URBAN NATURALIZATION FOR GREEN SPACES IN THE CITY OF EDMONTON, ALBERTA, CANADA

By

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Dedicated to my two shining stars, my wife Maria Ofelia Arzate Vazquez and my daughter Alicia Aguilar Arzate, and my parents Jaime Aguilar Estevez and Martha Rojas Moreno

ABSTRACT

Naturalization is a new and promising ecological approach to vegetation management for urban environments. Although there have been years of research focused on areas such as land reclamation, ecological restoration and plant establishment there is a lack of knowledge on how to reintegrate the native ecological component into green spaces of urban centres. Naturalization generally occurs in three stages: cessation of mowing, establishment of woody vegetation and site enhancement by planting native forbs (wild flowers).

In this two year research project the response to naturalization was evaluated at seven sites in the City of Edmonton for four native tree species, four native shrub species, twenty-four forb native species and plant communities where mowing had ceased. Naturalization treatments included soil preparation with combinations of tillage and herbicide and soil amendments with applications of compost at different rates.

Response to naturalization for the city of Edmonton and other similar urban centres was evaluated using mortality, height and stem diameter change (for woody species) and spread (for forb species), species richness and cover data. Woody species with the highest potential for use were *Picea glauca* and *Symphoricarpos albus,* Poorest performing tree and shrub species were *Populus tremuloides* and *Viburnum trilobum*, respectively. The native forbs, *Penstemon procerus*, *Fragaria virginiana*, *Heuchera cylindrica*, *Agastache foeniculum*, *Antennaria microphyla* and *Geum aleppicum* performed well.

Species response to soil treatments varied with species and site. For most of the evaluated seedlings, herbicide application prior to planting increased survival and growth, and compost application resulted in larger plants. Native forb species survival and spread was mostly influenced by amendment, with highest compost amounts leading to better growth and survival.

Plant community development after cessation of mowing did not follow any particular pattern in plant community succession after one year. In general live vegetation cover depletion was only significant for one of the research sites. The most influential soil treatment was herbicide, resulting in a lower non native species cover and a higher noxious weed cover. Highly concentrated compost amendments resulted in reduced vegetation cover across sites.

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I. INTRODUCTION

1. BACKGROUND

Urban environments have consistently grown in importance as biomes for the human race. In 2011, there were 6.9 billion people living in the world with 3.6 billion in urban settings (United Nations 2015). In 1950, 29.4 % of the world population were urban dwellers, which increased to 51.6 % by 2010 and is projected to increase to 67.2 % by 2050. A total of 1.5 million km^2 are occupied by cities or densely populated areas around the world (Ellis and Ramankutty 2008).

With highly dense human concentrations, significant direct disturbances to the natural landscape are continuously produced by housing and daily living activities. Indirect disturbances are related to food and materials supply in places other than those where the individuals actually live. Indirect disturbances represent a wider area of impact and are subject to environmental regulation, a time frame for exploitation (except for agricultural land) and reclamation. Direct disturbances are much smaller in overall area of impact and people tend to be less aware of them. In recent years global warming, environmental conscience and human health concerns have increased awareness of urban landscape systems. Direct environmental impacts of urban landscapes include altered temperature regimes, reduced light availability, increased pollutants (air, water, soil), altered hydrology, reduced soil quality, reduced nutrient cycling, increased invasive species, increased carbon dioxide footprint and altered disturbance regimes (walking paths, sidewalks).

Urban populations and their associated direct environmental disturbances will continue to grow in number, area of impact and concern for years to come. From this perspective, humans are an engineering species that build their own ecosystems. Humans will decide if they want to engage and be proactive with the increasing challenges of building a sustainable society or wait to see what awaits them as a sociable species.

2. URBAN NATURALIZATION

2.1. Naturalization

Naturalization is a process of ecological restoration that involves returning an altered or degraded site to a more natural condition through the use of trees, shrubs and flowers that are native to the area (Evergreen 2001). Although there are several differences in the definition of native plant species, for purposes of naturalization, they are defined as those that existed in an ecological area prior to European settlement (Evergreen 2001). According to the City of Edmonton (2015), naturalization is an alternative landscape management technique where natural processes of growth and change are less restricted, allowing the landscape to become more natural by planting trees and shrubs that are found naturally in Alberta. Naturalization helps improve the urban environment in numerous ways, including economically, environmentally and through quality of life.

Economic benefits include significant savings on maintenance costs of green areas by stopping mowing, decreasing irrigation needs and in the long term decreasing pesticide use (City of Edmonton 2015). Municipalities like Austin Texas and Tucson Arizona have compared costs between naturalized and conventional landscape and found an overall maintenance cost saving of 80 to 90 % over a 10 year period, a cost reduction of 10 to 50 % on heating and cooling costs and a 2:1 cost savings rate in storm sewer construction in new developments when using naturalized storm water management systems (Evergreen 2001).

Environmental benefits of naturalization include re-establishment of native plants, birds and other wildlife populations; erosion control by plants on slopes along river bank; reduced atmospheric greenhouse gas emissions; cleaner air and increased oxygen levels required to support life; and windbreaks for snow capture and dust reduction (City of Edmonton 2015). Naturalization improves ground water recharge, augments biofiltration capacities of storm management facilities and complies with water conservation programs and initiatives using drought tolerant species. Increasing naturalized areas can reduce urban heat island effects, thus lowering demand of hydric resources to keep expanding naturalized plantings.

Quality of life in urban settings benefits from naturalization in several ways (City of Edmonton 2015). Naturalization provides landscape beautification; community involvement in environmental programs when naturalization is paired with educational initiatives; increased green and shady areas for recreation; increased relaxation and improved mental health by time in forests, looking at trees; and reduced noise levels as dense plantings mature.

Modern challenges to sustainable naturalization are mostly related to lack of political will and vision, inappropriate or conflicting policy, public safety and liability concerns, limited interdepartmental coordination (Evergreen 2001). Naturalization is a landscape approach that evokes a long time process where local communities need to be aware and willing to cooperate. Education of local neighbours is the first step to achieve naturalization in an area. The next step involves engagement with community members to take action and participate in the construction phase of the naturalized area. Through this engagement, people develop an emotional link to the naturalized area and provide valuable input throughout the naturalization process. Technical challenges include weed control, especially on heavily mowed and open areas with invasive species; increased wild life presence in and around the site; escalation on integrated pest management strategies specific for each site; and increased public inquiries. Lack of appropriate native plant materials is a major challenge in most jurisdictions, particularly if there are large areas to naturalize.

2.2. City of Edmonton Naturalization Process

The City of Edmonton follows a specific naturalization process, similar to other urban centers. Cessation of mowing is the first step. Grass species tend to dominate previously mowed areas and are allowed to continue to dominate. Grasses provide a barrier against erosion, grow deep roots that help to release soil compaction and start to build up litter that will allow slow recovery of nutrient cycling capabilities of the soil.

Planting native woody species of trees and shrubs is the next step in the naturalization process. Once grasses are well established, the soil has been stabilized and any potential outbreak of noxious weeds has been managed or controlled, woody species are planted directly on the site. Woody species are strongly resistant plants, capable of withstanding stressful conditions and competing with grasses once they are established. Species selection is based on availability of plant material and previous experiences with species in other naturalized areas of a particular urban environment.

The City of Edmonton has plants shipped from nurseries across Alberta and British Columbia. Shipped plants are acclimatized at the City of Edmonton nursery until planted by planting crews. Two types of crews plant for the City of Edmonton, voluntary members of the community and City of Edmonton employees. All volunteers are trained by City of Edmonton planters. After site preparation, which includes no mowing for two years, the crew proceeds with planting, following a detailed process.

The final step of naturalization intends to enrich and beautify the landscape. Once a naturalized are has reached stability and the first woody species are established, there is an increase of microhabitats for small species like forbs to colonize. Addition of shrubs at this stage is beneficial as they can provide shelter to small species. Understory native plant species tend to be susceptible to anthropogenic influences like pollution or disturbance and therefore potentially hard to establish in a newly naturalized area.

Throughout the naturalization process the City of Edmonton monitors presence, growth and intensity of noxious weeds or noxious prohibited weeds according to provincial regulation (Table 1.1). These weeds are dealt with via integrated pest management approach including herbicides.

2.3. Naturalization Effects On Soils

Under urban conditions, soils are intensively affected by human activities, and can present features such as mixed horizons, foreign materials and thin topsoil (Short et al. 1986, Civeira and Lavado 2008). These urban soils are often low in organic matter (< 1 %) and fertility with reductions in their most important physical properties, such as structural stability and water retention. Eventually, these soil properties might have a detrimental effect on plant growth and development and subject the environment to erosion (Vetterlein and Hüttl 1999, Scharenbroch et al. 2005). In urban parks, soil compaction usually results from human traffic and vehicles operated for events and park maintenance. Soil conditions deteriorate with increased foot, bicycle and vehicle traffic, jeopardizing support for long term health of existing trees and ability of young trees to establish.

The effectiveness of parkland naturalization as a management technique to improve physical characteristics of disturbed park soils and thus promote conditions necessary to protect and enhance urban forests has been assessed (Millward et al. 2011). Parkland naturalization is defined as the process of letting an area return to a natural state by mainly discontinuing maintenance activities, such as mowing, and restricting public access (Heena et al. 1998, Richardson et al. 2000).

An experimental site at the small and heavily used Gardens Park in the City of Toronto showed variability in soil physical properties was spatially correlated with surface disturbance originating from decades of recreational park use and associated maintenance activities (Millward et al. 2011). Bulk density and penetration resistance frequently approached or exceeded thresholds at which root growth is restricted at > 2000 kPa and > 1.8 Mg/m^3, respectively. Bulk density at 10 cm depth was lower in naturalized areas (1:15 Mg/m^3) than non-naturalized areas (1:44 Mg/m^3). This difference also occurred at 30 cm depth, although the contrast was not as great (1:51 versus 1:64 Mg/m^3). Similar trends occurred for penetration resistance.

Naturalization can reduce soil compaction, likely through root expansion, biological activity (macro arthropods) and frost heave (Alakukku 1996, Niwa et al. 2001). Parkland naturalization allowed unrestricted growth of herbaceous understory plants. This likely increased root density in upper soil horizons within naturalization enclosures relative to adjacent soil in non-naturalized areas of the park. Accumulation and on-site decomposition of leaves in the naturalization enclosures likely enhanced earthworm and macro arthropod activity (Millward et al. 2011).

Water infiltration rates increased in soil subjected to naturalization in part due to biological factors (Beven and Germann 1982). Infiltration rates varied from 685 to 1.2 mm/h; water infiltration was fastest in the central part of the naturalized area and lower in areas at its edge (Millward et al. 2011). The practice of naturalization has meant leaf and woody debris are left to decompose and augment the soil organic material, which is known to positively correlate with the amount of soil water available to plants (Craul 1985, Gomez et al. 2002).

Parkland naturalization can potentially rapidly improve several soil physical properties important for plant growth (Millward et al. 2011). Root growth by understory vegetation, soil compaction release (from freeze-thaw), nutrient cycling (litter fall and action of soil organisms) and regular soil wetting and drying contributed to an accelerated recovery rate in soil subject to naturalization. However, rate at which improvements occur is the result of interrelated factors that include site disturbance history (intensity, duration), underlying soil structure, local climate (precipitation, temperature), onsite vegetation and presence of soil organisms. Therefore, parkland naturalization is expected to produce soil recovery rates that are site specific.

2.4. Naturalization Patch Dynamics

Urban habitats have their own typology covering a spectrum from fully functional ecosystems in remnant fragments to purely decorative plantings in pots and boulevards, expanding the mandate of ecological restoration and increasing complexity (Schaefer et al. 2004). In cities, native ecosystems usually occur as patches of habitat connected by corridors in a matrix of streets and buildings (Schaefer 2009). Conservation and passive management of degraded ecosystems is widely recognized as an insufficient strategy to ensure autogenic, spontaneous recolonization and recovery of native assemblages and ecosystem function (Hobbs 2007, Jackson and Hobbs 2009). Site context is critical as ecological and management legacies often exert large influences on system resilience and capacity for revegetation (Standish et al. 2012). The ecological memory and materials remaining may not be sufficient for a site to heal itself; in these cases restoration activities are required to direct the future of the site (Schaefer 2009).

A systemic approach to restoration and naturalization needs to be considered, regardless of the size of the area to be naturalized. A revegetated restored site may remain an ornamental planting with roots in the planting hole and no detritus added. Getting from ornamental to fundamental, to a system rather than a collection of ornaments, is one of the biggest challenges facing restoration projects within cities (Schaefer 2009). Examples in various urban environments exist for successfully making this change.

Green Links Project, in greater Vancouver British Columbia, used vegetation plantings over a ten year period to improve habitat quality and strengthen connectivity between patches. In this focal restoration (Higgs 2003), 15,000 volunteers planted 75,000 individual plants, primarily shrubs of 30 to 50 cm heights (Schaefer 1999). They planted in city parks, riparian areas along urban streams, in utility rights-of-way, boulevards, school grounds, gravel pits and in foundation plantings around buildings. Plants that were installed in natural settings flourished; however, those that were introduced into newly created foundation plantings or into well established but constraining environments, such as shrubs in fields or rights-of-way of dense grass, performed poorly and many did not survive. Many years later, these plantings that had performed poorly remained a collection of the original plants; in other words they were ornaments with little potential. They failed to establish a more complex expanding system with healthy nutrient cycles and food webs (Schaefer 2009).

As humans restore and reintroduce ecosystems and natural areas into their urban places, it is important to remember that this process of naturalization ‘‘involves more than placing plants on the surface” (Pollak 2006). Throughout all phases of urban restoration and naturalization, attention must be paid to social, cultural, economic and policy dimensions of the restoration or naturalization process to minimize conflict and meet broad goals for what is expected to be accomplished (Gobster 2001, Gross and Hoffmann-Riem 2005, Christian-Smith and Merenlender 2010).

2.5. Aesthetics

Linking plant ecology with urban design (architecture, landscape architecture, civil engineering and urban planning) can help integrate research and understanding of plants into city structure, and make use of urban design projects as ecological research tools (Pickett and Cadenasso 2008). Plant ecology in cities, suburbs and the urban fringe has not taken human agency fully into account. In recent years, plant ecology is engaging urban ecosystems as integrated natural-human systems, in which human agency is part of the complex of feedbacks. The first step in integrating plant ecology into design of cities is to make a structural assessment of urban areas. A new alternative approach focuses on how new or altered vegetation can contribute to improved ecological services in the future. Using this approach, plant ecologists can become involved in work examining how the vegetation component of urban patch types, spread throughout the urban ecosystem, can improve ecological function by design.

Ecologically orientated goals may be achieved in urban areas (Pickett and Cadenasso 2008). Plant ecology can contribute to understanding of structure and function of urban ecosystems, such as how plants contribute to carbon sequestration, nutrient retention and maintenance of biodiversity. Increased ecological function of urban areas such as storm water quality may be improved and its volume reduced by increasing permeability of urban surfaces or restoring urban streams and riparian zones (Groffmanm et al. 2003). Improving microclimate, reducing cooling and heating demands, can be achieved with trees (Nowak et al. 2002). Particulate pollution can be reduced by mature tree canopies (McPherson et al. 1997). Increased benefits to humans of vegetation of urban areas may include such social benefits as reduction in conflict (Kuo and Sullivan 2001), provision of a focus for neighbourhood revitalization (Burch and Grove 1993) and promotion of human health (Hill 2001, Northridge et al. 2003).

Human behaviour and exposure to environmental hazards and amenities influence health in cities. Ecological design can accommodate these concerns and ecosystem functions (Pickett and Cadenasso 2008). Naturalization in cities involves more than just alteration of soil conditions; the surrounding urban context must be managed (Pavao-Zuckerman 2008).

3. URBAN SOIL RECLAMATION

3.1. Urban Soils

Urban soils exist in different historical and formational trajectories than their local natural and non-urbanized counterparts, due to direct anthropogenic disturbance and indirect environmental impacts from urbanization (Pavao-Zuckerman 2008). The actions of people modify natural soil formation trajectories, thus an end result of urbanization is to produce novel soils. Creation of novel soil types, conditions that promote invasion by non-native plant species, the strong influence of past land use on soil properties and presence of strong interactions and alternative stable states present unique difficulties for urban soil reclamation or restoration. It is quite likely that within the context of urban ecological restoration, city specific soil ecological knowledge will be necessary (Heneghan et al. 2008).

Physical soil properties are strongly influenced by compaction during transformation of native and agricultural lands to urban environments (Pavao-Zuckerman 2008). The urban heat island effect, modifications from local cloud cover and precipitation and alterations to hydrologic regimes by urban infrastructure can strongly affect soil micro climates, water availability and soil organism activity (Oke 1995, Brazel et al. 2000). Urbanization influences soil chemical properties (Groffman et al. 1995, Pouyat et al. 1994), sometimes resulting in elevated metal concentrations (Pouyat and McDonnell 1991, Markkola et al. 1995) and elements such as nitrogen and sulfur (Markkola et al. 1995, Lovett et al. 2000). Soil biota respond to alterations of soil physical and chemical properties associated with urban environments (Pouyat et al. 1994, Pizl and Josens 1995, Steinberg et al. 1997, Pavao-Zuckerman and Coleman 2005).

