3,000 species have been documented the New York metropolitan alone (Moore *et al*. 2002). Urban areas typically, support higher species richness than the surrounding landscape (Gilbert 1989, Sukopp *et al*. 1979, Balmford *et al*. 2001, Araujo 2003, Hope *et al*. 2003, Kuhn *et al*. 2004) and larger cities often contain more species than smaller cities (Pysek 1995, Kendle and Forbes 1997). Greater species richness in cities can be attributed to the high rate of deliberate or accidental importation of species (introduced and native) as well as the relatively higher number of habitat types available in urban spaces compared to an equivalent area of non-urbanized land (Gilbert 1989, Kendle and Forbes 1997). Gilbert (1989) uses Grime's (1979) C-R-S plant strategy model to illustrate the wealth of habitat types frequently found in cities. The diversity in urban habitats accommodates almost the entire range of possible plant strategies in the model. Local climatic conditions and human settlement preferences also explain the higher species diversity observed in cities. Increased urban temperatures can facilitate the establishment of species normally limited by cold temperatures (Sukopp *et al*. 1979) and many cities are situated in geologically diverse landscapes that are naturally species rich (Kuhn *et al*. 2004).

Vegetation in urban areas is generally classified into three main types: encapsulated countryside, deliberately planted, and spontaneous flora (Gilbert 1989; Kendle and Forbes 1997). Encapsulated countryside comprises fragments of semi-natural vegetation, including forest land and marshes to lakes, ponds, and river corridors. These remnant natural areas are (for various reasons) left unaltered by urban development and are integrated into the urban matrix, but are not necessarily urban in form or function. The second type of urban vegetation is deliberately planted in spaces such as gardens, parks, and along road corridors. These areas, for the most part, require maintenance and inputs including mowing, trimming of shrubs and trees, weeding, removing dead material and application of fertilizer. The third type, spontaneous vegetation, colonizes the remainder of urban spaces, in derelict or disused land of vacant lots, industrial areas or other areas where bare substrate is available including railway corridors and alongside highways.

Often the most diverse of urban habitats are the spontaneously developed communities in wastelands and other previously developed areas (Gilbert 1989, Goode *et al*. 1995). These areas of urban spontaneous vegetation (USV) can be important contributors to urban biodiversity often supporting high numbers of higher trophic-level organisms (Gilbert 1989). Areas of unmanaged vegetation can act as refugia, and provide diverse foraging and habitat opportunities to support species that may not otherwise be present in urban areas. In a study of various urban habitats, Goode *et al*. (1995) found that wasteland areas had among the highest diversity of vascular plants, butterflies, grasshoppers, snails and woodlice.

Large numbers of plants and animals are introduced to urban areas each year, some of which find suitable habitat and become established, integrating with the urban flora. Horticultural specimens are an important source of new species establishments because they are selected for their tolerance of urban conditions or suitability to the local climate (Gilbert 1989). Many species of ornamentals, lawn grasses, and planted street trees have escaped cultivation and produced viable populations within urban communities. Industrial areas and rail yards are particularly important points of introduction for new species (Gilbert 1989).

2.1.2 NATIVE AND NON-NATIVE SPECIES COMPOSITION IN URBAN AREAS

Despite the opportunities for alien species introduction, native species usually account for the greatest proportion of an urban flora. Of the 4,159 plant species recorded in the study by Clemants and Moore (2003), 65.1% were considered native to one or more of the eight urban areas surveyed. In Berlin, Germany, 59% of the total urban flora is made up of native species and 82% of the most commonly occurring species are native (Kowarik 2008). In fact, the proportion of alien species in urban areas in central Europe seems to reach a limit of 50% even in the most industrialized cities (Sukopp *et al*. 1979, Gilbert 1989, Kowarik 2008).

Generally, urban areas tend to share similar vegetation distribution patterns. Many studies have found that the number and proportion of non-native species tends to increase towards the urban core (Sukopp *et al*. 1979, Whitney 1985, Kowarik 1995, McDonnell *et al*. 1997). In other words, native species are more prominent in the outer suburbs and decrease toward the central highly built-up areas of a city. This pattern reflects the increased non-native propagule pressure and disturbance regime towards the urban core (McKinney 2002). In residential areas, neighborhood age can influence the proportion of native species. Turner et al. (2005) found that 14% of plant species in an urban residential area in Halifax were native, while an adjacent semi-natural area supported 83% native species.

2.1.3 FACTORS INFLUENCING COMPOSITION AND RICHNESS OF USV SITES

A variety of factors unique to each site would influence the community composition of USV. Many initial colonizers of USV habitats are wind dispersed annuals and biennials and generally, these initial colonizers of disturbed urban sites usually reach their peak densities during the first ten years of site colonization (Gilbert 1989). If sites are left undisturbed, competition from native grasses can be strong enough to replace the bulk of the non-native species, but succession is often not predictable and can be subject to chance and irregular events (Gilbert 1989; Sukopp 2008). If frequently disturbed, USV communities can be stuck in a perpetually immature state. The range of conditions and disturbance frequencies at USV sites makes them interesting ecologically because community composition of similar aged sites within the same city may be very different. Proximity to potential seed sources, species dispersal, and other inoculation pressures will determine which species will reach and eventually establish in USV communities. Some species may be only locally abundant. Such species may be 'incidentals', typically arriving in areas of continual seed introduction like those frequented by car and rail transportation corridors. Some incidentals are able to grow but not set seed and self-disperse, thus not becoming permanent members of the urban flora. Up to 48% of the rarest species in the flora of Berlin are introduced species (Kowarik 2008), suggesting a significant proportion of the species richness in a city may be represented by incidental occurrences.

Abiotic factors such as local soil (or substrate) conditions (including nutrient availability, pH, moisture, depth and temperature) may be strong determinants of USV vegetation community composition. Urban soils frequently suffer from drainage problems, drought, nitrogen and macronutrient deficiencies or excess, as well as possible heavy metal or salt contamination or materials that cause extremes in pH (Bradshaw *et al*. 1995). Substrate conditions influence overall soil health, restricting habitat suitability for some plant species and therefore driving USV community composition. Soil pH can have influence on vascular species richness at a small scales ($1m^2$) in shallow soil. Native plant communities (Gough et al 2001) and high concentrations of heavy metals found in park soils have been shown to negatively affect soil micro-flora (Papa *et al.* 2010), which may limit growth and establishment of some plant species. Elevated levels of trace minerals such as copper, lead and zinc of urban soils influence plant composition in urban areas (Gilbert 1982). Soil depth and nutrient content are also known to significantly affect species richness and Shannon diversity at small (plot) scales (Stark and Redente 1985).

The variable and, at times, harsh environmental conditions present in urban situations provide habitat for plants that possess a certain suite of adaptations that likely vary from site to site and city to city. How soil conditions and other abiotic variables influence plant species diversity in urban habitats could help inform urban planners and others how to increase diversity of desirable vegetation in cities.

2.1.4 CHAPTER OBJECTIVES

Clearly, the diversity of plant life in urban habitats is noteworthy and the conditions that influence vegetation distribution patterns warrant further investigation. Descriptions of USV habitats are lacking in Canada and this study aims to address this deficiency. I describe USV habitats sampled and compare the species composition and diversity with other urban habitats (remnant natural forest and lawn). This study also attempts to explore drivers of species diversity and community variability at spontaneously developed sites. Site age, disturbance regimes and inoculation pressure certainly influence the distribution and composition of these communities, but abiotic gradients, including substrate conditions (substrate depth, moisture, pH and nutrient availability) are much easier to qualify. I hypothesized that vascular plant species richness (R), Shannon index (H') and native species richness (N) in urban sites would be correlated with soil depth, soil pH, soil moisture, and nutrient composition variables.

In brief, this chapter specifically addresses the following questions:

1. What is the species composition of USV in Metro Halifax? How do communities differ among site types (forest, lawn, USV)? Within urban spontaneous vegetation, how variable are the communities?
2. What abiotic variables influence USV species compositions?
3. Which abiotic variables influence selected plant species diversity (R, H', N)?

2.2 METHODS

2.2.1 OVERVIEW OF THE REGION: STUDY AREA – HALIFAX, NOVA SCOTIA

Halifax Regional Municipality (HRM) is the capital of the province of Nova Scotia. The urban area of HRM (Metro Halifax), which includes the former cities of Halifax and Dartmouth, has a population of over 280 000 and it has the highest population density in Atlantic Canada (Statistics Canada 2008). The study area encompasses the Halifax peninsula and mainland area of metro Halifax and adjacent Dartmouth within Highway 111 (see map in appendix A). Halifax lies on the southwest side of Halifax Harbor, while Dartmouth is located opposite on the northeast side.

The Town of Halifax founded in 1749 and Dartmouth founded in 1750 were of great strategic and economic importance mainly due to Halifax Harbor, a large natural harbor, making the area an important port and naval base along the Atlantic coast. Metro Halifax is an important place for the study of exotic urban plants because it represents a 'ground zero' for introductions via our port and the terminus of a cross-continental rail line. Today, 11 of the world's 15 top container lines (serving over 150 countries) use Halifax's port facility (Port of Halifax 2009).

The original natural vegetation of the region is Acadian forest, which occurs within ecoclimatic zones considered cool temperate boreal (Weber and Flannigan 1997). The underlying geology consists of pyritic slate, schist, and migmatite rock types (AGS 1994) with podzolic, brown shaley loam soils (MacDougall and Cann 1963).

2.2.2 SITE SELECTION

Examples of the following vegetation types were identified in 2007: (1) spontaneous vegetation, (2) lawns, and (3) remnant natural areas (forests). Sites were located by identifying possible areas using street maps and aerial photos (Google Earth) then chosen by ground surveys based on established criteria. Criteria for suitable urban spontaneous sites were as follows: candidate sites had all original (natural) vegetation removed, with spontaneous colonization of vegetation and not actively maintained (to my knowledge). Eligible sites were at least 10m x 10m with greater than 20% vegetation cover but less than 10% tree cover. Sampling sites were chosen from a list of eligible sites based on ease of access (i.e. not fenced in or in areas with “No Trespassing” signs) and safety (i.e. no areas suspected to be polluted or with hazardous debris).

For urban lawns, sites were at least 5m x 5m with greater than 90% vegetation cover and less than 10% by trees. Eligible lawns were actively maintained by mowing and have no ornamental shrubs or ground covers within the minimum size criteria. Urban forest sites were at minimum 10m x 10m with at least 80% tree cover and not actively maintained. Forests and lawns were also chosen as close to the USV sites as possible.

Twelve urban spontaneous sites and five of each forest and lawn were established during the 2007 sampling season. However, one of the sites was lost to construction shortly after summer 2007; therefore, only eleven urban spontaneous sites are included in the analyses (see appendix B for aerial photos of each site). Sidewalks and pavements adjacent to urban spontaneous sites were sampled as controls for some of the variables measured.

2.2.3 SAMPLING DESIGN

The flora of the eleven urban spontaneous sites was documented during the summer of 2007, by recording the plant species and cover in twelve 1 m^2 quadrats per site. Five quadrats in each forest and lawn sites were sampled. This quadrat size was chosen because it is considered optimal for non-treed vegetation (Krebs 1999). Quadrats were positioned using coordinates produced by a random number generator. The northeast corner was established at this point and the plot was oriented along a north-south axis. Plots were marked with flags, flagging tape and each corner was marked with orange marking paint. For ease in finding plots for the second field season via metal detector, each corner was marked by burying a metal washer just under the soil surface.

2.2.4 VEGETATION SAMPLING

The point-intersect (PI) method was used to estimate cover of species within the quadrats (Krebs 1999). Each 1 m^2 plot was divided into sixteen 25 cm x 25 cm subplots. Quadrat frames were constructed with one-inch PVC pipe. A thin metal rod (1 mm diameter) was inserted at the intersection of a subplot within the quadrat, and all plant species contacted by the rod were recorded. Plant species were recorded only once. Point-intersect counts were used to generate plot-level summaries of total species richness, native species richness, total species abundance and native species abundance. In addition, if a species was present in the plot but not intersected by the rod it was recorded and included the total plot species richness and given a value (0.25) when intersect counts were tallied. Non-native species determinations were made using species ranking data from the Atlantic Canada Conservation Data Center (AC CDC 2006). Species are ranked from S1 “rare” to S5 “common” and non-native species are given a SE rank.

Site-level vegetation data (for USV sites only) were generated by tallying species richness and summing PI counts for abundance and native species. In addition, surveys were made outside the plots at each urban spontaneous site and new species encounters were added to site-level species richness counts.

2.2.5 ABIOTIC VARIABLES

Substrate depth was measured by inserting a thin metal rod (2 mm diameter) at each of the four corners and in the center of a quadrat. The five readings was averaged to determine mean substrate depth of a plot.

Substrate moisture was measured using gravimetric sampling. Vials were preweighed, weighed with wet substrate and then weighed again after 48 hours in a 70°C drying oven. Moisture content was calculated by dividing water weight per vial (wet substrate+vial-dry substrate+vial) by dry substrate weight (dry substrate+vial-vial weight). Moisture sampling was performed three times during the sampling season (June, July, and August) after a rainfall event.

Substrate nutrient content was analyzed using samples of approximately 500 mL taken from the center of the each quadrat. If surface covering prevented sampling from the center of the quadrat, samples were taken from as close to the center as possible. The samples were assessed for pH, percent organic matter, phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), sulfur (S), iron (Fe), manganese (Mn), copper (Cu), zinc (Z), boron (B), nitrate (NO_3), and cation exchange capacity (CEC). Soil pH was determined following the Adams-Evans buffer method (COEC 1992) and a pH meter (Accumet AR25: Fisher Scientific, Ottawa, Canada). Organic matter content was determined by loss on ignition after 1 h at 450°C. Soil content of P, K, Ca, Mg, Na, Mn, Cu and Zn, was analyzed using Mehlich 3 extraction, followed by the inductively coupled argon plasma method. CEC was determined by calculating the sum of the milliequivalents of Na, Ca, K, Mg, and hydrogen per 100 g of soil (Baird 1999). Nitrate was extracted from 10 g of soil using a dilute salt solution and measured with a specific ion electrode and a double reference electrode. All analyses were conducted by Nova Scotia Agricultural College Lab Services (Truro, Nova Scotia).

2.2.6 STATISTICAL ANALYSES

Species diversity indices (species richness, Shannon index, and native species richness) were calculated using PI counts. Species richness was determined as the cumulative number of species encountered within a plot and native species richness was the number of native species (as determined by AC CDC ranks) within a plot. Shannon index is calculated with the following formula: $H = -\mathrm{sum}(P_i \log[P_i])$, where P_i is the abundance of a given species in a plot divided by the total number of species observed in that plot.

R (Version 6.12; R Foundation for Statistical Computing, Vienna, Austria) was used for all statistical analyses. Compositional patterns in plant communities were explored using non-metric multidimensional scaling (NMDS). NMDS is a recommended ordination method in community ecology and is commonly regarded as the most robust technique for indirect gradient analysis (Minchin 1987). NMDS produces a multidimensional picture of the relationships between vegetation plots based on their floristic similarity to each other. The coordinates of plots in the multidimensional space are then correlated with environmental information for each plot to detect possible environmental gradients driving vegetation patterns. Unlike some commonly used eigenvector ordination techniques (i.e. detrended correspondence analysis), NMDS works without assumption of linear or unimodal response and avoids many of the distortions of such techniques (Minchin 1987; Legendre and Legendre 1998). NMDS was performed in R as recommended by Minchin (1987) using Bray–Curtis distance as a measure of ecological similarity (Oksanen *et al*. 2007). This method attempts to produce a stable solution by using several random starts and scaling is standardized, resulting in configurations that are easier to interpret. Non-parametric multivariate ANOVA tests were performed on NMDS ordinations to determine statistical differences between community composition of the three urban habitats and within USV plots. Abiotic variables were added to ordination diagrams to explore correlations with vegetation plots.

Analysis of variance (ANOVA) and two-sample t-tests were performed to test for differences among the diversity indices (R, H', N) of each habitat type and between USV sites. ANOVA was performed with site and habitat type as the main effects of interest. Variances were examined for homogeneity with residual plots, and normality was checked with the Shapiro–Wilks statistic. Multiple regressions were carried out to examine the performance of the aboitic factors as predictor variables for each of the diversity indices. Significance was indicated by a *P*-value less than 0.05. For the regression analyses, the best models were chosen using both forward and backward stepwise model selection by AIC.

Principal component analysis (PCA) was performed to simplify substrate nutrient parameters for vector fitting and regression analysis. PCA transforms a number of possibly correlated variables into a smaller number of uncorrelated variables called principal components (PCs). The first principal component accounts for as much of the variance as possible, and each subsequent component accounts for as much of the remaining variability as possible. All PCs with eigenvalues greater than one were used in the analyses.

2.3 RESULTS

2.3.1 OVERVIEW OF ALL URBAN SITES

Vegetation and soil characteristics

Plot sampling of the twenty-one spontaneous, lawn and forest sites yielded 171 species. 151 species were recorded at spontaneous sites, 24 at lawn sites, 23 at forest sites (ground-level only, 29 with trees) (Appendices C, D and E). The additional site-level surveys added 112 species, for a total species richness of 264 across spontaneous sites.

The vegetation composition varied greatly among the three habitat types. USV sites showed the most variability among sites, with some sites having more tree cover and some sites having significant bare or unvegetated areas due to hard surface coverings (see appendix B for site photos). Maximum and average vegetation height among the sampled plots was greater at sites with greater tree establishment and lower in sites with only herbaceous colonizers present (maximum and average vegetation height per plot are listed in table 2.1). Substrate depth did not vary as much as expected in USV sites, but determining accurate substrate depth in extremely rocky soil/gravel with the method used proved difficult. Mean substrate depth varied from 3.6 – 8.2 cm among sites (table 2.1). Both forests and lawns had greater soil depth than the deepest USV site, see table 2.1.

Common species

Of the total number of species recorded for all sites, 132 occurred exclusively at spontaneous sites. Spontaneous sites shared 21 species with lawns and 6 species with forests. Lawns and forests shared no species.

The three most common species encountered during the point-intersect sampling were grasses in the genus Poa - *P. pratensis, P. palustris* and *P. compressa* (397, 342, 340 occurrences, respectfully). The ten most common species encountered during point-intersect sampling are listed in table 2.2. Grasses (Poaceae) appear six times in the top ten. The remainders are herbaceous perennials belonging to the family Asteraceae and *Daucus carota* a biennial plant in the family Apiaceae. The ten species in table 2.2 accounted for 40% of point-intersect counts across all sites (2387 out of 5972 occurrences).

Table 2.1 Mean substrate depth (with standard error) of urban spontaneous vegetation (USV), forest and lawn plots.

	Substrate depth (cm)
USV	
BS	4.0±0.3
DC	3.6±0.1
EX	3.6±0.9
HF	3.9±0.5
LS	5.6±0.4
ML	6.6±0.7
MT	4.6±0.5
PW	8.2±0.1
SB	4.5±0.3
SF	7.1±0.4
SP	5.5±0.5
Forests	
AL	26.0±0.8
LW	17.6±0.3
MU	18.1±1.1
OK	13.7±1.0
OL	11.7±0.8
Lawns	

JL	15.1±1.2
MB	10.7±0.5
SG	13.6±0.7
SR	16.6±0.9
TL	10.1±1.1

Six plant families are prominent in the plot data. The Asteraceae, Poaceae, Rosaceae, Fabaceae, Scrophulariaceae and Caryophyllaceae accounted for more than half of the species richness (99 of 171 species) and 75.7% of the total point-intersect occurrences (4521 out of 5972).

2.3.2 SPONTANEOUS VEGETATION SITES

Spontaneous plots summary

The average plot richness varies from 13 to 22 at the eleven USV sites. Table 2.3 shows each site and its corresponding diversity index value. SF had the highest average richness and H' diversity per plot, while DC had the highest percentage of native species per plot. The lowest average plot H' and average percent native richness was found at PW, while the lowest average plot richness was at HF.

Table 2.2 The ten most common species recorded during point-intersect sampling at all sites (spontaneous, lawn and forest), including family, PI count (number of intersects per species), percent of total intersects recorded for all species and number of sites where the species was found.

Species	Family	PI count	Percentage of total number of intersects (5972)	Number of sites found
Poa pratensis	Poaceae	397	6.7%	13
Poa palustris	Poaceae	342	5.7%	8
Poa compressa	Poaceae	340	5.7%	11
Centaurea nigra	Asteraceae	287	4.8%	12
Daucus carota	Apiaceae	280	4.7%	11
Festuca rubra	Poaceae	231	3.9%	12
Tussilago farfara	Asteraceae	153	2.6%	9
Phleum pratense	Poaceae	150	2.5%	8
Agrostis capillaris	Poaceae	149	2.5%	8
Aster novae-belgii	Asteraceae	132	2.2%	11

Table 2.3 Comparison between vegetation diversity indices of the USV sites with standard error. Included are mean richness (R), mean Shannon index (H') and mean percent cover of native species (N) of the 1 m^2 quadrats (n=144).

Site	**Mean R**	**Mean H'**	**Mean N**
SF	21.8±0.1	2.3±0.5	48.1±0.3
ML	18.1±0.6	2.2±0.5	45.5±0.4
MT	17.4±0.5	2.3±0.7	33.4±0.9
SB	14.4±0.3	2.0±0.1	29.6±0.5
EX	14.2±0.6	2.0±0.1	26.4±0.3
DC	13.3±0.1	1.9±0.1	67.1±1.7
BS	13.3±0.9	2.1±0.2	23.2±0.8
SP	13.1±0.8	1.8±0.1	27.0±0.5
PW	12.5±1.1	1.7±0.6	20.6±0.3
LS	12.3±1.3	2.0±0.5	51.2±1.9
HF	11.8±0.4	1.9±0.1	38.4±0.4

Common and uncommon species

The most frequently recorded species in spontaneous plots were *Poa palustris, Poa compressa, Centaurea nigra* and *Daucus carota*. Four species each accounted for over 250 intersect points and together account for 23.7% of all plant intersects recorded. They were recorded at all eleven sites with the exception of *Poa palustris*, which occurred at eight sites. Table 2.4 shows the top twenty most common species recorded at spontaneous sites during point-intersect sampling.

Uncommon species were very uncommon: almost half the species recorded (69 out of 151 species) occurred at two plots or less and 65 species (43.0% of total species pool) had five point intersect occurrences or less. Site SF had the most occurrences of unique species at 23, 13 of which were native species. Counts of unique species were lower in other sites. The next greatest record of unique species occurred at SB and DC, which each had five unique species. Only one site (HF) contained no unique species.

Inter-site common species

Nineteen species occurred in at least ten of the eleven sites. Table 2.5 shows the most commonly shared species at spontaneous sites. Of the 151 species, only seven were recorded at all eleven sites (4.6% of total species pool). These species are *Aster novae-belgii, Daucus carota, Poa compressa, Taraxacum officinale, Hieracium pilosella, Trifolium pratense,* and *Trifolium repens*. Most of these species belong to Asteraceae or Fabaceae families, with only one grass species (Poaceae). The Poaceae, Asteraceae and Fabaceae accounted for 73.9% of point intersect records at spontaneous sites (3885 of 5256 occurrences).

Native, exotic and invasive species

At spontaneous sites, 62 species native to Nova Scotia were recorded in sub-plots (41.7% or 62 of 151) and accounted for 30% of point intersect occurrences (1576 of 5256 occurrences). In lawn plots, seven of the 24 species recorded were native and 20 of the 23 species recorded in forest plots were native. See Appendices D and E for lists of species and native status of species recorded in lawns and forests. Table 2.6 lists the twenty most common native and exotic species recorded during point-intersect sampling at spontaneous sites. *Festuca rubra, Aster novae-belgii, Agrostis scabra,* and *Solidago canadensis* were the most frequently recorded native species in the spontaneous plots; accounting for 10.5% of all spontaneous vegetation intersects (551 of 5256 occurrences). Thirty percent of spontaneous plots (43 out of 144) had 50% or higher native species intersect occurrences and 48 plots had native occurrences that made up less than 25%. Only one plot had no recorded native species.

Site DC had the most observations of native species with 64.9% (257 of 396 occurrences), followed by site SF with 39.4% native species observations. *Festuca rubra, Betula papyrifera,* and *Danthonia spicata* were common natives found at DC, while *Agrostis scabra, Aster novae-belgii* and *Scirpus cyperinus* were common at SF. Site EX had the least observations with native species comprising 9.6% of observations. This site had a high number of intersect records of the legume, *Lotus corniculatus* and grasses such as *Poa palustris, Phleum pratense* and *Agrostis capillaris.*

Table 2.4 The twenty most common species recorded at spontaneous sites during point-intersect sampling, including family, PI count (number of intersects per species), percent of total intersects recorded for all species and number of sites where the species was found.

Species	Family	PI count	Percentage of total number of intersects (5972)	Number of sites found
Poa palustris	Poaceae	342	6.5%	8
Poa compressa	Poaceae	340	6.5%	11
Centaurea nigra	Asteraceae	287	5.5%	10
Daucus carota	Apiaceae	280	5.3%	11
Festuca rubra	Poaceae	160	3.0%	9
Tussilago farfara	Asteraceae	153	2.9%	9
Phleum pratense	Poaceae	150	2.9%	8
Agrostis capillaris	Poaceae	149	2.8%	7
Aster novae-belgii	Asteraceae	131	2.5%	11
Agrostis scabra	Poaceae	130	2.5%	8
Solidago canadensis	Asteraceae	130	2.5%	10
Trifolium pratense	Fabaceae	119	2.3%	11
Potentilla simplex	Rosaceae	116	2.2%	8
Lotus corniculatus	Fabaceae	113	2.2%	5
Elymus repens	Poaceae	109	2.1%	9
Trifolium campestre	Fabaceae	109	2.1%	9
Trifolium repens	Fabaceae	107	2.0%	11
Euthamia graminifolia	Asteraceae	105	2.0%	9
Poa pratensis	Poaceae	104	2.0%	9
Danthonia spicata	Poaceae	100	1.9%	8

Some sites contained species known to be invasive or have other economic, environmental or ecological adverse affects. *Convolvulus arvensis* and *Silene latifolia* ssp. *alba* are considered as ‘noxious weeds’ in Nova Scotia because of negative impacts in agricultural settings and are subject to control under the Weed Control Act (WCA) (Nova Scotia Department of Agriculture 2003). *Convolvulus arvensis* was recorded 30 times during point-intersect sampling and was found at 10 of 11 sites. *Silene latifolia* ssp. *alba* had 1 occurrence at site SF. Another species under WCA regulations, *Senecio jacobaea*, was found at two sites but only at the site-level surveys. Another well known invasive species of the Maritimes, *Polygonum cuspidatum* (Blaney 2001), was encountered at three sites during the additional site surveys but was not recorded during plot sampling.

Table 2.5 The most commonly shared species among spontaneous vegetation sites including family, PI count (number of intersects per species), percent of total intersects recorded for all species and number of sites where the species was found.

Species	Family	PI count	Percentage of total number of intersects (5972)	Number of sites found
Poa compressa	Poaceae	340	6.5%	11
Daucus carota	Apiaceae	280	5.3%	11
Aster novae-belgii	Asteraceae	132	2.5%	11
Trifolium pratense	Fabaceae	119	2.3%	11
Trifolium repens	Fabaceae	107	2.0%	11
Hieracium pilosella	Asteraceae	98	1.9%	11
Taraxacum officinale	Asteraceae	67	1.3%	11
Centaurea nigra	Asteraceae	286	5.4%	10
Solidago canadensis	Asteraceae	130	2.5%	10
Vicia cracca	Fabaceae	58	1.1%	10
Cerastium vulgatum	Caryophyllaceae	42	0.8%	10
Hieracium maculatum	Asteraceae	30	0.6%	10
Tussilago farfara	Asteraceae	153	2.9%	9
Elymus repens	Poaceae	109	2.1%	9
Trifolium campestre	Fabaceae	109	2.1%	9
Euthamia graminifolia	Asteraceae	105	2.0%	9
Leontodon autumnalis	Asteraceae	57	1.1%	9
Oenothera biennis	Onagraceae	39	0.7%	9
Juncus tenuis	Juncaceae	23	0.4%	9

Some species encountered during sampling are known as invasive species of natural habitats in Canada and are subject to national jurisdiction (White *et al*. 1993). *Hypericum perforatum* and *Melilotus alba* are considered ‘moderate invasive aliens’ and were found at 8 and 5 sites, respectfully, accounting for a total of 90 point intersect records (0.02% of total occurrences). Other species on Canada’s invasive species list found during the summer sampling period are listed in table 2.7. Two of the species listed in table 2.7, *Poa compressa* and *Poa pratensis*, are among the most encountered species in spontaneous vegetation plots, see 2.4.

Table 2.6 The twenty most common non-native (SE) and indigenous (S5) species recorded during point-intersect sampling at spontaneous sites, including family, S-rank (AC CDC 2009), PI count (number of intersects per species), percent of total intersects recorded for all species and number of sites where the species was found.

Species	**Family**	**S-rank**	**PI count**	**Percentage of total number of intersects (5972)**	**Number of sites found**
Poa palustris	Poaceae	SE	342	6.5%	8
Poa compressa	Poaceae	SE	340	6.5%	11
Centaurea nigra	Asteraceae	SE	286	5.4%	10
Daucus carota	Apiaceae	SE	280	5.3%	11
Tussilago farfara	Asteraceae	SE	153	2.9%	9
Phleum pratense	Poaceae	SE	150	2.9%	8
Agrostis capillaris	Poaceae	SE	149	2.8%	8
Trifolium pratense	Fabaceae	SE	119	2.3%	11
Potentilla simplex	Rosaceae	SE	116	2.2%	8
Lotus corniculatus	Fabaceae	SE	113	2.2%	5
Festuca rubra	Poaceae	S5	160	3.0%	7
Aster novae-belgii	Asteraceae	S5	132	2.5%	11
Agrostis scabra	Poaceae	S5	130	2.5%	8
Solidago canadensis	Asteraceae	S5	130	2.5%	10
Euthamia graminifolia	Asteraceae	S5	105	2.0%	9
Poa pratensis	Poaceae	S5*	104	2.0%	9
Danthonia spicata	Poaceae	S5	100	1.9%	8
Solidago juncea	Asteraceae	S5	84	1.6%	6
Betula papyrifera	Betulaceae	S5	76	1.4%	3
Oenothera biennis	Onagraceae	S5	39	0.7%	9

* AC CDC ranks *Poa pratensis* as S5 but it is well known that this species is likely an exotic race commonly introduced in lawn seed mixtures.