The specific properties of an urban soil are a function of the nature of urbanization and how the urban environment interacts with local environmental and climatic conditions (Pavao-Zuckerman 2008). Patterns described in one city may not apply directly to other cities (Pavao-Zuckerman and Coleman 2005, Pouyat et al. 2003). Urban restoration projects should avoid generalizations that urban soils are all compacted with low nutrient and carbon content (Gilbert 1989, Craul 1999) but should rely on site specific soil characterizations to guide restoration treatments and monitoring activities (Pavao-Zuckerman 2008).

During urban ecological restoration, anthropogenic modifications of soil factors (such as impacts on soils by temperature from urban heat islands, altered plant communities or depositional chemistry) may impact restoration success by shifting soil quality, competitive regimes, seedling establishment and disturbance patterns (Pavao-Zuckerman 2008). Drastic changes and degradation of soils require drastic actions, such as creating new soils and putting soils in novel places. In cities, species and ecological function can be restored and promoted (Beckett et al. 1998, Bolund and Hunhammar 1999, Rosenzweig 2003, Alberti 2005, Snep et al. 2006), recognizing humans are part of nature contributing to natural soil formation (Pickett and Cadenasso 2008) and constructing conditions in domesticated landscapes (Kareiva et al. 2007)

3.2. Topsoil Amendment

Using topsoil as a soil amendment to reclaim disturbed areas assumes a local source of topsoil would provide similar pre-disturbance plant growing conditions and that topsoil contains plant propagules that can potentially increase species richness and reduce bare ground exposure. Studies on topsoil as an amendment mainly focus on vegetation development and how different source materials affect development of the plant community on the amended site through time.

Skrindo and Pedersen (2004) studied the potential of natural revegetation based on propagules from topsoil as a restoration technique, in a roadside in Southeast Norway coniferous forest. A 10 cm layer of topsoil from the top 30 cm of soil from the predisturbed site was placed on top of subsoil on the road verge. Different topsoils were compared by the response of early succession vegetation cover and the number of species. Species composition and single species frequencies changed considerably from the first year to the second, representing the first steps in succession towards an ecosystem dominated by species of the indigenous vegetation. Vegetation cover increased significantly from year one to year two. Among the 16 species that increased significantly in frequency over the two year period, only two were considered weeds, *Cirsium arvense* (L.) Scop. (Canada thistle) and *Tussilago farfar* L. (colts foot). There was no clear pattern for plant functional groups related to the soil. Variation between macro plots from years one to two could not be explained by soil variables alone.

The origin of soil replaced on plots was not known due to soil mixing during stockpiling. Topsoil size and content of the propagule bank varied with plant age, species composition, disturbance level, predispersal seed predation and plant seed production (Skrindo and Pedersen 2004). Natural revegetation from redistributed topsoil is recommended in comparable ecosystems.

3.3. Municipal Solid Waste Compost Amendment

In recent decades, application of organic wastes from different local origins (manure, sewage sludge, municipal organic wastes) to degraded soils is a practice globally accepted to recover, replenish and preserve organic matter, fertility and to improve vegetation (Vetterlein and Hüttl 1999, Civeira and Lavado 2008). Use of composted organic wastes changes soil physical, chemical and biological properties and can enhance plant growth after its application. However, the influence of carbon rich materials, such as municipal organic wastes compost, on soil properties depends upon several factors, including amount and components of added organic materials, soil type and local weather conditions (Unsal and Ok 2001, Drozd 2003). As pointed out by Giusquiani et al. (1995) and Drozd (2003) the use of composts from municipal solid wastes improves the restoration of degraded soils and allows for an appropriate final disposition of such materials, solving a major environmental and economical problem generated in the cities of the world (Civeira 2010).

An experiment was conducted in Buenos Aires to measure the effects of municipal solid waste compost on urban soils (Civeira 2010). Compost was applied at one point in time at 0 (control), 2 (low), 4 (medium) and 7 kg/m^2 (high) rates on a fresh matter basis. Compost positively affected total soil nitrogen, significantly for applications of 2 kg/m^2 upwards. Higher organic carbon was found in low, medium and high compost application rates, the highest for 4 and 7 kg/m^2. Medium and high application rates had the greatest increase in extractable phosphorus in soils. Organic carbon, total nitrogen and extractable phosphorus increased with compost, significantly for 4 and 7 kg/m^2 application rates. A significant positive correlation was found between organic carbon and soil nitrogen and phosphorus for medium and high compost application rates. There was no significant difference between medium or high compost application rates. Increasing compost did not always augment organic carbon and nutrient contents (total nitrogen, extractable phosphorus) in soils. With medium and high application rates, augmentations in organic matter reduced bulk densities and enhanced water infiltration. Medium rates improved soil properties and plant yield by the same amount as the highest rate.

Other researchers found municipal solid waste composts provided an equivalent amount of phosphorus to soil as mineral fertilizers (Iglesias-Jiménez and Álvarez 1993). Elevated application rates of municipal solid waste compost increased inorganic nitrogen, providing a consistent nutrient supply during the initial growing season for plant demand (Iglesias-Jiménez and Alvarez 1993, Mylavarapu and Zinati 2009). Municipal solid waste compost consistently increased soil organic matter and soil carbon to nitrogen ratio greater levels than when unamended (Crecchio et al. 2004, Walter et al. 2006). Compost additions affected soil pH, with medium and high application rates raising pH from 6.5 to 6.9 (Tognetti et al. 2007). Changes in pH were not always proportional to application rates (Civeira 2010).

Municipal solid waste compost application reduced soil bulk density. The decrease was due to dilution of denser mineral soil by the less dense compost application rates (Civeira 2010). Soil water content and water infiltration were significantly affected by compost additions. Municipal solid waste compost penetrated the soil surface and improved measured physical properties including bulk density, water retention and water infiltration (Risse and Faucette 2001).

Using composts with carbon to nitrogen ratios greater than 30:1 will require additional nitrogen fertilizer during the first growing season, and sometimes longer, to achieve adequate establishment and growth of plants. The benefit of supplying nutrients during the establishment period is lost, and management is needed to maintain a healthy and functional landscape where materials with high carbon to nitrogen ratios are used (Cogger 2005). Addition of readily available composted urban waste may be used to ameliorate effects of urbanization on physical and chemical soil properties, although soil and water nutrient and contaminant enrichment from this practice require both pre-restoration assessment and post operation monitoring (Pavao-

Zuckerman 2008). Municipal solid waste compost application to urban soils is a viable soil amendment alternative, as it will allow for full reclamation of an area with existing environmental problems (Civeira 2010).

3.4. Soil Tillage

Site preparation techniques can alter soil water availability within the soil profile and, together with strategic plant treatments, can increase revegetation success (Ruthrof et al. 2013). Ripping is a commonly used tool in agriculture and land reclamation to reduce soil compaction, particularly in clay dominated soils (Yates et al. 2000, Sinnett et al. 2008).

An experiment was conducted on two Periurban woodlands in southwestern Australia, using two iconic tree species, *Eucalyptus gomphocephala* (tuart) L. and *Agonis flexuosa* Willd. Sweet (Australian willow myrtle) (Ruthrof et al. 2013). Two site preparation techniques were ripping to approximately 40 cm depth using a tractor (furrow spacing of 1 m) and control (no ripping), totalling six blocks at each site. Ripping significantly reduced penetration resistance to a depth of 25 to 30 cm, increased water infiltration, formed a stratified soil water profile and was associated with deeper root architecture, higher survival and growth in both tree species. Ripping produced strong significant positive effects on both species for height, survival and health. Seedlings planted in ripped soils had significantly longer, deeper root systems accessing portions of the soil profile with higher summer water contents. Ripping lowered soil densities and led to lower soil water in the upper profile. Clear, unilaterally positive effects of ripping on seedling survival, height and health were identified. Mean rooting depth of *Eucalyptus gomphocephala* (30 vs 58 cm) and *Agonis flexuosa* (35 vs 65 cm) was significantly greater with ripping than in controls. Promotion of deeper root growth and altered soil water profiles, particularly over the summer drought period, is considered the responsible mechanism for improved tree growth and survival.

4. REVEGETATION

4.1. Plant Species Selection And Planting

Species selection is an important part of naturalization, but is often hindered by lack of a steady supply of materials. Native forbs establishment potential under urban conditions is of specific interest as not many scientific based studies have been conducted other than using wild flowers to establish low maintenance green areas in Europe. These studies have shown that the floristic composition of wildflower meadows is controlled by soil fertility (Marrs and Gough 1989).

The Agency for the Development and Innovation in Agriculture and Forestry of Tuscany Italy, financed research on production and strategic employment of wildflowers for the beautification and environmental regeneration of derelict urban and peri-urban areas (Bretzel et al. 2009). Soil conditions were unsuitable for cultivation of traditional horticulture, such as ornamental shrubs, lawns and flowering borders, as nutrient levels were low and in some cases near stressful conditions. Sites were treated with glyphosate, cultivated, hand sown and mowed by winter. The seed mix was composed of 26 annuals and perennials native to Italy. No water, fertilizer or pesticides were applied. In spite of these limitations, the majority of species developed and flowered in the first and second year of the experiment, co-existing and creating an ornamental meadow rich in species. Multiple regression revealed that Shannon's diversity index was related to cation exchange capacity and carbon nitrogen ratio in the first year; the relation disappeared by the second year. In spite of the poor quality of soils, the plantings were successful from an ornamental point of view. In the first year dominant species were the annuals *Nigella damascene* L. (ragged lady), *Matricaria chamomilla* L. (chamomile), *Papaver rhoeas* L. (common poppy) and *Agrostema githago* L. (common corn cockle). In the second year several perennials germinated (*Achillea millefolium* L. (yarrow), *Daucus carota* L. (wild carrot), *Dianthus cartthusianorum* L. (carthusian pink) and *Knautia arvensis* (L.) Coulter (field scabious).

Compared to agricultural or mine reclamation contexts, the decision making process for urban naturalization needs to take into account proximity to utilities infrastructure, size of the working areas and safety issues that arise due to high exposure to the general public. Planting techniques for urban environments mainly focus on planting time. Planting early in the wet winter season was critical for revegetation success in Australia (Ruthrof et al. 2013). Maximizing seedling exposure to wet conditions reduced transplanting stress and increase survival.

4.2. Weed Control And Management

After a community or ecosystem is destroyed or last through urbanization, it may leave behind an ecological memory (Schaefer 2009). The site history, soil properties, spores, seeds, stem fragments, mycorrhizae, species, populations and other remnants may influence composition of the replacement community or ecosystem to varying degrees. Urbanization changes the dynamics of naturalization, as urban soils possess many traits that promote continued invasion of sites by undesirable and invasive species (Pavao-Zuckerman 2008).

Ecological memory consists of the species of an area and the ecological processes that will determine the trajectory for the ecosystem into the future. Ecological memory is less in areas with habitat loss such as cities, in areas dominated by invasive species and in otherwise disturbed sites (Schaefer 2009). The loss of ecological memory facilitates establishment of foreign invasive or weed species. These undesirable species may eventually create a new stable domain with its own ecological memory and degree of resilience. Without management intervention such as native seeding, common seed bank species, especially exotic and noxious plants, may exclude or inhibit desirable later successional species until resources are made available by their damage or death, possibly delaying the return of later successional species for considerable lengths of time (Connell and Slatyer 1977, Pickett et al. 1987).

Invasive and weed species successful strategies are often characteristics that facilitate successful seed banking including very high seed output, phenotypic and germination plasticity, adaptations for short and long distance dispersal, small seed size and high seed longevity (Baker 1974, Louda 1989, Radosevich et al. 2007). Invasive species can create new ecosystems and communities that had never occurred before on the planet. Such novel or emergent ecosystems no longer require human intervention to persist. They characteristically occur in urban, cultivated or otherwise degraded landscapes with dispersal barriers, and were created by direct or indirect disturbance from humans (Schaefer 2009).

To be successful, control of invasive and weed species must address internal within patch memory of invasive species and external between patch memory (Schaefer 2009). When dealing with undesirable species, the common approach for control is herbicide. Herbicide can potentially control invasive and weed species when applied with the appropriate timing and frequency, although survival mechanisms make weeds highly resilient. Resiliency is the key survival strategy of these undesirable species, and when using herbicide efficacy is directly related to application frequency. Highly resilient species need to be targeted frequently to break the reproduction cycle. However, repeated herbicide applications potentially lead to development of herbicide resistance. The great dilemma when defining a herbicide schedule is balancing specificity of the materials used, with efficacy and collateral damage (desirable species) (Schaefer 2009).

Effectiveness of herbicides in naturalization has not been well studied. No differences were found in vegetation cover, germinant density or species richness between herbicide and non-herbicide plots in any group, including noxious weeds (Buonopane et al. 2013). No differences were seen in germinant richness for herbicide treatment or distance to road edge.

Healthy natural ecosystems have an ability to protect themselves from invasive species (Schaefer 2009). More intact plant communities better resist invasions (Myers and Brazely 2003). The resistance of plant communities to invasion increases with plant diversity if there are no co-varying extrinsic factors (Naeem et al. 2000).

5. THESIS ORGANIZATION

This research was designed to enhance and scientifically quantify naturalization success in the City of Edmonton. The thesis is presented in the following way.

Chapter 1 provides the background for the research, including previous work in naturalization.

Chapter 2 focuses on introduction of woody species into the naturalization process. Using eight native woody species exposed to a combination of sixteen soil treatments in six naturalized locations across the City of Edmonton.

Chapter 3 focuses on introducing twenty-four native forb species at a naturalized location in the City of Edmonton. The forbs were exposed to sixteen soil treatments.

Chapter 4 focuses on each site and its plant community change through time since cessation of mowing, and the effect of soil treatment on species richness and percent cover.

Chapter 5 concludes the thesis with a summary of results and a discussion on the future research directions needed to follow up this research.

Chapter 6 presents the references for the entire thesis.

Table 1.1. Noxious weeds listed by the City of Edmonton.

Common Name	Scientific Name
Creeping bell flower	*Campanula rapunculoides* L.
Himalayan balsam	*Impatiens glandulifera* Royle
Bighead knapweed	*Centaurea macrocephala* Muss. Puschk. ex Willd.
Canada thistle	*Cirsium arvense* L.
Scentless chamomile	*Tripleurospermum perforatum* (Mérat) M. Lainz
Common tansy	*Tanacetum vulgare* L.
Leafy spurge	*Euphorbia esula* L.
Perennial sow thistle	*Sonchus arvensis* L.
Common mullein	*Verbascum thapsus* L.
Great burdock	*Arctium lappa* L.
Yellow toadflax	*Linaria vulgaris* Mill
Oxeye daisy	*Leucanthemum vulgare* Lam
White cockle	*Silene latifolia* Poir

II. URBAN NATURALIZATION WITH NATIVE TREE AND SHRUB SPECIES AND SITE PREPARATION TREATMENTS

1. INTRODUCTION

Urban naturalization is an alternative landscape management technique where natural processes of plant colonization and growth are generally unrestricted, allowing the landscape to return to a natural state. Environmental benefits include increased biodiversity and wildlife use, soil stabilization, improved ground water recharge, provision of windbreaks for snow capture and dust reduction, reduction of atmospheric greenhouse gases and cleaner air (Savard et al. 2000, Chiesura 2004, Millard 2004). Economic benefits include a significant reduction in maintenance costs such as mowing, irrigation and herbicide use. Quality of life benefits include landscape beautification, increased green and shady areas for recreation, increased community awareness of environmental issues and noise reduction by mature plantings (Chiesura 2004).

Urban naturalization historically focused on planting trees to restore urban forests. However, naturalization can occur in urban grassland and wetland areas. It requires careful selection of plant species for development of an appropriate plant community (Saebo et al. 2003, Pavao-Zuckerman 2008). Usually native plant species are used, although in many cities and other urban centres, local cultivars and non native species have been included. In many naturalization processes trees are planted and other species are allowed to establish naturally.

Naturalization can address inherent soil limitations (Pollak 2006, Pavao-Zuckerman 2008, Schafer and Alien 2009). Compacted soils can prevent or restrict root growth and therefore successful plant establishment and long term development (Millwood et al. 2011). Naturalization can reduce soil compaction, through root expansion, increased biological activity and frost heave (Alukukku 1996, Niwa et al. 2001), subsequently increasing infiltration rates (Beven et al. 1982, Savard et al. 2000). Naturalized sites retain leaf litter and woody debris, which decomposes, adding organic material, which is positively correlated with increased plant available soil water (Craul 1985, Gomez et al. 2002). Alternatively, these soil limitations can be reduced as part of the naturalization process through use of soil amendments.

Management strategies must be developed to augment natural successional processes of plant community development. Naturalization can result in unrestricted growth of herbaceous understory plants and increased root density in upper soil horizons (Millwood et al. 2011). Open spaces in an urban environment present an opportunity for plants to grow and disperse.

Naturalization is founded on the principle that native species adapted to local conditions will compete and establish with little human intervention. However, some of these species may be aggressive weeds or undesired competitive grasses. Thus pre-planting use of herbicides reduces competitive species, making resources accessible for new desired plantings.

Little scientific research has been conducted on methods to achieve naturalization of urban parklands with native woody species. Many of these sites require reclamation to address soil issues and all require revegetation to facilitate development into a naturalized ecological community. Results of naturalization efforts to date have been inconsistent.

2. RESEARCH OBJECTIVES

The research objectives for this naturalization project were as follows.

- To evaluate selected native woody species performance in naturalized areas based on survival, health and growth.
- To evaluate soil treatment influence on woody native species survival, health and growth.

3. MATERIALS AND METHODS

3.1. Research Sites

The study area is on the south side of the City of Edmonton in Alberta, Canada, located at 53°34'19.000" N latitude and 113°31'10.000" W longitude (Environment Canada 2015). Elevation is 671.4 m above sea level. Mean temperature is 4.2 °C; mean growing season temperature from May to October is 13.0 °C and mean winter temperature from November to April is -4.6 °C. Mean total average rainfall is 348 mm with greatest amounts from June to October (284.4 mm). Mean snowfall is 122 to 124 cm from October to May.

In May 2014 six research sites representing the variety of locations where naturalization is adopted in the City of Edmonton were established (Figure 2.1). The research sites reflected variability in topography, management and exposure to urban disturbance. Three flat and three sloped sites were selected (Table 2.1).

Lendrum site is flat and located between the back entrance of an old neighbourhood and the rail tracks of the Light Rail Transit system. A dense canopy of *Caragana arborescens* L. (caragana) surrounds the site. The area is dominated by grasses, with high populations of noxious weeds such as *Cirsium arvense* L. (Canada thistle) and *Tripleurospermum perforatum* L. Sch. Bip. (scentless chamomile). Most of the area was mowed annually until the beginning of this research. Mowing is not possible on a small area with *Caragana arborescens* trunks from a previous removal, presenting a management challenge as unmowed areas are seed banks for weeds which can disperse across the city, increasing weed management costs. Lendrum has low pedestrian and vehicle traffic. Evidence suggests the site may have been used as a dump. Grass was seeded, with no information on species, seeding method or seeding density.

Wagner site is located in an industrial area, inside Wagner Park at the back of the WP Wagner School and close to the train tracks. The area was managed as a flat grass area, and mowed until the beginning of this research. Traffic flow is light, with pedestrian traffic the main impact and some maintenance vehicle use. The site is a well established and maintained green space. *Taraxacum officinale* L. (common dandelion) is present due to the adjacent train tracks area.

The 91 Street site is located off a main street running north to south. It is a small hill, sloped to reduce noise to nearby buildings and enhance the landscape. The west slope faces a street; the east slope faces a lawn and a small urban forest of *Populus tremuloides* Michx. (trembling aspen). This area had not been mowed for over two years. Old dying trees and shrubs suggest past revegetation attempts. The site is exposed to wind and has a significant Canada thistle presence on the west facing slope bordered by forest. Vehicle traffic is very heavy on the street, but not on the green area; pedestrian traffic is limited. Coyotes and birds are present.

The 18 Avenue Blackmud (Blackmud) site is a flat area in a residential neighbourhood. The lawn was heavily mowed until the beginning of this research and is frequently exposed to pedestrian traffic and pets. A small forested area with a high diversity of native trees, shrubs and forbs borders the site. Herbivores such as deer and rabbits are present.

Smith Crossing site is a complex of slopes at 23 Avenue running east to west and crossed by White Mud Creek. An old forest borders the north and south and a high bridge crosses east to west. Vehicle traffic is heavy, with low traffic on green areas; pedestrian traffic mainly links to hiking paths. One portion of the south west edge is mowed where a green picnic area is located; the rest of the site has begun naturalization. Herbivores such as deer and rabbits are present.

Terwillegar Whitemud (Terwillegar) site is located at the intersection of two main streets, Terwillegar Drive and White Mud Drive. This site has highest vehicle traffic and lowest pedestrian traffic. Slopes face north and were planted with native vegetation in 1993. Mowing had not occurred for more than two years. There are no visible signs of herbivores.

3.2. Experimental Design

The experiment followed a complete randomized design with replication. Experimental plots (replications) were 10 m x 10 m, each divided into 16 small 2.5 m x 2.5 m subplots, covering an area of 6.25 m^2 (Figures 2.2, 2.3). Soil preparation treatments were randomly assigned vertically to plots in strips, with amendment treatments randomly applied within strips. Site preparation consisted of soil tilling, foliar herbicide application, a combination of tilling and herbicide and no site preparation (Table 2.2). Soil amendments were compost 100, compost 50, compost 20 and no amendment. Thus there were 4 soil preparation treatments x 4 amendment treatments x 3 replicates for a total of 48 plots per site.

3.3. Experimental Treatments

3.3.1. Herbicide

Roundup Transorb™ was applied as a 1 % solution (540 g/L glyphosate) by City of Edmonton personnel with backpack sprayers on June 12 2014, two weeks prior to soil preparation treatment implementation. Volumes applied depended on vegetation height and density (Table 2.3). Herbicide treatments were oriented in sections inside replicates for operational efficiency.

Roundup is a broad spectrum systemic herbicide, providing control for broad leaf and grasses species, with low persistence in the environment of 1 to 10 days. It controlled most weeds, although some species showed considerable resistance.

3.3.2. Soil tillage

Rototilling was performed June 24 and 25 2014 to a depth of approximately 10 to 15 cm with a rear tined, 9 HP hydraulic drive, Power Dog 209 rototiller. The gear was placed in forward and rotary blades in the opposite direction, for maximum soil penetration. Flat sites were tilled in one direction, then crossed perpendicularly; sloped sites were tilled in one direction and due to safety concerns complimented by a second pass in the same direction. Tillage was oriented in sections inside replicates for operational efficiency.

3.3.3. Amendments

Amendments were topsoil and compost, mixed in proportions based on availability and cost effectiveness of material for the City of Edmonton and standard naturalization materials available for operational work. Compost was from the City of Edmonton Waste Management Centre. Topsoil was from developments on previously agricultural land. Amendments were applied June 24 to 29 2014 using a mini steer loader and/or wheel barrow. Amendments were added to the surface of each subplot and spread by hand with shovels in a 15 cm deep layer.

Compost 100 was 80 % compost and 20 % wood chips by volume. It is a standard mix used by the City of Edmonton and was delivered ready to apply at each site. Compost 20, 80 % topsoil and 20 % compost, was delivered to each site mixed and ready to use. Compost 50, 50 % compost and 50 % topsoil, was prepared on subplots. To achieve a homogeneous mixture, compost mix was laid and distributed on treatment areas, capped with topsoil, then homogenized with a mini cultivator Honda model FG110K1CT.

3.4. Planting

Native woody species were standard planting stock for City of Edmonton naturalization (Table 2.4). Tree species were *Picea glauca* Moench Voss (white spruce), *Populus tremuloides* Michx (trembling aspen), *Populus balsamifera* L. (balsam poplar) and *Prunus virginiana* L. (chokeberry). Shrub species were *Rosa acicularis* Lindl. (wild rose), *Symphoricarpos albus* L. (snowberry), *Viburnum trilobum* L. (highbush cranberry) and *Salix exigua* Nutt (coyote willow).

Trees were planted the first two weeks of July 2014. Each day, planting stock was collected from the City of Edmonton nursery. After loading, a tarp was fixed over the plants to protect them during transportation. Planting holes were dug with a sharp shovel. Planting occurred away from treatment subplot edges to minimize edge effects. Each treatment subplot got one plant per species (total 8 plants, 4 trees and 4 shrubs) with minimum 15 cm spacing between plants (Table 2.5). Thus there were 128 plants in each plot (replicate), 384 plants at each site and 2,304 plants overall at the six research sites.

3.5. Plot Management

Plants were watered with an irrigation truck, 24 to 48 hours post planting; then every 2 to 3 days for two weeks, twice per week for the next four weeks, then once per week until the end of the growing season. In 2015, watering was based on availability of trucks as per standard City of Edmonton procedures for second year naturalization plantings; this approximated once per month from May to September. Lendrum was not watered in July 2015 and 18 Avenue Blackmud was not watered in August 2015.

All sites were managed for weed species to meet City of Edmonton standards. Lendrum, 91 Street, Wagner, Terwillegar and Smith Crossing plots were partially weeded by hand on August

11 2014. Lendrum was selectively sprayed with Trillion (2,4-D, mecoprop, dicamba) on September 4 2014 in response to complaints regarding increasing weed abundance. Spraying occurred as per manufacturer directions. Blackmud was not weeded in 2014.

Noxious weeds were hand pulled in 2015 by City of Edmonton personnel. It took 9 crew members 8 hours to clear all sites (72 hours weeding). Sites with highest noxious and non noxious weed densities were Lendrum and Blackmud, where pulled weeds filled 15 and 30 bags (89 x 127 cm), respectively. At Blackmud, weed pullers targeted *Chenopodium album* L. (lambs quarters) seedlings. On other sites 1 to 2 bags of noxious weeds per site were removed.

3.6. Vegetation Assessments

Plant health assessments were conducted in July 2014, August 2014, June 2015 and August 2015. Dates were to reflect early and peak growth each year. A 5 category scale was used to assess plant health as follows.

- 1: Healthy; plants 90 to 100 % green; no signs of water stress, pests or diseases; new buds and leaves developing or developed; no signs of nutrient deficiency.
- 2: Stressed; plants in fair health, plants 50 to 89 % green; some tissue damage visible; low to moderate signs of water stress, pests or diseases; some new shoot and leaf growth.
- 3: Severely stressed; plants in very poor health; plants less than 49 % green; clear signs of stress such as leaf chlorosis or necrosis; no leaves but some shoots starting to grow; some signs of wilting, pests, diseases, nutrient deficiencies.
- 4; Dead; plants with no green; plant and shoots dry; woody parts hard and break into pieces.
- 5. Not found; plants have either died or been removed (vandalism).

Plant height was measured in August 2014 and 2015. Plant height was measured as distance from the ground surface to the tip of the lead branch in each seedling. Height change was calculated by subtracting 2014 height from 2015 height to assess treatment effect. Negative values represented physical damage to the seedlings, from factors such as: predation, death, vandalism and stress. Positive heights implied growth and development one year after planting.

Stem diameter was measured in June and August 2015. Measurements were taken on the thickest stem of each individual plant at 2 to 5 cm above ground level using a vernier caliper. Stem diameter change was calculated by subtracting 2014 diameter from 2015 diameter. Stem diameter change was not as directly influenced by external factors as plant height and provides a reliable but smaller scale response variable to assess treatment effect.

3.7. Soils Assessments

Soil was sampled July 29 2014 and July 31 2015 to characterize each site. One 15 cm deep sample per replicate was taken with an auger from herbicide treatments to approximate original conditions without tillage. A composite sample of each amendment per site was collected with a hand shovel from the upper 15 cm. Samples were put into ziploc plastic bags and frozen until sent to a commercial laboratory for analyses.

Inorganic and organic carbon were determined by carbon dioxide loss (Loeppert and Suarez 1996) and total carbon by combustion (Nelson and Sommers 1996). Cation exchange capacity was determined through ammonium acetate extraction (Chapman 1965). Chloride in saturated paste was determined colorimetrically by auto-analyzer (Hendershot 2008). Mercury was determined spectrochemically (EPA 200.2/245.1). Metals were determined by acid digestion and inductively coupled plasma mass spectrometry (EPA 200.2). Total nitrogen was determined by combustion (Bremner 1996), available ammonium nitrogen by potassium chloride extraction and available nitrate nitrogen colorimetrically in calcium chloride solution (Maynard et al. 2008). Available phosphorus and potassium were determined by modified Kelowna process (Ashworth and Mrazek 1995). Particle size (sand, silt, clay) was determined by pipette with removal of organic matter and carbonate (Burt 2014). Sodium adsorption ratio was calculated and calcium, magnesium, sodium, potassium and sulfate were determined in saturated paste by inductively coupled plasma (Miller et al. 2007, EPA6010B). Electrical conductivity and pH were determined in saturated paste by meters (Miller et al. 2007).

3.8. Statistical Analyses

All statistical analyses were conducted using R version 3.1.2 (R Core Team 2014). In most cases data from the last monitoring date in 2015 were statistically analyzed to evaluate overall performance of species at the end of the experiment. An accident occurred at Smith Crossing in September 2014, destroying one replicate; hence for analyses this replicate was removed.

Chi-square analysis was used to identify effects of soil treatment on species survival using plant health data. Plant health scores were converted into yes and no survival categories. Not present and dead categories were converted to no; surviving healthy, stressed and severely stressed categories were converted to yes. Before performing chi-square analysis, assumptions were checked by calculating expected values for each treatment for individual species. Assumptions were met when no more than 20 % of the expected frequencies were less than 5.

Plant response to soil preparation and amendment was analyzed with an unbalanced two-way analysis of variance (ANOVA) with interactions. Response variables were height change and stem diameter change. Shapiro-Wilk test was used for normality of distribution and Levene's test for homogeneity of variance assessments. ANOVA tables were obtained using type III sum of squares to compensate for unbalanced data structure and least square means calculations to avoid misleading mean values. For significant factors an HSD Tukey's test was applied.

4. RESULTS

4.1. Plant Health And Survival

Without considering soil treatment or site, top surviving and performing species were *Symphoricarpos albus* and *Picea glauca* (Figure 2.4). They had highest numbers in healthy and stressed categories. *Symphoricarpos albus* had lowest mortality, followed by *Rosa acicularis* and *Picea glauca*. Shrubs with highest mortality were *Salix exigua* and *Viburnum trilobum*. Trees with highest mortality were *Populus tremuloides* and *Populus balsamifera*.

Plant mortality by species varied with time (Table 2.6). Non cumulative death percentage was calculated by multiplying number of dead individuals by 100 and dividing by 288 (total plants per species) (Figure 2.5). Cumulative death percentage was calculated to identify species with dramatic changes. In 2014 *Prunus virginiana* and *Salix exigua* had highest mortality in June; *Prunus virginiana* mortality was highest in August. Mortality generally dropped after June 2014, indicating transplanting stress was initially overcome. In June 2015 mortality increased for all species and kept rising until August 2015. At end of the experiment, mortality was highest for *Populus balsamifera* and *Viburnum trilobum*, *Salix exigua* and *Populus tremuloides* and lowest for *Symphoricarpos albus*, *Rosa acicularis*, *Picea glauca* and *Prunus virginiana*.

Plant mortality was site specific by species (Figure 2.6). Highest mortality occurred at 91 Street; lowest at Wagner. *Populus tremuloides*, *Viburnum trilobum* and *Symphoricarpos albus* had a slightly greater survival on flat than sloped sites. *Salix exigua*, *Populus tremuloides*, *Picea glauca*, *Rosa acicularis* and *Prunus virginiana* showed no preference for flat or slope sites.

4.2. Soil Preparation And Amendment Effects On Plant Survival

Species responded differently to soil treatments (Figures 2.7, 2.8; Tables 2.7, 2.8). Mortality for *Populus balsamifera* was significantly lowest with herbicide compost 100 and significantly highest with compost 50 and tillage compost 50. Mortality for *Prunus virginiana* was significantly lowest with herbicide tillage compost 100 and for *Populus tremuloides* was significantly lowest with herbicide and herbicide tillage. *Salix exigua* mortality was significantly highest with compost 50 and tillage compost 50 and significantly lowest with herbicide tillage. Viburnum trilobum mortality was significantly lowest with herbicide tillage and significantly highest with herbicide.

Species responded to soil amendment (Tables 2.9, 2.10). With amendment as a predictable variable, *Populus balsamifera*, *Prunus virginiana*, *Symphoricarpos albus* and *Rosa acicularis* mortality did not respond significantly to amendments. *Populus tremuloides* and *Salix exigua* mortality was significantly lowest with unamended treatments. *Picea glauca* mortality was significantly lowest in unamended soils and significantly highest with compost 50. *Viburnum trilobum* mortality was lowest in unamended soil and highest with compost 20 and compost 50.

Soil preparation had significant effects on plant survival (Tables 2.11, 2.12). Mortality for *Populus balsamifera* was lowest with herbicide and highest with tillage; for *Prunus virginiana* and *Salix exigua* it was lowest with herbicide tillage. Mortality for *Populus tremuloides* was lowest with herbicide and herbicide tillage and highest with untreated soil.

4.3. Soil Preparation And Amendment Effects On Plant Height Change

Mean tree height change responded to soil treatments with species specific effects (Tables 2.13, 2.14). Mean shrub height change also selectively responded to soil treatments by species (Tables 2.15, 2.16).