Interesting finds during the summer sampling period included *Laburnum anagyroides*, an ornamental tree in the Fabaceae family, which was recorded at one site in Halifax (SF). Although several plants were found on site, *L. anagyroides* has not been recorded as naturalized or self-seeding Nova Scotia.

Table 2.7 Invasive plants of natural areas found on spontaneous sites, PI count (number of intersects per species), and number of sites where the species was found.

Species	PI count	Number of sites found
Moderate Invasive Aliens*		
Melilotus alba	62	5
Hypericum perforatum	28	8
Minor Invasive Aliens*		
Poa compressa	340	11
Poa pratensis	104	8
Rosa multiflora	24	6
Acer platanoides	11	1
Artemisia absinthium	5	2
Ambrosia artemisiifolia	1	1
Verbascum thapsus	1	3

*Invasive status assigned by the Canadian Wildlife Service (White et al. 2003).

Other noteworthy species recorded during additional non-plot surveys include *Elaeagnus umbellata* (Autumn Olive), growing along the train tracks in Dartmouth, a species which is starting to become established in Nova Scotia and *Symphyotrichum ciliatum* (Rayless Aster), just recently found growing along a highway in northern Nova Scotia (Sean Blaney, Pers. Comm. 2009).

2.3.3 NON-METRIC MULTIDIMENSIONAL SCALING (NMDS) ANALYSIS

All sites

The NMDS analysis did not produce a convergent solution in two dimensions (stress: 19.6) and stress was further reduced with three dimensions (stress: 16.8). The three-dimensional ordination is used in all subsequent analyses. The first two axes in NMDS separated three distinct groups reflecting the distinct composition of the quadrats within the three urban habitats (figure 2.1). Spontaneous and lawn plots are grouped together when the first and third axes are graphed reflecting the number of shared species between these quadrats (figure 2.2). Lawn plots have the tightest cluster (indicating the lowest dissimilarity among plots), followed by spontaneous and forest plots. The forest plots, having a loosely aggregated cluster, show the least similarity among vegetation communities within the habitats sampled. The cluster of lawn plots is also positioned closer to the cloud of spontaneous plots reflecting the number of shared species relative to forest plots. Three spontaneous plots in figure 2.1 (PW 9, SF 12 and SF 13) are plotted close to the cluster of lawn plots because they had high grass cover. A significance test for vegetation community data (non-parametric multivariate ANOVA) reveals that the composition of the three urban communities are statistically different from each other and *post hoc* tests between groups reveal each group is different from the other two (L vs. F $p<0.01$; L vs. S $p<0.01$; S vs. F $p<0.01$).

When the plots are labeled by city (Halifax vs. Dartmouth), there appears to be some separation in the spontaneous vegetation plots, but not in the other urban vegetation types, see figure 2.3. Plots located in Dartmouth are concentrated in the bottom right of the graph, while the Halifax plots are oriented in the opposite direction.

Spontaneous vegetation community ordination

The NMDS analysis did not produce a convergent solution in two dimensions either and stress increased slightly (stress: 31.2). With more dimensions (three), stress was reduced to 22.8 (only after an ordination with nine dimensions did the stress fall below 10). The ordination does not reveal clear grouping among spontaneous vegetation communities sampled. However a significance test of the community data reveals that there are differences among vegetation at spontaneous sites ($p = 0.01$). When labeled by site (figures 2.4 and 2.5) some patterns among the plots can be seen. Some spontaneous vegetation sites have plots that show clustering (site HF) reflecting a high degree of community similarity. Conversely, some sites seem to show more similarity with plots from other sites than within site (LS). When plots are labeled by city on the NMDS ordination (figure 2.6) there appears to be a slight separation between sites located in Halifax and Dartmouth along NMDS Axis 1. A non-parametric multivariate ANOVA confirms that there is a significant difference between spontaneous vegetation communities in Halifax and Dartmouth ($p = 0.01$).

2.3.4 VECTOR FITTING WITH SUBSTRATE AND ENVIRONMENTAL VARIABLES

All sites

Variables representing environmental and substrate factors were fit to the three-dimensional NMDS ordination. Because several of the substrate nutrient parameters were correlated, a principal components analysis (PCA) was performed to reduce the number of nutrient variables used for vector fitting. The PCA identified five axes that could effectively summarize the substrate nutrient data (eigenvalue> 1), accounting for 72.6% of the total variance. ALLsub.PC1 has a negative correlation with pH, K, Ca, Mg, Cu, Zn, CEC and B (see table 2.8). ALLsub.PC2 correlates positively with pH and manganese and negatively with organic matter and CEC. ALLsub.PC3 is positively correlated with P and NO_3, while ALLsub.PC4 is negatively associated with P, and Zn. Lastly, ALLsub.PC5 shows a negative correlation with S.

Table 2.8 Results of principle components analysis (PCA) on the substrate nutrient parameters for all sites. Loadings for each parameter are listed for each of the five PC axes.

Substrate nutrient parameter	ALLsub.PC1	ALLsub.PC2	ALLsub.PC3	ALLsub.PC4	ALLsub.PC5
Organic matter	0.47	-0.93	0.25	-0.03	0.19
pH	-0.91	0.91	-0.25	0.40	-0.19
Phosphorus (P)	-0.05	-0.02	0.96	-0.91	-0.16
Potassium (K)	-0.92	-0.70	0.75	0.19	-0.01
Calcium (Ca)	-0.98	0.34	0.02	0.45	-0.06
Magnesium (Mg)	-0.94	-0.20	0.65	0.37	0.22
Sodium (Na)	-0.28	-0.90	-0.10	0.75	0.71
Sulphur (S)	-0.75	-0.78	-0.71	-0.03	-0.98
Iron (Fe)	-0.17	-0.88	-0.63	0.19	0.75
Manganese (Mn)	-0.77	0.96	0.56	0.42	0.60
Copper (Cu)	-0.92	0.40	-0.81	-0.77	0.47
Zinc (Zn)	-0.95	-0.38	-0.58	-0.93	0.64
Cation exchange capacity (CEC)	-0.92	-0.90	-0.03	0.63	-0.25
Boron (B)	-0.96	-0.12	-0.45	-0.18	-0.39
Nitrate (NO3)	-0.77	-0.28	0.91	-0.63	-0.05

The substrate nutrient PC axes and the remaining environmental variables (substrate depth, substrate moisture and surface temperature) were fitted with the NMDS ordination (see appendix H for site level summaries for all variables). All of the environmental vectors with the exception of ALLsub.PC5 are significantly correlated with the NMDS ordination ($p<0.05$), see table 2.9. ALLsub.PC2 shows the highest correlation (r^2 =0.52), followed by substrate moisture (r^2=0.45), substrate depth (r^2=0.36) and substrate temperature (r^2=0.35).

Substrate moisture, ALLsub.PC1, and ALLsub.PC2 score highest on NMDS axis 1; this indicates that the axis represents a substrate moisture, organic matter and acidity gradient. Plots on the negative end of NMDS axis 1 are have wetter, fertile (high organic matter and CEC) and more acidic substrates. Substrate depth, moisture and ALLsub.PC1 are directed toward forest plots in the NMDS ordination graphs (figures 2.7 and 2.8). ALLsub.PC2 and substrate temperature are directed toward the positive end of NMDS axis 1 where the majority of the spontaneous plots and all the lawn plots are located in the ordination graph. These plots were lower in organic matter and had higher pH and manganese than forest plots.

Table 2.9 Results of environmental vector fitting with the NMDS ordination for all the spontaneous, lawn and forest plots (n=194).

Vectors	NMDS Score Axis 1	NMDS Score Axis 2	NMDS Score Axis 3	r2	p
Moisture	-0.803	0.281	-0.518	0.445	<0.001 ***
Depth	-0.631	0.732	0.284	0.357	<0.001 ***
Temperature	0.525	-0.797	0.075	0.350	<0.001 ***
ALLsub.PC 1	-0.814	-0.536	0.213	0.284	<0.001 ***
ALLsub.PC 2	0.829	-0.548	0.071	0.519	<0.001 ***
ALLsub.PC 3	0.078	0.989	0.123	0.102	<0.001 ***
ALLsub.PC 4	-0.047	-0.511	-0.859	0.076	0.001 ***
ALLsub.PC 5	-0.221	0.744	-0.623	0.012	0.223

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.'

P values based on 1000 permutations.

Substrate depth, temperature and ALLsub.PC3 have the highest scores on NMDS axis 2. Since sub.PC3 is correlated with phosphorus and nitrate, this axis may represent a substrate depth and fertility gradient. ALLsub.PC3 is directed toward lawn plots and substrate depth is directed between lawn and forest plots. Deeper substrates were found in lawn and forest plots. Lawns had higher phosphorus and nitrate, likely due to fertilizer application.

NMDS axis 3 seems to represent a substrate nutrient gradient because it is most correlated with ALLsub.PC4. ALLsub.PC4 is oriented away from the lawn plots opposite ALLsub.PC3 which reflects the relatively low phosphorus values and higher sodium for spontaneous plots.

Spontaneous vegetation plots

Vector fitting with spontaneous plots only was performed similarly to all sites above. A PCA was completed with the substrate nutrient data to reduce variables for vector fitting. Five PC axes had eigenvalues greater than 1 and accounted for 71.0% of the variation. USVsub.PC 1 has a positive relationship with several substrate parameters including pH, K, Ca, Mg, S, B and CEC (see table 2.10). USVsub.PC 1 has a slight positive correlation with substrate depth, so it may reflect deeper substrates that contain higher values of several substrate parameters in general. USVsub.PC 2 correlates negatively with organic matter and Zn. USVsub.PC 3 is negatively related with P and NO_3. USVsub.PC 4 is positively associated with Mn and USVsub.PC 5 shows positive relationship with Fe and NO_3.

The results of the NMDS graph vector fitting for substrate PCA axes and other environmental variables on the spontaneous vegetation ordination are shown in table 2.11 and figures 2.9 and 2.10. All variables showed significant correlations ($p<0.05$) and r^2 values were similar to those found for the vector fitting with all urban plots. Substrate temperature has the highest correlation with the spontaneous plot ordination ($r^2=0.36$) followed by substrate depth ($r^2=0.25$) and moisture ($r^2=0.21$). All substrate nutrient PCs had r^2 values lower than 0.2.

NMDS axis 1 seems to represent a moisture and fertility gradient because it is positively correlated with substrate moisture and USVsub.PC5. This indicates that plots on the positive end of this axis have higher values of iron and nitrate. Plots ML8, LS10, SF12, SF13, and SB6 score high on NMDS Axis 1 which has high values for substrate moisture and other nutrients. Also EX plots score positively on NMDS Axis 1 and these plots were regularly flooded. Species that scored high on NMDS Axis 1 are grasses such as *Dactylis glomerata, Elymus repens, Poa palustris, Agrostis stolonifera* and herbaceous species such as *Equisetum arvense, Stellaria media, Lotus corniculatus, Carex scoparia* and *Viccia cracca*. Plots that score low on NMDS axis 1 are had a higher percentage of hard surface (rocks, gravel, asphalt/concrete), which restricts vegetation cover, substrate formation and moisture retention. The species that occur at this end of the gradient are *Solidago spp. Melilotus alba, Anaphalis margaritacea, Hieracium spp.* and *Poa compressa.* These species were often found in rocky/gravel substrates or rubble heaps. Higher substrate temperatures

Table 2.10 Results of principal components analysis (PCA) on the substrate nutrient parameters for USV sites. Loadings for each parameter are listed for each of the five PC axes.

Substrate nutrient parameter	USVsub.PC1	USVsub.PC2	USVsub.PC3	USVsub.PC4	USVsub.PC5
Organic matter	0.241	-0.927	-0.257	0.479	0.509
pH	0.960	0.679	0.252	-0.167	-0.508
Phosphorus (P)	0.303	-0.185	-0.970	-0.086	-0.752
Potassium (K)	0.976	-0.001	-0.860	-0.527	0.332
Calcium (Ca)	0.945	0.702	-0.120	0.413	0.037
Magnesium (Mg)	0.937	-0.166	0.153	-0.782	0.154
Sodium (Na)	0.162	0.180	0.338	0.127	0.478
Sulphur (S)	0.950	0.240	0.163	0.714	0.371
Iron (Fe)	0.367	0.367	0.329	-0.576	0.903
Manganese (Mn)	0.188	0.660	0.252	-0.913	-0.043
Copper (Cu)	0.805	-0.751	0.639	-0.366	-0.774
Zinc (Zn)	0.850	-0.903	0.653	-0.078	-0.192
Cation exchange capacity (CEC)	0.955	0.699	-0.118	0.472	0.187
Boron (B)	0.984	-0.276	0.122	0.069	-0.285
Nitrate (NO3)	0.424	-0.473	-0.961	-0.408	0.927

are associated with this increase in hard surface cover, which is strongly negatively associated with NMDS axis 1 (-0.79).

Substrate depth and maximum vegetation height is positively correlated with NMDS axis 2 and USVsub.PC2 is negatively correlated with this axis. USVsub.PC2 is positively associated with pH, manganese and negatively associated with organic matter. This indicates that NMDS axis 2 is a substrate depth and organic matter gradient. Substrates that are deeper, more acidic and contain more organic matter are represented on the positive end of this axis. Species that score positively on NMDS axis 2 are shrubs and trees like *Salix sp., Prunus pensylvanica, Betula spp.* and *Spirea spp.*. These species are found in plots at SF, SP, and LS. Plots in the negative end of NMDS axis 2 have shallower substrates or rocky substrates that support low growing ruderals (*Trifolium spp., Medicago lupulina, Chenopodium album, Matricaria discoidea* and *Senecio spp*.). Plots at this end of the gradient are associated with HF, DC and MT.

Table 2.11 Results of environmental vector fitting with the NMDS ordination for spontaneous plots (n=144).

Vectors	NMDS Score Axis 1	NMDS Score Axis 2	NMDS Score Axis 3	r2	p
Sub.depth	0.270	0.812	-0.518	0.252	<0.001 ***
Sub.temp	-0.793	-0.497	0.352	0.361	<0.001 ***
Moisture	0.950	-0.078	0.303	0.209	<0.001 ***
USVsub.PC 1	0.592	-0.281	-0.755	0.165	<0.001 ***
USVsub.PC 2	-0.307	-0.943	0.131	0.191	<0.001 ***
USVsub.PC 3	-0.014	-0.254	0.967	0.082	0.006 **
USVsub.PC 4	0.301	-0.019	0.953	0.069	0.011 *
USVsub.PC 5	0.928	0.216	0.305	0.157	<0.001 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.'

P values based on 1000 permutations.

NMDS axis 3 seems to represent a type of substrate fertility gradient because it is strongly correlated with USVsub.PC3 and 4. USVsub.PC3 is negatively related with P and NO_3 and positively related to Fe. USVsub.PC4 is positively associated with S and negatively associated with Cu and Zn. Plots high in P and NO_3 have higher levels of Cu and Zn and are plotted on the negative end of NMDS axis 3. All PW plots are seen in this area of the graph as well as SB 7, SP 1, LS 10 and MT 10. Species that are associated with these plots are: *Poa compressa, Festuca rubra, Phleum pratense, Centurea nigra* and *Linaria vulgaris.* Plots that score positively on NMDS axis 3 are SP 3, LS 9, SB 5, and DC 11. These plots have substrates with relatively low NO_3 and P and high Fe and S concentrations. Species that score high on NMDS axis 3 are: *Acer rubrum, Poa annua, Matricaria chamomilla, Chenopodium album* and *Juncus spp..*

2.3.5 DIVERSITY INDICES AND PREDICTORS OF DIVERSITY

All sites summary

The following indices of diversity were measured in the three urban habitat types: species richness(R), Shannon index (H') and percent native species richness (N). Spontaneous plots had higher average plot richness and H' than forest and lawn plots. The average percent native species per plot was highest (as expected) in forests, followed by spontaneous and lawn. Lawn plots had higher average richness than forests. Results of the comparison are presented in table 2.12.

Table 2.12 Comparison among vegetation diversity indices of the sampling sites, with standard error. Included are mean richness (R)(per m^2 quadrat), mean Shannon index (H') and mean percent cover of native species (N)(per m^2 quadrat) (spontaneous, n=144; forest, n=25; lawn, n=25).

	Mean R	**Mean H'**	**Mean N**
USV	14.7±2.8	2.0±0.6	37.9±2.1
Forest	4.9±0.5	1.1±0.3	96.0±0.3
Lawn	7.5±0.4	1.1±0.2	19.1±0.1

General linear models - All plots

Regression analyses were performed with the diversity indices and abiotic variables. None of the aboitic variables were strong predictors of diversity indices, results are shown in table 2.13. Species richness was the least well predicted (r^2=0.001)

H' has a positive relationship with temperature and ALLsub.PC2 and a negative relationship with substrate depth and ALLsub.PC1, 3 and 5, but the r^2 is very low (0.30). This indicates H' may be increased in plots that have warmer, more alkaline soils, with higher manganese and sodium and lower phosphorus and nitrate.

The percent native species model, which had the highest r^2 value, indicates that percent native species has a positive relationship with ALLsub.PC1 and has a negative relationship with ALLsub.PC2 and 3. This indicates a positive relationship with organic matter and CEC. It also indicates that native species show a negative relationship with pH, P, NO_3 and other parameters accounted for by ALLsub.PC1. Native species were recorded more often in plots that had high organic matter content, slight acidity and low on enriched nutrients (P and NO_3). These parameters describe the substrate in forests where native species accounted for an average of 96.0% of species recorded in plots.

Table 2.13 Results of the general linear model analysis for all sites showing the formula for the best model for each diversity index (n=194).

Index	Model fomula	r2	p
Richness	R ~ depth+moisture+ALLsub.PC3+ALLsub.PC4+ ALLsub.PC5	0.25	<0.001
Shannon index	H' ~ depth+temp+ALLsub.PC1+ALLsub.PC2+ ALLsub.PC3+ ALLsub.PC4+ALLsub.PC5	0.30	<0.001
% Native species	N ~ ALLsub.PC1+ALLsub.PC2+ALLsub.PC3	0.47	<0.001

Table 2.14 Results of the general linear model analysis of spontaneous sites showing the formula for the best model for the diversity indices (n=144).

Index	**Model fomula**	**r2**	**p**
Richness	R ~ USVsub.PC4	0.06	0.00
% Native species	N ~ USVsub.PC1+USVsub.PC2+USVsub.PC3	0.11	<0.001

General linear models - Spontaneous plots

Species richness and percent native species were significantly predicted by substrate nutrient vectors (table 2.14). Although the models were significant (p=<00.1) the r^2 values are extremely low, meaning that they explain little variation within the diversity indices. H' was found not to be significantly correlated with any of the environmental variables.

2.4 DISCUSSION

2.4.1 VEGETATION COMPOSITION IN SELECT HABITATS OF METRO HALIFAX

Species diversity and habitat differences

The combined floral diversity of the urban sites sampled was, as predicted, quite species-rich. Across the three habitats, 171 species were encountered roughly representing 11% of the total flora of Nova Scotia (which is comprised of more than 1500 species (Flora of Nova Scotia 1999)). The additional USV site surveys increase this to over 17%. Since between 60 and 70% of urban vegetation is planted (Gilbert 1989), a floral inventory including parks, gardens and other cultivated grounds in the study area would reveal many species to the urban flora. Additionally, this study only covered a small proportion of spontaneously growing vegetation in the city. An inventory of all such areas in metro Halifax would dramatically increase the number of species. Urban floral inventories in other parts of the world vary considerably in the percentage of the total country's flora represented in an urban area. Godefroid (2001) reports 730 plant species in Brussels, representing 50% of Belgium's flora and Hu *et al*. (1995) recorded 1049 species in the city of Tianjin, representing 3.87 percent of China's flora.

As expected, USV plots average R and H' were greater than lawn and forest plots, but it was surprising that they had an average of two times the number of species. This seems low compared to a study by Gödde *et al*. (1995), which found wasteland sites supported five times the number of species present in urban native woodlands and fields in Germany.

The vegetation composition of the three habitat types (USV, lawn and forest) were statistically different. Forests plots were coniferous dominated, with little understory cover, supporting mostly native species; lawn plots had a few non-native grasses with a small number of herbaceous species; and USV plots were extremely diverse. USV plots shared some species with both forests and lawns but differences were obvious in the ordination graphs. Some USV plots that had high grass cover were nearest lawn plots than other USV plots, but this was the exception and not the rule. Section 2.4.2 discusses species composition and other floral characteristics of USV sites in detail.

Native species

USV sites in this study supported more native species than the regularly maintained mowed lawns, but less than remnant natural vegetation, which is consistent with what was expected and in published descriptions of urban vegetation patterns (McKinney 2002). All lawn sites contained between 80-95% cover of non-native species and had a large percentage of built up area within the 1 km buffer. Lawns are usually seeded and maintained with non-native grass mixtures so a high percent of non-native species was expected. Remnant forests contained few non-native species, notably lacking usage as recreational areas or other apparent human-activity. Forested site AL was the only forest with non-native species and it was only one of the two (other being OK) which had evidence of recreational activity (i.e. established footpaths). In urban forested areas, paths and other human uses cause ground layer disturbances, increasing the chance of invasion by non-native species (Guntensperger 1997) and developed land area surrounding natural habitat patches act as sources of non-native propagules, increasing the susceptibility of highly fragmented habitats to invasion (McKinney 2002). If area of built up area around each site were indicative of inoculation pressure of non-native species, AL would have the greatest influx of non-native seed sources.

Native species composition in USV samples ranged from plots dominated by native species to one plot that was comprised of only non-native species. Native species patterns in USV plot and site data are described in detail in the following section.

2.4.2 SPONTANEOUS VEGETATION: PLOT AND SITE-LEVEL PATTERNS

We observed 151 species during plot sampling, and an additional 123 species were recorded in the site surveys, for a total of 264 species occurring as USV. This is surprisingly high compared to previous studies of urban spontaneous vegetation habitats in larger cities of North America and Europe. Crowe (1979) recorded 128 species of vascular plants in twenty-six vacant lots in Chicago, Illinois; Lund (1974) observed 220 species of spontaneously colonized plants with in a 0.6-mile radius of downtown Atlanta, Georgia; and Sukopp *et al*. (1979) reports 121 species of plants in wasteland areas of Berlin, Germany. I could only find one report of an urban area with greater USV richness that this study: (Angold *et al*. (2006) recorded 378 species in fifty urban wasteland sites in Birmingham, England). Reasons for the high richness in metro Halifax are unclear, but perhaps the lack of this type of urban inventory to compare with is the main reason.

Although individual plot counts ranged between 33 to 95 species only and between 45 and 197 for the full site surveys, the ordination showed that USV plots were relatively similar in composition, indicating a common urban flora exists in metro Halifax. The twenty most commonly shared species made up about 43% of all intersect records, a large portion of species recorded were infrequent (40% occurred at two sites or less) and some such as *Sorbus aucuparia* and *Aster umbellatus* were relatively abundant on the sites they were found. If the rarest species were taken out of the ordinations, the picture of urban floral communities would be more representative of the study area as a whole. The presence of these locally abundant species may be attributed to site environmental conditions and species dispersal patterns.

The majority of the most commonly reported and commonly shared species were grasses and herbaceous species (especially members of the Asteraceae and *Daucus carota*). Grasses and composites account for a large portion of urban flora because they are typically tolerant of disturbance (Lund 1974, Whitney 1985, Kowarik 1995) and are generally wind dispersed (McKinney 2002). Their wind borne seeds are able to arrive first to freshly disturbed soil. Although grasses and herbs were widespread at USV sites, several trees and woody plants were recorded: *Betula papyrifera*, *Rosa multiflora*, and *Spiraea alba* accounted for (1.4, 0.5, and 0.4% of USV and occurred at 3, 6 and 5 sites respectively). The woody vegetation and the lack of annuals also indicates that most of the study sites chosen were not recently disturbed. I expected that annual ruderal species would contribute more to the USV flora because of the potential high rate of disturbances to such sites, but perennials were more prominent. Lund (1974) found that annuals and biennials were more common than perennials in the spontaneous flora of Chicago. The largely perennial flora indicates relatively stable circumstances at USV sites in this study. Over the two summer sampling season only one site (LS) had evidence of human disturbance (besides light recreational, i.e. footpaths), being used as storage site for gravel, necessitating the re-location of two previously established plots.

Species richness was high across USV sites, but familial richness was not. Relatively few plant families represented the majority of species occurrences. The Poaceae, Asteraceae and Fabaceae accounted for almost 75% of all point intersect records and familiar similarities included both native and non-native species. Patterns of low phylogenetic diversity have been noted in other studies of urban vegetation and reflect influences of urbanization on biodiversity (Hu *et al*. 1995, Knapp *et al*. 2008). Phylogenetic diversity is often related to functional diversity and closely related species often share traits arising from their common origin and evolutionary history (Knapp *et al*. 2008). In other words, USV is dominated by closely related species that share functional traits that make them more suited to urban conditions. This study supports this by showing that families like Poaceae and Asteraceae are more capable of tolerating urban situations and stresses (such as increased levels of disturbance and fragmentation) than species from other plant families. These families have many traits that make them well suited for urban conditions such as, intermediate seed weight, ability to germinate immediately, rapid growth and flexible regeneration strategies (i.e. the ability to spread laterally) (Gilbert 1989).

Non-native species accounted for the majority of USV plot cover and made up the bulk of species recorded. This can be attributed to the presence of a few exceptionally abundant species, most notably: *Poa palustris*, *P. compressa*, *Centaurea nigra* and *Daucus carota*. The percentage of non-native species at individual USV sites ranged from around 40 to 80%, with the average being about 63%. Non-natives have been shown to increase to up to 50% in the most built-up areas of the urban core (Whitney 1985, Kowarik 1995) and this study indicates areas of USV are hotspots of non-native plant diversity within urban landscapes. Even sites not likely be considered part of the urban core of metro Halifax (ML and SF, see map appendix A) supported over 50% non-native species. This does not infer that USV sites support vegetation that is damaging to natural areas. Nine of the non-native species recorded at USV sites are considered 'invasive plants of natural areas' but, the majority of the species were "not considered to be a problem" by Canadian botanists in a survey conducted by the Canadian Wildlife Service (White *et al*. 1993). Most are considered plants of anthropogenic, disturbed habitats and problems only occur in agricultural situations or disturbed natural habitats outside of Nova Scotia.

The full species inventories at USV sites greatly increased the overall species lists due to species not found in plots. Benefits of urban floral inventories are the discovery of new species introductions and monitoring spread of problematic species. One species recorded during the additional surveys, *Elaeagnus umbellata* (Autumn Olive), is a deciduous shrub or small tree native to eastern Asia is invasive in the eastern United States and parts of Canada (USDA 2009, CBCN 2007). *E. umbellata* is known as an aggressive competitor in natural settings, displacing native species and interfering with succession and nutrient cycling in native plant communities because of its ability to fix nitrogen (US NPS 2004). At the site it was recorded (LS), there were several large individuals (~3 meters tall) and a smaller individual (<1 meter tall) was found at another site (HF). Given that *E. umbellata* has a high invasive potential (CBCN 2007) spreading mainly by birds that eat the fruits (US NPS 2004) and each of the individuals at LS were observed to be fruiting heavily, it is possible that this species has already spread well beyond the site and has gone unnoticed. Another interesting record for the metro Halifax area was also found at LS. The small aster, *Symphyotrichum ciliatum* (Rayless Aster) is native to northern Ontario in the saltmarshes around James Bay. It is however, considered introduced further east where it grows in winter-salted waste ground and roadsides (Flora of North America 2009). LS is situated between a rail line and the Halifax Harbor with no winter salted roads adjacent. Salt spray from the harbor likely provides the high salt habitat that this species requires.

The site in Spryfield (SF) was by far the most diverse floristically. The additional non-plot survey doubled the species richness and many of the additions were native species (such as *Drosera rotundifolia, Salix discolor* and *Typha latifolia*) and garden escapes (such as *Symphoricarpos albus*, *Origanum vulgare*, *Ligustrum vulgare,* and *Laburnum anagyroides*) unique only to that site. SF was also the most diversity of topographically. The wealth of species on that site can likely be attributed to the range of micro-sites created by topographic variation and the substrate diversity of fill material that is present. This is consistent with Kuhn *et al*. (2004) who found that structural and geological heterogeneity contributes to higher species richness. Small-scale habitat variability can provide for a wide range of species and allow different vegetation types to occur in relatively the small areas of derelict sites (Sukopp *et al*. 1979). Sites with lower diversity values (HF, LS and DC) were among the flattest, but other sites with greater diversity values seemed to have comparable low variations in topography. The high incidence of ornamental species at SF may also just be a product of its past use as a residential area where seeds or other propagules remained on site. Further study of small-scale differences in topography and urban site diversity would be necessary to prove definite correlations.

2.4.3 FACTORS INFLUENCING COMMUNITY COMPOSITION AND DIVERSITY IN USV SITES

The results indicate that species composition of USV communities are not strongly determined by the variables measured (soil moisture, depth, nutrient composition and temperature). In Brussels, Gödefroid *et al*. (1997) found a significant relationship between species composition in urban wastelands and soil nutrient content, soil moisture and soil pH, but in this study the r^2 values were too low (0.06-0.36) to infer strong correlations. However, closer investigation of the data revealed some general trends in plant composition and diversity of USV. These trends are highlighted below including a discussion of other possible driving factors of USV community not investigated in this study.

Woody plants were exclusively associated with plots with deeper soils, low nitrate and low moisture content. Plots with shallow substrates supported more annual species, regardless of nutrient or moisture values. While it is not surprising that deeper substrates support more perennial and woody vegetation, it is unknown why these plants are associated with drier, less fertile sites.

Plot diversity (species richness and percent native species only) were exclusively influenced by soil nutrient factors (despite low r^2 values), with high copper and zinc correlating with low plot richness and low pH, high organic content and low nutrients correlating with presence of native species. Perhaps the heavy metals had an effect on plant establishment either by direct contamination of tissues or by altering vital soil processes. Heavy metals can interrupt nutrient cycling by drastically reducing soil microorganisms and soil fauna (Gilbert 1989, Wheater 1999). Pre-settlement soils of

Halifax are significantly more acidic than at USV sites (mean forest pH =4.0 versus mean USV pH=6.4), thus it is not surprising that native species are associated with lower pH. Generally more alkaline due to the presence of calcium in manufactured materials (Gilbert 1989), the high pH of wasteland sites promotes the presence of non-native species (Godefroid *et al*. 2007).

It is not obvious why there was a significant difference between community composition on either side of Halifax Harbor (Halifax and Dartmouth), but other factors not directly measured in this study could be driving these composition patterns. Successional age, site history, available species pool, frequency and level of disturbance, and site microtopography can affect species patterns and diversity and may be different of either side of the harbour. Comments regarding these factors and their possible influences on some of the sites and are described below.

Although time since initiation of vegetation development was not directly quantified in this study, vegetation characters such as height of the tallest woody species may be used to approximate site age and successional status (Gilbert 1992, Gödefroid et al. 2007). The sites presumed to be youngest (MT and ML) and oldest (LS and DC) did not reveal any richness patterns relating to perceived age of site, but more accurate information on time since disturbance is needed to confirm any possible temporal relationships. However, the two sites presumed to be the oldest, did had the greatest percentage of native vegetation (51.2% and 67.1% respectively). This supports that succession tends to reduce the diversity of non-native species in urban areas (Gibson *et al*. 2000, Kowarik 2008).

The low phylogenetic diversity at USV sites is an effect of low phylogenetic diversity in cities in general, a widely recognized consequence of urbanization on biodiversity (Gilbert 1989, Hu *et al*. 1995, Kendle and Forbes 1997, Knapp *et al*. 2008). Urban plant composition in general is dominated few families, namely Asteraceae, Poaceae and Lamiaceae due to a variety of shared traits which make them more successful in urban environments than other plant families (Gilbert 1989). Other effects on urban species pools are direct human introductions. Spatial patterns in urban vegetation may be determined by human factors alone especially income (Hope *et al*. 2003) and neighborhood age (Hope *et al*. 2003; Turner *et al*. 2005). Also sites near railroads (such as LS and SP) might be expected to contain a higher number of non-natives or a higher number of species in general) because of the introduction of seeds and propagules through accidental and intentional importation of materials via freight cars. These sites actually had lower species richness and Shannon index values than most USV sites. This is consistent with Lund's (1974) findings that railway adjacent areas did not contain more casual or incidental species than other sites (such as parking lot edges).

2.5 CONCLUSIONS

Urban spontaneous vegetation is especially species rich in metro Halifax, but it is unclear the exact reasons for such high numbers. Halifax is a hub of an international transportation with a heavy traffic in the container terminal, and subsequent rail/truck industry. The volume of international trade may make Halifax susceptible to greater propagule pressure than other cities, but without further study, this conclusion can only be hypothesized. It is clear that a unique urban flora exists in Halifax comprising of mostly herbaceous communities heavy in non-native grasses and composites, but the presence of non-native species is not an indication that these plants have negative effects in natural habitats in Nova Scotia. Opportunities to detect and monitor invasive species are improved by studying areas of USV and this is revealed by this study.

Large gains toward increasing urban biodiversity are obtainable with minimal site management of USV sites. Simple efforts could be incorporated into urban landscape planning strategies depending on project goals. Allowing topographic variation at sites would encourage a greater diversity of microhabitats therefore increasing overall plant diversity (e.g. Spryfield site), removing as much construction materials as possible may encourage lower soil pH to encourage native species colonization and ensuring soil depth is enough to support woody vegetation would encourage succession to woodland.

Chapter 2 Figures

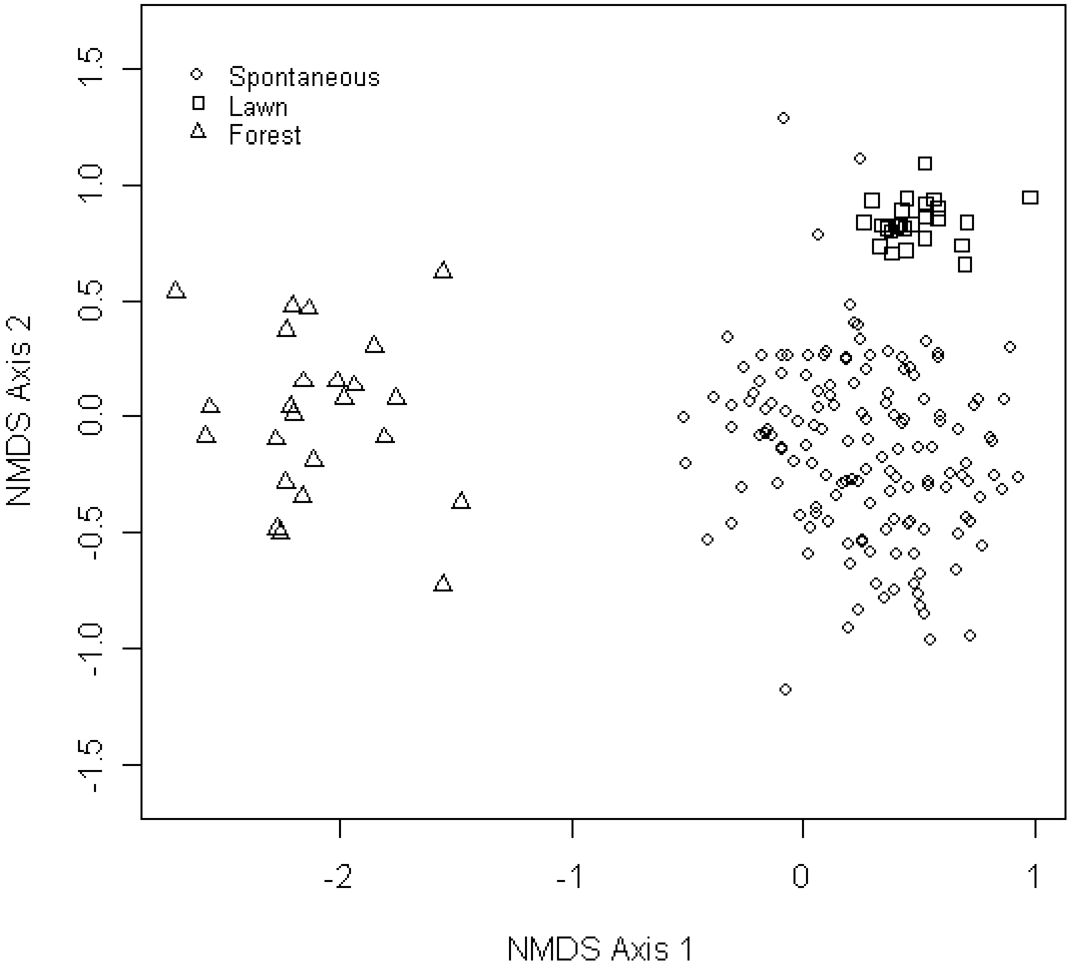


Figure 2.1 Nonmetric-multidimensional scaling ordination of all urban habitat quadrats (stress: 16.8). Symbols show position of 1 m^2 quadrats on first two axes of ordination. Symbol shape designates habitat type as indicated.

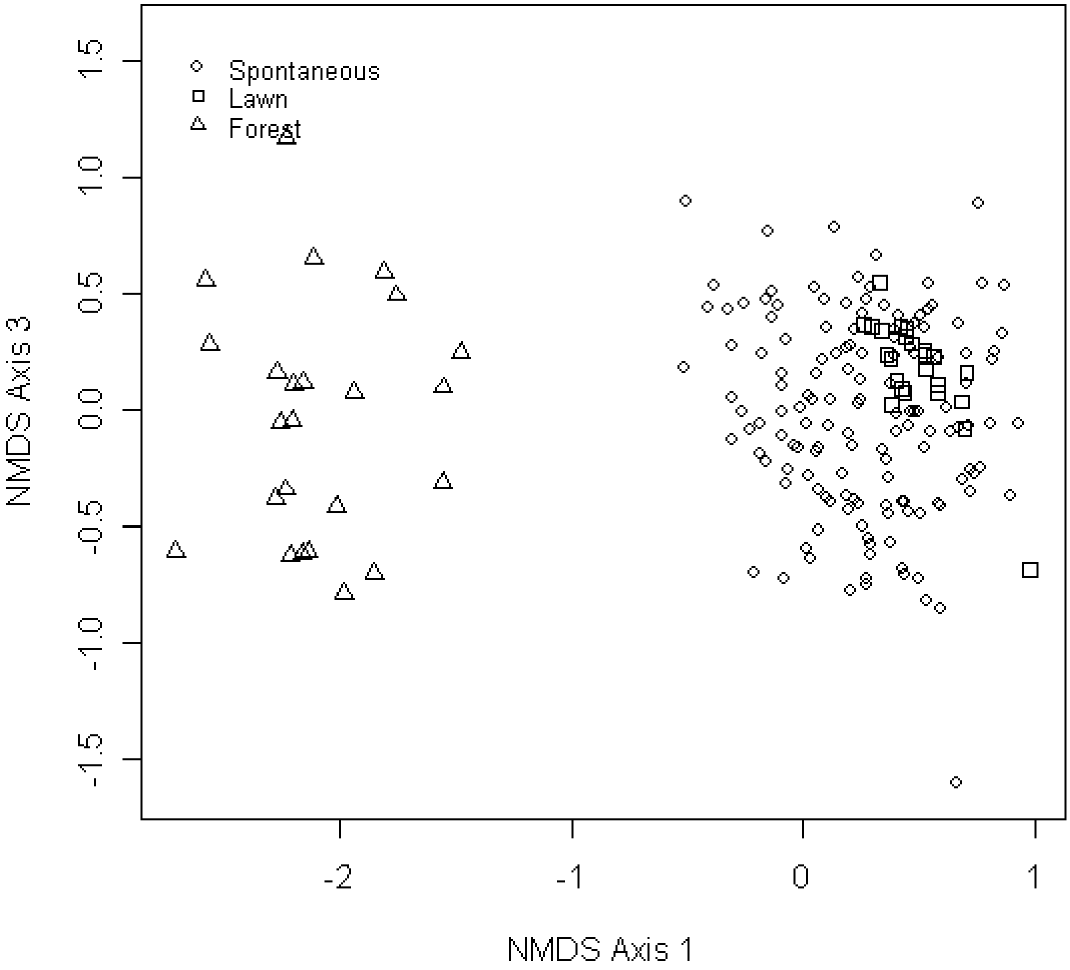


Figure 2.2 Nonmetric-multidimensional scaling ordination of all urban habitat quadrats (stress: 16.8). Symbols show position of 1 m^2 quadrats on the first and third axes of the ordination. Symbol shape designates habitat type as indicated.

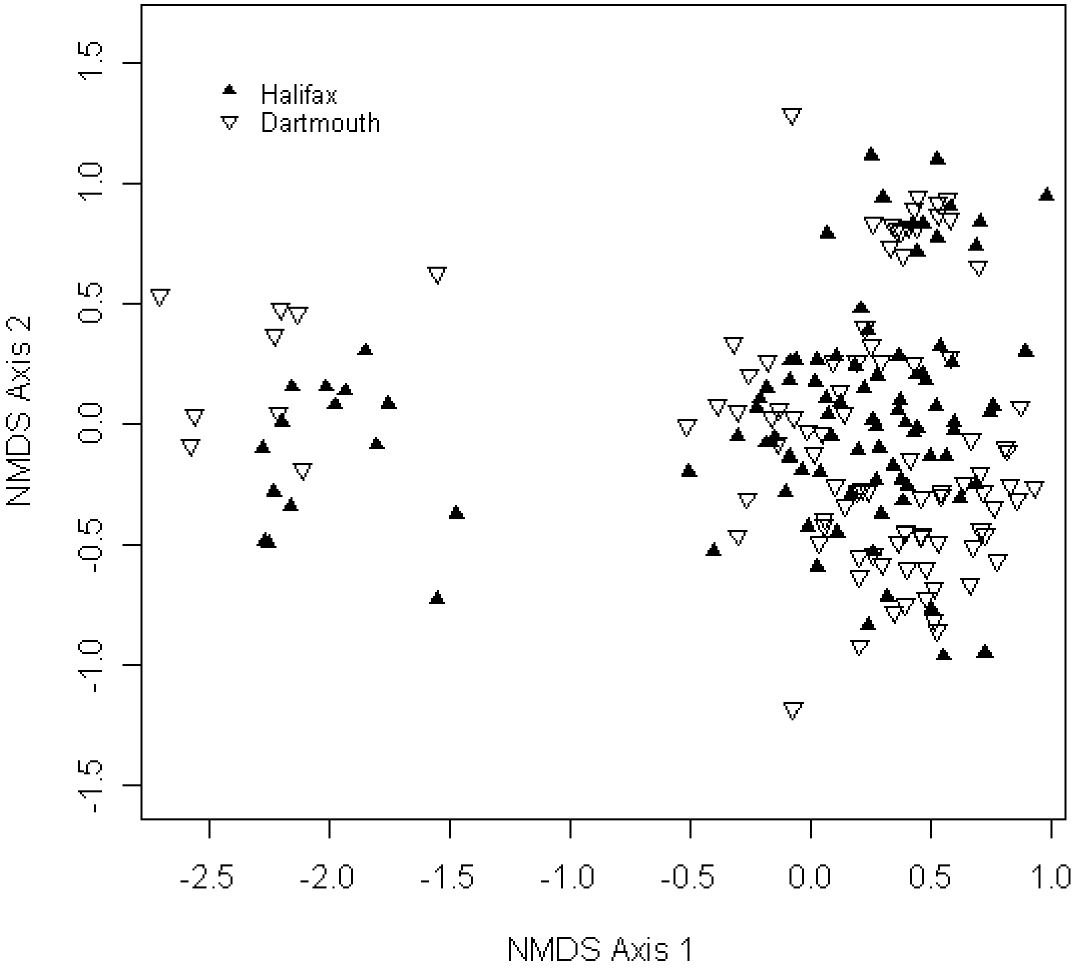


Figure 2.3 Nonmetric-multidimensional scaling ordination of all urban habitat quadrats (stress: 16.8). Symbols show position of 1 m^2 quadrats on the first two axes of ordination. Symbol shape designates city as indicated.

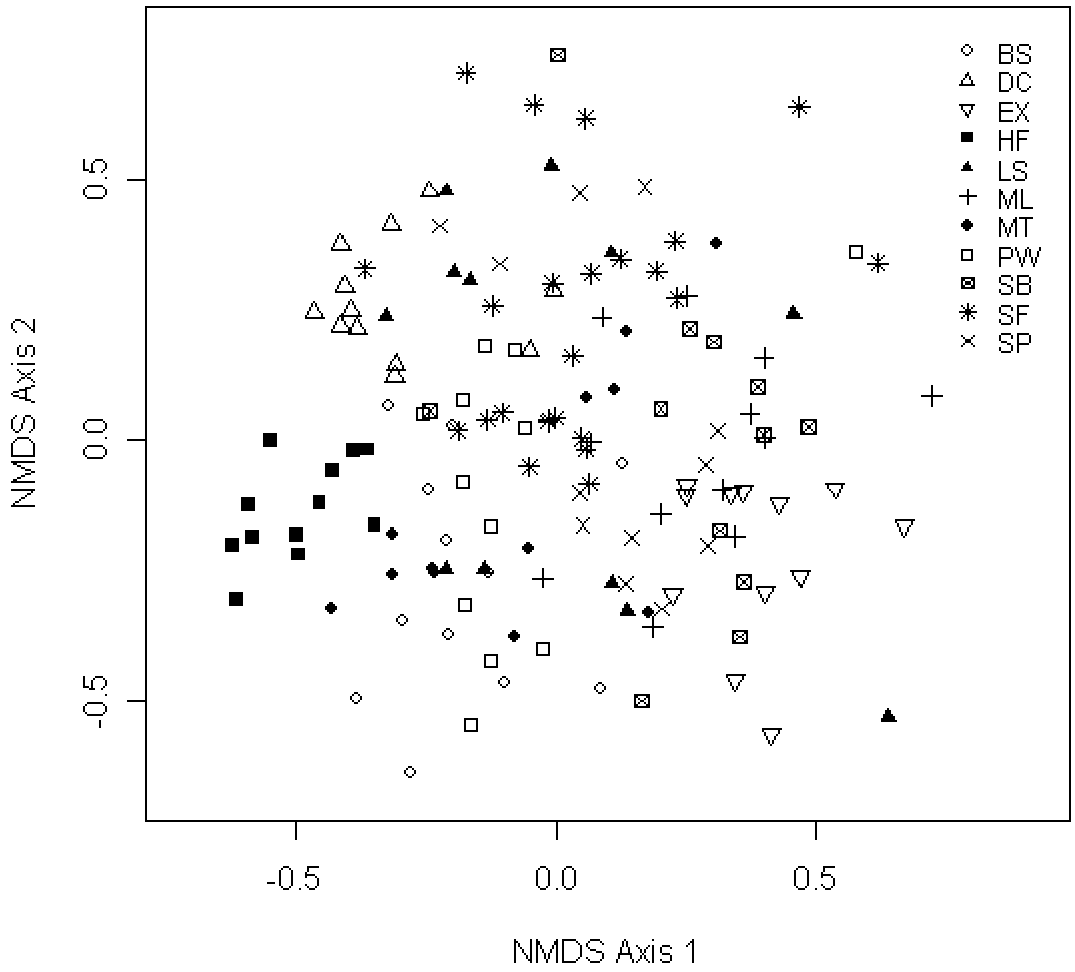


Figure 2.4 Nonmetric-multidimensional scaling ordination of urban spontaneous quadrats. Symbols show position of 1 m^2 quadrats on the first two axes of ordination. Symbol shape designates urban spontaneous site as indicated.

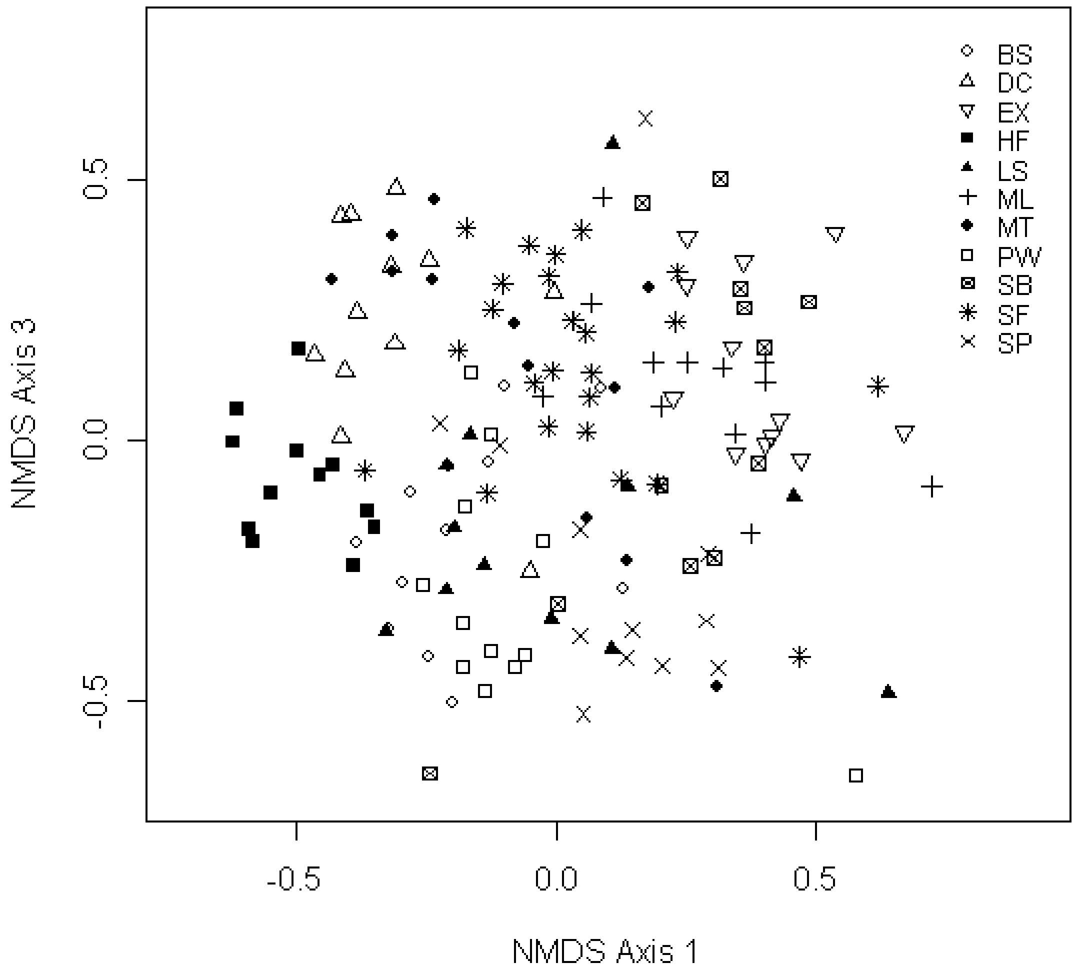


Figure 2.5 Nonmetric-multidimensional scaling ordination of urban spontaneous quadrats. Symbols show position of 1 m^2 quadrats on the first and third axes of the ordination. Symbol shape designates urban spontaneous site as indicated.

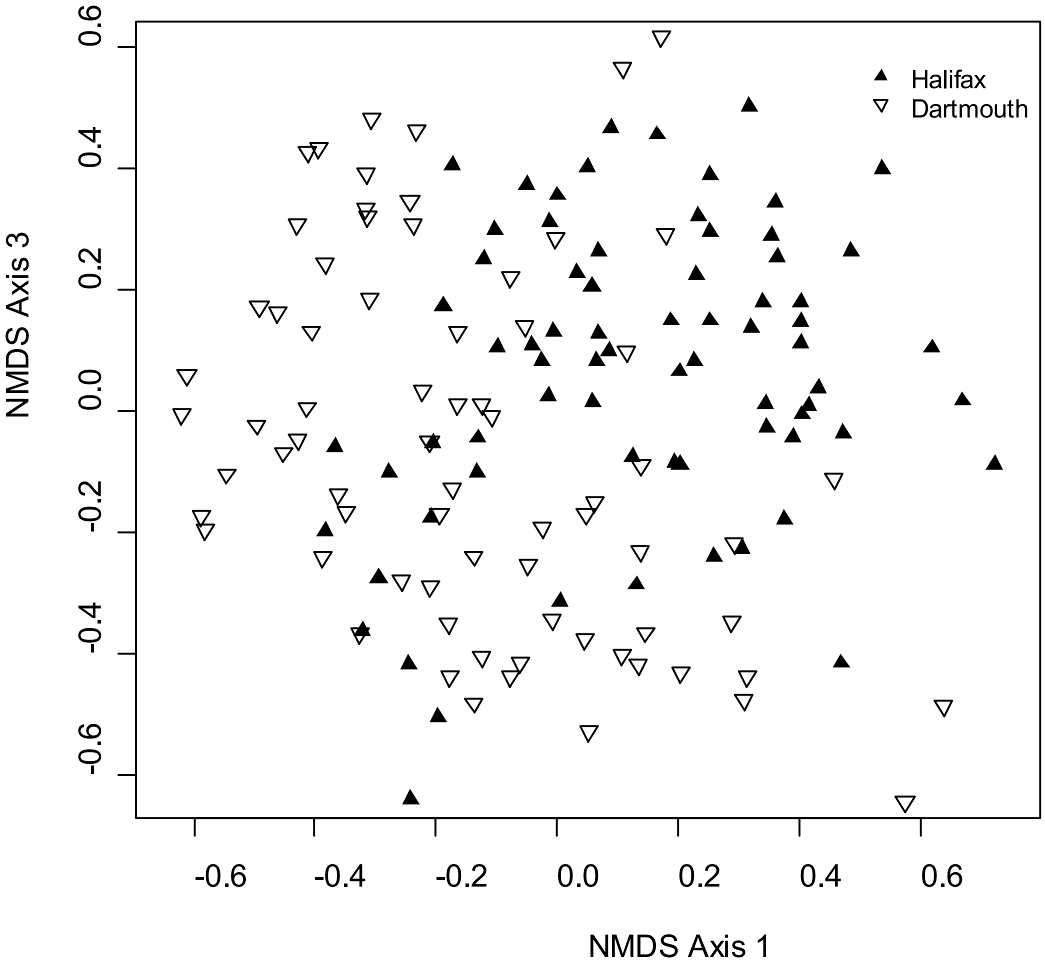


Figure 2.6 Nonmetric-multidimensional scaling ordination of urban spontaneous quadrats. Symbols show position of 1 m^2 quadrats on the first two axes of ordination. Symbol shape designates city as indicated.

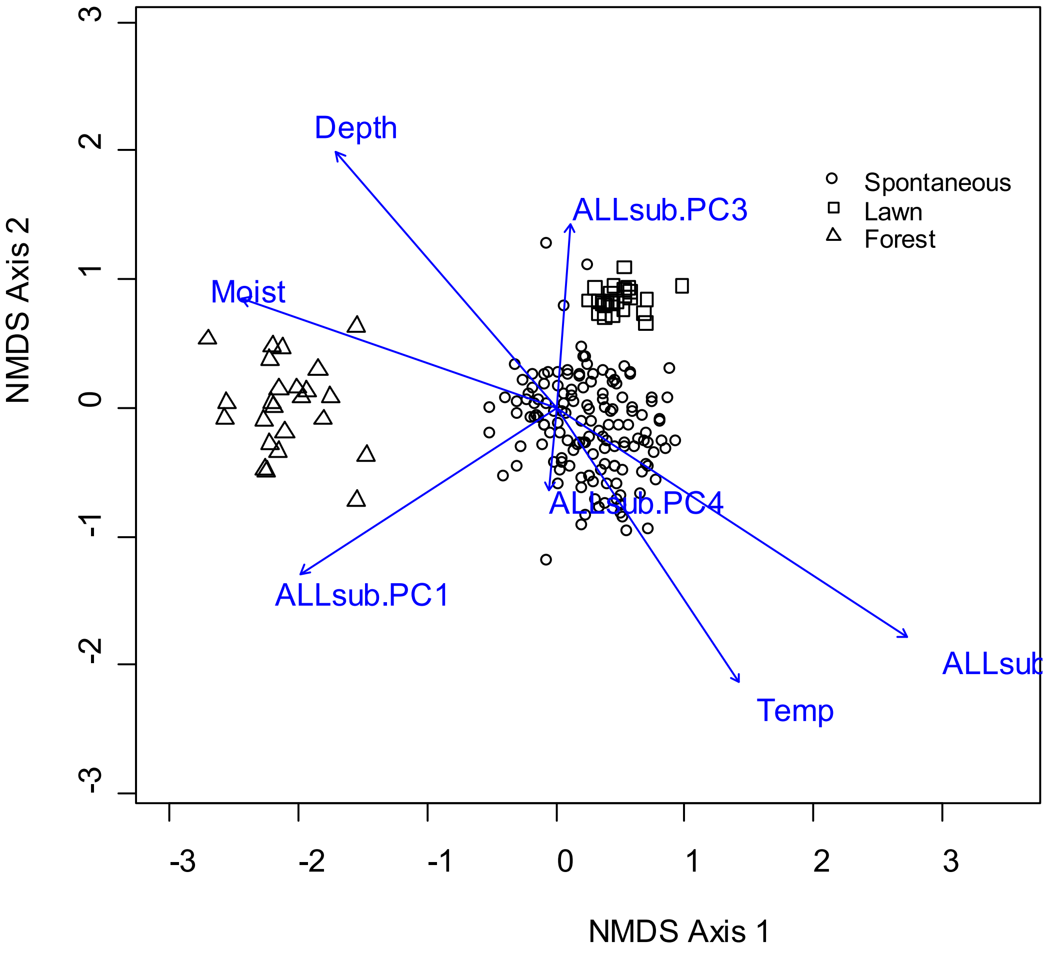


Figure 2.7 Nonmetric-multidimensional scaling ordination of all urban habitat quadrats fitted with substrate nutrient PC and other environmental vectors (stress: 16.8). Symbols show position of 1 m^2 quadrats on the first two axes of ordination. Symbol shape designates urban habitat as indicated.

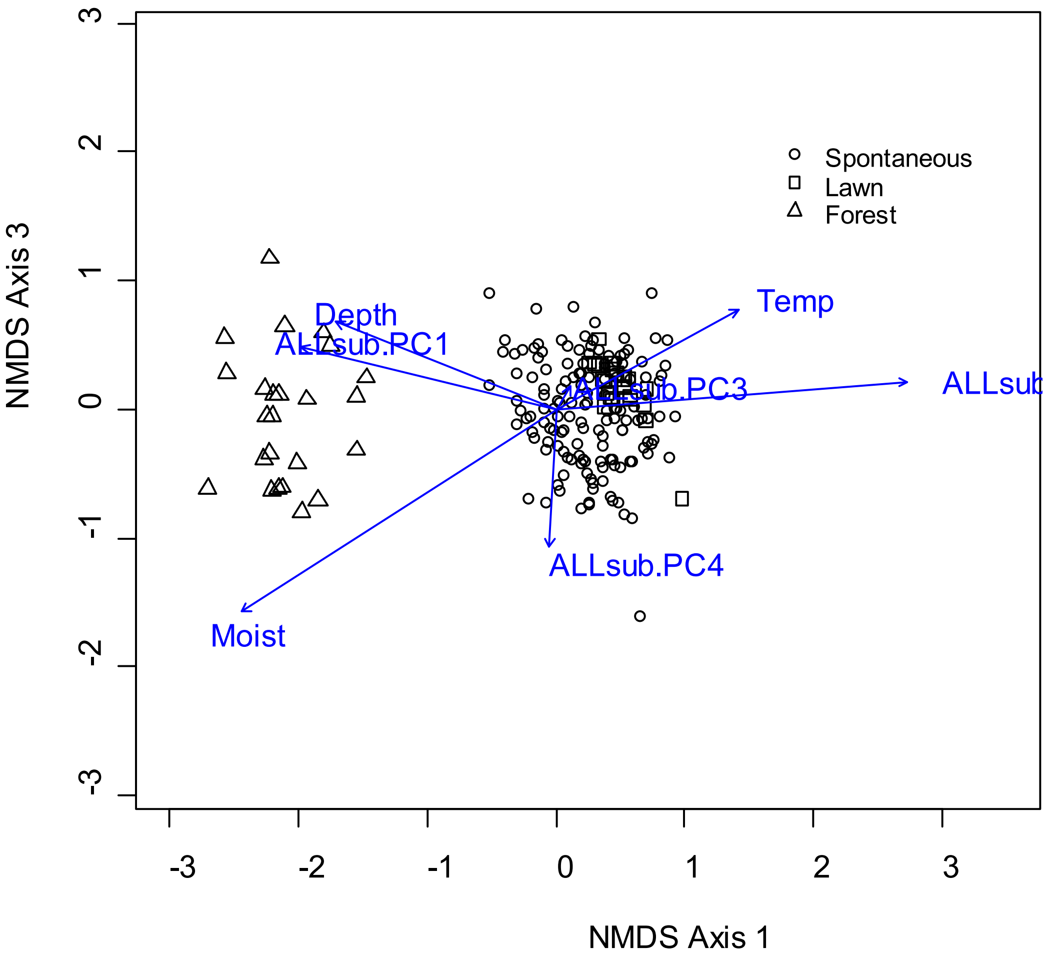


Figure 2.8 Nonmetric-multidimensional scaling ordination of all urban habitat quadrats fitted with substrate nutrient PC and other environmental vectors (stress: 16.8). Symbols show position of 1 m^2 quadrats on the first and third axes of the ordination. Symbol shape designate urban habitat as indicated.