Soil preparation treatments had a significant effect on height change for all tree species except *Populus balsamifera* and *Prunus viginiana*, and all shrub species except *Viburnum trilobum* (Table 2.17). *Populus tremuloides* height change was significantly greatest with herbicide tillage and lowest with no treatment. *Picea glauca* height change was significantly higher with herbicide and herbicide tillage than tillage and no treatment. *Salix exigua* height change with herbicide tillage was significantly greater than with all other treatments. Height change for *Symphoricarpos albus* and *Rosa acicularis* were significantly affected by soil preparation treatment, with greatest significant effects with herbicide tillage.

Amendment application only had a significant effect only for *Picea glauca* and *Symphoricarpos albus* (Table 2.18). Compost 100 had the highest mean height change for both of these species. The lowest was in unamended. Compost 20 and compost 50 amendment treatments had a similar height change values.

4.4. Soil Preparation And Amendment Effects On Stem Diameter Change

Soil preparation treatments affected stem diameter change for several tree species (Tables 2.19, 2.20) and shrub species (Tables 2.21, 2.22). All changes were positive, indicating growth.

Soil preparation treatments significantly affected stem diameter change in *Populus balsamifera*, *Populus tremuloides* and *Picea glauca* (Table 2.23). The greatest stem diameter change was with herbicide tillage for *Picea glauca* and *Populus tremuloides*, the smallest stem diameter change was with no treatment. *Populus balsamifera* change was greatest with herbicide and lowest with tillage. *Rosa acicularis* and *Symphoricarpos albus* stem diameter change was significantly lowest with tillage and no treatment and significantly highest with herbicide and herbicide tillage. For *Salix exigua* untreated soil was significantly lowest and herbicide significantly highest.

Mean stem diameter change in trees with amendment was significant for some species (Table 2.24). With compost 100 mean stem diameter change was highest and with compost 50 mean stem diameter change was lowest for both *Populus tremuloides* and *Picea glauc*a. For all four of the shrub species, stem diameter change was not significant with any of the soil amendment treatments.

4.5. Soil Response To Treatment

Soil nutrients generally decreased from 2014 to 2015 (Table 2.25). Soil chemical properties were similar between 2014 and 2015 and across experimental sites (Table 2.26). Cation concentrations were similar for sites and years (Table 2.27). Most site variability was with macro nutrients. Most chemical properties were stable over time with little variability across sites.

The soil amendments used for treatments had different chemical properties (Table 2.28). Compost had high available phosphorus. The highest source of nitrogen in composts was nitrate. Macronutrients were similar with amendments, with high macronutrient concentrations in 2014 decreasing by 2015. Chemical properties of amendments varied as expected related to compost proportion (Table 2.29). Highest values were in 100 compost and least in 20 compost. Analytes diminished by the second year. Cation exchange capacity was higher in compost 100 followed by compost 50, then compost 20. Electrical conductivity was highest in the first year with compost 100 but diminished by the second year. Cations in amendments varied with compost proportion (Table 2.30). Major positive charged elements in compost were sulphur in sulphate form and calcium.

5. DISCUSSION

5.1. Plant Response To Treatments

Native woody species can survive when transplanted and under the right conditions can be used to naturalize areas across the city. Soil treatment prior to planting may provide advantages to new seedlings by temporarily reducing competition for resources and providing nutrients to facilitate establishment. This is consistent with the findings at the green links project where shrub species planted into natural settings flourished; however, those that were introduced into newly created foundation plantings or into well established but constraining environments, such as shrubs in fields or rights-of-way of dense grass, performed poorly and many did not survive (Schaefer 2009). Changes in growing conditions may not benefit all species the same or those intended for naturalized sites, thus soil treatments should be based on needs of the species and local site conditions.

Soil preparation with herbicide tillage and herbicide alone was consistently most successful, with effectiveness mostly attributable to herbicide effects on surrounding vegetation. Naturalized locations tended to be dominated by grasses. Soil preparation without herbicide resulted in increased growth of grasses, mainly driven by added water to irrigate new seedlings. Herbicide suppressed grass species and benefited new seedlings the year of planting, although later weeds surrounding the seedlings also benefited. A major implication of watering new plantings using water trucks is that water will be spread broadly and be useful to desired plantings and competing vegetation, which may lead to an overwhelming growth of grasses or weeds.

Under urban conditions, soils often present reductions in their most important physical properties such as structural stability and water retention. Others have suggested that eventually these properties might have a detrimental effect on plant growth (Vetterlein and Hüttl 1999, Scharenbroch et al. 2005). Water availability was likely a major factor in plant response to treatment in the current study. Among the better performing species were those that are more resistant to drought, such as *Symphoricarpos albus* and *Rosa acicularis*. Plant size may have contributed to mortality as worst performing species, *Populus tremuloides* and *Viburnum trilobum*, were among the largest plants at the time of planting. These larger plants may have higher water demand for rooting and long term establishment. Survival was lowest at 91 Street beside a high traffic street and with overall landscape architecture resembling a wind and noise barrier. Wagner is flat with minimal disruption by vehicle traffic and pedestrians and is located near a water stream.

Amendments were most valuable to plant development expressed by height change and stem diameter change; in most cases it did not contribute to seedling survival. Locally produced compost, especially when used at high rates (with little to no mixing with topsoil) can maximize growth of new seedlings. Long term monitoring of height and stem diameter change would provide reliable data on soil treatments effects for each species common in naturalization.

Height and stem diameter changes developed at a different phase for shrub and tree species. Shrub species height changes were more dynamic than tree species. Shrubs grew new stems from one year to the other. Shrubs species can potentially be used in the short to mid term monitoring to measure soil treatment effects.

Soil analyses provided information to suggest that macro nutrients vary with sites and factors influencing macro nutrient cycles. However, when evaluating soil properties of the different sites, differences were very small. For amendments, it was clear that a higher proportion of compost contributed to increased nutrients available for plants, but those nutrients are considerably mobile so these concentrations decline through time.

5.2. Other Factors Affecting Naturalization

Main drivers influencing performance in naturalized plots are present in any major reclamation site, although they interact differently when naturalizing an urban area. Different sites have different exposure to these factors, and hence are affected differently by them. Naturalization in cities involves more than just alteration of soil conditions; the surrounding urban areas must be managed (Pavao-Zuckerman 2008).

Sites that are isolated in an urban center will respond differently to naturalization relative to highly trafficked ones. Pedestrian traffic, especially at the beginning of the naturalization process when grass is relatively short, may physically damage new plantings. Other researchers have addressed the human traffic factor in their research, stating that in cities, species and ecological function can be restored and promoted (Beckett et al. 1998, Bolund and Hunhammar 1999, Rosenzweig 2003, Alberti 2005, Snep et al. 2006), recognizing humans are part of nature contributing to natural soil formation (Pickett and Cadenasso 2008) and constructing conditions in domesticated landscapes (Kareiva et al. 2007).

Wildlife traffic can affect seedling establishment. Thinking that wildlife was not a threat in an urban environment proved to be false as wildlife predation was not uncommon. Most wildlife interfering with new planting establishment were small rodents, although deer were spotted in naturalized areas located in proximity to larger natural areas. As naturalized areas are excluded from regular maintenance, an increase in vegetation cover provides a food source for small and large herbivores. Herbivore populations around the naturalized sites found reliable shelter and food for grazing and browsing with minimal exposure to predation.

The neighboring plant community to planted seedlings can influence attractiveness of a particular area for human disturbance or wildlife. Plant height change measurements were useful to assess plant development and also to track predation or disturbance. For example, a negative height change may not only be due to poor growth, but more frequently due to physical damage to seedlings by herbivores and by human vandals pulling out the plants.

Conservation and passive management of degraded ecosystems is widely recognized as an insufficient strategy to ensure autogenic, spontaneous recolonization and recovery of native assemblages and ecosystem function (Hobbs 2007, Jackson and Hobbs 2009). Humans are a major component to manage in naturalization strategy. Human dimensions must be addressed through social engagement campaigns to facilitate transition of a mowed area to a naturalized area, and to educate neighbouring communities to minimize undesirable disturbance and contribute to its management. Failing to engage humans in urban environments can lead to vandalism and unwillingness to naturalize a certain area.

Weather was an influential factor. Unusual rain patterns, high temperatures and mild winters had a clear impact on new seedlings and mature plants inside and outside the influential area of an urban settlement (See Appendix). The urban heat island effect, modifications from local cloud cover and precipitation and alterations to hydrologic regimes by urban infrastructure can strongly affect soil micro climates, water availability and soil organism activity (Oke 1995, Brazel et al. 2000). Using water trucks to compensate for lack of precipitation is an appropriate approach but it cannot be the final solution. It does not provide a reliable, targeted and evenly distributed water source for new plantings, especially looking to uncertain future global weather as forecasted by climate change and extreme weather events.

Varying site features could potentially affect seedling performance under particular weather conditions. Site preparation techniques can alter soil water availability within the soil profile and, together with strategic plant treatments, can increase revegetation success (Ruthrof et al. 2013). The 91 Street site was located right on the windbreaks to the side of a busy street. As this site was heavily exposed to wind currents, seedlings tend to be more affected by water stress relative to the other sites. A standard watering schedule was not enough for naturalizing sites with high exposure to wind currents in a warm and dry year.

Weed management approach is a crucial component to naturalize a specific area. Urban naturalization could be particularly sensible to weed management as these areas are subject to high public visibility and usage. Compiling an integrated weed management strategy that minimizes interventions while preserving a visually appealing site appearance is one of the biggest challenges of naturalizing urban settings. Invasive species and other weed species have successful strategies with characteristics that facilitate successful seed banking, including high seed output, phenotypic and germination plasticity, adaptations for short and long distance dispersal, small seed size and high seed longevity (Baker 1974, Louda 1989, Radosevich et al. 2007). Thus they are often difficult to control in the newly naturalized landscape where they can quickly dominate and outcompete desired species.

6. CONCLUSIONS

Several woody plant species responded positively to naturalization practices in the City of Edmonton. The top surviving and performing tree and shrub species were *Picea glauca* and *Symphoricarpos albus*, respectively. *Symphoricarpos albus* was one of the hardiest and most resilient species for planting in a naturalized area. The poorest performing tree and shrub species were *Populus tremuloides* and *Viburnum trilobum*, respectively.

Plant species evaluated in this study responded differently to soil treatments. Survival and plant growth were positively influenced by soil preparation treatments relative to no soil preparation treatment. In general, soil preparation treatments involving either herbicide with tillage or herbicide alone were most effective. Amendments were not as important to survival and plant growth as soil preparation, but were significant for some species. Amendments generally resulted in larger plants with 100 % compost the leading treatment. Interaction between soil preparation and amendment application was not very strong in this two year study.

Table 2.1. Site location, last mowing event and traffic exposure.

Topography	City Address	Last Mow	Pedestrian Traffic
Flat			
Lendrum	11240 59 Avenue	1 year	Light
Wagner	6359 Wagner Road	1 year	Light
Blackmud	11407 18 Avenue	1 year	Heavy
Sloped			
91 Street	4321 91 Street	> 2 years	Light
Smith Crossing	11903-13063 23 Avenue	> 2 years	Light
Terwillegar	4004-4460 Terwillegar Drive	> 2 years	None

Table 2.2. Research treatment details.

Treatment	Tillage	Herbicide	Amendment
Control	None	None	None
Compost 100	None	None	Compost
Compost 20	None	None	Compost Soil
Compost 50	None	None	Compost Soil
Herbicide	None	Glyphosate	None
Herbicide Compost 100	None	Glyphosate	Compost Soil
Herbicide Compost 20	None	Glyphosate	Compost Soil
Herbicide Compost 50	None	Glyphosate	Compost Soil
Tillage	Rototill	None	None
Tillage Compost 100	Rototill	None	Compost
Tillage Compost 20	Rototill	None	Compost Soil
Tillage Compost 50	Rototill	None	Compost Soil
Tillage, Herbicide	Rototill	Glyphosate	None
Tillage, Herbicide Compost 100	Rototill	Glyphosate	Compost
Tillage, Herbicide Compost 20	Rototill	Glyphosate	Compost Soil
Tillage, Herbicide Compost 50	Rototill	Glyphosate	Compost Soil

Table 2.3. Herbicide application rates by site.

Site Name	1 % Solution Rate L/ha	Glyphosate Rate L/ha
Lendrum	1,514.0	15.140
Wagner	1,009.3	10.090
91 Street	1,009.3	10.090
Blackmud	882.6	8.826
Smith Crossing	882.6	8.826
Terwillegar	768.0	7.680

Table 2.4. Planted trees and shrubs common and scientific names.

Common Name	Scientific Name	Category
White spruce	*Picea glauca* (Moench) Voss	Tree
Trembling aspen	*Populus tremuloides* Michx.	Tree
Balsam poplar	*Populus balsamifera* L.	Tree
Choke cherry	*Prunus virginiana* L.	Tree
Wild rose	*Rosa acicularis* Lindl.	Shrub
Snowberry	*Symphoricarpos albus* L.	Shrub
Highbush cranberry	*Viburnum trilobum* L.	Shrub
Coyote willow	*Salix exigua* Nutt	Shrub

Table 2.5. Planted trees and shrubs, container type and planting date for each research site.

Site	Plant Species	Planting Date	Container Type
Lendrum	White spruce (*Picea glauca*)	04/07/14	Naked plug
	Trembling aspen (*Populus tremuloides*)	04/07/14	Medium pot ½ l
	Balsam poplar (*Populus balsamifera*)	10/07/14	Big styro 1 l
	Choke cherry (*Prunus virginiana)*	10/07/14	Small styro
	Wild rose (*Rosa acicularis)*	10/07/14	Medium pot ½ l
	Snowberry (*Symphoricarpos albus*)	11/07/14	Big styro 1 l
	Highbush cranberry (*Viburnum trilobum)*	11/07/14	Big styro 1 l
	Coyote willow (*Salix exigua)*	11/07/14	Small styro
Wagner	White spruce (*Picea glauca*)	04/07/14	Naked plug
	Trembling aspen (*Populus tremuloides*)	04/07/14	Medium pot ½ l
	Balsam poplar (*Populus balsamifera*)	10/07/14	Big styro 1 l
	Choke cherry (*Prunus virginiana)*	10/07/14	Small styro
	Wild rose (*Rosa acicularis)*	10/07/14	Medium pot ½ l
	Snowberry (*Symphoricarpos albus*)	11/07/14	Big styro 1 l
	Highbush cranberry (*Viburnum trilobum)*	11/07/14	Big styro 1 l
	Coyote willow (*Salix exigua)*	11/07/14	Small styro
91 Street	White spruce (*Picea glauca*)	04/07/14	Naked plug
	Trembling aspen (*Populus tremuloides*)	04/07/14	Medium pot ½ l
	Balsam poplar (*Populus balsamifera*)	10/07/14	Big styro 1 l
	Choke cherry (*Prunus virginiana)*	10/07/14	Small styro
	Wild rose (*Rosa acicularis)*	10/07/14	Medium pot ½ l
	Snowberry (*Symphoricarpos albus*)	11/07/14	Big styro 1 l
	Highbush cranberry (*Viburnum trilobum)*	11/07/14	Big styro 1 l
	Coyote willow (*Salix exigua)*	11/07/14	Small styro
Blackmud	White spruce (*Picea glauca*)	04/07/14	Naked plug
	Trembling aspen (*Populus tremuloides*)	04/07/14	Medium pot ½ l
	Balsam poplar (*Populus balsamifera*)	10/07/14	Big styro 1 l
	Choke cherry (*Prunus virginiana)*	10/07/14	Small styro
	Wild rose (*Rosa acicularis)*	10/07/14	Medium pot ½ l
	Snowberry (*Symphoricarpos albus*)	12/07/14	Big styro 1 l
	Highbush cranberry (*Viburnum trilobum)*	12/07/14	Big styro 1 l
	Coyote willow (*Salix exigua)*	12/07/14	Medium pot ½ l
Smith Crossing	White spruce (*Picea glauca*)	04/07/14	Naked plug*
	Trembling aspen (*Populus tremuloides*)	04/07/14	Medium pot ½ l
	Balsam poplar (*Populus balsamifera*)	10/07/14	Big styro 1 l
	Choke cherry (*Prunus virginiana)*	10/07/14	Small styro
	Wild rose (*Rosa acicularis)*	10/07/14	Medium pot ½ l
	Snowberry (*Symphoricarpos albus*)	13/07/14	Big styro 1 l
	Highbush cranberry (*Viburnum trilobum)*	13/07/14	Big styro 1 l
	Coyote willow (*Salix exigua)*	13/07/14	Medium pot ½ l
Terwillegar	White spruce (*Picea glauca*)	04/07/14	Naked plug
	Trembling aspen (*Populus tremuloides*)	04/07/14	Medium pot ½ l
	Balsam poplar (*Populus balsamifera*)	10/07/14	Big styro 1 l
	Choke cherry (*Prunus virginiana)*	10/07/14	Small styro
	Wild rose (*Rosa acicularis)*	10/07/14	Medium pot ½ l
	Snowberry (*Symphoricarpos albus*)	11/07/14	Big styro 1 l
	Highbush cranberry (*Viburnum trilobum)*	11/07/14	Big styro 1 l
	Coyote willow (*Salix exigua)*	11/07/14	Small styro

Table 2.6. Number of dead plants and non cumulative and cumulative mortality by species.

Species		July 2014	August 2014	June 2015	August 2015
Picea glauca	Number of plants	0	1	29	80
	% non-cumulative	0.00	0.35	10.07	27.78
	% cumulative	0.00	0.35	10.10	30.89
Populus tremuloides	Number of plants	3	9	107	136
	% non-cumulative	1.04	3.13	37.15	47.22
	% cumulative	1.04	3.16	38.35	75.14
Prunus virginiana	Number of plants	42	30	37	78
	% non-cumulative	14.58	10.42	12.85	27.08
	% cumulative	14.58	12.20	14.34	31.08
Populus balsamifera	Number of plants	2.00	1	50	172
	% non-cumulative	0.69	0.35	17.36	59.72
	% cumulative	0.69	0.35	17.42	72.27
Symphoricarpos albus	Number of plants	0	0	6	14
	% non-cumulative	0.00	0.00	2.08	4.86
	% cumulative	0.00	0.00	2.08	4.96
Rosa acicularis	Number of plants	14	2	13	41
	% non-cumulative	4.86	0.69	4.51	14.24
	% cumulative	4.86	0.73	4.55	14.91
Salix exigua	Number of plants	37	5	85	154
	% non-cumulative	12.85	1.74	29.51	53.47
	% cumulative	12.85	1.99	30.04	75.86
Viburnum trilobum	Number of plants	4	2	82	172
	% non-cumulative	1.39	0.69	28.47	59.72
	% cumulative	1.39	0.70	28.67	83.50

Table 2.7. Chi square p values by soil treatment interactions.

Species	Chi Square	Degrees of Freedom	P Value
Picea glauca	38.3791	15	0.0007929*
Populus tremuloides	48.0342	15	2.511e-05**
Prunus virginiana	44.6118	15	8.815e-05**
Populus balsamifera	49.6584	15	1.369e-05**
Salix exigua	52.5413	15	4.595e-06**
Viburnum trilobum	70.9565	15	3.016e-09***

* Slightly significant effect; ** Moderately significant effect; *** Highly significant effect
Species not included did not meet normality assumptions

Table 2.8. Mortality by soil treatment (number of dead plants).

Treatment	*Populus tremuloides*	*Prunus virginiana*	*Populus tremuloides*	*Picea glauca*
Compost 100	11 b	14 b	14 b	10
Compost 20	12 b	13 b	15 b	6
Compost 50	15 c	16 b	17 b	10
Control	10 b	11 b	12 b	2
Herbicide	5 b	7 b	5 a	1
Herbicide Compost 100	3 a	12 b	10 b	7
Herbicide Compost 20	8 b	9 b	13 b	4
Herbicide Compost 50	7 b	10 b	12 b	7
Herbicide Tillage	6 b	6 b	5 a	1
Herbicide Tillage Compost 100	7 b	4 a	11 b	6
Herbicide Tillage Compost 20	10 b	8 b	10 b	6
Herbicide Tillage Compost 50	10 b	8 b	11 b	6
Tillage	12 b	10 b	9 b	1
Tillage Compost 100	13 b	14 b	14 b	5
Tillage Compost 20	13 b	14 b	13 b	5
Tillage Compost 50	15 c	14 b	16 b	10
	Salix exigua	*Viburnum trilobum*	*Symphoricarpos albus*	*Rosa acicularis*
Compost 100	12 b	14 b	5	7
Compost 20	15 b	15 b	NA	5
Compost 50	17 c	16 b	3	8
Control	11 b	10 b	NA	1
Herbicide	7 b	5 c	NA	2
Herbicide Compost 100	10 b	9 b	1	NA
Herbicide Compost 20	9 b	16 b	1	3
Herbicide Compost 50	11 b	13 b	NA	3
Herbicide Tillage	3 a	2 a	1	3
Herbicide Tillage Compost 100	7 b	10 b	1	1
Herbicide Tillage Compost 20	9 b	14 b	1	3
Herbicide Tillage Compost 50	10 b	11 b	NA	2
Tillage	12 b	7 b	NA	1
Tillage Compost 100	11 b	11 b	2	7
Tillage Compost 20	14 b	15 b	NA	7
Tillage Compost 50	17 c	16 b	3	3

Means within columns for a species followed by the same letters are not significantly different

Table 2.9. Chi square p values by amendment treatment.

Species	Chi Square	Degrees of Freedom	P Value
Picea glauca	30.1997	3	1.253e-06**
Populus tremuloides	24.4193	3	2.042e-05**
Prunus virginiana	6.7137	3	0.0816
Populus balsamifera	9.2729	3	0.02587*
Rosa acicularis	6.2963	3	0.09805
Salix exigua	17.0971	3	0.000675*
Viburnum trilobum	52.6798	3	2.145e-11***

* Slightly significant effect, ** Moderately significant effect, *** Highly significant effect
Species not included did not meet normality assumptions

Table 2.10. Mortality by soil amendment treatment (number of dead plants).

Amendment	*Populus balsamifera*	*Prunus virginiana*	*Populus tremuloides*	*Picea glauca*
Compost 100	34	44	49 b	28 b
Compost 20	43	44	51 b	21 b
Compost 50	47	48	56 b	33 c
Unamended	33	34	31 a	5 a
	Salix exigua	*Viburnum trilobum*	*Symphoricarpos albus*	*Rosa acicularis*
Compost 100	40 b	44 b	9	15
Compost 20	47 b	60 c	2	18
Compost 50	55 b	56 c	6	16
Unamended	33 a	24 a	1	7

Means within columns for a species followed by the same letters are not significantly different

Table 2.11. Chi square p values by soil preparation treatment.

Species	Chi Square	Degrees of Freedom	P Value
Picea glauca	3.7010	3	0.2956
Populus tremuloides	20.1754	3	0.0001561*
Prunus virginiana	32.3137	3	4.494e-07**
Populus balsamifera	37.4702	3	3.659e-08***
Rosa acicularis	11.3333	3	0.01005*
Salix exigua	31.7106	3	6.022e-07**
Viburnum trilobum	12.0949	3	0.007065*

* Slightly significant effect, ** Moderately significant effect, *** Highly significant effect
Species not included did not meet normality assumptions

Table 2.12. Mortality by soil preparation treatment (number of dead plants).

Soil Preparation	*Populus balsamifera*	*Prunus virginiana*	*Populus tremuloides*	*Picea glauca*
Herbicide	23 a	38 b	40 a	19
Herbicide Tillage	33 b	26 a	37 a	19
Tillage	53 c	52 b	52 b	21
Untreated	48 b	54 b	58 c	28
	Salix exigua	*Viburnum trilobum*	*Symphoricarpos albus*	*Rosa acicularis*
Herbicide	37 b	43	2	8
Herbicide Tillage	29 a	37	3	9
Tillage	54 b	49	5	18
Untreated	55 b	55	8	21

Means within columns for a species followed by the same letters are not significantly different

Table 2.13. Tree species soil treatment effect on plant height change.

Tree Species	Soil Treatment	Sum of Squares	Degrees of Freedom	F Value	P (>F)
Picea glauca	Intercept	2661.2	1	94.0200	< 2.2e-16 ***
	Soil preparation	996.4	3	11.7346	3.284e-07 ***
	Amendment	347.2	3	4.0889	0.007404 **
	Soil preparation amendment	268.6	9	1.0543	0.397578
	Residuals	6934.5	245		
Populus tremuloides[1]	Intercept	3132.0	1	6.1073	0.01429 *
	Soil preparation	17716.0	3	11.5157	5.342e-07 ***
	Amendment	3977.0	3	2.5850	0.05436
	Soil preparation amendment	6530.0	9	1.4149	0.18353
	Residuals	103076.0	201		
Prunus virginiana	Intercept	0.0	1	0.0001	0.9937
	Soil preparation	598.3	3	1.2256	0.3024
	Amendment	468.8	3	0.9602	0.4132
	Soil preparation amendment	1441.3	9	0.9840	0.4555
	Residuals	24899.2	153		
Populus balsamifera	Intercept	8899.0	1	23.2999	2.515e-06 ***
	Soil preparation	916.0	3	0.7991	0.4955
	Amendment	1072.0	3	0.9359	0.4240
	Soil preparation amendment	5541.0	9	1.6121	0.1126
	Residuals	88606.0	232		

[1] Homoscedasticity assumption slightly violated (0.031)

Table 2.14. Mean tree height change (cm) by soil treatment.

Treatment	Calculation	*Populus balsamifera*	*Prunus virginiana*	*Populus tremuloides*	*Picea glauca*
Compost 100	Mean change	-8.0	-1.2	-0.3	1.5
Compost 100	Standard deviation	7.0	7.5	21.7	3.3
Compost 20	Mean change	-1.1	-5.6	-4.1	1.7
Compost 20	Standard deviation	17.4	8.2	11.4	6.8
Compost 50	Mean change	-11.6	-2.9	-9.1	0.3
Compost 50	Standard deviation	20.4	5.4	10.9	3.9
Control	Mean change	-8.9	-3.8	-8.8	0.6
Control	Standard deviation	24.1	4.4	9.3	3.1
Herbicide	Mean change	-14.9	-3.5	8.0	1.4
Herbicide	Standard deviation	33.3	6.1	16.4	3.9
Herbicide Compost 100	Mean change	7.5	2.6	11.6	6.7
Herbicide Compost 100	Standard deviation	17.4	11.2	28.4	6.9
Herbicide Compost 20	Mean change	-7.7	2.8	7.8	6.3
Herbicide Compost 20	Standard deviation	22.4	9.5	19.0	3.4
Herbicide Compost 50	Mean change	-11.5	3.5	-4.3	2.3
Herbicide Compost 50	Standard deviation	28.5	4.7	44.7	5.6
Herbicide Tillage	Mean change	-1.9	2.0	17.7	4.2
Herbicide Tillage	Standard deviation	8.4	6.6	26.5	4.7
Herbicide Tillage Compost 100	Mean change	-0.9	4.6	37.8	8.3
Herbicide Tillage Compost 100	Standard deviation	9.9	9.7	37.3	8.3
Herbicide Tillage Compost 20	Mean change	-7.9	0.7	5.2	4.7
Herbicide Tillage Compost 20	Standard deviation	23.4	9.0	18.8	4.5
Herbicide Tillage Compost 50	Mean change	0.0	-1.0	10.6	6.5
Herbicide Tillage Compost 50	Standard deviation	10.8	5.2	30.0	8.9
Tillage	Mean change	-7.4	-2.3	-0.9	1.1
Tillage	Standard deviation	12.5	6.3	18.3	2.9
Tillage Compost 100	Mean change	-11.3	-0.2	-4.9	3.3
Tillage Compost 100	Standard deviation	28.0	13.0	14.6	6.1
Tillage Compost 20	Mean change	-2.6	10.0	-6.2	0.7
Tillage Compost 20	Standard deviation	10.9	44.4	12.1	4.8
Tillage Compost 50	Mean change	-7.8	-5.9	1.0	1.6
Tillage Compost 50	Standard deviation	9.3	7.4	18.7	3.3

Table 2.15. Shrub species soil treatment effect on plant height change.

Shrub Species	Soil Treatment	Sum of Squares	Degrees of Freedom	F Value	P (>F)
Symphoricarpos albus	Intercept	793.0	1	4.1489	0.04272 *
	Soil preparation	5207.0	3	9.0749	1.009e-05 ***
	Amendment	1603.0	3	2.7937	0.04095 *
	Soil preparation amendment	522.0	9	0.3031	0.97336
	Residuals	47428.0	248		
Rosa acicularis[1]	Intercept	635.0	1	1.8405	0.176173
	Soil preparation	4193.0	3	4.0532	0.007791 **
	Amendment	2087.0	3	2.0172	0.112169
	Soil preparation amendment	1708.0	9	0.5504	0.836547
	Residuals	82072.0	238		
Salix exigua	Intercept	9778.0	1	15.1950	0.0001271 ***
	Soil preparation	5875.0	3	3.0435	0.0296384 *
	Amendment	1600.0	3	0.8287	0.4792681
	Soil preparation amendment	5011.0	9	0.8653	0.5570075
	Residuals	148642.0	231		
Viburnum trilobum	Intercept	15909.1	1	118.5419	<2e-16 ***
	Soil preparation	742.9	3	1.8451	0.1397
	Amendment	455.6	3	1.1316	0.3370
	Soil preparation amendment	1191.5	9	0.9864	0.4519
	Residuals	31270.1	232		

[1]Homoscedasticity assumption wasn’t met (0.005)

Table 2.16. Mean shrub height change (cm) by soil treatment.

Treatment	Calculation	*Salix exigua*	*Viburnum trilobum*	*Symphoricarpos albus*	*Rosa acicularis*
Compost 100	Mean change	-4.4	-12.6	-1.7	-2.1
Compost 100	Standard deviation	24.5	8.8	18.0	17.1
Compost 20	Mean change	-11.6	-7.9	-8.2	-3.8
Compost 20	Standard deviation	17.1	14.3	10.4	10.9
Compost 50	Mean change	-10.8	-2.1	-7.0	-4.9
Compost 50	Standard deviation	23.0	19.8	7.7	16.7
Control	Mean change	-10.2	-10.9	-9.3	-1.1
Control	Standard deviation	28.9	11.9	19.1	5.2
Herbicide	Mean change	-10.2	-7.0	-1.7	-0.1
Herbicide	Standard deviation	27.4	9.0	13.2	24.3
Herbicide Compost 100	Mean change	-10.5	-11.5	7.0	11.8
Herbicide Compost 100	Standard deviation	31.5	17.7	18.0	17.1
Herbicide Compost 20	Mean change	-10.1	-13.7	-1.3	7.0
Herbicide Compost 20	Standard deviation	31.4	12.4	12.1	17.2
Herbicide Compost 50	Mean change	-5.1	-7.4	-1.6	1.6
Herbicide Compost 50	Standard deviation	19.6	7.2	9.7	13.9
Herbicide Tillage	Mean change	10.1	-4.5	0.7	1.8
Herbicide Tillage	Standard deviation	19.3	8.1	12.6	17.3
Herbicide Tillage Compost 100	Mean change	5.6	-5.1	8.4	15.7
Herbicide Tillage Compost 100	Standard deviation	29.7	10.4	18.5	31.2
Herbicide Tillage Compost 20	Mean change	4.8	-6.4	6.3	4.9
Herbicide Tillage Compost 20	Standard deviation	16.5	9.0	18.5	24.0
Herbicide Tillage Compost 50	Mean change	-12.0	-5.0	2.1	2.3
Herbicide Tillage Compost 50	Standard deviation	32.6	6.2	13.2	14.1
Tillage	Mean change	-14.2	-8.2	-6.7	0.2
Tillage	Standard deviation	18.3	10.1	9.9	14.8
Tillage Compost 100	Mean change	-1.9	-6.4	-4.4	-0.7
Tillage Compost 100	Standard deviation	25.8	15.9	12.2	28.5
Tillage Compost 20	Mean change	-7.7	-10.3	-4.1	-1.9
Tillage Compost 20	Standard deviation	29.2	7.9	11.9	18.1
Tillage Compost 50	Mean change	-12.8	-9.5	-6.3	-5.2
Tillage Compost 50	Standard deviation	22.3	6.9	8.7	5.5

Table 2.17. Mean height change (cm) by soil preparation treatment.

Soil Preparation	Calculation	*Populus balsamifera*	*Prunus virginiana*	*Populus tremuloides*	*Picea glauca*
Herbicide	Mean change	-6.9	1.3	5.7 b	4.2 a
Herbicide	Standard deviation	27.0	8.6	29.1	5.6
Herbicide Tillage	Mean change	-2.8	1.6	15.8 a	5.9 a
Herbicide Tillage	Standard deviation	14.6	7.9	29.4	6.9
Tillage	Mean change	-7.3	0.6	-2.8 bc	1.7 b
Tillage	Standard deviation	16.7	24.9	15.9	4.5
Untreated	Mean change	-7.4	-3.2	-5.7 c	1.0 b
Untreated	Standard deviation	18.2	6.5	13.9	4.4
		Salix exigua	*Viburnum trilobum*	*Symphoricarpos albus*	*Rosa acicularis*
Herbicide	Mean change	-9.0 b	-9.8	0.5 ab	5.2 ab
Herbicide	Standard deviation	27.3	12.1	13.7	18.6
Herbicide Tillage	Mean change	2.0 a	-5.2	4.4 a	6.2 a
Herbicide Tillage	Standard deviation	26.3	8.3	15.9	22.9
Tillage	Mean change	-9.4 b	-8.4	-5.4 bc	-2.0 ab
Tillage	Standard deviation	24.1	10.9	10.6	18.2
Untreated	Mean change	-9.5 b	-8.5	-6.7 c	-3.0 b
Untreated	Standard deviation	23.3	14.4	14.6	13.1

Means within columns for a species followed by the same letters are not significantly different

Table 2.18. Mean height change (cm) by soil amendment treatment.