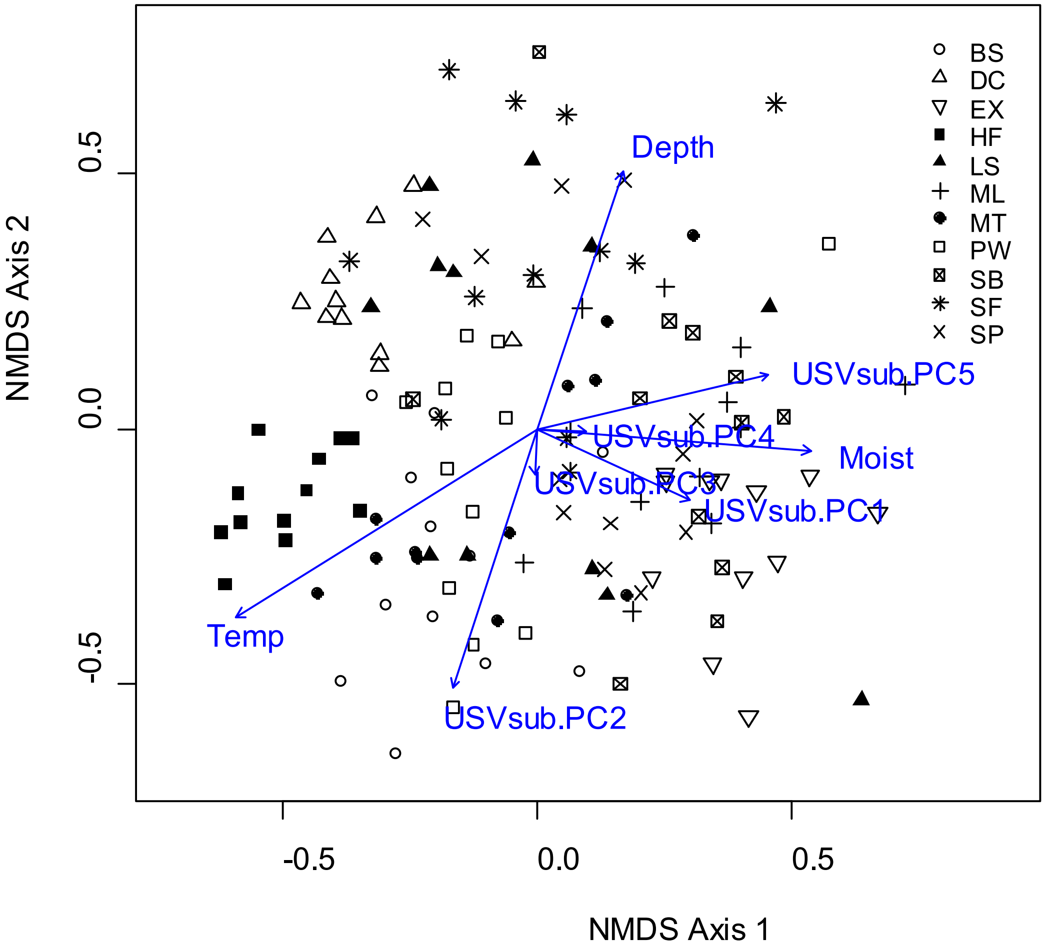


Figure 2.9 Nonmetric-multidimensional scaling ordination of urban spontaneous quadrats fitted with substrate nutrient PC and other environmental vectors. Symbols show position of 1 m^2 quadrats on the first two axes of ordination. Symbol shape designates urban spontaneous site as indicated.

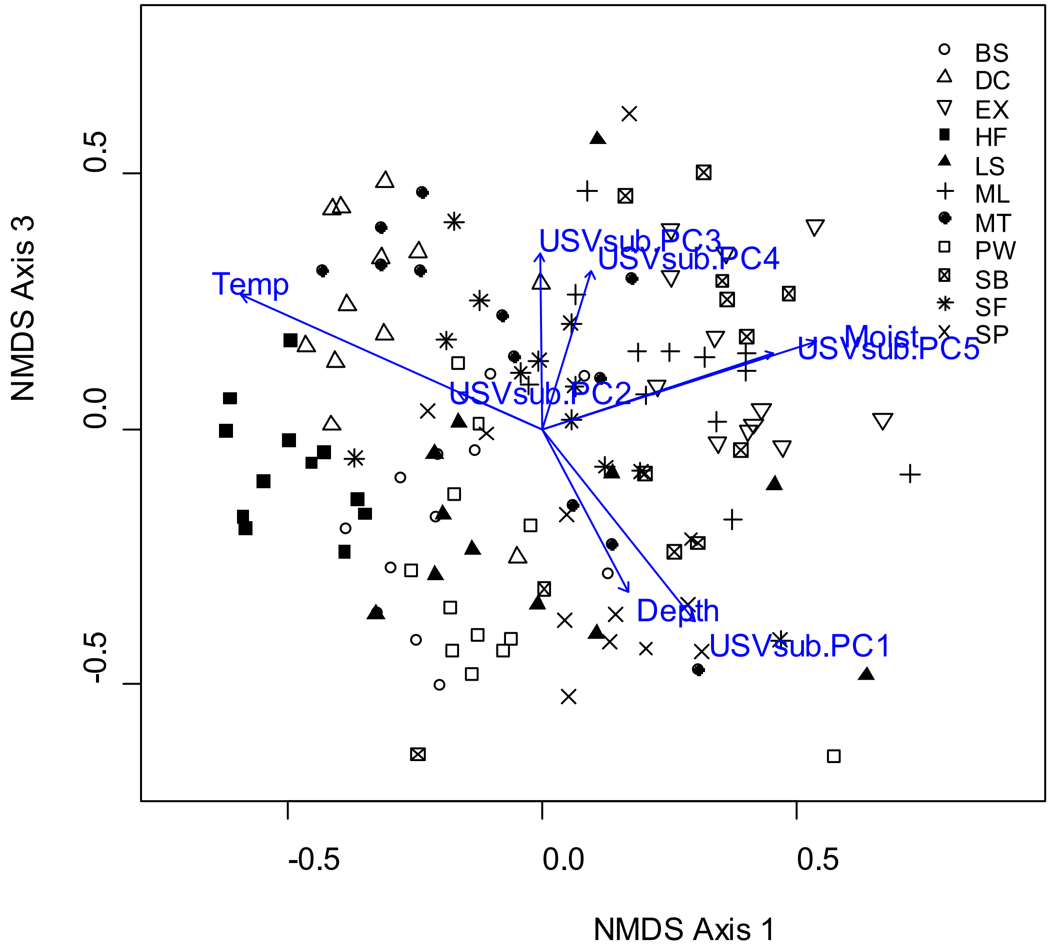


Figure 2.10 Nonmetric-multidimensional scaling ordination of urban spontaneous quadrats fitted with substrate nutrient PC and other environmental vectors. Symbols show position of 1 m^2 quadrats on the first and third axes of the ordination. Symbol shape designates urban spontaneous site as indicated.

CHAPTER 3 - CONTRIBUTIONS TO ECOSYSTEM FUNCTIONS AND SERVICES BY URBAN SPONTANEOUS VEGETATION AND PREDICTORS OF SERVICES

3.1 INTRODUCTION: ECOSYSTEM FUNCTIONING AND SERVICES IN CITIES

Although ecosystem processes differ in human-dominated environments, urban vegetation provides valuable ecosystem functions that benefit city inhabitants (Bolund and Hunhammar 1999). The role of urban forests (street trees), parks, and gardens in urban ecosystem functioning are well known (Bolund and Hunhammar 1999, Nowak 1995, Freedman *et al.* 1996; Akbari *et al.* 2001), but contributions to ecosystem functioning by other semi-natural areas and created habitats like spontaneously colonized areas are not well recognized. Ecosystem functions are the capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly (de Groot *et al.* 2002). Natural processes, such as decomposition, production of plant matter and nutrient cycling, are the result of complex interactions between biotic (living organisms) and abiotic (chemical and physical) components of ecosystems. There are four primary groups of ecosystem functions: production, regulatory, habitat and information functions (de Groot *et al.* 2002). Each function is the result of natural processes of the ecological sub-system of which it is a part and each ecosystem process has associated goods and services. Typically, ecosystem services are those considered to have value to people, either individuals or society (IPCC 2001). (For simplicity, I will refer to ecosystem functions, goods and services together as ecosystem functions.)

Areas of urban spontaneous vegetation (USV) may contribute significantly to a range of ecosystem processes not currently captured in urban ecosystem models, providing equivalent or greater ecosystem value as other common urban habitats including carbon and nutrient cycling, regulation of air temperature, habitat provision, erosion control, and the absorption and detoxification of wastes (i.e. road salt). This study seeks to prove that natural, semi-natural and created habitats all play an important role in maintaining the overall quality of life in urban areas. I investigate how USV contributes to three of the four groups of ecosystem functions (production, regulatory, habitat functions) by measuring indicator variables chosen to representing these functions at three common urban habitat types: urban spontaneous vegetation, lawn and remnant forest. The ecosystem functions and their chosen indicator variables are outlined below.

3.1.1 PRODUCTION FUNCTIONS

Through photosynthesis, plants and other autotrophs convert energy, carbon dioxide, water and nutrients into a wide variety of carbohydrate structures. These carbohydrates support secondary producers, which then creates a greater variety of living biomass. Production functions provide ecosystem services such as the food production, raw materials, genetic material, medicinal and ornamental resources. Biomass (dry weight) of aboveground vegetation and abundance of invertebrates will serve as indicator variables for the provision of food or conversion of solar energy into plants and animals. USV may also serve as areas for wildcrafting or the practice of harvesting uncultivated plants for food, medicinal, or other purposes. Lund (1974) noted that 75% of uncultivated urban vegetation in central Atlanta, Georgia had some recorded ethnobotanical significance ranging from food, medicinal and horticultural use.

3.1.2 REGULATORY FUNCTIONS

Regulatory functions refer to the capacity of natural and semi-natural ecosystems to control essential ecological processes and life support systems through bio-geochemical cycles and other biospheric processes (de Groot *et al* 2002). In addition to maintaining the ecosystem (and biosphere health), regulatory functions provide many services with direct and indirect benefits to humans (i.e. clean air, water and soil and biological control). The advantages of urban trees and other plants in an urban setting include improved air quality, reduced air temperatures and lower energy demands for buildings (Akbari *et al.* 2001). Trees, shrubs and other natural vegetation lower urban air temperatures through the process of evapotranspiration, which uses energy to evaporate water, and the reflection of incoming solar radiation causing the air to heat less. Vegetation may lower overall urban temperatures by 1 °C, while closed vegetation canopies may lower local temperatures by an additional 2 °C (Kurn *et al.* 1994). Lower temperatures improve air quality because the production of smog increases at higher temperatures (Akbari *et al.* 2001). Plants also remove atmospheric and terrestrial contaminants, including the process of converting carbon dioxide to oxygen and water through photosynthesis. Other gaseous pollutants (i.e. ozone and carbon monoxide) are absorbed through leaf stomata and can be retained in tissues (Nowak *et al.* 1998). Particulate pollutants are intercepted by leaf and stem surfaces as wind passes over the plants and most of the trapped particles adhere to plant surfaces and get washed off or resuspended but some may be absorbed and incorporated into plant biomass (Nowak 1995). Nitrogen dioxide, sulfur dioxide, carbon monoxide, and ozone are removed from the atmosphere by plants through dry deposition (Currie 2005). The potential to positively affect air quality and air temperature is linked with the area of leaf surface (leaf area index or LAI) available for gas and water exchange and particle interception and reflectivity (albedo) of the vegetated area. Leaf surface area is used as the indicator for the capacity to mitigate air pollution and cool the air through transpiration. The higher the LAI, the greater the potential for pollutant mitigation, gas exchange and transpiration. Vegetation cover and ground surface temperature were measured as indicators for the degree of surface shading from sample sites. Dark surfaces absorb solar radiation later releasing it as heat, while vegetated surfaces absorb and reflect incoming solar radiation. Any vegetation canopy would provide some shading therefore reducing heat absorption (and later release) of dark surfaces. When less heat is absorbed and stored there is less contribution to urban warming.

Soils serve as the basis of many biogeochemical processes such as nutrient and water cycling and providing nutrients and habitat for soil fauna and flora (Bullock and Gregory 1991). Urban soils store carbon and intercept pollutants and other contaminants from human activities such as deicing salt (Cunningham *et al.* 2008). The contribution of urban soils as a carbon sink will be measured by the amount of organic carbon in soil samples of the three urban habitats. The relative level of organic carbon is used as the indicator for the capacity of soil to act as a carbon sink.

Pollination is a vital ecosystem function in terrestrial systems. Early successional wasteland vegetation can support a great diversity of pollinating insects due to the abundance of nectar producing flowering vegetation (Harrison and Davies 2002). Indicator variables for the support of regulatory pollinating services in this study are the abundance and diversity of pollinators present in urban habitats.

3.1.3 HABITAT PROVISION

Urban habitats provide refuge, food and habitat for a many plant and animal species. As noted in the previous chapter, USV floral communities can be very floristically diverse. USV can also support high numbers of animal species. Likely, the most prominent groups of animals of USV areas are birds and invertebrates. USV areas support many foraging and seed eating birds (Gilbert 1989) and invertebrate populations find suitable habitat for several life stages including egg laying, nesting and feeding. Studies in the UK have shown high invertebrate richness and diversity in derelict and brownfield sites (see Angold *et al.* 2006, Eyre *et al.* 2003, Small *et al.* 2003). These sites can provide conditions similar to natural habitats (such as sandy heaths and chalk grassland) and may help maintain populations of rare insect species (Eyre *et al.* 2003). In fact, some wasteland habitats associated with derelict and vacant land has received conservation status due to the presence of rare insect species (Harrison and Davies 2002). Plant species diversity (species richness, Shannon index, and native species richness) and invertebrate species diversity (species richness) were chosen as indicator variables for habitat provision in the three urban habitats. Although birds (and other groups such as mammals) find habitat in USV areas, it was out of the range of this study to include them.

The provision of habitat for urban plants and animals ultimately depends on the condition and nutritional profile of soil. Thus, in addition to floral diversity and invertebrate diversity, soil nutrient composition will serve as an indicator variable of the capacity of USV habitats to perform habitat functions. Levels of primary nutrients such as phosphorus, nitrogen and potassium will be compared as a measure of soil fertility and habitat provision functions.

3.1.4 CHAPTER OBJECTIVES

In order to measure the contribution of USV to valuable ecosystem services a series of variables were chosen to represent each of the three ecosystem functions.
This chapter sets out to address the following question:

1. How do different urban habitats (USV, lawn and forests) differ in levels of ecosystem functions?
2. What environmental factors are associated/correlated with which functions?

3.2 METHODS

For an overview of the study region, site selection and sampling design see **Methods** Chapter 2 (2.2)

3.2.1 VARIABLES REPRESENTING ECOSYSTEM SERVICES

Variables representing ecosystem services and functions were sampled throughout the 2008 the growing season (May-October), see table 3.1. Species richness, Shannon index, and native species richness were calculated from PI vegetation data from summer 2007. Substrate temperature, light availability at ground level and albedo (reflectivity of surface), were measured at each plot at midday (1100-1400 hours) on a clear-sky day. Temperature measurements were taken by placing a digital thermometer at the substrate surface three times over the sampling season (June, July, and August). Temperature readings were also taken at nearby paved surfaces. Light and albedo measurements were made in the center of the quadrat using a light meter (model number: LI-250A, Licor Biosciences). Light availability at ground level was measured using a light sensor (Model number: LI-190SA, Licor Biosciences) that measures incoming photosynthetically active radiation (400 to 700 nanometers). To be able to compare surface shading for multiple days, light availability at surface was calculated as a ratio of unobstructed incoming radiation and light at ground surface. Albedo was measured by taking upward and downward readings with a pyranometer sensor (model number: LI-200, Licor Biosciences) at a height of approximately 1 m. Albedo of the quadrat was calculated as the ratio of upward and downward values. Albedo was measured three times over the sampling season (June, July, and August) and an average of measurements is used in the analysis.

Above-ground plant biomass was sampled in mid-August by clipping all vegetation at ground level within a 10 cm strip oriented along a north-south axis centered in each quadrat. Plant material was placed in paper bags and oven-dried at 70°C for at least 48 h and weighed. For lawns biomass was estimated by multiplying the biomass of the clipping sample by the number of times one of the lawns was mown (n=13). Forest biomass was not sampled directly but references were obtained from several published studies of similar forest types (mixedwood and Acadian, see Simpson *et. al.* 1993; Botkin and Simpson 1990).

Leaf area index (LAI) or one sided green leaf area per unit ground area was calculated using a 20 randomly selected spontaneous plots and 5 randomly selected lawn plots collected during biomass sampling. All leaves were scanned at 600 dpi on a flatbed scanner and leaf area calculated using Leaf Area Measurement software (version 1.3) (University of Sheffield 2003). Linear regression was performed to obtain a regression equation that would predict LAI based on plot cover ($LAI=0.0072x+0.7568$, where x=plot cover).

Substrate from each plot was assessed for pH, % organic matter, and the following nutrient components as described in chapter 2: P, K, Ca, Mg, Na, S, Fe, Mn, Cu, Z, B, nitrate, and CEC.

Sweep net samples were taken to capture flower-visiting insects at each plot, three times during the May-October 2008 sampling period. All samples were collected between the hours of 1000 and 1430 on a sunny day with little wind. Four sweeps were taken while proceeding in a line through the center of each sub-plot, beginning and ending about 0.5m from the edge of the sub-plot. Because some sub-plots were contiguous, during sweep netting insects may "flee" from a sub-plot and be subsequently captured in an adjacent plot. To prevent this, non-adjacent plots were sampled before going back to sample the remaining plots. Samples were immediately transferred to jars and then transported to a freezer in the laboratory for later identification.

Table 3.1 Indicator variables measured during the 2008 growing season (May-October) representing ecosystem functions. Included are the ecosystem processes of the related functions.

Function	Ecosystem processes	Indicator variables
Production and habitat functions	Conversion of solar energy into biomass and provision of habitat for wild plant and animal species	Vegetation biomass Plant species diversity and abundance Invertebrate diversity and abundance Soil nutrient composition
Regulation functions	Maintenance of vital prosesses and life support systems including gas and climate regulation	Albedo Substrate temerature % vegetation cover Light availability at substrate Leaf area Polinator diversity and abundance Soil organic carbon content

Ground invertebrates were sampled using pitfall traps placed in the center of each sub-plot. The pitfall traps were unbaited, consisting of plastic cups (diameter 65 mm, volume 250 mL) containing approximately 50mL of 75% ethylene glycol as a killing/preserving solution. The traps were covered with linoleum/ceramic tiles, larger rocks or bark pieces to protect them from litter and rain. Trapped invertebrates were collected at 2 week intervals during the sampling period. Samples were stored in the laboratory refrigerator until processing and identification. For analysis the samples were pooled from the 5 month period.

All adult invertebrates were identified to species if possible and assigned to a family or morphogroup. Many invertebrates were identified to only family and in some cases order, because of the volume of samples. Invertebrate identification was facilitated by use of insect collections at the Nova Scotia Natural History Museum in Halifax, Nova Scotia and the Nova Scotia Department of Natural Resources in Shubenacadie, NS, as well as the expertise of Dr. Christopher Majka, research associate of the Nova Scotia Museum and J. Scott McIvor, PhD. Candidate, Biology Department, York University, Toronto, ON.

Insect guilds regarded as important pollinators (bees (Hymenoptera, Apoidea); wasps (Hymenoptera, Vespidae); flower flies (Diptera, Syrphidae); bee-flies (Diptera, Bombyliidae) and butterflies (Lepidoptera, Papilionoidea and Hesperioidea)) were tallied and diversity (species richness) and abundance were generated for each plot.

3.2.2 STATISTICAL ANALYSES

Independent two-sample *t*-tests were performed on the means of the variables representing ecosystem functions to determine statistical differences between habitat types. The measured variables were also compared with reference values (where relevant) from the literature.

3.3 RESULTS

3.3.1 COMPARISON BETWEEN HABITAT TYPES

All indicator variables differed significantly between habitat types (Table 3.2). Spontaneous plots differ significantly in all variables and lawns and forests differ significantly in all but three indicator variables. Details of each variable are presented below.

Table 3.2 Mean and standard error for variables representing ecosystem functions for each of the three urban habitats sampled. Different letters indicate statistically significant differences at α =0.05.

Variable	**Spontaneous**	**Lawn**	**Forest**
Vegetation richness (mean number of species per plot)	14.7±3.1a	7.5±2.4b	4.9±2.6c
Vegetation diversity (H')	2.0±0.2a	1.09±0.41b	1.12±0.55b
Soil organic carbon (%)	4.3±0.5a	5.42±0.69b	24.41±5.12c
Vegetation biomass (g/m2)	342.6±44.5a	1564.1±117.3b	4180±1010*
Vegetation cover (%)	0.7±0.1a	1.0±0.1b	1.0±0.0c
Surface temperature (ºC)	24.10±0.76a	20.39±0.95b	16.99±0.48c
Light (at surface) (µmol/s/m2)	479.96±82.57a	1499.92±114.76b	26.66±5.33c
Albedo (% reflected/incoming radiation)	0.22±0.01a	0.19±0.01b	0.15†
Leaf area index (m2/m2)	3.0±0.1a	1.3±0.0b	6.9‡
Total invertebrate richness - family	12.4±0.8a	9.3±1.1b	8.4±1.3b
Total invertebrate richness - order	8.1±0.4a	7.2±0.6b	6.6±0.7c
Total invertebrate abundance	217.9±47.7a	123.3±76.9b	58.6±21.2b

*Botkin and Simpson 1990

†Barry and Chorley 1992

‡Chen et. al. 2002

3.3.2 BIOMASS

On average spontaneous plots had lower biomass per 1 m^2 plot than lawn plots (342.6±22.7 g/m^2 versus 1564.1±59.9 g/m^2). Forest biomass varies greatly depending on type of forest. Deciduous forest typically has higher biomass (8100±1400 g/m^2; Simpson *et. al.* 1993) than boreal forest (4180±1010g/m^2; Botkin and Simpson 1990). Both spontaneous and lawn habitats have significantly lower biomass per m^2 than forests.

3.3.3 ALBEDO, LAI, VEGETATION COVER, SOIL TEMPERATURE AND LIGHT AVAILABILITY AT SURFACE

Albedo of spontaneous plots was significantly higher than lawns (0.21±0.01 and 0.19±0.01 respectively. Both of these habitats have higher albedo than reference forests. Forest albedo usually ranges from about 0.15-0.18 for deciduous forests to between 0.09-0.15 for coniferous forests (Barry and Chorley 1992).

Leaf area index of spontaneous vegetation was almost double that of lawns (3.03±0.10 m/m^2 and 1.26±0.04 m/m^2 respectively. LAI in Acadian forest can range from 3.5 m/m^2 (in deciduous stands) to 6.9 m/m^2 (in conifer stands) (Chen et. al. 2002). Franklin *et al.* (1997) calculated the mean LAI in New Brunswick mixwood forest to be 5.28 m/m^2.

Temperature at ground surface under vegetation was significantly higher in spontaneous plots than lawns and forests. Forests had the lowest average soil surface temperature at an average of 16.99±0.48 ºC across all plots. Temperature readings for nearby paved surfaces ranged from 8 to 20 ºC warmer than air temperatures.

All three habitat types had significantly different measurements for light availability at soil surface. Lawn plots had the highest values for light under the vegetation canopy followed by spontaneous vegetation, and forests (1499.92±114.76 μmol $s^{-1}m^{-2}$, 479.96±82.57μmol $s^{-1}m^{-2}$, and 26.66±5.33μmol $s^{-1}m^{-2}$ respectively)

3.3.4 ORGANIC CARBON, PH AND SUBSTRATE NUTRIENTS

Organic carbon was significantly lower in substrates of spontaneous plots, than in lawns and forests. Forests had the greatest amount of organic carbon and other nutrients such as Na, Fe and CEC. Spontaneous vegetation plots had significantly higher pH, Ca, S, Cu, Zn and B than both lawns and forest. Lawn plots had higher amounts of P, K, Mg, Mn, and NO_3^- in soils.

3.3.5 POLLINATORS

Insects known as pollinators were caught in both sweep net and pitfall sampling. Bees and wasps were found in pitfall traps early in the season (May-June) and were not found in the later part of the sampling period. Fourty-nine species of bees and wasps were found, including the European honey bee (*Apis mellifera*) and eight species of bumble bees (*Bombus spp*.). Twelve species of flower flies (Syrphidae) were collected and other pollinating wasps, butterflies and other flower dependent insects were found exclusively at spontaneous vegetation plots. No insects belonging to the "pollinator" guilds were found in forest or lawn plots. See appendix F for a list of all invertebrates identified from plot surveys.

3.3.6 PLANT SPECIES RICHNESS AND DIVERSITY

The average plot richness and H' was significantly greater in USV plots than in the other urban habitats. Lawns supported more species than forest understory but were similarly diverse (H').

3.3.7 INVERTEBRATE RICHNESS, ABUNDANCE AND A NEW SPECIES RECORD

We counted a total of at least 262 species and morphospecies of invertebrates representing 93 families or morphogroups in both the pitfall and sweep net sampling (see appendix F for a list of families and morphogroups collected in both sweep net and pitfall sampling). Across all pitfall samples, a total of 34 919 individuals were sampled; 30 397 in spontaneous plots, 3 083 in lawns and 1 439 in forests. Average plot abundance and family richness is found in table 2. Spontaneous plots had significantly higher values for all abundance and richness measures. For sweep net sampling only, a total of 669 individuals were found, with the majority found at spontaneous plots. No invertebrates were caught during sweep net sampling at lawn plots and 29 individuals were caught across all forest plots. Interestingly, lawns supported a greater number of individuals and species than forest habitats.

Table 3.3 Mean invertebrate abundance and family richness per plot and standard error for each of the three urban habitats sampled. Letters indicate statistical significance.

	Spontaneous	**Lawn**	**Forest**
Sweep abundance	3.38±0.55a	0	1.08±0.54b
Pitfall abundance	214.84±47.73a	123.32±76.94b	57.56±21.38c
Total abundance	217.92±47.70a	123.32±76.95b	58.60±21.21c
Sweep Family Richness	2.57±0.16a	0	0.84±0.21b
Pitfall Family Richness	10.02±0.35a	9.08±0.76b	7.84±0.51c
Total Family Richness	12.38±0.40a	9.28±0.54b	8.40±1.33c

During pitfall sampling, a Coleopteran species (*Hyperaspis inflexa* Casey) was discovered for the first time in the Maritime Provinces at one of the sites (HF). Little is known about the distribution of this genus of small coccinellids is in the Maritimes, as this discovery represents a range extension of roughly 600 km (closest records are reported from Québec and New Hampshire) (Majka and Robinson 2009).

3.4 DISCUSSION

3.4.1 PRODUCTION FUNCTIONS

Live biomass was assumed to measure primary productivity and was the indicator variable for production functions in the three urban habitat types. Spontaneous plots had significantly lower biomass than lawn plots (342.61±22.68 g/m^2 versus 1564.12±59.87 g/m^2); however, this may not be a fair comparison. The value for spontaneous plots represent standing biomass at time of sampling and lawn plots represent production over the whole growing season. Values for turf production are reported to be 300 g/m^2/yr by Milesi *et al.* (2004) which is actually lower than the turf production estimate in this study. This means that spontaneous plots outperform lawns in terms of primary productivity if the production of spontaneous plots (assuming the sampled represented peak standing biomass) was compared to this value. Forested habitats are expected to produce more biomass in urban areas due to the growth of large woody trees and shrubs, so their contribution to production function is greater than the other habitats sampled.

The abundance and variety of substrates and flowering plants appears to support a diverse invertebrate community that is distinct from those in the other habitats. The volume of invertebrates caught at USV sites was higher than at forests and lawns combined. The capacity of USV to support higher trophic organisms is likely enhanced by the diversity of species and lack of maintenance (i.e. biomass removal). USV sites are at least contributing greater invertebrate abundance than lawn sites by providing greater food and habitat values. The diversity of foods and habitats (richness of plant species) for invertebrates likely increases the production services of USV sites. Forested habitats certainly contribute considerably to urban production functioning, providing over 20 times more biomass than the other habitat types sampled. Invertebrates are undoubtedly abundant in remnant forest patches in metro Halifax; however sampling methods would not have captured the abundance of invertebrates that primarily utilize mature tree habitat of forested areas such as canopy dwellers and bark borers.

During plot sampling, a woman was gathering grape leaves from the DC site. This shows that USV sites have more than production functions than quantified here. Areas of USV are indeed places where urbanites can gather wild foods and perform other wildctafting activities.

3.4.2 REGULATION FUNCTIONS

Albedo, LAI, vegetation cover and ground surface shading

Albedo at urban spontaneous plots (0.216±0.009) was higher than lawns (0.194±0.006), and lawn albedo measurements were very comparable to values reported by others (Betts and Ball 1997). Albedo is lower in forested stands (maximum of 0.15 for coniferous stands (Barry and Chorley 1992)) so it seems both lawn and spontaneous vegetation have better reflectivity than forests. Forest albedo is highest in deciduous stands. At USV plots, the presence of concrete and other light colored substrate materials may have contributed to higher albedos. Vegetated high albedo surface coverings can reduce urban heat absorption. Green (vegetated) roofs, for instance, have surface reflectivities as low as 0.23 (Lazzarin *et al*. 2005) but can be as high as 0.7 to 0.85, depending on water availability (Gaffin *et al.* 2005). Paved and other dark gravel surfaces such as roofs typically have an albedo of 0.1, so any vegetated surface area including spontaneous vegetation would contribute to lower urban surface temperatures by reducing a city's albedo**.**

The leaf surface area of USV indicates a considerable capacity to filter and trap air pollution. Spontaneous vegetation plot LAI was twice as high as lawns and near the low end of the values for Acadian forests. Treed and forested areas indisputably outperform other vegetation in the city, but unmown grasses and other herbaceous vegetation also make an important contribution toward improving air quality (Currie and Bass 2008). With regular mowing, lawns barely reach an LAI of 1.5 m^2/m^2 (Milesi *et al.* 2005), while uncut grass typically has twice as much leaf surface area (3 m^2/m^2) (Currie and Bass 2008). USV plots also have taller vegetation and an increased complexity of leaf shapes and textures than lawn plots that would likely increase the ability to trap windborne particles. Community composition and complexity needs to be accounted for when assessing benefits of USV to urban air quality. Trees and shrubs have the greatest positive effect on air quality and plants with a large leaf surface area or finely divided leaves may be more efficient at trapping airborne pollutants.

Vegetation cover was lower at USV sites than lawns and forests. Typically, USV sites had substrates with high gravel content including paved surfaces and remnants of built structures. The vegetation cover at some USV plots was limited due to hard substrate surfaces, but shading of these dark surfaces is particularly important. Any vegetation canopy would provide some shading therefore reducing heat absorption of a dark surface. When compared to unvegetated urban surfaces, USV show dramatic shading and surface temperature differences. Temperatures at the surface of unvegetated concrete and pavement were on average 10°C warmer than USV plots.

Soil organic carbon (C storage)

On a global scale, soils function as a carbon sink but degradation by human activities has greatly influenced their functioning and development in urbanized areas (Effland and Pouyat 1997). The heat island effect influences carbon storage of urban soils because higher ambient temperatures increase CO_2 production (respiration) (Emmett *et al.* 2004). Organic content was considerably higher in forest soils, because of the greater contribution of organic matter by leaves and fallen trees. USV sites with high tree cover were also high in organic C. On average, lawns had greater soil carbon than USV plots. This may be explained by increases in productivity due to the input of nutrients and water, and lower compaction (low physical disturbance) often encountered in low-density residential and institutional land use types (Lorenz and Lal 2009). The longer growing season of cool season turf grasses also contributes to an increased soil carbon density (Pouyat *et al.* 2003). Grassy parks, especially with planted trees, can contain greater carbon (organic matter) content than local forested areas (Takahashi *et al.* 2008) and soil organic carbon content of residential lawns can be greater than in parks (Pouyat *et al.* 2006).

Above ground carbon storage was not estimated for spontaneous habitats mostly because the amount of woody vegetation among sites was not consistent. However, some sites supported larger trees and/or had significant shrub cover. Mature urban forests can store comparable amounts of organic carbon to more natural areas, including forested parkland (Freedman *et al.* 1996). If woody vegetation were to mature in spontaneously colonized urban spaces, the capacity for carbon storage (and therefore pollution mitigation) would be increased.

Pollinator diversity

The presence of pollinating insects exclusively at USV sites highlights the capability to support important insect pollinator populations along with gardens and other types of urban cultivated vegetation. Twenty-two species of bees and many flower-visiting wasps were recorded at USV sites including *Apis mellifera* (european honey bee) and eight species of bumble bees (*Bombus sp*.). The Hymenoptera (ants, bees, wasps and sawflies), Diptera, and Lepidoptera (butterflies and moths) are important flower visiting and pollinating insects. Among the flies, Syrphidae, Bombyliidae, and Muscoidea are particularly important contributors to pollination function (Larsen *et al.* 2001). At USV sites twelve Syrphidae, three Bombyliidae, and fourteen Muscoidea species were present. Syrphids are particularly economically important group; they often perform more pollination services than native bees in orchards and other agroecosystems (Thompson 1999). A few butterfly species were caught including *Vanessa virginiensis* (American lady), *Coenonympha tullia* (Common ringlet), and *Pieris rapae* (Cabbage white), while many others were sighted but not caught at USV sites. No Lepidoptera were seen at lawns or forests inside or outside the plots and these site are not known to support many butterflies. Spontaneously vegetated wastelands, however, are known to support a higher diversity of butterflies than any other urban habitat. Goode *et al.* (1995) recorded 15 species of butterfly in wasteland habitat, more than parkland (11 species), native woodland (6 species) and field habitats (2 species). We found at least 21 species of Lepidoptera including eight species of butterfly.

The USV sites supported a diverse community of pollinating insects that have aesthetic and economic value. Forest and lawn sites were not pollinator rich due to the relatively small diversity of flowering plants in forest understory and mown grass lawns. However, it is likely that the lack of invertebrates caught at forest plots by sweep netting was caused by the sampling method not being optimal for sampling pollinating invertebrates in forests. The type of forest sampled had little understory vegetation which may also have contributed to low invertebrate abundance. Several bees were seen visiting patches of white clover at lawn sites. It is likely that bees and wasps are present in urban forest and lawn habitats but not at numbers seen at the flower-rich USV sites.

3.4.3 HABITAT FUNCTIONS

Floral and invertebrate diversity

USV sites provided habitat for many plant and invertebrate species. Plant species diversity was expected to be lower in forests because local forests are not especially species rich and lawns experience physical and chemical removal of non-desirable species. Of all urban habitat areas, USV sites are known to support the greatest diversity of plant species. In Berlin, wasteland and gravel pit sites supported the most plant species of all urban habitat types investigated, including forests and parkland (Goode *et al.* 1995). USV sites also supported a great variety of life forms and functional types including annuals, biennials, herbaceous perennials, shrubs, trees, nitrogen-fixing plants (species in the Fabaceae), and species with nectar-producing flowers.

Diversity of functional types may be significant for ecosystem functioning because ecosystem processes may depend more on the functions species play in an ecosystem (functional diversity) than the number of species present (species diversity) (Diaz and Cabido 2001). A functional type is a collection of species that share a similar set of attributes (Hunt *et al.* 2004). The diversity of arthropod groups was also highest in USV plots. Group diversity may depend entirely on successional stage of the USV community. Carabid diversity in wasteland systems in has a significant relationship with vegetation structure: greatest diversity is found among early successional tall herb plants (Angold 2006). Gilbert (1989), reported a greater diversity of Carabidae and Lepidoptera larvae species at brick rubble sites which were 4 to 6 years old than at older sites (12 to 15 years). This is likely due to the prevalence of nectar and pollen producing flowering plants found on the younger sites.

Sampling bias may have resulted in the lack of invertebrates found at forest sites. Tree canopies can harbor significant invertebrate communities especially Diptera (flies), aphids and hymenoptera (Luniak 2008), but sampling methods limited the sampling of these groups.

Soil nutrient composition

Substrates at USV sites were considerably more alkaline then forest and lawn sites likely due to the presence of dirt and construction rubble (cement, bricks and mortar) indicated by the increased calcium content (Sukopp *et al.* 1979). Noticeable traces of concrete were seen at sites with highest calcium content (MT, PW and SB). High metal concentrations were also seen at USV sites, particularly iron and manganese, likely from construction debris or refuse waste dumping. Sites with extreme iron and manganese values did have obvious waste metal in the substrate (i.e. site SB).

Primary nutrients such as phosphorus, nitrogen and potassium were not necessarily deficient at USV sites compared to the forested sites. On average, the USV sites have a greater phosphorous content than forested sites likely due to animal waste particularly cats and dogs, but the difference is not significant. Phosphorus spikes were seen in most sites at individual plots especially PW, SB and SF. Dog walkers were encountered at SF. LS had relatively low phosphorus content among USV sites, possibly explaining why the site does not support more trees and shrubs despite being one of the (presumably) oldest sites. In addition, one of the forested sites showed a similarly low level of phosphorus. Though not as great as in lawns, USV sites had greater nitrogen content than forest sites. Potassium content was similar among the three urban habitat types. Additionally, CEC, or cation exchange capacity, which is a measure of soil fertility, was not significantly different among the sites sampled.

Conditions detrimental to soil flora due to heavy metals have been found in urban forest soils (McDonnell *et al.*1997). Elevated levels of copper were seen at USV sites. Although values were not as high as reported for a waste land site in Berlin (Sukopp *et al.* 1979), copper contamination in these study sites is likely detrimental to soil flora. Zinc was significantly lower in forest sites than in lawns and USV, which had similar values.

Heavy metal contamination can also affect litter decomposition rates, but the copper and zinc content found in this study are not likely to have an effect (see Johnson and Hale 2004; values found here are significantly lower than those for uncontaminated sites in Ontario).

3.5 CONCLUSIONS

The value of ecosystem functions are often not addressed in urban planning and development decisions (CBIN 2005). Integrating the value of ecosystem services from all city habitats including USV in vacant areas and transport right of ways will support the understanding of a complex and dynamic urban landscape. Of all the variables representing ecosystem functions LAI, albedo and species richness and abundance measures provide the strongest evidence that USV contributes equivalently or greater to certain urban climate regulation processes and habitat provision than other urban habitat types. The combination of higher reflectivity (albedo), LAI, and surface shading (light available at ground level), and substrate temperature are all indicators for gas exchange and microclimate regulation. Pockets of USV within the urban land cover matrix may have a significant moderating effect on local climactic conditions. Vegetation has significant microclimatic effects in cities, reducing summer temperatures by several degrees (Dimoudi and Nikolopoulou, 2003). This beneficial effect on air temperature improves as area of green space increases but also as the ratio of green to built area increases. Therefore, by tolerating the growth of USV city-wide, the cumulative effect of these unofficial green spaces may be realized.

USV sites that support more woody species would be more effective in climate regulation functions because trees and shrubs perform filtering out more air pollutants than herbaceous vegetation (Currie 2005). However, younger, earlier successional USV sites seem to support a greater diversity and abundance of plant and arthropod species. Encouraging a variety of successional states will contribute to a range of ecosystem services measured in this study.

Since some of the variables representing ecosystem functions were comparable to those of forests and lawns, the presence of USV within the urban landscape should be seen as a compliment and enhancement of the urban quality of life. Ensuring a diversity of habitats within urban areas will increase ecosystem functioning for the city as a whole.

CHAPTER 4 - DISCUSSION

4.1 STUDY APPLICATIONS

Human alteration of the Earth is substantial and growing. Land use changes associated with urban development have profound environmental and social consequences. Urban land in the contiguous United States is projected to increase from 2.5% in 1990 to 8.1% by 2050 (Nowak 2006) and similar patterns are likely seen in Canada. Although the process of urbanization is a major threat to global biodiversity (McKinney 2002), opportunities are present for urban planners and policy makers to improve existing and plan future urban infrastructure to support a variety of plant and animal species. Increased vegetation cover in cities is linked to many positive benefits at local and global scales. One of the easiest ways to increase vegetation within the urban landscape is by conserving remaining natural features, but in areas where all natural features have been eliminated, suitable habitat may need to be encouraged or created. It is in the latter case where knowledge of urban environmental conditions and species that tend to survive and flourish in built environments can be particularly useful.

As urbanization rates rise, it is necessary to understand the effects on global and local patterns of species richness and diversity. As human development alters natural ecosystems, new organisms and biotic communities arise and establish in urban habitats. Unmanaged derelict, vacant and USV areas are able to give refuge to a variety of vegetation types within a small area. These environments are typically patchy and heterogeneous which allow them to support many different communities that coexist near each other in a site even when patches themselves are not particularly species-rich (Kendle and Forbes 1997). Although most of the plants in USV areas are common, human-associated species, rare species can be found in urban habitats (Gilbert 1989, Kendle and Forbes 1997). Sites where rare species may occur in urbanized areas include railways, and other rights-of-way that are protected from development.

Knowledge of species composition of urban environments is useful in its own right to better understand the natural world. The more urban dwellers know about the species that live and thrive around them the more they develop an appreciation for urban biodiversity. This may encourage more effective support of political and economic policies toward preserving urban biodiversity. Better public education can also teach the benefits of using native species in plantings to promote other forms of diversity and also highlight problems with the use of non-native species (Kendle and Forbes 1997).

The unique combinations of stresses, disturbances, structures, and functions in urban ecological systems and lack of urban ecological information, especially in North America, calls for an increased need for ecological studies in urban areas (Pickett *et al.* 1997). Studies such as this add to the understanding of ecosystems in general, how they change, and what limits their performance when faced with the stressors of human activities. Urban ecological studies also add to the understanding of habitats in cities and increasing public support of low maintenance approaches to landscape management. Studies such as this are complimentary to the challenge of understanding urban biodiversity and incorporating of unmanaged, spontaneously colonized habitats into future ecosystem models.

Spontaneously colonized vegetation patches often represent a temporary land use since many of these areas are scheduled to be re-developed for other uses. The constant development and demolition cycle of cities may mean that USV habitat remains relatively constant in terms of area at the landscape level of a city. Regular disturbance also ensures that such sites are maintained at conditions for greater species diversity (Gilbert *et al.* 1989). As pressure for land redevelopment continues, several measures can be implemented to maintain biological diversity in cities by utilizing patches of USV. It has been suggested by other authors that slowing the pace of redevelopment of urban wasteland and brownfield sites can have positive effects on urban biodiversity (see Angold *et al.* 2006). By not removing vegetation until absolutely necessary or by removing/reducing maintenance operations such as mowing, benefits of USV can be fully realized. Also by not leveling a site and retaining some variation in microtopography, heterogeneity of a site would increase thereby facilitating the establishment of a greater range of species. In some cases, inputs may be required to increase beneficial attributes and public support of USV patches. In particularly nutrient poor sites, improved growth can be achieved by applying fertilizers at low levels to encourage flowing attractive species while limiting fertility-demanding perennial grasses (Ash *et al.* 1994). Artificial introductions of suitably adapted native species from ecologically similar areas could be implemented to increase species richness, eliminating the difficulties of immigration, as suggested by Davis (1986). With the increasing interest in native plant gardening and habitat provision in urban settings, the introduction of ecologically suited species to derelict areas would be consistent with popular public policy. Using native species would also reduce the decline of these species. In addition, using USV in remediation of contaminated or perceived contaminated lands may have several benefits. Reclamation techniques with reliance on natural colonization would be desirable where budgets are limited. Results of seed introduction on waste heaps found that newly sown species did not negatively affect the existing spontaneously colonized flora and required little intervention beyond planting the seed (Ash *et al.* 1994).

4.2 BIODIVERSITY, SPECIES RICHNESS AND NON-NATIVES IN URBAN AREAS

Although many studies have shown species richness of many taxa is relatively low within the extreme urban core, including plants (Kowarik 1995), birds and butterflies (Blair 2001), insects (McIntyre 2000) and mammals (Mackin-Rogalska *et al.* 1988) generally urbanized areas support more species of plants than the surrounding non-urban area. This is due, for the most part, to the introduction of non-native species which out paces the loss of native species resulting in a net gain in plant species in cities (McKinney 2002). Non-natives however do not typically exceed more than 50% of the flora even in the most built-up areas of the urban core (Whitney 1985, Kowarik 1995). Select urban vegetation communities can be dominated by native species such as the remnant natural forests surveyed in this study, but the spontaneously vegetated areas in Metro Halifax are dominated by non-native species. The non-natives species typical of the

USV communities likely have pre-adaptations that allow them to thrive in such habitats (McKinney 2008). The prevalence of non-natives seen in USV does not necessarily pose a threat to natural habitats. Most of the “invasive” species found in this study were considered to be exclusive urban dwellers and not harmful when isolated from natural habitats (White *et al.* 1993) and benefits of non-natives in improving ecosystem functioning have been documented (see Smith *et al.* (2006) for agroecosystems and Mahaney *et al.* (2006) for low-diversity wetlands). However, changes in ecosystem functioning due to alien plants are real and should be recognized (see Kourtev *et al.* 2003) and patches of USV provide an excellent opportunity to track and monitor the introduction and spread of potentially harmful flora and fauna. Further investigation on the role of native and non-native species on urban ecosystem functioning is needed to fully understand these relationships.

4.3 APPLICATIONS OF USV TO ENHANCE URBAN ECOSYSTEM FUNCTIONING

Benefits for mitigating pollution and the urban heat island effect

Vegetation is shown to have significant microclimactic effects, reducing summer urban temperatures by several degrees (Dimoudi and Nikolopoulou 2003). This may represent significant cost savings for urban energy demands and health care. Air pollution removal services and energy savings due to shading by urban trees have been valued in millions of dollars (McPherson *et al.* 1997, Akbari *et al.* 2001). However, urban trees require planting and maintenance costs to provide net long-term benefits. USV left to succeed into a woody vegetative state may provide comparable benefits to urban street trees without any initial investment or maintenance costs and the beneficial effect of vegetation on air temperature is improved as area of green space increases but also as the ratio of green to built area increases (Dimoudi and Nikolopoulou 2003). So areas of USV are left unaltered will compliment the other vegetated patches of a city to mitigate effects of urban heat island and pollution.

USV sites in this study had few trees or woody plants, but if left unaltered by human activities more woody species will likely establish. Benefits of USV may also be realized in winter months. The contribution of urban spontaneous vegetation to increasing urban albedo may be greater in the winter because vegetation would trap more snow than paved and other unvegetated surfaces. Albedo values for snow covered grass can be up to 0.75, compared to 0.13 of conifer sites with snow under the canopy (Betts and Ball 1997).

Habitat values

Promoting environmental heterogeneity within urban and sub-urban areas including reducing maintenance of wasteland and other areas of USV will help accommodate for the greatest number of species. Areas of unmanaged, spontaneous vegetation can serve as refugia of diversity in even the most densely built-up areas. Species rich USV habitats may also support a diversity of higher level trophic organisms as the number of plant species tends to correlate with the number of birds and insects in an area (McKinney 2002). Arthropods are considered to be major components in the functioning of ecosystems and moderately human disturbed land may facilitate the conservation of select bee species (Winfree *et al.* 2007).

Other ecosystem functions

USV may contribute to other regulatory ecosystem functions and services not discussed in detail here, such as disturbance prevention, biological control, genetic diversity, the provision of human medicinal or food resources and information functions like nature education or spiritual connections. For example, Syrphidae (also known as flower flies or hover flies) are a diverse and important group of flies which are predators of aphids (Marshall 2006). As such, they are important natural regulators of aphid populations (many of which are pests). Several species in this group were found in this study.

The field of ecological economics is expanding as there is increased interest in the valuation of ecosystem functions, goods and services and benefits of natural ecosystems to human society (de Groot 2002). Further research is needed to assign monetary values of ecosystem services provided by USV and urban vegetation in general. The ecosystem services discussed here are not trivial, but are important to the well being of humans and other organisms in urban and non-urban areas.

4.4 FINAL CONCLUSIONS

Because the ecological footprint of our urban centers expands as the population grows, the arrangement of green areas in a city and their connection with the surrounding countryside are critical to sustainability. In an increasingly urbanized society, exposure to biodiversity can play an important role in nature and conservation education of city dwellers (Miller and Hobbs 2002). Although gardens have been typically highlighted as hotspots for enhancing local urban biodiversity (Gaston *et al.* 2005, Thompson *et al.* 2003), USV habitats often support a greater number of species without the intensive maintenance regime. Also most gardens in cities are privately owned, which can result in a lack of consistent biodiversity management strategies. The wealth of diversity in spontaneously vegetated urban habitats should encourage the need to incorporate them into urban biodiversity management plans and they should not be discounted in the ability to produce economic benefits. As illustrated by this study, consideration should be given to the potential of USV to provide environmental benefits, particularly through pollution mitigation and the provision of habitat.

Initiatives are gaining momentum and new values are being established in many cities, especially in Europe. Studies by Herbert Sukopp in West Berlin led the way in the development of a nature conservation program for the city which has provided a model elsewhere in Europe. Many British cities now have nature conservation strategies adopted by planning authorities that focus on urban land.

Tolerating and encouraging areas of USV can increase valuable habitat in cities with little investment or management. Sukopp *et al.* (1979) suggests that it is worthwhile to preserve the vegetation that develops in some urban spaces such as railway banks, roadsides and vacant areas within industrial areas to allow for the continual development of urban-adapted ecotypes. Sukopp *et al.* (1979) suggests several species found in Berlin’s wasteland as plants of great value for open urban spaces in need of vegetation cover, many of which were also found in USV sites in this study. Knowledge of wasteland conditions and associated spontaneously developed vegetation can be very useful for regeneration of wasteland where traditional ornamentals are likely to fail without site amendments and intensive maintenance (Sukopp *et al.* 1979).

Urban planners should find ways to enhance urban biodiversity and increase the proportion of native species as cities grow. Techniques to increase native species include preserving as much remnant natural vegetation as possible and re-vegetation of disturbed lands with native species while protecting re-vegetated habitats from disturbances to allow succession to proceed (McKinney 2002). Too often urban spaces are replanted with non-native species and are managed with great financial costs (Gilbert 1989, Kendle and Forbes 1997).

In conclusion, this paper has sought to address three basic questions. To describe vegetation communities of unmanaged urban spaces, to estimate beneficial ecosystem services of these communities and to compare them to more traditional urban habitats. My results indicated that USV communities are unique and provide measurable ecosystem benefits complementary to other urban habitat types. Although this study explored many aspects of spontaneously vegetated urban spaces further research on these misunderstood yet ubiquitous plant communities warrant further investigation.

REFERENCES

Akbari H., Pomerantz M. and Taha H., 2001. Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas. *Solar Energy* Vol. 70, No. 3, pp. 295–310.

Angold P.G., Sadler J.P., Hill M.O., Pullin A., Rushton S., Austin K., Small E, Wood B., Wadsworth R, Sanderson R., Thompson K., 2006. Biodiversity in urban habitat patches. *Science of the Total Environment* 360, 196– 204.

Araujo M.B., 2003. The coincidence of people and biodiversity in Europe. *Global Ecology & Biogeography* 12, 5–12.

Ash H.J., Gemmell, R.P., Bradshaw A.D., 1994. The introduction of native species on industrial waste heaps: A test of immigration and other factors affecting primary succession. *Journal of Applied Ecology* 31, 74-84.

Atlantic Geoscience Society 1994. Geology Map of Nova Scotia. Land Registration and Information Services & Province of Nova Scotia Department of Supply and Services. Nova Scotia, Canada.

Balmford A., Moore J.L., Brooks T., Burgess N., Hansen L.A., Williams P., and Rahbek C., 2001. Conservation Conflicts Across Africa. *Science* 291, p. 2616.

Baird C., 1999. Environmental Chemistry, W.H. Freeman and Company, New York (1999).

Bardgett R.D. and Shine A., 1999. Linkages between plant litter diversity, soil microbial biomass and ecosystem function in temperate grasslands. *Soil Biology and Biochemistry*, 31(2), 317-321.

Barry R.G. & Chorley, R.J., 1992. *Atmosphere, Weather & Climate,* 6th edn. Routledge, London.
Bartelt-Ryser J., Joshi J., Schmid B., Brandl H., Balser T., Bartelt-Ryser J., 2005. Soil feedbacks of plant diversity on soil microbial communities and subsequent plant growth. *Perspectives in Plant Ecology, Evolution & Systematics* 7(1), 27-49.

Betts A. K., and Ball J. H. , 1997. Albedo over the boreal forest. *Journal of Geophysical Research*, 102, 901-909.

Blair, R.B. 2001. Creating a homogenous avifauna. In: Marzluff, J.M., Bowman, R., Donelly, R. (Eds). *Avian Ecology and Conservation in an Urbanizing World.* Kluwer Academic Publishers, Boston. pp. 460-486.

Bolund P. and Hunhammar S., 1999. Ecosystem services in urban areas. *Ecological Economics*, 29 293–301.

Botkin D.B. and Beveridge C.E., 1997. Cities as environments. *Urban Ecosystems* 1, 3–19.

Botkin D. and Keller E., 1995. Environmental science: Earth as a living planet. John Wiely and Sons, USA.

Bradshaw AD, Hunt B, and Walmsley T, 1995. Trees in the urban landscape, E & FN Spon, London.

Brandes D., 1995. Flora of old town centres in Europe. In: H. Sukopp, M. Numata & A. Huber (eds.): *Urban ecology as the basis of urban planning*. The Hague.

Broll G. and Keplin B., 1995. Ecological Studies on Urban Lawns. In: Sukopp H, Numata M & Huber A (Eds.) *Urban Ecology as the Basis of Urban Planning.* SPB Academic Publishing, The Hague.

Bullock P. and Gregory P.J., 1991. *Soils in the Urban Environment,* Blackwell Scientific Publications, London.

Burley S., Robinson, S.L., Lundholm J.T., 2008 Post-hurricane vegetation recovery in an urban forest. *Landscape and Urban Planning,* 85 (2), 111-122.

Canadian Biodiversity Information Network, 2005. Urban Biodiversity. http://www.cbin.ec.gc.ca/enjeux-issues/urbain-urban.cfm?lang=eng [Accessed May 2008].

Canadian Botanical Conservation Network 2007. CBCN Newsletter 2 (1)

Chen J.M., Pavlic G., Brown L., Cihlar J., Leblanc S.G., White H.P., Hall R.J., Van der Sanden J. , Pellikka P.K.E, 2002. *Remote Sensing of Environment* 80, 165– 184.

Clemants S. and Moore G., 2003. Patterns of species richness in eight northeastern united states cities. *Urban Habitats* 1(1), 4-16.

Council Officers Executive Committee (COEC) 1992, Handbook on Reference Material for Soil Analysis, Soil and Plant Analysis Council, Inc., Georgia, USA.

Crowe T.M., 1979. Lots of Weeds: Insular Phytogeography of Vacant Urban Lots. *Journal of Biogeography,* 6 (2), 169-181.

Cunningham M.A., Snyder E. Yonkin D. Ross M., Elsen T., 2008. Accumulation of deicing salts in soils in an urban environment. *Urban Ecosystems* 11, 17–31.

Currie B.A. and Bass B., 2008. Estimates of air pollution mitigation with green plants and green roofs using the UFORE model. *Urban Ecosystems* 11, 409–422.

Currie, B.A., 2005. Air Pollution Mitigation with Green Roofs Using the UFORE Model Proceedings of Green Roofs for Healthy Cities Conference.

Darlington A., 1969. Ecology of refuse tips. Heinemann Educational, London.

Davis B.N.K., 1986. Colonization of newly created habitats by plants and animal. *Journal of Environmental Mnaagement*, 22, 361-371.

de Groot, R.S., Wilson, M.A., Boumans, R.M.J., 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics*, 41(3), 393-408.

De Sousa C.A. 2006. Urban brownfields redevelopment in Canada: the role of local government. *Canadian Geographer*, 50 (3) p. 392.

Diaz S. and Cabido M., 2001. Vive la différence: plant functional diversity matters to ecosystem processes. *Trends in Ecology & Evolution*, 16, 646-655.

Dimoudi A., Nikolopoulou, M., 2003. Vegetation in the Urban Environment: Microclimatic Analysis and Benefits. *Energy and Buildings*, 35 (1), 69-76.

Edwards C.A., 2002. Assessing the effects of environmental pollutants on soil organisms, communities, processes and ecosystems. *European Journal of Soil Biology*, 38(3-4), 225-231.

Effland W.R. and Pouyat R.V., 1997. The genesis, classification and mapping of soils in urban areas. *Urban Ecosystem*s, 1, 217–228.

Emmett B.A., Beier C., Estiarte M., Tietema A., Kristensen H.L.,Williams D., Penuelas J., Schmidt I., Sowerby A. 2004. The Response of Soil Processes to Climate Change: Results from Manipulation Studies of Shrublands across an Environmental Gradient. *Ecosystems*, 7 (6), 625-637.

English Partnerships 2006. Brownfield research summary: The economic impact of recycling brownfield land. http://www.englishpartnerships.co.uk/brownfieldstrategy.htm [Accessed September 2008].

Eyre M.D., Luff M.L. and Woodward J.C., 2003. Beetles (Coleoptera) on brownfield sites in England: An important conservation resource? *Journal of Insect Conservation* 7, 223–231.

Falk J., 1976. Energetics of a suburban lawn ecosystem. *Ecology* 57 (1), 141-150 .

Flora of North America 2008. http://www.fna.org/ [Accessed may 2008].

Freedman, B., Love, S., O'Neil, B., 1996. Tree species composition, structure, and carbon storage in stands of urban forest of varying character in Halifax, Nova Scotia. *Canadian Field-Naturalist*. 110(4), 675-682.

Gaffin S. Rosenzweig C., Parshall L., Beatie D., Berghage R., O'Keeffe G., Braman D., 2005. Energy balance modeling applied to a comparison of white and green roof cooling efficiency. http://www.roofmeadow.com/technical/publications/GaffinetalPaperDC-0009.pdf [Accessed May 2008].

Gaston K.J., Warren P.H., Thompson K., Smith R.M., 2005. Urban domestic gardens (IV): The extent of the resource and its associated features. *Biodiversity and Conservation* 14, 3327-3349.

Ge Y., Murray P., Hendershot W.H. 2000. Trace metal speciation and bioavailability in urban soils. *Environmental Pollution* 107, 137-144.

Gibson D.J., Adams E.D., Ely J.S, Gustafson D.J, McEwen D., Evans T.R., 2000. Eighteen Years of Herbaceous Layer Recovery of a Recreation Area in a Mesic Forest. Journal of the Torrey Botanical Society, 127(3), 230-239.