Amendment	Calculation	*Populus balsamifera*	*Prunus virginiana*	*Populus tremuloides*	*Picea glauca*
Compost 100	Mean change	-3.3	1.9	9.6	5.0 a
Compost 100	Standard deviation	18.6	10.1	29.9	6.8
Compost 20	Mean change	-4.9	2.1	0.4	3.3 ab
Compost 20	Standard deviation	19.1	21.7	16.3	5.4
Compost 50	Mean change	-7.8	-1.1	0.1	2.6 ab
Compost 50	Standard deviation	19.3	6.4	29.3	6.0
Unamended	Mean change	-8.3	-1.7	3.6	1.8 b
Unamended	Standard deviation	21.8	6.3	20.6	3.9
		Salix exigua	*Viburnum triilobum*	*Symphoricarpos albus*	*Rosa acicularis*
Compost 100	Mean change	-2.8	-8.9	2.4 a	6.4
Compost 100	Standard deviation	28.1	13.7	17.4	25.0
Compost 20	Mean change	-6.4	-9.6	-1.9 ab	1.7
Compost 20	Standard deviation	24.9	11.3	14.3	18.4
Compost 50	Mean change	-10.2	-6.1	-3.1 ab	-1.7
Compost 50	Standard deviation	24.5	11.3	10.5	13.3
Unamended	Mean change	-6.2	-7.5	-4.3 b	0.2
Unamended	Standard deviation	25.2	9.8	14.4	16.3

Means within columns for a species followed by the same letters are not significantly different

Table 2.19. Tree species soil treatment effect on stem diameter change.

Tree Species	Soil Treatment	Sum of Squares	Degrees of Freedom	F Value	P (>F)
Picea glauca[1]	Intercept	106.51	1	65.7750	2.499e-14 ***
	Soil preparation	13.91	3	2.8626	0.03746 *
	Amendment	18.31	3	3.7696	0.01132 *
	Soil preparation amendment	7.35	9	0.5041	0.87087
	Residuals	393.48	243		
Populus tremuloides[2]	Intercept	172.11	1	29.9340	1.361e-07 ***
	Soil preparation	89.43	3	5.1846	0.001814 **
	Amendment	48.84	3	2.8314	0.039561 *
	Soil preparation amendment	41.00	9	0.7924	0.623729
	Residuals	1121.20	195		
Prunus virginiana	Intercept	14.82	1	2.1259	0.1469
	Soil preparation	2.98	3	0.1424	0.9344
	Amendment	3.39	3	0.1621	0.9217
	Soil preparation amendment	66.68	9	1.0631	0.3934
	Residuals	1052.43	151		
Populus balsamifera	Intercept	47.82	1	6.9178	0.009106 **
	Soil preparation	63.15	3	3.0453	0.029562 *
	Amendment	29.87	3	1.4403	0.231763
	Soil preparation amendment	156.56	9	2.5165	0.009095 **
	Residuals	1603.71	232		

[1]Homoscedasticity slightly not met (0.025), [2]Homoscedasticity slightly not met (0.04)

Table 2.20. Mean tree stem diameter change (mm) by soil treatment.

Soil Treatment	Calculation	*Populus balsamifera*	*Prunus virginiana*	*Populus tremuloides*	*Picea glauca*
Compost 100	Mean change	0.5	-0.3	0.4	0.6
Compost 100	Standard deviation	1.8	0.9	3.1	1.9
Compost 20	Mean change	-0.7	0.1	-0.4	0.3
Compost 20	Standard deviation	3.9	0.6	1.6	0.9
Compost 50	Mean change	0.6	0.6	-0.1	0.1
Compost 50	Standard deviation	3.8	1.7	0.7	1.1
Control	Mean change	0.9	0.0	0.4	0.2
Control	Standard deviation	3.0	1.2	1.2	0.7
Herbicide	Mean change	0.3	1.1	0.9	0.7
Herbicide	Standard deviation	2.6	3.1	1.6	0.6
Herbicide Compost 100	Mean change	3.6	-1.5	2.3	1.1
Herbicide Compost 100	Standard deviation	3.6	8.0	3.1	1.6
Herbicide Compost 20	Mean change	0.1	0.8	1.2	0.9
Herbicide Compost 20	Standard deviation	1.8	0.9	2.5	1.8
Herbicide Compost 50	Mean change	1.0	0.9	0.3	0.0
Herbicide Compost 50	Standard deviation	2.4	1.3	3.1	0.9
Herbicide Tillage	Mean change	-0.1	0.0	1.9	1.3
Herbicide Tillage	Standard deviation	2.3	1.1	2.3	1.0
Herbicide Tillage Compost 100	Mean change	1.1	1.1	3.2	0.9
Herbicide Tillage Compost 100	Standard deviation	2.3	1.6	3.4	1.8
Herbicide Tillage Compost 20	Mean change	0.1	0.4	0.8	1.1
Herbicide Tillage Compost 20	Standard deviation	1.4	0.9	2.2	1.6
Herbicide Tillage Compost 50	Mean change	0.3	0.2	1.4	0.5
Herbicide Tillage Compost 50	Standard deviation	1.4	1.3	4.1	0.7
Tillage	Mean change	0.4	0.2	1.5	0.7
Tillage	Standard deviation	3.9	0.9	2.0	0.7
Tillage Compost 100	Mean change	-1.4	1.1	0.5	0.8
Tillage Compost 100	Standard deviation	2.3	1.4	1.8	1.7
Tillage Compost 20	Mean change	0.4	0.1	0.7	0.7
Tillage Compost 20	Standard deviation	1.8	0.8	2.1	1.2
Tillage Compost 50	Mean change	-0.1	0.4	-0.3	0.2
Tillage Compost 50	Standard deviation	1.4	0.7	0.7	0.9

Table 2.21. Shrub species soil treatment effect on stem diameter change.

Shrub Species	Soil Treatment	Sum of Squares	Degrees of Freedom	F Value	P (>F)
Symphoricarpos albus[1]	Intercept	679.14	1	73.2647	1.263e-15 ***
	Soil preparation	163.03	3	5.8625	0.0007003 ***
	Amendment	57.72	3	2.0757	0.1040049
	Soil preparation amendment	122.71	9	1.4709	0.1592324
	Residuals	2271.06	245		
Rosa acicularis[2]	Intercept	246.52	1	42.0024	5.303e-10 ***
	Soil preparation	97.40	3	5.5321	0.001097 **
	Amendment	13.57	3	0.7706	0.511493
	Soil preparation amendment	43.45	9	0.8225	0.595963
	Residuals	1379.24	235		
Salix exigua	Intercept	51.83	5	5.6652	0.018139*
	Soil preparation	139.38	3	5.0780	0.002021 **
	Amendment	52.12	3	1.8988	0.130623
	Soil preparation amendment	97.13	9	1.1795	0.309108
	Residuals	2058.64	225		
Viburnum trilobum	Intercept	19.34	1	4.6495	0.03209 *
	Soil preparation	14.54	3	1.1650	0.32382
	Amendment	27.82	3	2.2294	0.08549
	Soil preparation amendment	35.58	9	0.9507	0.48194
	Residuals	969.03	233		

[1] Homoscedasticity not met (0.0018), [2] Homoscedasticity slightly not met (0.028)

Table 2.22. Shrub species mean stem diameter change by soil treatment.

Soil Treatment	Calculation	*Salix exigua*	*Viburnum trilobum*	*Symphoricarpos albus*	*Rosa acicularis*
Compost 100	Mean change	0.0	0.0	0.8	0.0
Compost 100	Standard deviation	1.2	1.5	2.6	0.8
Compost 20	Mean change	-0.6	0.3	1.9	0.6
Compost 20	Standard deviation	1.2	1.8	3.1	1.0
Compost 50	Mean change	-1.8	-0.2	1.4	-0.2
Compost 50	Standard deviation	6.3	2.0	2.0	0.9
Control	Mean change	0.4	-0.5	0.5	0.5
Control	Standard deviation	1.6	1.7	2.1	1.7
Herbicide	Mean change	0.6	1.2	1.2	1.3
Herbicide	Standard deviation	3.3	3.8	2.9	1.9
Herbicide Compost 100	Mean change	1.4	0.7	0.9	1.8
Herbicide Compost 100	Standard deviation	2.3	2.2	2.0	2.3
Herbicide Compost 20	Mean change	1.6	-0.1	2.5	2.2
Herbicide Compost 20	Standard deviation	2.6	1.3	4.0	3.1
Herbicide Compost 50	Mean change	1.5	0.2	2.8	2.2
Herbicide Compost 50	Standard deviation	2.8	1.9	3.0	3.7
Herbicide Tillage	Mean change	3.2	1.5	0.9	0.8
Herbicide Tillage	Standard deviation	6.2	1.6	1.5	1.2
Herbicide Tillage Compost 100	Mean change	0.7	0.5	4.3	2.6
Herbicide Tillage Compost 100	Standard deviation	3.2	1.6	4.7	4.9
Herbicide Tillage Compost 20	Mean change	0.9	0.3	2.7	0.8
Herbicide Tillage Compost 20	Standard deviation	1.8	1.7	2.9	2.6
Herbicide Tillage Compost 50	Mean change	-0.1	-0.2	3.2	0.9
Herbicide Tillage Compost 50	Standard deviation	3.0	2.0	5.2	1.7
Tillage	Mean change	0.2	0.3	1.0	0.2
Tillage	Standard deviation	1.5	2.1	2.5	0.7
Tillage Compost 100	Mean change	0.2	1.0	0.3	0.8
Tillage Compost 100	Standard deviation	2.0	2.3	2.7	3.4
Tillage Compost 20	Mean change	-0.3	0.2	-0.2	0.9
Tillage Compost 20	Standard deviation	1.3	2.3	2.2	2.2
Tillage Compost 50	Mean change	-0.3	-0.6	1.5	0.7
Tillage Compost 50	Standard deviation	1.7	1.4	2.6	1.8

Table 2.23. Mean stem diameter change (mm) by soil preparation treatment.

Soil Preparation	Calculation	*Populus balsamifera*	*Prunus virginiana*	*Populus tremuloides*	*Picea glauca*
Herbicide	Mean change	1.2 a	0.3	1.1 ab	0.7 ab
Herbicide	Standard deviation	2.9	4.4	2.7	1.4
Herbicide Tillage	Mean change	0.4 ab	0.4	1.7 a	1.0 a
Herbicide Tillage	Standard deviation	1.9	1.3	3.1	1.4
Tillage	Mean change	-0.1 b	0.4	0.6 b	0.6 ab
Tillage	Standard deviation	2.6	1.0	1.9	1.2
Untreated	Mean change	0.3 ab	0.0	0.1 b	0.3 b
Untreated	Standard deviation	3.2	1.2	1.8	1.2
		Salix exigua	*Viburnum trilobum*	*Symphoricarpos albus*	*Rosa acicularis*
Herbicide	Mean change	1.3 a	0.5	1.9 ab	1.9 a
Herbicide	Standard deviation	2.7	2.5	3.1	2.8
Herbicide Tillage	Mean change	1.2 a	0.5	2.8 a	1.3 ab
Herbicide Tillage	Standard deviation	4.1	1.8	4.0	3.0
Tillage	Mean change	0.0 ab	0.2	0.7 b	0.6 b
Tillage	Standard deviation	1.6	2.1	2.5	2.2
Untreated	Mean change	-0.5 b	-0.1	1.2 b	0.2 b
Untreated	Standard deviation	3.3	1.7	2.5	1.2

Means within columns for a species followed by the same letters are not significantly different

Table 2.24. Mean stem diameter change (mm) by soil amendment.

Amendment	Calculation	*Populus balsamifera*	*Prunus virginiana*	*Populus tremuloides*	*Picea glauca*
Compost 100	Mean change	0.9	0.0	1.5 a	0.9 a
Compost 100	Standard deviation	3.1	4.6	3.0	1.7
Compost 20	Mean change	0.0	0.4	0.6 ab	0.8 ab
Compost 20	Standard deviation	2.4	0.9	2.2	1.4
Compost 50	Mean change	0.5	0.5	0.4 b	0.2 b
Compost 50	Standard deviation	2.5	1.3	2.7	0.9
Unamended	Mean change	0.4	0.3	1.2 ab	0.7 ab
Unamended	Standard deviation	3.0	2.0	1.9	0.9
		Salix exigua	*Viburnum trilobum*	*Symphoricarpos occidentalis*	*Rosa acicularis*
Compost 100	Mean change	0.6	0.5	1.6	1.3
Compost 100	Standard deviation	2.3	1.9	3.5	3.3
Compost 20	Mean change	0.4	0.1	1.7	1.1
Compost 20	Standard deviation	1.9	1.7	3.2	2.4
Compost 50	Mean change	-0.2	-0.2	2.2	0.9
Compost 50	Standard deviation	3.9	1.8	3.5	2.4
Unamended	Mean change	1.1	0.7	0.9	0.7
Unamended	Standard deviation	3.8	2.5	2.3	1.5

Means within columns for a species followed by the same letters are not significantly different

Table 2.25. Mean available nutrients (mg/kg) of soils by site in 2014 and 2015.

Site	Year	Ammonium	Nitrate	Phosphorus	Potassium	Sulfur	Copper	Zinc
91 Sreet	2014	10.4	15.3	101.3	1,142.3	16.0	23.0	92.7
	2015	2.4	14.7	67.3	959.0	19.1	1.1	9.4
Blackmud	2014	14.8	17.7	9.6	518.0	8.5	20.0	85.7
	2015	2.5	28.3	10.8	317.7	11.8	0.7	4.2
Lendrum	2014	7.6	19.3	123.8	666.7	25.5	24.5	95.0
	2015	18.0	12.7	73.4	624.7	23.6	1.5	6.1
Smith	2014	5.7	15.3	29.5	542.3	8.8	21.2	73.7
Crossing	2015	2.1	33.3	21.0	403.0	12.1	1.1	2.1
Terwillegar	2014	19.0	19.3	44.1	897.3	16.2	20.4	101.3
	2015	5.8	8.7	29.0	693.3	15.6	1.1	5.6
Wagner	2014	7.0	17.7	8.1	565.3	8.9	21.1	98.7
	2015	10.1	18.7	16.8	400.7	16.7	1.1	9.5

Table 2.26. Mean soil properties by site in 2014 and 2015.

Site	Year	Cation Exchange Capacity meq/100g	Electrical Conductivity dS/m	PH	Sodium Adsorption Ratio %	Total Carbon %	Total Nitrogen %	Total Organic Carbon %
91 Street	2014	41.4	0.7	6.4	0.5	6.8	0.6	6.8
	2015	43.3	0.8	6.8	0.6	5.5	0.6	5.5
Blackmud	2014	40.7	0.4	6.4	0.6	7.0	0.6	7.0
	2015	42.0	0.6	6.5	1.3	4.7	0.5	4.6
Lendrum	2014	44.1	0.8	6.8	0.9	6.9	0.6	6.8
	2015	44.1	0.8	7.2	0.5	4.4	0.4	4.2
Smith	2014	30.5	0.7	7.3	0.3	3.3	0.3	3.2
Crossing	2015	33.7	0.6	7.4	0.4	2.5	0.3	2.4
Terwillegar	2014	38.2	0.9	6.1	0.4	5.2	0.4	5.2
	2015	40.3	0.7	6.5	0.3	3.5	0.4	3.4
Wagner	2014	39.4	0.4	6.4	0.2	6.7	0.5	6.7
	2015	40.0	0.6	6.5	0.2	5.2	0.5	5.1

Table 2.27. Mean soil cation content (mg/L) by site in 2014 and 2015.

Site	Year	Calcium	Chloride	Potassium	Magnesium	Sodium	Sulphate
91 Street	2014	60.2	20.3	81.6	21.8	17.9	52.1
	2015	85.0	17.3	53.9	29.2	25.7	61.7
Blackmud	2014	35.6	8.7	23.1	8.6	15.9	34.9
	2015	66.8	11.0	14.3	14.4	46.1	51.3
Lendrum	2014	71.8	8.7	36.3	26.1	35.5	97.2
	2015	99.0	24.0	34.2	28.3	21.6	94.3
Smith Crossing	2014	86.8	16.7	36.7	19.2	12.6	32.4
	2015	81.1	22.0	23.5	17.6	13.7	43.7
Terwillegar	2014	90.8	17.0	72.0	17.7	14.1	62.9
	2015	89.4	19.0	34.7	16.0	12.2	51.3
Wagner	2014	38.8	3.3	32.4	11.8	5.8	29.7
	2015	81.1	24.0	23.1	23.0	7.6	60.7

Table 2.28. Mean available nutrient content (mg/kg) of amendments.