Gilbert O.L., 1992. The Flowering of Cities: The Nature Flora of 'Urban Commons'' Peterborough: English Nature.

Gilbert O.L. 1989. The ecology of urban habitats. Chapman and Hall, London and New York.

Gödde M, Richarz N and Walter B 1995. Habitat conservation and development in the city of Dusseldorf (Germany). In: Sukopp H, Numata M and Huber A (eds) *Urban Ecologys the Basis for Urban Planning,* SPB Academic Publishing, Amsterdam, The Netherlands.

Godefroid S. 2001. Temporal analysis of the Brussels flora as indicator for changing environmental quality. *Landscape and Urban Planning*, 52, 203-224.

Godefroid S., Monbaliu D., Koedam N., 2007. The role of soil and microclimatic variables in the distribution patterns of urban wasteland flora in Brussels, Belgium. *Landscape and Urban Planning*, 80, 45–55.

Gough L., Shaver G. R., Carroll J., Royer, D. L. and Laundre, J. A. (2000), Vascular plant species richness in Alaskan arctic tundra: the importance of soil pH. *Journal of Ecology*, 88: 54–66.

Grime J. P. 1979. Plant Strategies and Vegetation Processes. John Wiley & Sons Ltd.
Grimm N.B., Faeth S.H., Golubiewski N.E., Redman C.L., Wu J., Bai X., Briggs J.M., 2008. Global Change and the Ecology of Cities. *Science,* 8, 319 (5864) 756 – 760.

Grimm, N.B., Grove, J.M., Pickett, S.T.A., Redman, C.L., Grimm, N.B., 2000. Integrated approaches to long-term studies of urban ecological systems. *Bioscience* 50 (7), 571.
Guntspergeren G.R. and Levenson J.B., 1997. Understory plant species composition in remnant stands along an urban-to-rural land-use gradient. *Urban Ecosystems,* 1, 155–169.

Harrison C. and Davies G., 2002. Conserving biodiversity that matters: Practitioners' perspectives on brownfield development and urban nature conservation in London. *Journal of Environmental Management* 65(1), 95-108.

Heath Canada 2006. Smog and your health. http://www.hc-sc.gc.ca/hl-vs/iyh-vsv/environ/smog-eng.php. [Accessed December 2008].

Hope D., Gries C., Zhu W., Fagan W.F., Redman C.L., Grimm N.B., Nelson A.L, Martin C., and Kinzig A., 1993. Socioeconomics drive urban plant diversity. PNAS 100 (15).

Hu D., Wang R., Tang T., 1995. In: Sukopp H, Numata M and Huber A (Eds) *Urban Ecology as the Basis for Urban Planning*, SPB Academic Publishing, The Hague.

Hunt R., Hodgson J. G., Thompson K. , Bungener P. , Dunnett N. P., and Askew A. P., 2004. A new practical tool for deriving a functional signature for herbaceous vegetation. *Applied Vegetation Science* 7(2), 163-170.

Intergovernmental Panel on Climate Change (IPCC), 2001. IPCC's Third Assessment Report. Annex B useful glossary of terms. http://www.ipcc.ch/pdf/glossary/tar-ipcc-terms-en.pdf [Accessed December 2010].

Jiang, X.L., Zhang, W.G., Wang, G., 2007. Effects of different components of diversity on productivity in artificial plant communities. *Ecological Restoration*, 22(4), 629-634.

Johnson D. and Hale B., 2004. White birch (Betula papyrifera Marshall) foliar litter decomposition in relation to trace metal atmospheric inputs at metal-contaminated and uncontaminated sites near Sudbury, Ontario and Rouyn-Noranda, Quebec, Canada, *Environmental Pollution* 127, 65–72.

Kendle T. and Forbes S., 1997. *Urban nature conservation: landscape management in the urban countryside*. London, New York.

Khan M. and Scullion J., 2000. Effect of soil on microbial responses to metal contamination. *Environmental Pollution, 110*, 115–125.

Klimes L., 1987. Succession in road bank vegetation. *Folia Geobotanica & Phytotaxonomica,* 22 (4), 435-440.

Knapp S., Kuhn I., Schweiger O., and Klotz S., 2008. Challenging urban species diversity: contrasting phylogenetic patterns across plant functional groups in Germany. *Ecology Letters* 11, 1054–1064.

Kourtev, P.S., Ehrenfeld, J.G., Haggblom, M., 2003. Experimental analysis of the effect of exotic and native plant species on the structure and function of soil microbial communities. *Soil Biol. Biochem.* 35 (7), 895–905.

Kowarik, I., 2008. "On the role of alien species in urban flora and vegetation" in: Marzluff, J. et al. (Eds.): *Urban ecology. An international perspective on the interaction between humans and nature.* Springer, New York.

Kowarik, I. 1995. On the role of alien species in urban flora and vegetation. In: PysecP, Prach K, Rejmanek M, Wade M (eds) *Plant Invasions. General species and special problems.* SPB Academic Publishing, Amsterdam.

Kuhn I., Brandl R. and Klotz, S. 2004. The flora of German cities is naturally species rich. *Evolutionary Ecology Research* 6, 749–764.

Kurn, D. M., S. Bretz, B. Huang, and H. Akbari. 1994. "The Potential for Reducing Urban Air Temperatures and Energy Consumption Through Vegetative Cooling," *Proceedings of the ACEEE 1994 Summer Study on Energy Efficiency in Buildings*, August 1994, Pacific Grove, CA, 9, p. 155.

Larson B. M. H., P. G. Kevan and D. W. Inouye. 2001. Flies and flowers: Taxonomic diversity of anthophiles and pollinators. *Canadian Entomologist* 133, 439-465.

Lazzarin R.M., Castelloti F., and Busato F., 2005. Experimental measurements and numerical modeling of a green roof. *Energy Build.* 37, 1260–1267.

Legendre, Pierre & Louis Legendre. 1998. *Numerical ecology.* 2nd English edition. Elsevier Science BV, Amsterdam.

Li M.H., Barrett M.E., Rammohan P., Olivera F., Landphair H.C., 2008. Documenting Stormwater Quality on Texas Highways and Adjacent Vegetated Roadsides. *J. Envir. Engrg*. 34 (1), 48-59.

Lorenz K. and Lal R., 2009. Biogeochemical C and N cycles in urban soils. *Environment International* 35, 1–8.

Lund A.C. 1974. Analyses of urban plant communities of Atlanta, Georgia. PhD Thesis. Emory University.

Lundholm, J.T. and Marlin, A., 2006. Habitat origins and microhabitat preferences of urban plant species. Urban Ecosystems 9, 139-159.

Luniak M., 2008. "Fauna of the Big City – Estimating Species Richness and Abundance in Warsaw Poland" in Marzluff, J. et al. (Eds*.): Urban ecology. An international perspective on the interaction between humans and nature*. Springer, New York.

M.G. Weber and M.D. Flannigan, Canadian boreal forest *ecosystem structure and function in a changing climate: impact on fire regimes, Environ. Rev.* 5, 145–166.

MacDougall, J.I., Cann, D.B., 1963. Soil Survey of Halifax County, Nova Scotia. Report No. 13, N.S. Soil Survey, Truro, Nova Scotia.

Mackin-Rogalska R., Pinowski J., Solon J. and Wojcik Z., 1988. Changes in vegetation, avifauna and small mammals in a suburban habitat. *Pol. Ecol. Stud.* 14, 293–330.

Mahaney, W. M. et al. 2006. Impacts of Lythrum salicaria invasion on plant community and soil properties in two wetlands in central New York, USA. *Canad. J. Bot.* 84, 477-484.

Majka C.G. and Robinson S. 2009. Hyperaspis and Brachiacantha (Coleoptera: Coccinellidae): two poorly known genera of native lady beetles in the Maritime Provinces. *Journal of the Acadian Entomological Society*, 5, 3-11.

Marshall S.A., 2006. *Insects. Their Natural History and Diversity. With a photographic guide to insects of eastern North America.* Firefly Books.

Marzluff J., 2008. Forward in Marzluff, J. et al. (Eds.): *Urban ecology. An international perspective on the interaction between humans and nature.* Springer, New York.

McDonnell M. J. and Pickett S. T. A., 1990. Ecosystem Structure and Function along Urban-Rural Gradients: An Unexploited Opportunity for Ecology. *Ecology*, 71 (4), 1232-1237.

McDonnell M.J., Pickett, S.T.A., Groffman P., Bohlen P. Pouyat R.V., Zipperer W.C., Parmelee R.W., Carreiro M.M., Medley K. 1997. Ecosystem processes along an urban-to-rural gradient. *Urban Ecosystems*, 1, 21–36.

McIntyre N.E., 2000. Ecology of urban arthropods: a review and a call to action. *Ann Entomol Soc Am*, 93,825–835.
McKinney M.L. 2002. Urbanization, biodiversity, and conservation. *BioScience*, 52 (10), 883-890.

McPherson E.G., Nowak D., Heisler G., Grimmond S., Souch C., Grant R., Rowntree R., 1997. Quantifying urban forest structure, function, and value: the Chicago Urban Forest Climate Project. *Urban Ecosystems*, 1, 49–61.

Milesi C., Running S.W., Elvidge C.D., Dietz J.B., Tuttle B.T., Nemani R.R., 2004. Mapping and Modeling the Biogeochemical Cycling of Turf Grasses in the United States. *Environmental Management,* 36 (3), 426–438.

Miller J.R., 2006. Restoration, reconciliation, and reconnecting with nature nearby. *Biological Conservation* 1 2 7, 3 5 6 –3 6 1.

Miller, James and Hobbs, Richard. Conservation Where People Live and Work. *Conservation Biology* 16(2), 330-337.

Minchin, P.R. (1987) An evaluation of relative robustness of techniques for ecological ordinations. *Vegetatio* 69, 89–107.

Moore, G., Steward, A., Clemants, S., Glenn, S., Ma, J., 2002. An overview of the New York metropolitan flora project. Urban Habitats 1 (1), 17-24.

Nowak, D. (1995). Trees Pollute? A "Tree Explains It All". Proceedings of the 7th National Urban Forest Conference.

Nowak, D., 2006. Institutionalizing urban forestry as a “biotechnology” to improve environmental quality. *Urban Forestry & Urban Greening*, 5 (2), 93-100.

Nowak, D.J., McHale P.J., Ibarra, M., Crane, D., Stevens, J., and Luley, C., 1998, Modeling the effects of urban vegetation on air pollution, In: *Air Pollution Modeling and Its Application XII*. S. Gryning and N. Chaumerliac, (Eds.) Plenum Press, New York.

Oliver L., Ferber U., Grimski D., Millar K., Nathanail P., 2005. The Scale and Nature of European Brownfields. http://www.cabernet.org.uk/resourcefs/417.pdf [Accessed June 2009]

Paul, M.J., Meyer, J.L., Paul, M.J., 2001. Streams in the urban landscape. *Annual Review of Ecology & Systematics* 32, 333.

Pickett S.T.A., Cadenasso M.L., Grove J.M., Nilon C.H., Pouyat R.V., Zipperer W.C., Costanza R., 2001. Urban Ecological Systems: Linking terrestrial ecological, physical, and socioeconomic components of metropolitan areas. Annual *Review of Ecology & Systematics* 32, 127

Pickett S.T.A., Burch W.R. Jr, and Dalton S.E., 1997. Integrated urban ecosystem research. *Urban Ecosystems* 1, 183-184.

Pickett S.T.A., Cadenasso M.L., Grove J.M., Groffman P.M., Band L.E., Boone C.G., Burch Jr., William R., Grimmond C.S.B., Hom J., Jenkins J.C., and others, 2008. Beyond urban legends: An emerging framework of urban ecology, as illustrated by the baltimore ecosystem study. *Bioscience* 58(2), 139-150.

Pitt R., Chen S., and Clark S., 2001. Infiltration Through Compacted Urban Soils and Effects on Biofiltration Design. Presented at the Low Impact Development Roundtable Conference, Baltimore, MD, July 2001.

Port of Halifax 2009. Homepage, http://www.portofhalifax.ca/index.html [Acessed may 2009].

Pouyat, R.V., J. Russell-Anelli, I.D. Yesilonis, and P.M. Groffman. 2003. "Soil carbon in urban forest ecosystems" in J.M. Kimble et al. (ed.) *The potential of U.S. forest soils to sequester carbon and mitigate the greenhouse effect*. CRC Press, Boca Raton, FL. p. 347–362.

Pouyat, R.V., K. Belt, D. Pataki, P.M. Groffman, J. Hom, and L. Band. 2006. "Urban land-use change effects on biogeochemical cycles" in P. Canadell et al. (Ed.) *Terrestrial ecosystems in a changing world. Global Change and Terrestrial Ecosystems Synthesis Book*, Canberra, Australia.

Pysek P, 1995. Approaches to studying spontaneous settlement flora and vegetation in central Europe: A review. In: Sukopp H, Numata M and Huber A (eds) *Urban Ecology the Basis for Urban Planning*, SPB Academic Publishing, Amsterdam, The Netherlands.

Roland's Flora of Nova Scotia, 1999. Editor: Marion Zinck. Nimbus Publishing.

Schadek U., Strauss B., Biedermann R., Kleyer M., 2009. Plant species richness, vegetation structure and soil resources of urban brownfield sites linked to successional age. Urban Ecosystems 12 (2), 115-126.
Sean Blaney, Pers. Comm. October 2008.

Simons, R. (1998). Turning brownfields into greenbacks: Developing and Financing Environment. Urban Land Institute.

Small, E.C., Sadler, J.P. and Telfer M.G., 2003. Carabid beetle assemblages on urban derelict sites in Birmingham, UK. *Journal of Insect Conservation* 6, 233–246.

Smith RG, Maxwell B, Menalled FD, Rew LJ (2006) Lessons from agriculture may improve the management of invasive plants in wildland systems. *Frontiers in Ecology and the Environment 4(8), 428–434.*

Stark, J.M. and Redente, E.F., 1985. Soil-plant Diversity Relationships on a Disturbed Site in Northwestern Colorado. Soil Sci. Soc. Am. J. 49, 1028-1034.

Stearns F., 1970. Urban Ecology Today: AAAS Symposium, 30 December 1970, Chicago. Science, New Series, 170, (3961), 1007.

Sukopp H, Blume HP, Kunick W, 1979. The soil, flora, and vegetation of Berlin's waste lands. In: Laurie IC (ed) *Nature in Cities: The natural environment in the design and development of urban green space*. John Wiley and Sons Ltd.

Sukopp, H, 2008. “On the Early History of Urban Ecology in Europe” in: *Urban Ecology: An International Perspective on the Interaction Between Humans and Nature.* (Eds.) JM Marzluff, E Shulenberger, W Endlicher, M Alberti, G Bradley, C Ryan, U Simon and C ZumBrunnen. Springer, US. 79-97.

Takahashi, T., Amano Y., Kuchimura K., Kobayashi T., 2008. Carbon content of soil in urban parks in Tokyo, Japan. *Landscape Ecol Eng* 4, 139–142.

Thompson, K, Colsell, S, Carpenter, J, Smith RM, Warren PH, Gaston KJ. 2005. Urban domestic gardens (VII): a preliminary survey of soil seed banks. *Seed Science Research* 15 (2), 133 - 141.

Thompson, K., Austin, K., Smith, R., Warren, P., KJ, 2003. Urban domestic gardens I: Putting local garden diversity in context. *Journal of Vegetation Science,* 14, 71-78.

Turner K., Lefler L., Freedman B., 2005Plant communities of selected urbanized areas of Halifax, Nova Scotia. *Landscape and Urban Planning*, 71, 191–206.

UNEP 2002. GEO-3: GLOBAL ENVIRONMENT OUTLOOK, http://www.unep.org/Geo/geo3/english/551.htm [Accessed January 2009]

United Nations 2007. World Urbanization Prospects: The 2007 Revision. http://www.un.org/esa/population/publications/wup2007/2007wup.htm

United States Census Bureau (USCB), 2001.
http://www.census.gov/main/www/cen2000.html [Accessed January 2009].

United States Department of Agriculture, 2009. PLANTS Profile: Elaeagnus umbellata. http://plants.usda.gov/java/profile?symbol=ELUM [Accessed October 2008].

United States Environmental Protection Agency, 1997. 'Brownfields Definition' Unpublished Webpage available at http://ww.epa.gov/swerosps/bf/glossary.htm, [Accessed September 2003].

United States National Park Service (US NPS) BayScapes Conservation Landscaping Program, 2004. Plant Invaders of Mid-Atlantic Natural Areas: Shrubs: Autumn Olive. http://www.nps.gov/plants/alien/pubs/midatlantic/elum.htm. [Accessed May 2008].

Vitousek, P., Mooney, H., Lubchenco, J., Melillo, J., 1997. Human domination of ecosystems. *Science* 277 (5325) 494-499.

Wessolek, G., 2008. "Sealing of Soils" in: *Urban Ecology: An International Perspective on the Interaction Between Humans and Nature.* (Eds.) JM Marzluff, E Shulenberger, W Endlicher, M Alberti, G Bradley, C Ryan, U Simon and C ZumBrunnen. Springer, US. 161-179

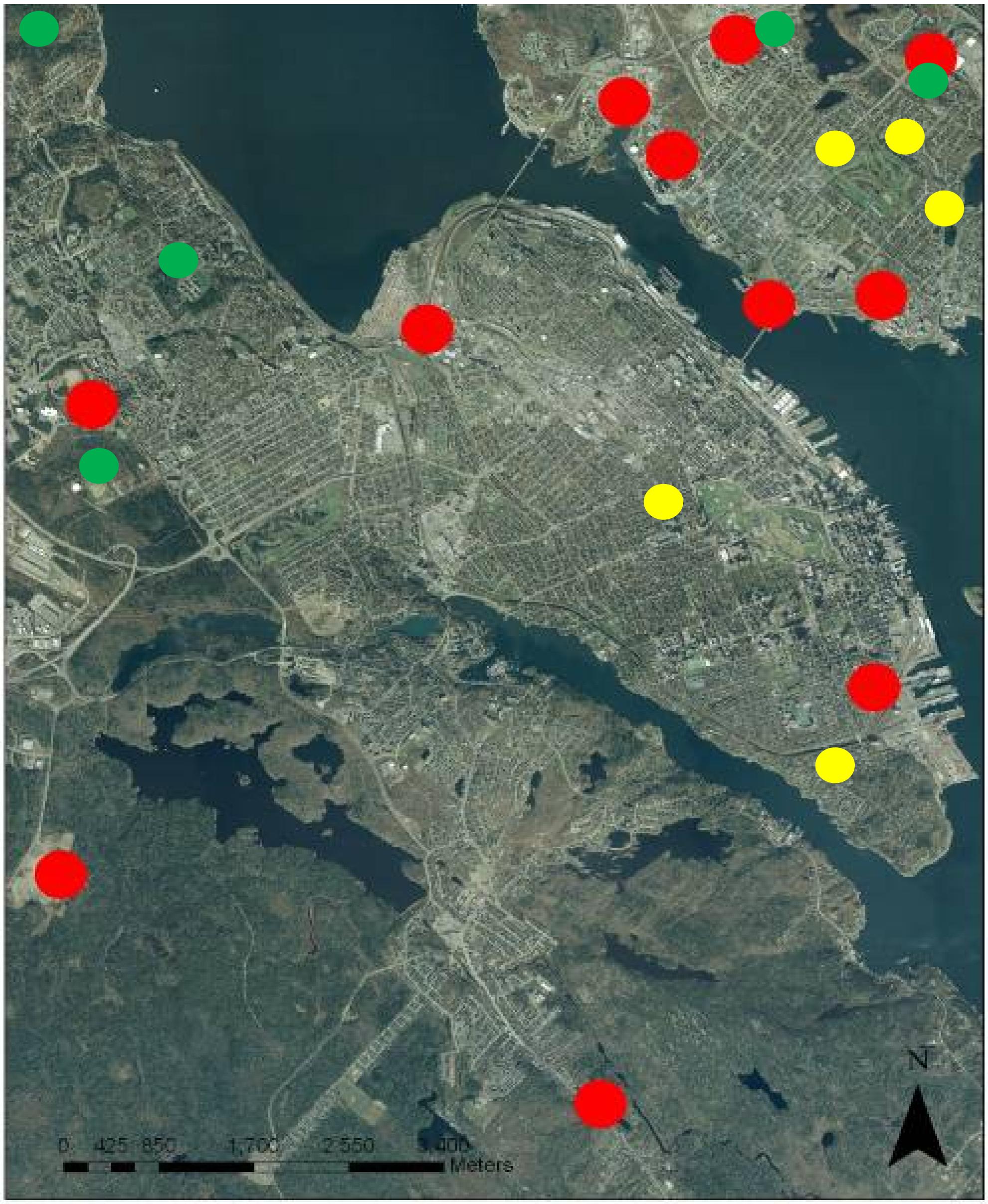
Wheater P.J., 1999. *Urban habitats*. Routledge, London.

White D.J., E. Haber and C. Keddy. 1993. Invasive plants of natural habitats in Canada: an integrated review of wetland and upland species and legislation governing their control. Canadian Wildlife Service, Ottawa, Canada.

Whitney, G.G. 1985. A quantitative analysis of the flora and plant communities of a representative midwestern US town. *Urban Ecology* 9, 143-160.

Winfree R., Griswold T., and Kremen C., Effect of human disturbance on bee communities in a forested ecosystem. *Conservation Biology*, 21 (1), 213–223.

APPENDIX A - SITE MAP OF THE STUDY AREA AND LOCATIONS OF THE ELEVEN USV SAMPLING AREAS.



Aerial photo of metro Halifax, Nova Scotia showing the location of the study sites. USV plots are indicated with red circles, forest plots are indicated with green circles and lawn plots are indicated with yellow circles.

APPENDIX B - AERIAL PHOTO OF EACH OF THE ELEVEN USV SAMPLING SITES AND SITE PHOTOS OF TYPICAL USV SITES.

Bayne Street (BS)

Dartmouth Common (DC)

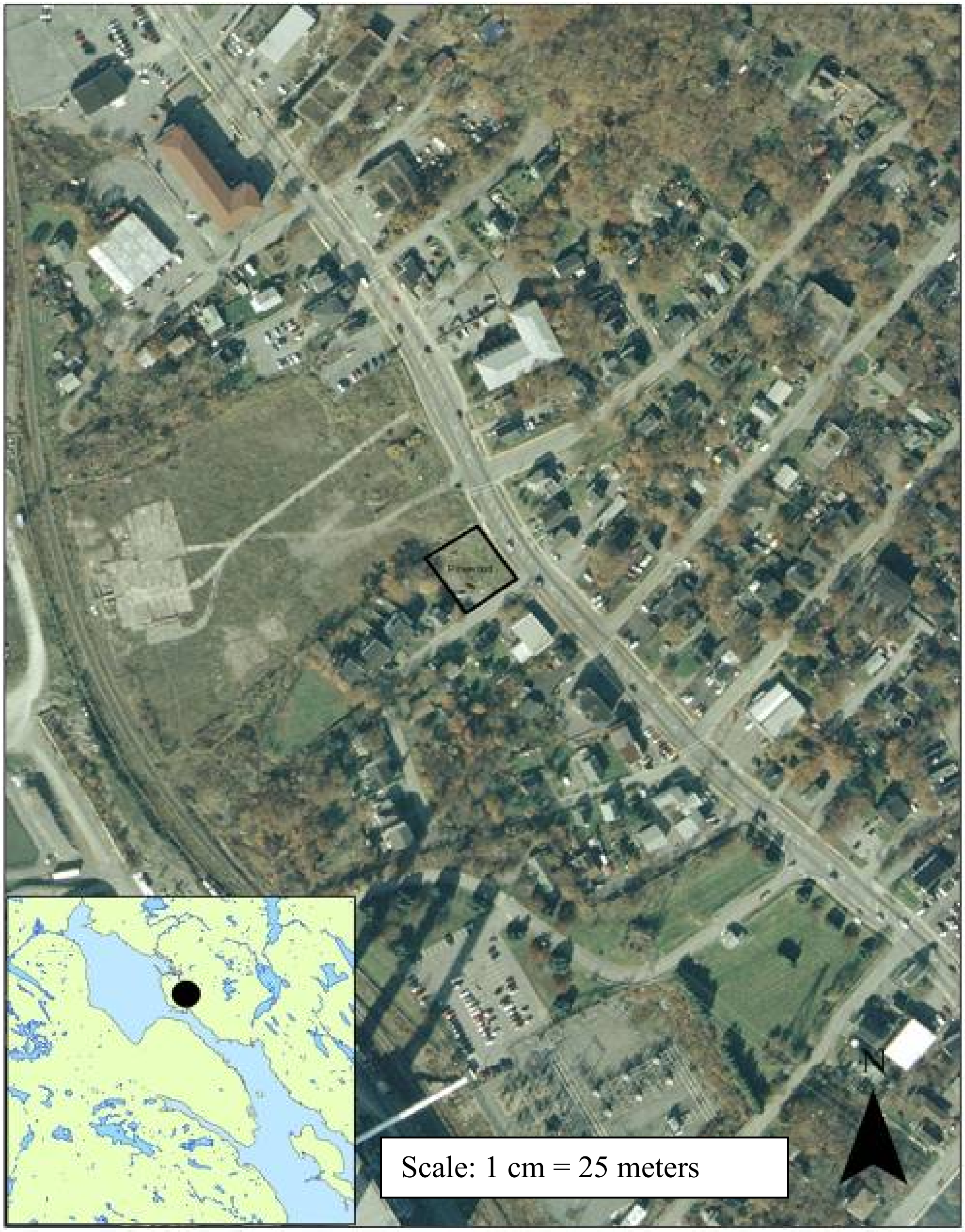
Exhibition Park (EX)

Lyle Street (LS)

Mainland Common (ML)

Woodland Avenue (MT)

Pinewood (PW)



South Bland (SB)

Spryfield (SF)

Shannon Park (SP)

Photos of typical USV sites. On the right is Dartmouth Common (DC) and the left is Lyle Street (LS).

APPENDIX C - SPECIES RECORDED AT USV PLOTS. INCLUDING S-RANK AND SITES WHERE RECORDED.