Amendment	Year	Ammonium	Nitrate	Phosphorus	Potassium	Sulfur	Copper	Zinc
Compost 100	2014	75.7	612.8	2,801.7	1,280.0	1,253.7	316.5	562.2
	2015	17.3	134.1	1,615.0	1,080.8	524.1	38.4	111.8
Compost 20	2014	10.1	87.0	405.3	192.0	123.0	31.8	83.7
	2015	2.1	128.0	213.0	187.3	69.4	2.4	10.1
Compost 50	2014	11.7	175.6	526.2	324.7	318.7	61.3	132.0
	2015	3.0	35.6	554.0	385.5	131.8	7.2	25.7

Table 2.29. Mean amendment properties in 2014 and 2015.

Amendment	Year	Cation Exchange Capacity meq/100g	Electrical Conductivity dS m^{-1}	PH	Sodium Adsorption Ratio	Total Carbon %	Total Nitrogen %	Total Organic Carbon %
Compost 100	2014	60.8	5.6	5.5	0.5	19.4	1.5	19.3
	2015	61.4	2.5	5.8	0.3	17.6	1.4	17.4
Compost 20	2014	27.4	2.6	6.3	0.4	4.1	0.3	4.1
	2015	31.2	1.7	6.6	0.4	3.6	0.4	3.5
Compost 50	2014	33.2	4.3	6.3	0.5	5.3	0.4	5.3
	2015	37.1	2.3	6.1	0.4	6.0	0.5	6.0

Table 2.30. Mean cation concentration (mg/L) by amendment in 2014 and 2015.

Amendment	Year	Calcium	Chloride	Potassium	Magnesium	Sodium	Sulphate
Compost 100	2014	765.5	18.2	111.9	350.8	67.7	1,765.0
	2015	364.8	18.7	80.4	144.8	28.2	1,071.3
Compost 20	2014	405.3	12.8	17.1	87.6	34.0	674.3
	2015	269.7	15.3	16.1	59.9	28.5	471.0
Compost 100	2014	679.5	15.5	34.9	175.4	52.4	1,283.3
	2015	360.0	23.7	41.1	103.2	30.05	938.8

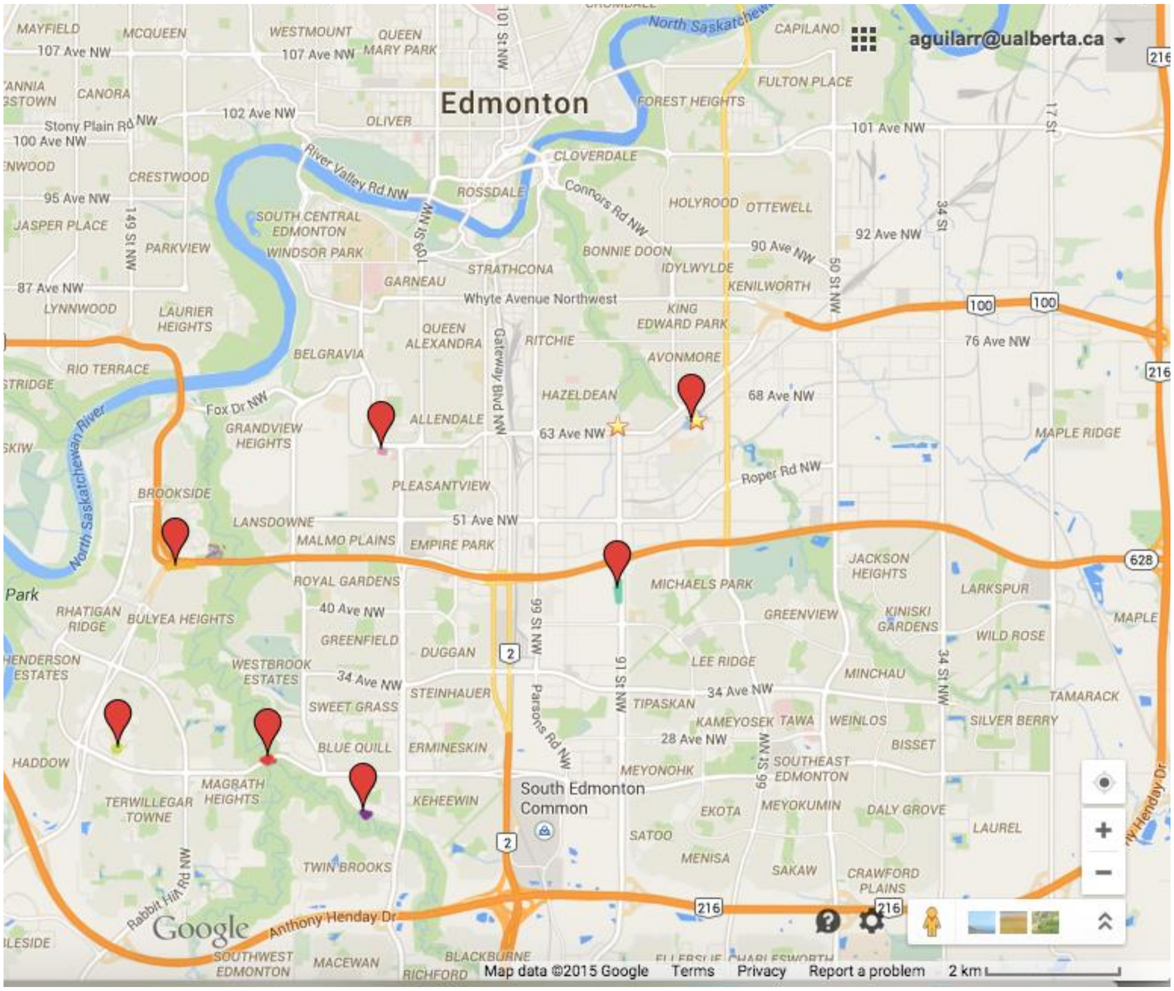

Figure 2.1. Site location map in the city of Edmonton.

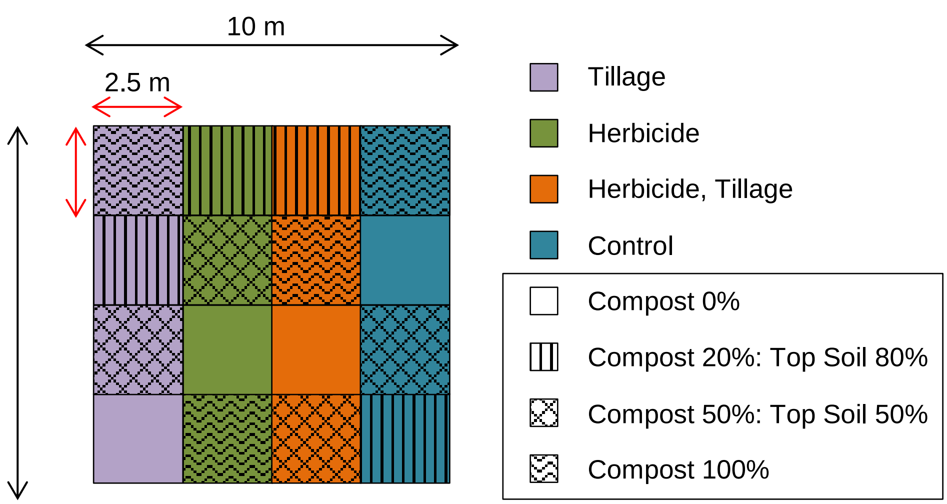

Figure 2.2. Replicate plot soil preparation treatments (coloured boxes) randomly applied in columns. Amendment treatments (patterns) randomly distributed within columns.

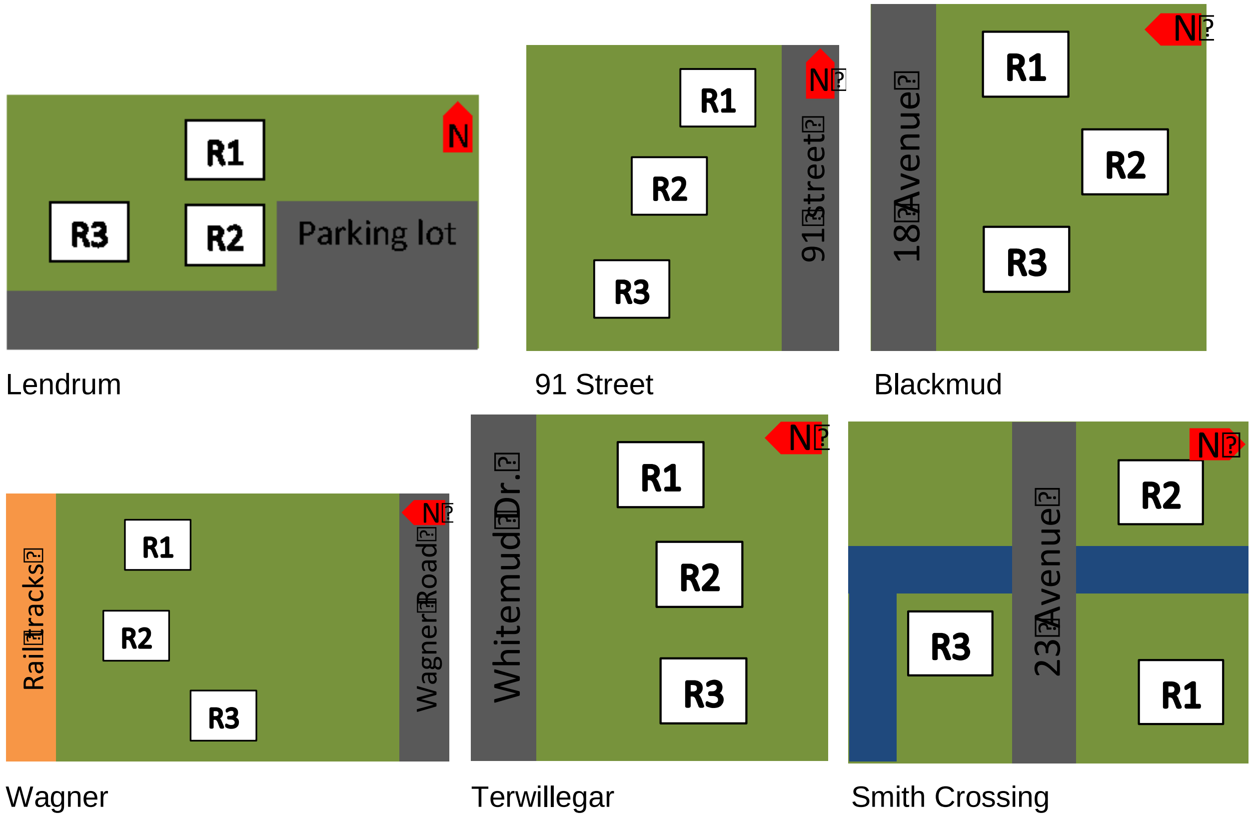

Figure 2.3. Locations and plot arrangements for individual research sites.

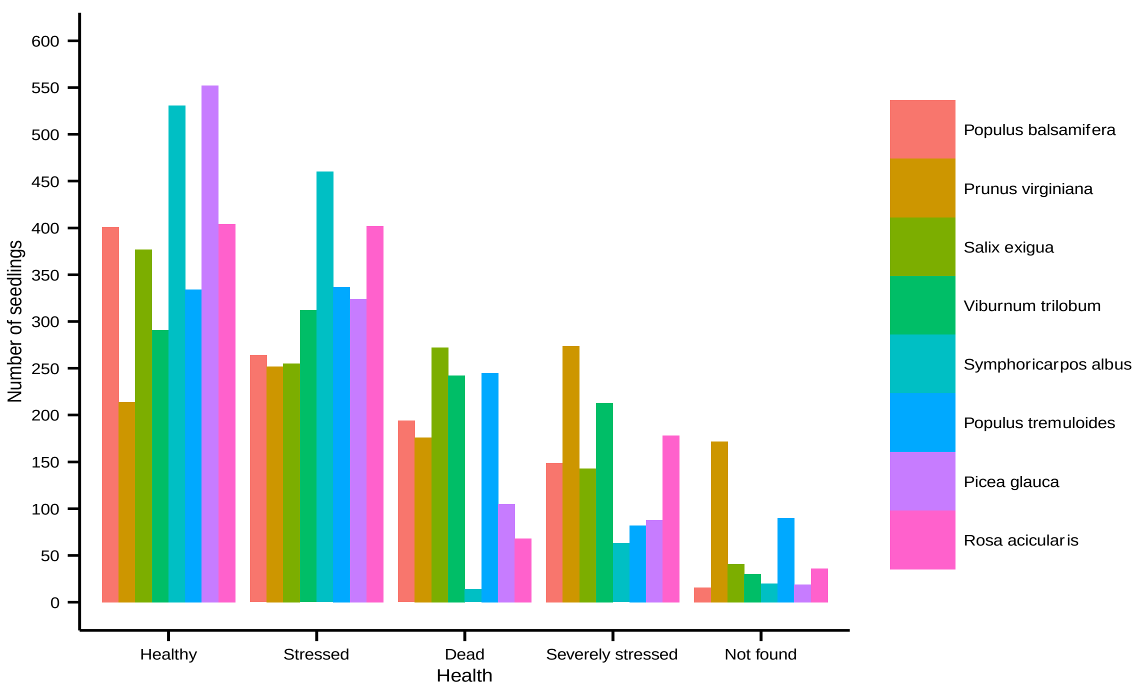

Figure 2.4. Total number of plants by species in health categories.

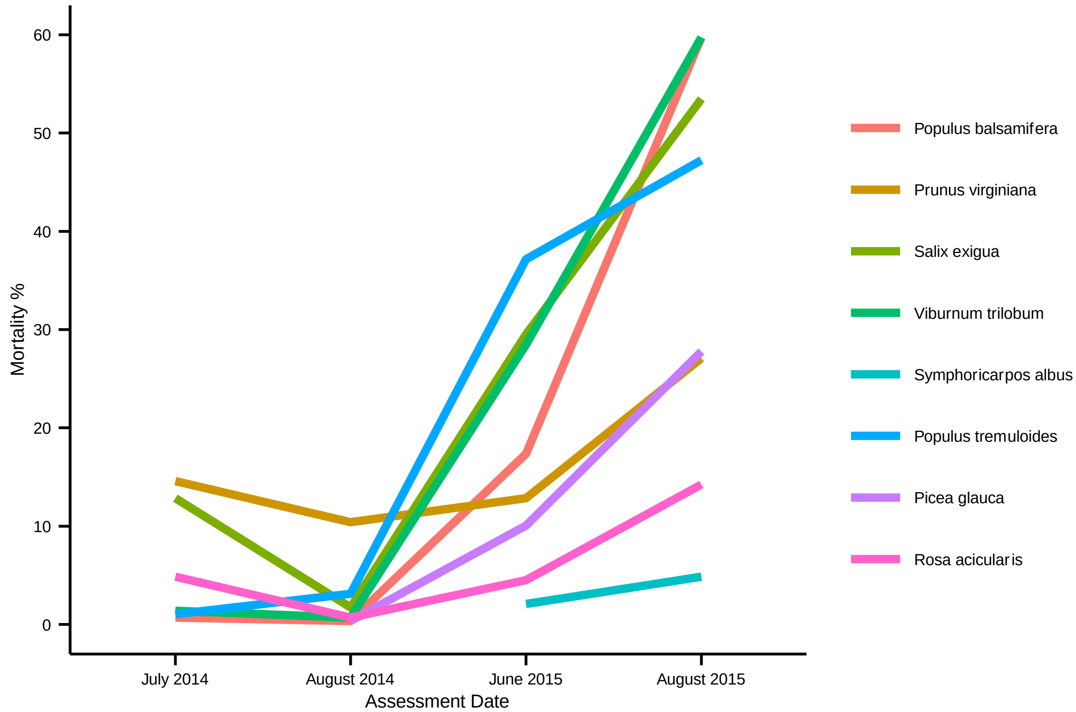

Figure 2.5. Percent mortality of species at four monitoring dates in 2014 and 2015.