Species	**S-Rank**	**BS**	**DC**	**EX**	**HF**	**LS**	**ML**	**MT**	**PW**	**SB**	**SF**	**SP**
Alopecurus pratensis	SE	0	0	0	0	0	0	0	0	0	1	0
Ambrosia artemisiifolia	S5	0	0	0	0	0	0	0	0	1	0	0
Anthemis cotula	SE	0	0	0	0	0	1	0	0	1	1	0
Aralia hispida	S5	0	0	0	0	0	0	0	0	0	1	0
Arctium minus	SE	0	0	0	0	0	0	0	0	1	0	0
Bidens frondosa	S5	0	0	0	0	0	1	0	0	0	1	0
Brassica nigra	SE	0	0	0	0	0	0	0	0	0	1	0
Chenopodium album	SE	0	0	0	0	0	0	1	0	1	0	0
Comptonia peregrina	S5	0	0	0	0	0	0	0	0	0	1	0
Conyza canadensis	S5	0	0	0	0	0	1	1	0	0	1	0
Cornus sericea	S5	0	0	0	0	0	0	0	0	0	1	0
Dactylis glomerata	SE	0	0	0	0	0	0	0	0	1	1	0
Diervilla lonicera	S5	0	0	0	0	0	0	0	0	0	1	0
Epilobium ciliatum	S5	0	0	0	0	0	1	1	0	0	1	0
Erysimum cheiranthoides	S5SE	0	0	0	0	0	0	0	0	0	1	0
Fagopyrum esculentum	SE	0	0	0	0	0	1	0	0	0	0	0
Juncus canadensis	S5	0	0	0	0	0	1	0	0	0	0	0
Juncus effusus	S5	0	0	0	0	0	0	0	0	0	1	1
Lupinus polyphyllus	SE	0	0	0	0	0	0	0	0	0	1	0
Lysimachia terrestris	S5	0	0	0	0	0	0	0	0	0	1	0
Malva moschata	SE	0	0	0	0	0	0	0	1	0	0	0
Matricaria discoidea	SE	0	0	0	0	0	0	0	0	1	0	0
babys breath	SE	0	0	0	0	0	0	0	0	0	1	0
Onoclea sensiblis	S5	0	0	0	0	0	0	0	0	0	1	0
Parthenocissus quinquefolia	SE	0	0	0	0	0	0	0	1	0	0	0
Picea glauca	S5	0	0	0	0	0	0	1	0	0	0	0
Poa annua	SE	0	0	0	0	0	1	1	0	1	1	0
Primula sp.		0	0	0	0	0	0	0	0	0	1	0
Prunus pensylvanica	S5	0	0	0	0	0	0	0	0	1	1	0
Rosa virginiana	S5	0	0	0	0	0	0	0	0	0	1	0
Euphrasia sp.		0	0	0	0	0	0	0	0	0	1	1
Rubus hispidus	S5	0	0	0	0	0	0	0	0	0	1	0
Rubus idaeus	S5	0	0	0	0	0	1	0	1	0	1	0
Rumex crispus	S5	0	0	0	0	0	0	0	0	0	0	1

Species	**S-Rank**	**BS**	**DC**	**EX**	**HF**	**LS**	**ML**	**MT**	**PW**	**SB**	**SF**	**SP**
Salix abla	SE	0	0	0	0	0	0	1	0	0	1	0
Salix bebiana	S5	0	0	0	0	0	0	0	0	0	1	0
Scirpus atrovirens	S5	0	0	0	0	0	0	0	0	0	1	0
Scirpus cyperinus	S5	0	0	0	0	0	0	0	0	0	1	0
Senecio vulgaris	SE	0	0	0	0	0	0	1	0	0	0	0
Silene vulgaris	SE	0	0	0	0	0	0	1	0	0	1	0
Solidago gigantea	S4	0	0	0	0	0	0	0	0	0	1	0
Sonchus oleraceus	SE	0	0	0	0	0	1	0	0	0	0	0
Spiraea x vanhouttei	SE	0	0	0	0	0	0	0	0	0	1	0
Stellaria media	SE	0	0	0	0	0	1	1	1	1	1	1
Tanacetum vulgare	SE	0	0	0	0	0	0	0	0	0	1	0
Tragopogon pratnesis	SE	0	0	0	0	0	0	0	1	0	0	0
Taraxacum officinale	SE	0	0	1	1	1	1	1	1	1	1	1
Trifolium hybridum	SE	0	0	0	0	0	0	1	1	1	1	1
Ulmus glabra	SE	0	0	0	0	0	0	0	0	1	0	0
Veronica officinalis	S5SE	0	0	0	0	0	0	1	0	0	0	1
Viburnum nudum	S5	0	0	0	0	0	0	0	0	0	0	1
Centaurium umbellatum	SE	0	0	0	0	1	0	0	0	0	0	0
Equisetum arvense	S5	0	0	0	0	1	1	0	0	1	0	0
Poa pratensis	S5	0	0	0	0	1	0	0	0	0	1	0
Solanum dulcamara	SE	0	0	0	0	1	0	0	0	1	1	0
Anaphalis margaritacea	S5	0	0	0	1	0	1	0	0	0	0	0
Aster lateriflorus	S5	0	0	0	1	0	1	0	0	1	1	0
Aster umbellatus	S5	0	0	0	1	0	0	0	0	0	1	0
Senecio viscosus	SE	0	0	0	1	0	0	1	0	0	1	1
Dianthus armeria	SE	0	0	0	1	1	0	0	1	0	0	0
Myrica pensylvanica	S5	0	0	0	1	1	0	0	1	0	0	1
Carex scoparia	S5	0	0	1	0	0	1	1	0	0	1	1
Juncus bufonius	S5	0	0	1	0	0	0	0	0	0	0	0
Lotus corniculatus	SE	0	0	1	0	0	0	0	0	1	1	1
Plantago lanceolata	SE	0	0	1	0	0	0	1	0	0	0	1
Polygonum aviculare	S5SE	0	0	1	0	0	0	0	0	1	0	0
Polygonum persicaria	SE	0	0	1	0	0	0	0	0	1	1	0
Prunella vulgaris	S5	0	0	1	0	0	0	0	0	1	1	0
Cirsium vulgare	SE	0	0	1	0	0	0	0	0	0	1	0
Veronica arvensis	SE	0	0	1	0	0	0	0	0	0	0	0

Species	**S-Rank**	**BS**	**DC**	**EX**	**HF**	**LS**	**ML**	**MT**	**PW**	**SB**	**SF**	**SP**
Veronica peregrina	SE?	0	0	1	0	0	0	0	0	0	0	0
Leucanthemum vulgare	SE	0	0	1	0	1	1	1	1	1	1	1
Gnaphilum uglinosum	SE	0	0	1	0	1	0	0	0	1	0	0
Plantago major	SE	0	0	1	0	1	1	0	1	1	1	0
Oxalis stricta	S5	0	0	1	1	0	1	1	1	1	1	0
Veronica serpyllifolia	S5	0	0	1	1	0	0	1	0	0	1	0
Acer pseudoplatanus	SE	0	1	0	0	0	0	0	0	0	0	0
Acer rubrum	S5	0	1	0	0	0	0	0	0	0	1	0
Betula papyrifera	S5	0	1	0	0	0	0	1	0	1	1	0
Campnula rapunculoides	SE	0	1	0	0	0	0	0	0	0	0	0
Erigeron strigosus	S5	0	1	0	0	0	1	0	0	0	0	0
Euphrasia officianale	S5SE	0	1	0	0	0	0	0	0	0	0	0
Populus tremuloides	S5	0	1	0	0	0	0	0	0	0	0	0
Quercus rubra	S5	0	1	0	0	0	0	0	0	0	0	0
Sagina procumbens	S5SE	0	1	0	0	0	0	1	1	0	1	0
Setaria glauca	SE	0	1	0	0	0	0	0	0	0	0	0
Acer platanoides	SE	0	1	0	0	1	0	0	0	1	0	0
Rosa multiflora	SE	0	1	0	0	1	0	0	1	1	0	1
Rumex acetosella	S5	0	1	0	0	1	0	1	1	1	0	1
prob Sorbus aucuparia	SE	0	1	0	0	1	0	0	0	0	0	0
Spiraea alba	S5	0	1	0	0	1	0	1	0	0	1	1
Spiraea tomentosa	S5	0	1	0	0	1	1	0	0	0	0	0
Hypericum perforatum	SE	0	1	0	1	0	1	1	1	1	1	1
Oenothera biennis	S5	0	1	0	1	0	1	1	1	1	1	1
Hieracium lachnealii	SE	0	1	0	1	1	1	1	0	0	1	1
Solidago rugosa	S5	0	1	0	1	1	0	1	0	1	1	1
Festuca rubra	S5	0	1	1	0	0	0	0	1	1	0	1
Solidago nemoralis	S4S5	0	1	1	0	0	0	0	0	0	0	1
Fragaria vesca	S4	0	1	1	0	1	0	1	0	0	1	0
Juncus tenuis	S5	0	1	1	0	1	1	1	1	1	1	1
Potentilla reptans	SE	0	1	1	0	1	1	0	1	1	1	1
Danthonia spicata	S5	0	1	1	1	1	0	1	0	0	1	1
Artemisia absinthium	SE	1	0	0	0	0	0	0	0	1	0	0
Digitaria ischaemia	SE	1	0	0	0	0	0	0	0	1	0	0
Lepidium virginicum	SE	1	0	0	0	0	0	0	0	0	0	0
Matricaria chamomilla	SE	1	0	0	0	0	0	0	0	1	0	0

Species	**S-Rank**	**BS**	**DC**	**EX**	**HF**	**LS**	**ML**	**MT**	**PW**	**SB**	**SF**	**SP**
Phalaris arundinacea	S5	1	0	0	0	0	0	0	0	0	0	0
Ranunculus repens	SE	1	0	0	0	0	1	1	1	1	1	0
Verbascum thapsus	SE	1	0	0	0	0	0	0	1	0	0	0
Agrostis stolonifera	S5SE	1	0	0	0	1	1	0	0	1	0	0
Melilotus albus	SE	1	0	0	1	0	1	0	1	0	1	0
Tanacetum vulgare	SE	1	0	0	1	0	0	0	0	0	0	1
Achillea millefolium	S5	1	0	0	1	1	1	1	1	0	1	0
Medicago lupulina	SE	1	0	0	1	1	1	0	1	1	1	0
Echinochloa crusgalli	SE	1	0	1	0	0	0	0	0	1	0	0
Hordeum jubatum	S5	1	0	1	0	0	0	0	0	1	0	0
Panicum capillare	SE	1	0	1	0	0	1	1	0	0	1	0
Plantgo rugelii	S1SE	1	0	1	0	0	1	1	1	0	1	0
Potentilla recta	SE	1	0	1	0	0	1	0	0	0	1	0
Agropyron repens	SE	1	0	1	0	1	1	1	1	1	1	1
Phleum pratense	SE	1	0	1	0	1	1	0	0	1	1	1
Sonchus arvensis	SE	1	0	1	0	1	0	0	0	1	1	0
Cerastum vulgatum	SE	1	0	1	1	1	1	1	0	1	1	1
Hieracium maculata	SE	1	0	1	1	1	1	1	1	1	1	0
Tussilago farfara	SE	1	0	1	1	1	1	1	1	1	1	0
Erigeron annuus	S4S5	1	1	0	0	0	1	1	1	1	1	1
Fraxinus excelsior	SE	1	1	0	0	0	0	0	0	0	0	1
Linaria vulgaris	SE	1	1	0	0	1	1	1	0	0	1	1
Luzula multiflora	S5	1	1	0	0	1	0	0	0	0	1	1
Solidago juncea	S5	1	1	0	1	0	1	1	1	0	1	0
Agrostis capillaris	SE	1	1	1	0	0	1	1	0	1	1	1
Leontodon autumnalis	SE	1	1	1	0	0	1	1	1	1	1	1
Sporobolus vaginiflorus	SE	1	1	1	0	0	0	1	1	0	0	0
Deschampsia flexuosa	S5	1	1	1	0	1	1	1	0	0	1	1
Euthamia graminifolia	S5	1	1	1	0	1	1	1	1	1	1	1
Poa palustris	S5	1	1	1	0	1	1	1	0	1	1	0
Taraxacum officinale	SE	1	1	1	0	1	1	1	1	1	1	1
Trifolium campestre	SE	1	1	1	0	1	0	1	1	1	1	0
Vicia cracca	SE	1	1	1	0	1	1	1	1	1	1	0
Agrostis hyemalis	S5	1	1	1	1	0	0	1	0	1	1	1
Convolvulus arvensis	SE	1	1	1	1	0	0	0	1	0	1	0
Trifolium aureum	SE	1	1	1	1	0	0	1	0	0	0	0

Species	**S-Rank**	**BS**	**DC**	**EX**	**HF**	**LS**	**ML**	**MT**	**PW**	**SB**	**SF**	**SP**
Trifolium arvense	SE	1	1	1	1	0	1	1	1	1	1	0
Aster novae-belgii	S5	1	1	1	1	1	1	1	1	1	1	1
Centaurea nigra	SE	1	1	1	1	1	1	1	1	1	1	1
Daucus carota	SE	1	1	1	1	1	1	1	1	1	1	1
Hieracium pilosella	SE	1	1	1	1	1	1	1	1	1	1	0
Poa compressa	SE	1	1	1	1	1	1	1	1	1	1	1
Solidago canadensis	S5	1	1	1	1	1	1	1	1	1	1	1
Trifolium pratense	SE	1	1	1	1	1	1	0	1	1	1	1
Trifolium repens	SE	1	1	1	1	1	1	1	1	0	1	1

APPENDIX D -SPECIES RECORDED AT LAWN PLOTS INCLUDING S-RANK.

Species	**S-Rank**	**JL**	**MB**	**SG**	**SR**	**TL**
Aster lateriflorus	S5	1	0	0	0	0
Centurea nigra	SE	1	0	0	0	0
Cerastium vulgare	SE	1	0	1	1	1
Cirisum vulgare	SE	1	0	0	0	0
Festuca rubra	S5	1	1	1	1	1
Glechoma her	SE	0	0	1	0	1
Hedra helix	SE	1	0	0	0	0
Leucanthemum vulgare	SE	1	1	1	1	1
Lolium perennis	SE	1	1	0	1	1
Oxalis stricta	S5	1	1	1	1	1
Plantago major	SE	1	0	0	1	0
Poa annua	SE	0	0	0	1	0
Poa pratensis	SE	1	1	1	1	1
Primula vulgaris	S5	1	1	1	1	0
Ranunclus repens	SE	1	1	1	1	1
Rubus ideaus	S5	1	0	0	0	0
Spirea alba	S5	1	0	0	0	0
Stellera media	SE	0	1	1	1	0
Taraxicum officinale	SE	1	1	1	1	1
Trifolium pratense	SE	0	0	0	1	0
Trifolium repens	SE	1	1	1	1	1
Veronica officianalis	S5SE	0	1	1	1	1
Veronica serotina	S5	1	1	1	1	1
Viola sp.	SE	0	0	0	1	0
Viola tri	SE	1	1	0	1	1

APPENDIX E - SPECIES RECORDED AT FOREST PLOTS INCLUDING S-RANK.

Species	S-Rank	AL	LW	MU	OK	OL
Acer rurbum	S5	1	1	1	1	1
Amalalanchier bartramiana	S5	0	0	0	0	1
Amalanchier sp.	S5	0	1	0	0	0
Aralia hispidula	S5	1	1	0	0	1
Betula papyifera	S5	0	0	1	0	1
Clontonia boreale	S5	1	0	0	0	0
Cyperunus acuale	S5	0	0	0	1	0
Doelligeria umbellatus	S5	0	1	0	0	0
Erigeron strigosus	S5	1	0	0	0	0
Fagus grandiflolia	S5	0	1	0	0	1
Gautheria procumbens	S5	0	0	0	1	1
Gaylussacia dumosa	S4	0	0	0	0	1
Hammamellis virginica	S5	1	1		0	1
Hieracium lachenales	SE	1	1	0	0	0
Hypericum perforata	SE	1	1	0	0	0
Kalmia angustifolia	S5	0	0	0	0	1
Lupunu	SE	1	1	0	0	0
Maianthemum canadensis	S5	0	0	1	1	1
Monotropa uniflorus	S5	0	0	0	1	0
Mysotis sp.	SE	1	1	0	0	0
Picea glauca	S5	0	0	1	0	0
Rumex acetocella	S5	1	0	0	0	0
Seteria glauca	SE	0	1	0	0	0
Tragopogon pratensis	SE	0	1	0	0	0
Tridetalis borealis	SE	0	0	0	0	1
Vaccinium angustifolium	S5	1	0	1	0	1
Viburnum nudum	S5	0	0	1	1	0
Viccia cracca	SE	1	0	0	0	0
Viola sp.		1	0	0	0	0

APPENDIX F - A LIST OF ALL INVERTEBRATE TAXA ARRANGED BY SITE.

Table F1. Family or morphogroup of all invertebrates collected during study sampling period. Family or groups in ***bold*** indicate those used for pollinator analysis.

Family or morphogroup	USV											Forest					Lawn				
	BS	DC	EX	HF	LS	ML	MT	PW	SB	SF	SP	LW	OL	MS	OK	AL	JL	MB	SG	SR	TL
Acrididae	2	7	-	-	1	11	-	-	3	2	1	-	-	1	-	-	-	-	-	-	-
Andrenidae	-	1	-	-	-	1	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-
Annelids	-	-	2	1	15	25	5	1	8	12	4	-	-	-	1	-	4	-	1	2	-
Anthomyiidae	-	-	-	-	-	1	1	-	3	-	-	-	-	-	-	-	-	-	-	-	-
Apidae	7	-	2	9	6	2	1	5	2	5	5	-	-	-	-	-	-	-	-	-	-
Arachnida	23	12	18	10	27	101	201	11	77	136	18	-	-	2	-	2	3	13	2	-	1
Arctiidae	-	-	1	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Asilidae	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Berytidae	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Blissidae	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bombyliidae	1	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-
Braconidae	-	-	3	1	-	3	-	2	1	8	2	1	1	-	-	-	-	-	-	-	-
Brentidae	-	-	-	10	-	1	1	-	2	6	-	-	-	-	1	-	3	-	-	-	-
Byrrhidae	-	-	2	2	6	-	1	-	-	5	1	2	-	-	-	-	1	1	-	-	-
Cantharidae	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-
Carabidae	7	5	7	24	59	103	25	21	134	119	68	22	10	88	8	16	6	-	53	24	25
Cercopidae	-	7	1	3	5	1	-	4	-	4	3	-	-	-	-	-	-	-	-	-	-
Chalcidoidea	3	1	2	2	3	-	1	-	-	14	2	-	-	-	-	-	-	-	-	-	-

Chamaemyiidae	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-
Chloropidae	-	-	3	-	-	2	1	-	-	-	-	-	-	1	3	-	-	-	-	-	-
Chrysomelidae	4	-	-	1	-	3	-	-	2	2	3	-	-	-	-	1	-	-	-	-	-
Chrysopidae	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cicadellidae	1	-	2	-	-	3	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Cleridae	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Coccinellidae	13	-	3	1	1	-	3	-	4	1	-	-	-	-	-	-	-	-	-	-	-
Coleoptera (larvae)	5	-	54	1	3	8	6	-	19	2	9	7	-	-	1	-	17	3	21	15	3
Colletidae	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Crabronidae	-	-	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Chrysomelidae	2	1	-	4	1	3	1	-	-	3	-	-	-	-	-	-	-	-	-	-	-
Culicidae	-	-	8	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Curculionidae	10	-	1	17	23	17	2	-	2	30	2	-	-	3	16	2	6	-	7	5	-
Dolichopodidae	1	2	-	-	1	-	2	1	1	-	-	2	3	1	1	2	-	-	-	-	-
Drosophilidae	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Dryomyzidae	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Elateridae	22	-	4	6	21	10	15	-	5	26	181	-	-	1	-	-	-	3	-	-	-
Empididae	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ephydridae	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Fanniidae	-	1	-	1	1	1	1	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Forficulidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	4	-	-
Formicidae	23	465	187	2154	1917	379	1212	216	1620	1580	1597	33	2	15	18	3	1953	27	90	76	87
Gastropoda	5	-	1	34	2	8	19	84	5	30	2	1	8	2	5	1	6	10	9	6	8
Gelechiidae	-	-	1	-	-	1	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-
Gryllidae	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Halictidae	3	-	1	2	2	2	2	2	-	3	4	-	-	-	-	-	-	-	-	-	-
Hesperiidae	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-
Histeridae	-	-	-	-	-	3	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydrophilidae	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	2	-	6	-	-
Ichneumonidae	4	3	-	2	2	1	3	-	-	3	4	1	-	-	-	-	-	-	-	-	-
Isopoda	96	876	7	2673	2523	176	3175	1216	423	256	2161	356	60	77	246	72	35	7	94	62	44
Julidae	83	65	7	46	29	79	43	101	96	296	155	35	10	16	1	30	24	22	180	43	63
Lampyridae	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	1	-	-	-	-	-
Lauxaniidae	-	-	3	1	-	2	-	-	1	5	-	-	-	-	-	-	-	-	-	-	-
Lepidoptera (other)	-	-	1	-	-	2	2	1	1	2	3	-	-	-	-	-	-	-	-	-	-
Leuctridae	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lithobiomorpha	-	-	-	-	-	7	-	-	-	2	-	-	-	-	-	1	-	27	-	4	-
Lycaenidae	-	-	1	-	1	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Megachiliade	-	-	-	-	1	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Melittidae	-	-	-	1	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Melyridae	-	-	-	-	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Membracidae	16	2	-	2	1	8	3	4	-	5	3	-	-	-	-	-	-	-	-	-	-
Miridae	8	4	15	-	2	2	1	2	1	11	1	-	-	-	-	-	-	-	-	-	-
Mordellidae	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-
Muscidae	1	-	-	-	1	-	1	1	-	-	-	-	1	-	-	-	-	-	-	-	-
Nabidae	-	-	1	-	-	1	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Nitidulidae	-	-	-	1	-	-	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-
Nymphalidae	1	-	-	-	1	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Odonata	-	-	-	1	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-
Opiliones	24	-	-	16	8	69	44	18	29	16	1	6	12	5	5	2	-	-	-	-	-

Orthoptera (other)	-	-	-	11	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Diptera (other)	7	-	13	41	10	6	15	2	27	3	10	5	16	32	29	5	6	13	80	26	66
Pentatomidae	1	-	2	1	-	1	3	-	-	4	2	-	-	-	-	-	-	-	-	-	-
Pieridae	2	-	-	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Polydesmidae	20	45	5	23	78	116	54	72	442	181	73	66	42	14	11	4	4	5	1	7	-
Pyralidae	-	-	1	1	1	1	2	1	-	6	-	-	-	-	-	-	-	-	-	-	-
Rhaphidophoridae	-	-	-	5	-	8	2	-	-	43	-	-	-	-	-	-	-	-	-	-	-
Sarcophagidae	1	2	-	-	-	2	-	3	-	-	1	-	-	-	-	-	-	-	-	-	-
Scarabaeidae	-	-	3	1	-	4	15	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Sciomyzidae	-	-	-	-	-	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Silphidae	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Simuliidae	-	-	-	-	1	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-
Sphecidae	1	-	-	-	1	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Staphylinidae	8	24	14	28	40	14	15	12	16	98	73	7	7	1	6	-	25	17	61	18	5
Syrphidae	5	2	-	2	4	5	3	3	7	8	10	-	-	-	-	-	-	-	-	-	-
Tabanidae	-	-	2	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Tachinidae	1	2	-	-	-	2	1	-	-	5	-	-	-	-	-	-	-	-	-	-	-
Tephritidae	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tetrigidae	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-
Tettigoniidae	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tingidae	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tipulidae	-	-	2	-	-	1	2	-	-	1	-	-	6	-	-	2	-	-	-	-	-
Ulidiidae	3	1	-	2	1	3	-	-	1	-	2	-	-	-	-	-	-	-	-	-	-
Vespidae	2	2	-	-	2	-	1	1	-	9	1	-	-	-	-	-	-	-	-	-	-
Xiphydriidae	-	1	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table F2. Species collected by sweep net sampling

		USV											Forest				
Family or group	**Species or morphospecies**	**BS**	**DC**	**EX**	**HF**	**LS**	**ML**	**MT**	**PW**	**SB**	**SF**	**SP**	**LW**	**OL**	**MS**	**OK**	**AL**
Syrphidae	*Eristalsis anthophorina*	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
	Eristalis tenax	-	-	-	-	1	-	-	1	2	2	1	-	-	-	-	-
	Eristalis dimidata	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-
	Syritta pipiens	1	-	-	-	-	-	2	-	1	1	-	-	-	-	-	-
	Eristalis arbustorum	2	-	-	-	3	-	1	-	-	1	2	-	-	-	-	-
	Syrphus torvus	-	1	-	1	-	-	-	1	1	1	-	-	-	-	-	-
	Melanostoma mellinum	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
	Eristrophe sp.	1	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-
	Meliscaeva cinctella	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
	Toxomerus germinatus	1	-	-	-	-	1	-	-	1	1	-	-	-	-	-	-
	Toxomerus marginatus	-	-	-	1	-	4	-	1	1	-	2	-	-	-	-	-
	Syrphid sp. 1	-	1	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Bombyliidae	*Bombylius pygmaeus*	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
	Bombylius major	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
	Villa sp.	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Apidae	*Bombus marginatus*	-	-	-	2	1	1	-	-	-	-	-	-	-	-	-	-
	Bombus ternarius	-	-	2	-	-	-	-	-	1	1	-	-	-	-	-	-
	Bombus impatiens	1	-	-	3	-	1	1	2	1	-	2	-	-	-	-	-
	Bombus vagans	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
	Apis mellifera	3	-	-	3	1	-	-	1	-	-	-	-	-	-	-	-

	Bombus fervidus	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
	Bombus sp. 1	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-
	Bombus sp. 2	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
	Bombus sp. 3	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Ceratina calcarata	1	-	-	1	2	-	-	-	-	2	1	-	-	-	-	-
	Melissodes druriella	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
	Melissodes sp. 1	1	-	-	-	1	-	-	1	-	-	-	-	-	-	-	-
Megachiliade	*Anthidium sp.*	-	-	-	-	1	-	-	-	1	-	-	-	-	-	-	-
Melittidae	*Macropsis sp.*	-	-	-	1	-	1	-	-	1	-	-	-	-	-	-	-
Colletidae	*Colletes sp.*	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Andrenidae	*Andrena sp.*	-	1	-	-	-	1	-	-	-	-	2	-	-	-	-	-
Halictidae	*Augochlorella sp.*	1	-	-	-	1	-	1	-	-	-	1	-	-	-	-	-
	Sphecodes sp.	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
	Lasioglossum sp. 1	1	-	-	-	1	-	-	1	-	-	1	-	-	-	-	-
	Lasioglossum sp. 2	-	-	1	-	-	-	1	1	-	1	-	-	-	-	-	-
	Lasioglossum sp. 3	1	-	-	1	-	1	-	-	-	1	2	-	-	-	-	-
	Lasioglossum sp. 4	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-
Sphecidae	*Sceliphron caementarium*	1	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
	Chalybion californicum	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Crabronidae	Crabronid 1	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
	Crabronid 2	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Vespidae	*Symmorphus sp.*	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Symmorphus albomarginatus	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Eumenes crucifera	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
	Vespula maculifrons	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

	Vespula consobrina	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-
	Vespula acadia	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
	Vespula vulgaris	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
	Polistes fuscatus	-	-	-	-	1	-	-	1	-	5	-	-	-	-	-	-
	Polistes dominula	-	-	-	-	1	-	-	-	-	-	1	-	-	-	-	-
Ichneumonidae	Ichneumonid 1	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-
	Ichneumonid 2	2	2	-	-	1	-	1	-	-	2	-	-	-	-	-	-
	Ichneumonid 3	1	1	-	1	-	1	1	-	-	-	2	1	-	-	-	-
	Ichneumonid 4	1	-	-	1	1	-	1	-	-	1	-	-	-	-	-	-
Braconidae	Braconid 1	-	-	1	-	-	2	-	-	-	4	-	1	1	-	-	-
	Braconid 2	-	-	-	1	-	-	-	1	-	2	1	-	-	-	-	-
	Braconid 3	-	-	2	-	-	1	-	1	1	2	1	-	-	-	-	-
Xiphydriidae	Xiphydriid 1	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-
	Xiphydriid 2	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chalcidoidea	Perilampidae	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Chalcidoid 1	-	1	1	-	1	-	-	-	-	5	-	-	-	-	-	-
	Chalcidoid 2	-	-	-	-	1	-	1	-	-	4	2	-	-	-	-	-
	Chalcidoid 3	-	-	-	1	1	-	-	-	-	2	-	-	-	-	-	-
	Chalcidoid 4	1	-	1	1	-	-	-	-	-	3	-	-	-	-	-	-
Pentatomidae	*Dicromerus bidens*	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
	Euschistus servus	-	-	-	1	-	-	-	-	-	1	-	-	-	-	-	-
	Banasa dimidata	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
	Chlorochroa persimilis	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
	Pentatomid 1	1	-	1	-	-	-	1	-	-	-	1	-	-	-	-	-
	Pentatomid 2	-	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-

	Pentatomid 3	-	-	-	-	-	-	2	-	-	1	-	-	-	-	-	-
Membracidae	*Ceresa sp.*	1	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-
	Ceresa diceros	7	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
	Campylenchia latipes	-	2	-	2	1	7	-	4	-	1	-	-	-	-	-	-
	Publilia concava	7	-	-	-	-	1	1	-	-	2	2	-	-	-	-	-
	Campylenchia latipes	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Entylia carinata	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-
Tingidae	Tingid	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cercopidae	*Philaneus sp. 1*	-	-	-	-	1	-	-	2	-	1	-	-	-	-	-	-
	Philaneus spumarius	-	7	1	3	4	1	-	2	-	1	2	-	-	-	-	-
	Lepyronia quadranularis	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-
	Philaneus sp.2	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Cicadellidae	Cicadellid 1	-	-	1	-	-	2	1	-	-	1	-	-	-	-	-	-
	Cicadellid 2	1	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-
Nabidae	*Nabis americaterus*	-	-	1	-	-	1	-	-	-	1	-	-	-	-	-	-
Miridae	*Miris dolabratus*	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
	Stenotus binotatus	-	-	7	-	-	-	-	-	-	-	-	-	-	-	-	-
	Caspus ater	-	1	-	-	-	-	-	1	1	1	-	-	-	-	-	-
	Lygus lineolaris	3	-	1	-	2	-	1	-	-	4	-	-	-	-	-	-
	Trigonotylus coelestialium	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
	Megaloceroea recticornis	1	2	-	-	-	-	-	-	-	4	1	-	-	-	-	-
	Lygocoris sp.	3	-	1	-	-	1	-	1	-	1	-	-	-	-	-	-
	Plagiognathus sp.	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Heterotoma merioptera	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Mirid 1	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-

	Mirid 2	-	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-
	Mirid 3	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
	Mirid 4	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
	Mirid 5	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Berytidae	*Neoneides sp.*	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Arctiidae	*Ctenucha virginica*	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
	Ctenucha sp.	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Nymphalidae	*Vanessa virginiensis*	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
	Coenonympha tullia	1	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-
Lycaenidae	*Lycaena phlaeas*	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
	Glaucopsyche lygdamus	-	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-
	Celastrina neglecta	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
Pieridae	*Pieris rapae*	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
	Colias eurytheme	2	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-
Hesperiidae	*Thymelicus lineola*	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-	-
Lepidoptera (Micro moths)	Moth 1	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
	Moth 2	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-
	Moth 3	-	-	-	-	-	-	2	-	1	-	-	-	-	-	-	-
	Moth 4	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
	Moth 5	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
	Moth 6	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
	Moth 7	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
	Moth 8	-	-	-	-	-	1	-	-	-	-	0	-	-	-	-	-
	Moth 9	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Pyralidae	Pyralid	-	-	1	1	1	1	2	1	-	6	-	-	-	-	-	-

Gelechiidae	Gelechiid	-	-	1	-	-	1	-	-	1	1	-	-	-	-	-	-
Odonata	Dragonfly	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-
	Damselfly	-	-	-	1	-	-	-	-	-	1	-	-	-	-	-	-
Acrididae	Acridid	2	7	-	-	1	11	-	-	3	2	1	-	-	1	-	-
Tetrigidae	Tetrigid	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-
Gryllidae	Gryllid	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tettigoniidae	Tettigoniid	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Lampyridae	*Ellychnia corrusca*	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-
	Lucidota atra	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Chrysomelidae	*Trirhabda virgata*	1	-	-	4	1	3	-	-	-	-	-	-	-	-	-	-
	Colaspis sp.	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
	Calligrapha sp.	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
	Chrysolina hyperici	1	1	-	-	-	-	-	-	-	2	-	-	-	-	-	-
Mordellidae	*Mordella atrata*	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-
Hesperiidae	Histerid	-	-	-	-	-	3	-	1	-	-	-	-	-	-	-	-
Apionidae	Apionid	-	-	-	-	-	-	-	-	-	5	-	-	-	-	-	-
Curculionidae	*Sitona hipspidulus*	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
	Circulionid 1	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
	Circulionid 2	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
	Circulionid 3	-	-	-	1	-	-	-	-	-	2	-	-	-	-	-	-
	Circulionid 4	4	-	1	-	-	1	1	-	-	5	-	-	-	-	-	-
Sarcophagidae	*Sarcophagid 1*	1	2	-	-	-	2	-	3	-	-	1	-	-	-	-	-
Tabanidae	*Chrysops sp.*	-	-	1	-	-	-	-	-	-	1	-	-	-	-	-	-
	Tabanid 1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Lauxaniidae	*Lauxania sp.*	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-

	Minettia sp.	-	-	2	1	-	1	-	-	-	-	-	-	-	-	-	-
	Lauxaniid	-	-	1	-	-	1	-	-	1	1	-	-	-	-	-	-
Tachinidae	*Gymnosoma sp.*	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
	Cylindromyia sp.	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
	Tachinid 1	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
	Tachinid 2	1	2	-	-	-	1	1	-	-	3	-	-	-	-	-	-
Muscidae	Muscid	1	-	-	-	1	-	1	1	-	-	-	-	1	-	-	-
Chloropidae	*Thaumatomyia sp.*	-	-	3	-	-	1	-	-	-	-	-	-	-	-	3	-
	Chlorops sp.	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
	Parectecephala sp.	-	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-
Dryomyzidae	Dryomyzid	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Asilidae	Asilid	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Anthomyiidae	Anthomyiid	-	-	-	-	-	1	1	-	3	-	-	-	-	-	-	-
Tephritidae	Tephritid	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Drosophilidae	Drosophilid	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
Ephydridae	Ephydrid	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Empididae	Empidid	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Dolichopodidae	Dolichopodid	1	2	-	-	1	-	2	1	1	-	-	2	3	1	1	2
Culicidae	Culicid	-	-	8	-	-	-	-	-	-	1	-	-	-	-	-	-
Simuliidae	Simuliid	-	-	-	-	1	-	-	-	-	2	-	-	-	-	-	-
Ulidiidae	Ulidiid	3	1	-	2	1	3	-	-	1	-	2	-	-	-	-	-
Fanniidae	Fanniid	-	1	-	1	1	1	1	-	-	-	-	1	-	-	-	-
Chamaemyiidae	Chamaemyiid	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-
Tipulidae	Tupulid	-	-	2	-	-	1	2	-	-	1	-	-	6	-	-	2
Sciomyzidae	Sciomyzid	-	-	-	-	-	-	1	-	-	1	-	-	-	-	-	-

Blissidae	*Blissuslecopterus hirtus*	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Leuctridae	Leuctrid	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Formicidae	Formicid	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-
Chrysopidae	*Chrysoperia sp.*	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Staphylinidae	Staphylinid	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Cleridae	*Thanasimus dubius*	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Melyridae	*Malachius aeneus*	-	-	-	-	-	1	-	-	1	-	-	-	-	-	-	-
Cantharidae	*Cantharis rufa*	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-
Coccinellidae	*Propylea quatuordecimpunctata*	-	-	-	1	-	-	-	-	2	-	-	-	-	-	-	-
	Harmonia axyridis	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
	Coccinella trifasciata	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
	Coccinella septempunctata	4	-	3	-	-	-	1	-	2	-	-	-	-	-	-	-
	Hippodamia variegata	9	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-
Silphidae	*Necrophila americana*	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-

APPENDIX G - SOIL NUTRIENT PARAMETERS BY SITE.

Plot	Plot Type	Organic matter (%)	pH	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Na (ppm)	S (ppm)	Fe (ppm)	Mn (ppm)	Cu (ppm)	Zn (ppm)	B (ppm)	N (ppm)	CEC
BS 01	S	1.6	7.1	70	206	2324	189	52	38	315	50	8.55	15.6	0.25	0.1	7
BS 02	S	1.3	7.7	77	219	3686	224	61	31	283	65	7.24	9.3	0.21	0.1	11
BS 03	S	7.8	7.1	316	510	4910	259	45	36	209	47	11.37	42.3	0.90	5.4	14
BS 04	S	3.1	7.7	124	581	13600	441	50	366	235	19	8.69	8.0	1.10	0.6	37
BS 05	S	2.1	7.6	125	336	5974	245	54	73	224	46	8.20	20.8	0.40	0.3	17
BS 06	S	4.8	7.3	177	309	4764	302	42	39	204	32	10.01	32.5	0.64	0.8	14
BS 07	S	2.0	7.7	79	257	6162	236	54	48	259	30	10.89	15.9	0.25	1.8	17
BS 08	S	2.5	7.7	80	305	7006	303	46	71	295	34	10.69	21.2	0.44	0.8	19
BS 09	S	4.8	7.8	109	276	6340	242	52	49	212	35	12.08	49.9	0.68	1.0	17
BS 10	S	2.5	7.5	118	275	4540	194	40	40	215	34	6.60	18.5	0.39	0.7	13
BS 11	S	3.1	7.4	145	284	5902	329	54	87	290	27	7.96	26.9	0.44	1.6	17
BS 12	S	3.1	7.5	201	299	4784	227	48	53	270	31	8.33	25.0	0.37	1.3	13
DC 01	S	6.1	5.5	167	81	578	44	52	65	198	20	4.93	58.7	0.19	0.4	5
DC 02	S	5.9	5.7	340	292	1334	154	104	45	213	24	5.16	28.5	0.25	0.7	7
DC 03	S	1.1	6.5	53	80	474	93	25	10	189	35	6.71	6.7	0.10	0.1	2
DC 04	S	3.1	6.0	204	311	1359	169	44	31	204	55	6.61	22.0	0.21	0.3	5
DC 05	S	7.8	5.3	55	242	1409	199	41	84	341	12	2.57	16.1	0.32	0.4	8
DC 06	S	1.2	6.3	46	104	482	102	30	14	224	36	5.35	5.0	0.12	0.1	2
DC 07	S	2.6	5.8	95	197	927	116	44	32	174	46	4.80	12.4	0.12	0.1	4
DC 08	S	2.7	5.7	67	118	361	47	25	82	92	8	2.63	7.5	0.12	0.1	3
DC 09	S	3.0	5.1	37	94	142	26	23	160	278	6	1.76	2.3	0.10	0.1	3
DC 10	S	2.0	5.8	82	135	446	100	30	31	227	28	6.05	10.1	0.11	0.1	2
DC 11	S	4.3	5.7	30	27	148	32	24	7	79	11	1.68	2.4	0.10	0.1	1
DC 12	S	3.7	5.5	73	81	483	117	27	15	228	26	6.19	13.7	0.10	0.1	2

EP 01	S	1.3	6.5	78	229	1962	223	109	18	255	87	4.09	5.0	0.15	0.3	6
EP 02	S	1.8	6.2	95	225	2178	244	147	21	276	67	2.06	2.6	0.12	0.1	8
EP 03	S	1.7	6.0	61	174	1258	168	93	19	277	110	5.95	27.9	0.19	1.2	4
EP 04	S	1.8	6.7	187	217	1501	183	41	20	247	87	5.51	6.8	0.27	1.3	6
EP 05	S	2.0	6.2	65	303	2502	254	45	15	274	75	2.39	2.1	0.13	0.4	8
EP 06	S	1.8	6.5	60	308	3298	259	40	25	226	87	2.19	2.0	0.15	1.1	10
EP 07	S	1.6	6.7	64	287	2380	254	47	13	248	94	2.59	2.6	0.14	0.1	7
EP 08	S	1.5	6.2	55	316	1944	272	37	15	309	88	5.25	10.0	0.19	12.8	6
EP 09	S	2.3	6.9	124	446	2896	308	69	12	272	126	2.97	3.7	0.22	0.2	9
EP 10	S	2.6	5.9	80	321	1808	237	34	19	346	76	5.91	10.4	0.24	13.1	6
EP 11	S	3.8	5.7	211	311	1548	321	131	24	360	66	2.27	3.2	0.18	0.1	8
EP 12	S	4.4	5.7	158	364	2812	335	58	29	262	103	3.38	5.2	0.24	1.3	10
HF 01	S	2.9	6.7	203	206	2322	179	39	26	200	41	12.74	12.2	0.23	0.6	8
HF 02	S	1.5	6.4	182	126	754	76	34	18	161	44	3.67	7.1	0.50	0.3	2
HF 03	S	1.6	6.5	134	100	1030	121	29	14	206	132	5.13	11.5	0.14	0.3	3
HF 04	S	1.5	5.6	319	83	304	39	34	32	111	44	2.89	3.4	0.10	0.1	1
HF 05	S	2.2	6.3	137	190	1498	95	31	26	169	64	2.97	5.0	0.19	1.6	4
HF 06	S	3.7	5.9	341	208	2224	147	36	41	214	49	3.07	8.4	0.20	6.3	7
HF 07	S	5.2	4.9	51	84	207	22	28	76	172	10	1.17	2.6	0.10	0.2	5
HF 08	S	1.7	6.1	112	183	1324	146	38	26	254	100	9.82	10.0	0.26	0.3	4
HF 09	S	1.5	6.4	102	134	998	84	35	22	189	69	3.94	4.3	0.16	0.3	3
HF 10	S	2.1	5.9	188	129	517	44	33	39	100	25	2.21	3.4	0.15	0.2	2
HF 11	S	2.3	6.1	107	134	1318	96	40	30	180	38	5.45	16.5	0.19	1.6	4
HF 12	S	2.4	6.8	195	119	2662	79	74	56	183	37	6.10	12.1	0.62	0.2	8
LS 01	S	4.4	4.7	30	21	118	17	33	66	113	4	1.81	4.9	0.10	0.2	3
LS 02	S	4.0	6.6	67	203	1091	315	225	44	254	47	49.50	89.1	0.52	1.4	6
LS 03	S	5.5	6.2	56	173	1621	153	93	29	332	42	47.96	79.3	0.29	0.6	5
LS 04	S	3.5	6.5	67	245	1555	280	61	17	173	35	13.06	73.0	0.33	0.3	6
LS 05	S	4.0	6.7	57	297	2306	288	62	33	304	59	20.03	43.4	0.48	0.3	8
LS 06	S	4.6	6.6	51	274	2166	308	67	27	289	31	19.88	62.3	0.51	0.6	8

LS 07	S	4.6	6.4	50	241	1736	347	69	26	271	36	15.07	69.8	0.36	1.0	7
LS 08	S	5.0	6.5	65	201	1900	377	40	22	199	29	22.24	170.6	0.37	0.7	7
LS 09	S	5.7	6.5	75	387	2566	568	45	26	319	39	22.82	115.9	0.61	0.4	10
LS 10	S	5.0	6.3	39	157	3058	375	45	240	331	34	26.27	101.2	0.92	3.2	11
LS 11	S	5.2	6.4	152	556	3490	476	70	44	312	42	31.34	147.7	0.70	0.2	12
LS 12	S	7.0	6.7	50	220	3792	429	43	513	290	38	25.89	220.7	2.01	2.2	12
ML 01	S	4.4	6.6	123	180	4140	326	58	34	280	39	6.95	13.8	0.64	5.3	13
ML 02	S	3.1	6.7	104	183	1854	97	26	25	191	32	6.46	7.1	0.22	4.6	5
ML 03	S	3.3	7.4	110	258	4654	145	38	122	223	40	7.98	11.1	0.51	8.5	13
ML 04	S	5.5	6.4	111	332	2912	162	44	36	218	38	8.20	37.0	0.38	1.4	9
ML 05	S	6.8	6.4	71	222	2908	135	84	33	331	54	8.90	20.0	0.51	1.2	8
ML 06	S	8.2	6.3	90	267	3032	146	40	31	230	19	6.74	50.7	0.27	0.6	11
ML 07	S	6.7	6.4	86	219	4348	237	169	73	264	29	12.58	37.9	0.53	2.6	13
ML 08	S	34.2	6.0	84	80	366	39	39	19	127	12	2.02	187.2	0.14	3.0	1
ML 09	S	4.0	6.7	117	182	2174	111	36	26	274	28	12.80	62.8	0.30	15.6	6
ML 10	S	3.9	6.7	77	154	1893	248	25	24	194	33	6.67	22.1	0.31	0.6	6
ML 11	S	15.6	5.8	71	223	2444	162	44	34	315	6	3.06	35.7	0.16	0.7	12
ML 12	S	15.1	6.1	213	348	5874	327	31	22	233	26	3.10	23.2	0.77	38.7	17
MT 01	S	1.3	6.7	89	118	1438	131	69	32	295	75	3.65	11.6	0.15	0.1	4
MT 02	S	3.1	6.2	135	331	1229	124	57	38	173	38	10.01	44.0	0.19	0.6	6
MT 03	S	1.9	7.0	127	161	1706	75	49	29	128	32	2.03	3.5	0.10	0.2	5
MT 04	S	1.5	8.0	302	136	8090	150	55	69	150	44	3.81	3.2	0.36	0.1	21
MT 05	S	2.0	9.2	128	569	33740	308	126	510	214	24	3.25	16.8	1.64	0.2	87
MT 06	S	1.2	7.9	343	125	2624	79	39	32	105	22	1.91	4.7	0.24	0.1	7
MT 07	S	1.4	7.8	287	214	2062	54	44	26	93	20	1.46	1.9	0.36	0.1	6
MT 08	S	2.3	6.9	277	195	4370	94	98	59	105	23	1.92	6.5	0.23	0.1	13
MT 09	S	3.3	5.9	86	355	786	84	42	39	241	34	2.42	4.3	0.25	0.1	6
MT 10	S	5.7	5.6	334	660	1307	174	31	33	235	61	3.52	8.4	0.33	38.3	6
MT 11	S	2.3	6.2	55	90	923	77	38	16	249	60	4.03	5.0	0.13	0.3	67
MT 12	S	1.2	7.2	46	133	1534	93	43	9	294	121	3.43	3.4	0.15	0.1	5

PW 01	S	7.0	6.7	165	128	1924	157	22	19	210	17	80.28	79.3	0.95	0.9	6
PW 02	S	3.4	6.7	96	175	2252	168	34	25	230	43	42.57	45.5	0.63	3.5	7
PW 03	S	2.9	7.2	95	113	1682	128	30	18	182	27	48.81	39.9	0.46	0.8	5
PW 04	S	3.6	7.2	136	200	3702	227	39	30	180	34	49.89	47.8	0.64	1.5	11
PW 05	S	1.3	7.4	88	175	2126	156	41	15	198	40	20.23	22.3	0.38	0.4	6
PW 06	S	4.2	6.9	233	308	4320	335	42	32	183	45	91.57	108.8	1.46	3.1	13
PW 07	S	4.4	7.6	412	258	8310	318	34	124	165	27	35.40	57.8	1.26	8.7	23
PW 08	S	6.4	7.0	269	159	7024	202	31	41	190	34	27.83	40.5	0.93	0.7	19
PW 09	S	4.0	7.7	269	358	14470	363	47	80	186	30	37.05	63.6	1.18	0.9	38
PW 10	S	4.5	7.1	188	309	4114	260	41	40	180	24	10.29	25.5	0.72	2.6	12
PW 11	S	4.3	7.5	399	330	7282	404	56	59	205	36	32.06	62.7	1.21	1.9	20
PW 12	S	4.8	6.4	507	365	2294	192	60	39	238	29	9.32	36.9	0.40	4.3	9
SB 01	S	5.2	6.7	274	248	3750	144	74	144	287	62	20.95	55.6	0.64	4.0	11
SB 02	S	3.1	7.4	203	186	4232	102	225	184	267	44	9.34	26.2	0.58	9.4	12
SB 03	S	7.3	6.2	344	283	2970	196	106	114	336	20	6.22	18.8	0.78	23.0	10
SB 04	S	7.2	6.7	458	486	3594	448	44	30	217	25	13.49	25.1	0.64	14.3	13
SB 05	S	4.5	7.5	134	236	5000	250	70	46	350	41	15.40	30.2	0.78	5.5	14
SB 06	S	4.4	6.1	327	245	2236	186	43	174	494	24	14.75	25.4	0.53	1.2	8
SB 07	S	8.8	6.3	142	248	1868	127	49	46	249	39	15.39	22.5	0.28	6.8	6
SB 08	S	3.1	5.3	57	127	552	55	29	130	481	12	4.23	13.4	0.24	0.2	3
SB 09	S	7.1	7.1	209	207	3436	331	31	61	279	49	9.54	26.3	0.51	2.9	11
SB 10	S	3.8	7.6	81	318	17096	397	55	152	327	18	7.54	15.1	0.71	6.7	45
SB 11	S	3.9	6.4	437	201	1687	146	33	29	387	33	11.06	60.7	0.29	0.5	6
SB 12	S	7.5	6.7	257	399	5298	339	67	85	291	29	12.58	42.0	0.94	26.3	15
SF 01	S	3.9	6.6	254	386	2322	133	39	31	173	19	8.00	15.9	0.33	23.3	9
SF 02	S	4.8	6.1	311	939	1991	208	38	65	201	21	4.72	13.9	0.38	0.7	10
SF 03	S	3.6	5.6	276	130	898	92	36	33	232	21	6.33	13.7	0.15	0.1	6
SF 04	S	6.4	5.7	145	420	2272	182	36	37	344	20	4.08	10.1	0.26	0.5	10
SF 05	S	4.8	4.8	159	109	390	56	34	55	321	18	3.17	5.3	0.15	0.2	5
SF 06	S	3.4	5.5	249	208	1096	87	42	39	155	13	8.14	18.8	0.22	0.1	6

SF 07	S	3.9	5.9	195	284	2114	135	48	34	204	25	9.92	16.0	0.29	1.3	8
SF 08	S	4.6	6.0	215	222	1793	112	52	32	195	24	12.79	32.3	0.35	4.9	6
SF 09	S	1.3	5.5	179	72	427	72	34	15	167	54	1.70	6.6	0.10	0.2	2
SF 10	S	1.3	5.3	259	79	385	84	35	12	148	63	1.31	6.0	0.11	0.1	2
SF 11	S	6.5	5.2	171	310	1116	97	35	50	258	18	3.74	10.9	0.18	0.9	8
SF 12	S	6.4	5.9	492	491	2280	219	39	48	222	31	15.10	39.1	0.46	13.2	10
SF 13	S	6.4	5.5	386	313	2310	160	50	89	217	24	21.63	59.4	0.46	4.5	9
SF 14	S	5.3	5.6	170	181	1684	121	37	40	231	21	8.82	16.4	0.19	1.4	7
SF 15	S	9.6	5.8	111	141	2936	116	70	47	242	17	3.41	14.7	0.23	1.3	10
SF 16	S	5.4	5.6	82	271	1308	90	33	42	289	9	3.91	7.4	0.22	1.3	8
SF 17	S	6.8	5.8	68	289	2192	135	42	40	247	7	3.37	5.1	0.20	0.7	10
SF 18	S	2.6	6.3	100	198	1679	104	39	22	248	28	3.75	6.3	0.27	1.1	7
SF 19	S	6.0	6.0	178	575	2850	168	45	44	208	27	29.47	20.2	0.45	7.2	14
SF 20	S	6.9	5.7	54	232	1257	82	41	42	320	8	1.53	3.3	0.21	0.4	8
SF 21	S	7.1	5.6	56	192	1581	95	43	36	269	7	1.69	4.5	0.19	0.3	8
SF 22	S	7.0	6.0	71	269	2654	106	61	37	257	8	2.88	5.2	0.23	0.4	12
SF 23	S	4.4	6.7	89	148	1578	64	804	45	261	11	6.95	8.3	0.29	1.0	9
SF 24	S	7.8	5.7	56	314	1126	88	41	39	331	7	1.24	2.7	0.22	0.5	11
SP 01	S	2.9	6.7	265	83	1186	58	95	23	188	48	2.14	3.6	0.16	0.9	4
SP 02	S	2.6	6.0	268	156	669	62	65	35	175	43	2.46	4.7	0.14	0.1	4
SP 03	S	5.1	6.0	83	137	1039	55	106	48	390	61	2.05	2.8	0.27	0.4	5
SP 04	S	2.8	6.0	222	115	1005	88	31	29	189	44	2.67	3.6	0.13	1.7	4
SP 05	S	2.7	6.2	168	263	1268	107	44	41	199	52	3.72	4.9	0.19	0.3	6
SP 06	S	3.0	5.4	192	159	410	56	31	51	171	35	4.00	3.9	0.12	0.2	5
SP 07	S	3.2	5.4	231	134	685	58	28	37	180	29	4.94	4.2	0.13	0.2	4
SP 08	S	4.1	5.3	164	221	715	59	37	55	220	49	5.12	7.5	0.16	0.2	5
SP 09	S	2.8	6.5	128	263	1926	177	31	29	196	57	3.41	2.6	0.21	3.6	7
SP 10	S	2.3	5.7	220	257	390	51	28	40	109	43	2.28	2.3	0.14	0.2	3
SP 11	S	2.3	5.5	243	158	265	35	26	43	130	54	2.12	3.7	0.12	0.1	2
SP 12	S	4.2	6.2	153	266	2056	139	42	29	184	56	6.00	5.3	0.36	9.4	6

JL 01	L	3.7	6.0	216	287	1651	302	50	25	268	27	5.39	32.5	0.24	1.8	8
JL 02	L	3.4	5.6	177	334	1362	311	37	30	197	57	2.15	11.3	0.20	1.7	7
JL 03	L	4.4	6.0	122	227	2856	609	73	33	210	90	2.60	6.5	0.50	15.5	12
JL 04	L	4.0	5.8	184	323	1570	442	62	37	213	38	2.53	8.3	0.28	4.0	8
JL 05	L	5.9	5.9	157	306	2198	287	44	47	209	24	5.11	42.1	0.34	13.2	9
MB 01	L	5.3	6.3	301	523	2416	324	101	38	243	81	4.44	17.6	0.33	9.5	10
MB 02	L	2.5	6.2	281	374	1566	151	71	32	242	97	3.33	24.9	0.17	1.8	5
MB 03	L	3.4	6.1	145	293	1218	114	109	31	157	58	2.95	27.8	0.17	3.0	5
MB 04	L	4.0	6.7	188	433	3676	213	69	75	200	67	4.25	10.4	0.33	6.6	12
MB 05	L	5.7	5.8	110	181	1236	144	82	37	141	31	5.03	27.7	0.19	3.6	6
SG 01	L	8.8	5.6	430	486	3500	339	63	44	191	25	12.02	33.6	0.65	28.2	13
SG 02	L	6.3	5.5	228	237	1566	131	38	40	158	16	6.77	25.9	0.23	11.6	8
SG 03	L	6.0	5.4	469	157	1728	147	37	49	210	20	21.75	55.2	0.24	10.5	9
SG 04	L	6.6	5.4	260	225	691	68	100	61	237	10	8.70	50.7	0.24	12.2	6
SG 05	L	6.1	5.2	1076	174	730	77	102	47	299	6	6.59	28.8	0.12	4.3	6
SR 01	L	5.6	7.1	299	375	3348	773	41	37	167	54	3.16	16.0	0.59	10.1	13
SR 02	L	5.7	6.6	922	367	3598	829	37	30	211	50	1.88	6.7	0.51	12.5	14
SR 03	L	6.1	6.7	571	324	3624	714	40	30	178	66	4.95	11.9	0.49	24.8	14
SR 04	L	5.7	6.8	355	362	2792	730	42	39	153	84	1.98	5.9	0.47	20.1	12
SR 05	L	4.7	7.0	296	198	3160	914	43	32	182	55	1.93	4.6	0.44	17.2	13
TL 01	L	4.2	5.5	474	85	1569	143	34	26	249	22	6.98	69.9	0.19	4.6	6
TL 02	L	6.2	5.0	606	263	749	100	72	52	318	30	3.69	22.5	0.17	0.5	6
TL 03	L	7.6	5.5	1541	544	1877	140	60	47	276	25	9.94	81.2	0.33	15.3	10
TL 04	L	3.5	5.7	1057	380	2246	166	47	37	245	51	6.88	71.0	0.57	35.3	9
TL 05	L	10.2	5.3	691	223	1589	236	48	50	245	46	4.11	25.1	0.27	1.8	10
AL 01	F	34.8	4.1	232	484	498	246	74	36	139	27	1.90	21.9	0.10	2.6	12
AL 02	F	15.2	4.0	93	239	218	112	53	44	514	10	1.41	14.2	0.13	1.2	9
AL 03	F	43.8	4.0	187	536	356	217	84	32	151	13	1.87	13.5	0.10	3.5	12
AL 04	F	8.7	3.9	75	137	174	80	39	26	339	7	1.21	14.8	0.11	0.3	8
AL 05	F	5.2	4.7	121	109	107	33	32	91	135	6	1.71	9.7	0.10	0.3	5

LW 01	F	11.4	4.0	39	169	247	132	73	59	441	4	0.64	13.2	0.16	0.6	9
LW 02	F	10.6	4.0	103	179	375	165	64	20	221	9	0.68	8.6	0.22	0.5	8
LW 03	F	10.6	4.1	62	182	291	187	60	19	198	7	0.39	9.5	0.10	0.4	8
LW 04	F	27.3	3.8	161	347	476	236	104	25	172	14	1.17	15.9	0.10	2.4	13
LW 05	F	22.7	3.9	66	285	351	187	103	39	303	12	0.79	10.2	0.19	0.8	12
MS 01	F	31.4	4.0	144	347	203	198	113	38	274	6	1.11	10.7	0.13	3.1	14
MS 02	F	23.6	3.8	120	227	312	195	99	42	465	7	0.90	30.7	0.19	1.6	13
MS 03	F	26.6	3.9	202	235	378	177	65	33	384	10	0.75	6.0	0.16	0.9	14
MS 04	F	16.3	3.7	145	234	137	134	66	30	410	4	0.88	9.2	0.14	1.0	11
MS 05	F	11.9	4.0	172	190	261	118	55	29	445	3	0.78	7.2	0.16	0.7	10
OK 01	F	15.5	4.4	59	223	293	75	50	57	455	5	51.57	13.5	0.15	0.5	9
OK 02	F	11.2	4.2	31	179	96	63	56	68	481	2	18.56	9.5	0.14	0.5	8
OK 03	F	25.7	4.1	73	326	781	264	91	37	348	11	2.46	12.1	0.12	1.1	10
OK 04	F	25.5	4.0	105	293	328	131	57	33	508	6	7.08	11.2	0.23	1.2	9
OK 05	F	18.6	4.5	52	216	74	57	39	56	502	2	3.45	8.3	0.26	0.9	8
OL 01	F	48.4	3.8	173	345	1192	233	98	34	148	9	1.62	17.4	0.12	2.8	17
OL 02	F	35.1	3.9	147	242	530	121	81	32	264	16	1.67	8.2	0.13	1.6	12
OL 03	F	46.4	3.9	168	253	1269	200	89	41	130	35	1.54	12.2	0.18	3.6	15
OL 04	F	41.3	4.3	154	232	1321	200	78	54	334	7	1.46	7.6	0.19	2.4	18
OL 05	F	42.5	4.4	340	210	924	120	89	53	243	9	2.75	6.3	0.17	0.5	15

APPENDIX H - SITE LEVEL SUMMARIES FOR ALL VARIABLES MEASURED.

	Site	Vegetation richness (mean number of species per plot)	Vegetation diversity (H')	Soil organic carbon (%)	Vegetation biomass (mg/m2)*	Vegetation cover (%)	Surface temperature (ºC)	Light (at surface) (µmol/s/m2)
USV	BS	13.25±0.43	2.08±0.59	3.2±1.8	24.6±12.6	0.67±0.29	25.6±3.59	414.6±576.5
	DC	13.33±0.00	1.89±0.64	3.6±2.0	29.7±33.9	0.64±0.30	25.4±6.33	688.4±757.0
	EX	14.16±0.78	1.95±0.39	2.1±0.9	28.7±17.9	0.81±0.22	22.6±2.43	783.4±548.7
	HF	11.83±0.98	1.89±0.07	2.4±1.0	19.7±20.2	0.61±0.30	29.4±2.91	1034.8±532.2
	LS	12.25±0.24	1.97±0.27	4.5±1.3	41.9±27.1	0.83±0.27	18.9±2.02	301.2±249.5
	ML	18.08±0.87	2.24±0.74	9.3±8.8	51.7±22.5	0.96±0.08	20.4±2.72	1256.1±439.0
	MT	17.41±0.02	2.26±0.07	2.2±1.3	15.1±13.6	0.96±0.57	29.8±4.66	1271.5±526.0
	PW	12.5±0.85	1.73±0.87	3.8±1.4	35.6±15.9	0.76±0.34	23.7±3.16	808.0±740.8
	SB	14.41±0.82	2.01±0.29	5.5±1.8	26.2±16.0	0.82±0.34	23.6±4.78	373.9±676.7
	SF	21.75±0.17	2.34±0.42	5.4±2.4	32.9±29.2	0.73±0.36	24.0±5.08	1133.0±249.9
	SP	13.08±0.73	1.75±0.04	3.0±1.0	41.1±34.0	0.65±0.35	21.2±1.39	1571.9±115.3
Forest	OL	5.8±3.1	0.84±0.43	18.6±3.9	-	1±0	18.65±1.22	14.75±3.43
	LW	4.1±1.9	0.76±0.32	48.4±4.4	-	1±0	14.75±0.35	42.91±10.65
	AL	3.5±2.2	1.04±0.97	35.1±5.1	-	1±0	16.2±0.43	14.55±5.38
	MS	3.9±1.1	1.12±0.22	46.4±4.7	-	1±0	18.35±0.76	19.21±2.34
	OK	6.1±1.3	1.60±0.18	21.3±6.5	-	1±0	17.125±0.87	13.65±6.33
Lawn	JL	5.4±2.1	0.73±0.24	4.2±0.98	156.9±21.5	0.86±0.61	18.61±0.23	1785.25±89.33
	MB	7.1±1.8	0.94±0.18	6.2±0.12	210.1±53.3	0.98±0.02	21.14±0.25	1125.33±122.44
	SG	4.9±2.3	1.19±0.12	7.6±0.55	103.4±10.8	0.89±0.02	18.65±0.09	1390.8±167.88
	SR	7.6±1.9	1.51±0.06	3.5±0.78	99.3±19.5	0.97±0.01	19.63±0.32	1662.2±205.21

TL	5.9±1.2	1.73±0.75	10.2±0.91	140.6±12.7	0.88±0.01	16.15±0.43	1258.93±90.83

	Site	Albedo (% reflected/incoming radiation)*	Leaf area index (m2/m2)*
USV	BS	0.18±0.02	2.0±0.6
	DC	0.29±0.15	3.0±5.8
	EX	0.22±0.01	2.0±0.0
	HF	0.15±0.02	1.3±4.7
	LS	0.20±0.02	0.9±0.3
	ML	0.20±0.02	1.9±0.0
	MT	0.27±0.31	1.5±5.0
	PW	0.20±0.01	2.2±0.1
	SB	0.24±0.09	1.9±0.1
	SF	0.21±0.02	0.7±5.5
	SP	0.19±0.02	0.8±0.1
Forest	OL	-	-
	LW	-	-
	AL	-	-
	MS	-	-
	OK	-	-
Lawn	JL	0.21±0.01	0.21±0.01
	MB	0.16±0.04	0.16±0
	SG	0.19±0.02	0.19±0.02

SR	0.22±0.01	0.22±0
TL	0.15±0.05	0.15±0.04

* Forest values not measured, see text for reference values