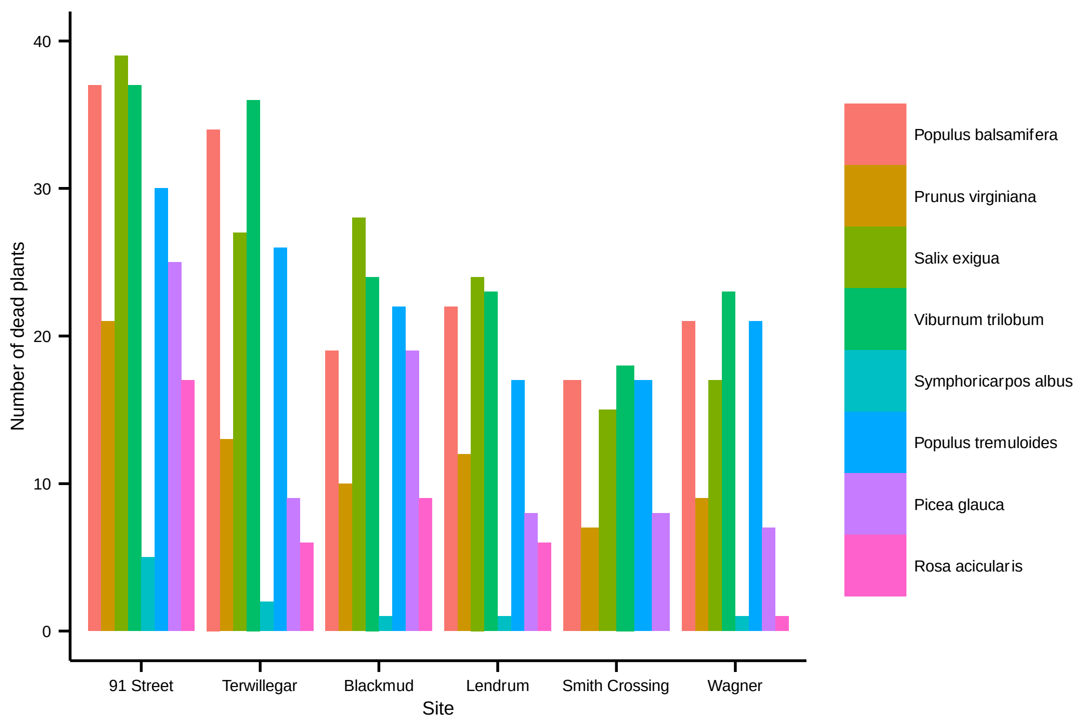

Figure 2.6. Number of dead seedlings by species at each research site in August 2015.

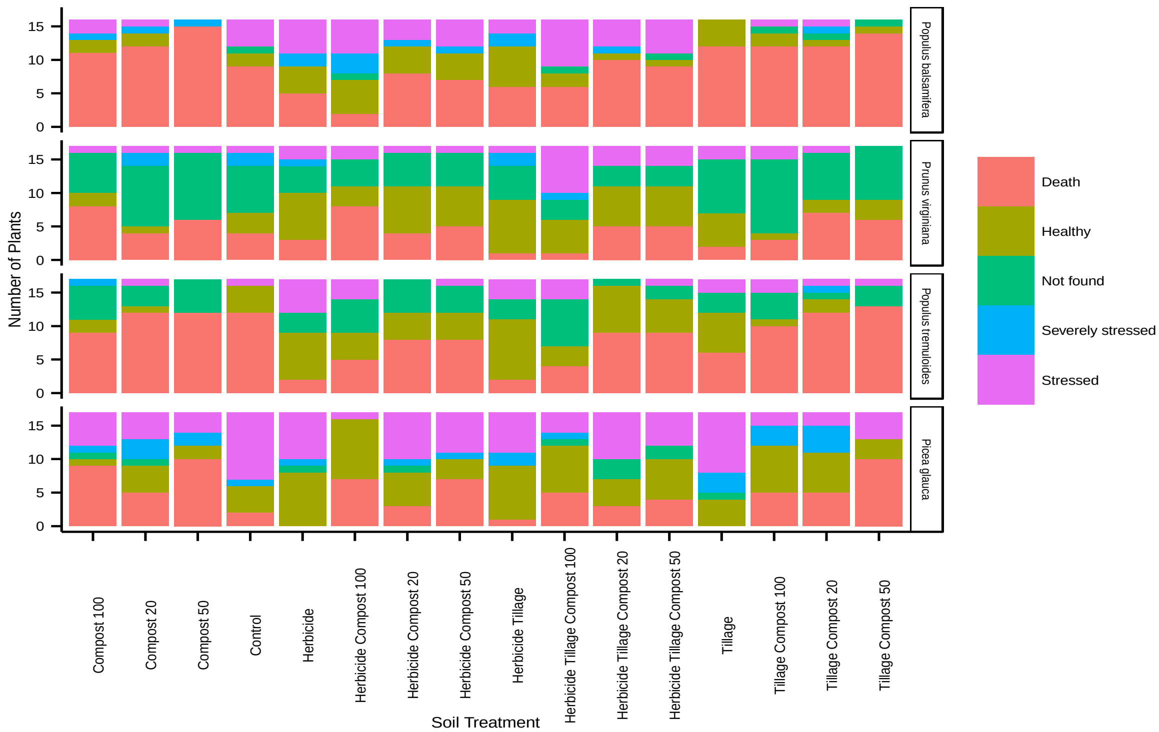

Figure 2.7. Number of plants of each tree species in health categories and soil treatments.

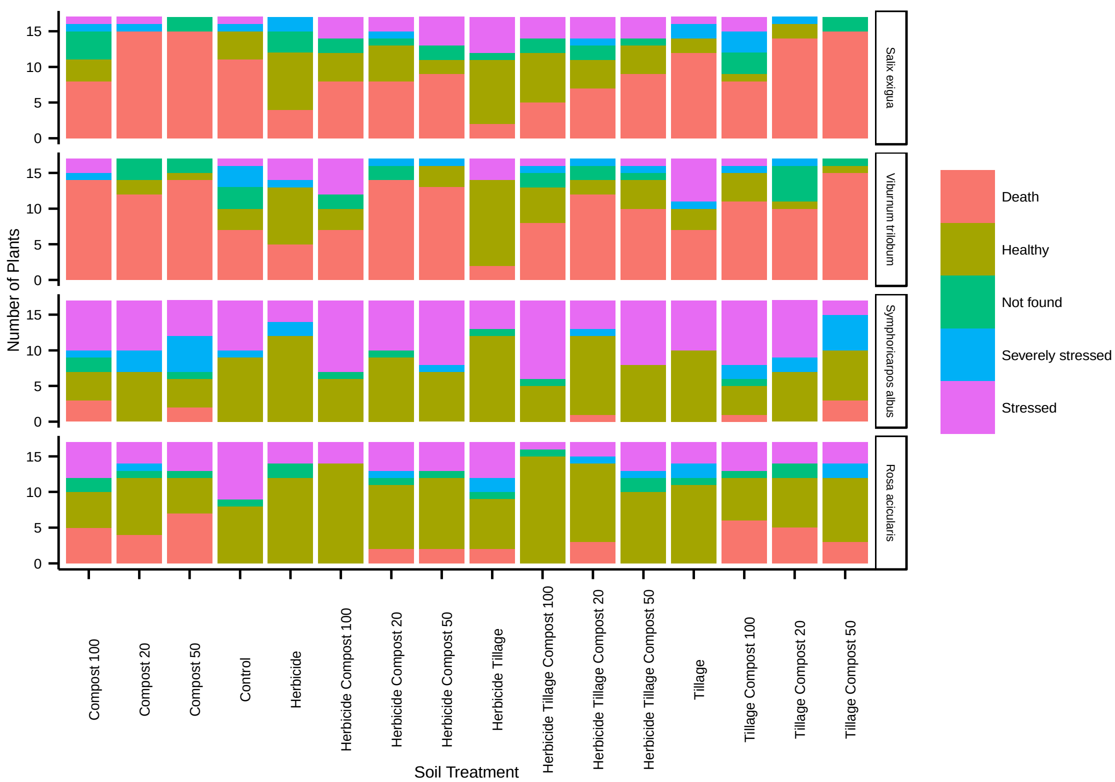

Figure 2.8. Number of plants of each shrub species in the health categories and soil treatments.

III. URBAN NATURALIZATION WITH NATIVE FORB SPECIES AND SITE PREPARATION TREATMENTS

1. INTRODUCTION

Urban naturalization is an alternative landscape management technique where natural plant colonization and growth are generally unrestricted, allowing the landscape to return to a natural state. Environmental benefits include increased biodiversity and wildlife use, soil stabilization, improved ground water recharge, provision of windbreaks for snow capture and dust reduction, reduction of atmospheric greenhouse gases and cleaner air (Savard et al. 2000, Chiesura 2004, Millard 2004). Economic benefits include a significant reduction in maintenance costs such as mowing, irrigation and herbicide use. Quality of life benefits include landscape beautification, increased green and shady areas for recreation, increased community awareness of environmental issues and noise reduction by mature plantings (Chiesura 2004).

Urban naturalization historically focused on planting trees to restore urban forests. However, naturalization can occur in urban grasslands and wetlands. It requires careful selection of plant species for development of an appropriate plant community (Saebo et al. 2003, Pavao-Zuckerman 2008). Usually native plant species are used, although in many urban centres, local cultivars and non native species have been included. In most naturalization processes trees are planted and other species are allowed to establish naturally.

Naturalization can address inherent soil limitations (Pollak 2006, Pavao-Zuckerman 2008, Schafer and Alien 2009). Naturalization can reduce soil compaction, through root expansion, increased biological activity and frost heave (Alukukku 1996, Niwa et al. 2001), subsequently increasing infiltration rates (Beven et al. 1982, Savard et al. 2000). Naturalized sites retain leaf litter and woody debris, which decompose, adding organic material, which can increase plant available soil water (Craul 1985, Gomez et al. 2002). Alternatively, these soil limitations can be reduced as part of the naturalization process through use of soil amendments.

Management must augment natural successional processes of plant community development. Naturalization can result in unrestricted growth of herbaceous understory plants and increased root density in upper soil horizons (Millwood et al. 2011). Open spaces in an urban environment present an opportunity for plants to grow and disperse. Naturalization is founded on the principle that native species adapted to local conditions will compete and establish with little human intervention. However, some of these species may be aggressive weeds or undesired competitive grasses. Thus pre-planting use of herbicides reduces competitive species, making resources accessible for new desired plantings. Little scientific research has been conducted on methods for naturalization of urban parklands, particularly using forb species. Many of these sites require reclamation to address soil issues and all require revegetation to facilitate development into a naturalized ecological community. Results of naturalization efforts to date have been inconsistent.

Use of native forb species, commonly called wild flowers, is a landscape architecture approach gaining momentum among urban planners and landscapers. Forbs can provide beautification during naturalization. There are considerable possibilities for native forb use in naturalization although their huge variety presents complexity for use. At present species selection is based on visual appearance and availability of plant material but naturalization requires plants that are competitive and hardy to be resilient in a highly competitive urban naturalized area. Native forb response to urban conditions thus needs to be better understood.

2. RESEARCH OBJECTIVES

The research objectives for this naturalization research project were as follows.

- To evaluate selected native forb species performance in a naturalized area based on survival, health and growth.
- To evaluate soil treatment influence on native forb species survival, health and growth.

3. MATERIALS AND METHODS

3.1. Research Site

The study area is in south side of the City of Edmonton in Alberta, Canada, at 53°34'19.000" N latitude and 113°31'10.000" W longitude (Environment Canada 2015). Elevation is 671.4 m above sea level. Mean temperature is 4.2 °C; mean growing season temperature from May to October is 13.0 °C and mean winter temperature from November to April is -4.6 °C. Mean total rainfall is 348 mm with 284.4 mm from June to October; mean snowfall is 122 to 124 cm.

The research site was located near the Terwillegar Recreation Centre, 2051 Leger Road at the roundabout entrance of a community sports facility and the Lillian Osborne High School. The area is flat with a gentle slope to the south west. Immediately surrounding the roundabout is asphalt, then buildings, small canopy trees and open lawn areas. Traffic conditions are very high for vehicles near the roundabout; pedestrian traffic is concentrated on walking paths, although occasionally pedestrians cross on the green area. Site landscaping aimed to incorporate native species and was initially seeded with native grasses (Tables 3.1, 3.2). Only short species can be used for planting and/or seeding. Grass was mowed until summer 2014; in 2012 Milestone™ herbicide was applied to control *Cirsium arvense* L. (Canada thistle). Presence of wild fauna such as rabbits has been an issue for plant establishment.

3.2. Experimental Design

The experiment followed a complete randomized design with replication. Experimental plots (replications) were 10 m x 10 m, each divided into 16 small 2.5 m x 2.5 m subplots, covering an area of 6.25 m^2 (Figure 3.1). Soil preparation treatments were randomly assigned vertically to plots in strips, with amendment treatments applied randomly within each strip. Site preparation consisted of soil tilling, foliar herbicide application, a combination of tilling and herbicide and no site preparation (Table 3.3). Soil amendments were compost 100, compost 50, compost 20 and no amendment. Thus there were 4 soil preparation treatments x 4 amendment treatments x 4 replicates for a total of 64 plots per site.

3.3. Experimental Treatments

3.3.1. Herbicide

Roundup Transorb™ was used as a 1 % solution (540 g/L glyphosate), applied at a rate of 7.57 litters per hectare by City of Edmonton personnel with backpack sprayers on June 12 2014, two weeks before soil preparation. Herbicide treatments were oriented in sections inside replicates for operational efficiency. Roundup is a broad spectrum systemic herbicide, controlling broad leaf and grass species, with low environmental persistence of 1 to 10 days. It controlled most weeds, although some species showed considerable resistance. For example, dandelion was stressed but did not completely die like the rest of the sprayed vegetation.

3.3.2. Soil tillage

Rototilling was performed June 24 and 25 2014 to a depth of 10 to 15 cm with a rear tined, 9 HP hydraulic drive, Power Dog 209 rototiller. The gear was placed in forward and rotary blades in the opposite direction, for maximum soil penetration. Tillage was in one direction, then crossed perpendicularly. Tillage was oriented in sections inside replicates for operational efficiency.

3.3.3. Amendments

Amendments were topsoil and compost, mixed in proportions based on availability and cost effectiveness and standard naturalization materials for operational work. Compost was from the City of Edmonton Waste Management Centre. Topsoil is from undergoing construction developments, in most cases from previous agricultural land. Amendments were applied June 24 to 29 2014 using a mini steer loader and/or wheel barrow. Amendments were added to the surface of subplots and spread by hand with shovels in a 15 cm deep layer.

Compost mix (compost 100) was 80 % compost and 20 % wood chips by volume. It is a standard mix used by the City of Edmonton and was delivered ready to apply at each site. Topsoil mix (compost 20) was 80 % topsoil and 20 % compost. It was delivered ready to use at each site. Topsoil mix (compost 50) was 50 % compost and 50 % topsoil. It was prepared on subplots. To achieve a homogeneous mixture, compost was distributed on the treatment area, capped with the topsoil, then homogenized with a mini cultivator Honda model FG110K1CT.

3.4. Planting

Native forbs of 24 species were planted July 8 and 9 2014 (Table 3.4). Each day, planting stock was collected from the City of Edmonton nursery. After loading, a tarp was fixed over the plants to protect them during transportation. Planting holes were dug with a sharp shovel. Planting occurred away from treatment subplot edges to minimize edge effects. Each treatment subplot got one plant per species (total 24 plants) with minimum 15 cm spacing between plants. Thus there were 384 plants in each plot (replicate) and 1536 plants overall at the research site.

3.5. Plot Management

Plants were watered with an irrigation truck, 24 to 48 hours post planting; then every 2 to 3 days for two weeks, twice per week for the next four weeks, then once per week until the end of the growing season. In 2015, plant watering was based on availability of water trucks as per standard City of Edmonton procedures for second year naturalization plantings; this approximated once per month from May to September.

The site was managed for weed species as needed to meet City of Edmonton standards. All noxious weeds were hand pulled inside research plots; non-noxious weeds located within 10 cm of planted seedlings were hand pulled. Manual weeding was conducted within 2 m from the edge of research plots as a weed control buffer zone. Outside the buffer zone, the herbicide 2,4 dichlorophenoxyacetic acid (2-4-D) was used according to manufacturer directions. City of Edmonton personnel conducted the applications in July 2015.

3.6. Vegetation Assessments

Plant survival assessments were conducted in August 2014, October 2014, June 2015 and August 2015. Live and dead planted seedlings were counted and general health noted.

In June and August 2015 spread was measured for each seedling. Diameter of plants from tip to tip was measured with a metric tape. For species with cluster growth habit, the tape was placed on the farthest tip of one individual then pulled to the tip of the farthest individual of the cluster. Seedlings were considered clusters when several of the same species were less than 5 cm apart with no vegetation between them.

A four category scale was used to describe plant phenological stages of each planted seedling in June and August 2015 as follows.

- Flowering: Flowers visible and functional, no signs of flower decay, insect pollination evident.
- Seeding: Seeds visible and/or easy to find, reproductive structures dry and spewing seeds.
- Started seeding: Flowers present or absent, reproductive structures active and turgid, may show signs of partial release of seeds with another load of seeds still maturing.
- Vegetative growth: No reproductive structures visible, including for asexual reproduction.

Vegetation cover was assessed in August 2014 and 2015 in three randomly located 0.1 m^2 quadrats inside each treatment (2.5 x 2.5 m plot). Each 0.1 m^2 quadrat was ocularly assessed for % live vegetation, bare ground, litter and other (rocks, trash, feces) cover. Live vegetation was assessed on an individual species basis for both planted and naturally occurring species.

3.7. Soil Assessments

Soil was sampled July 29 2014 and July 31 2015. Herbicide treatments were sampled to approximate original conditions without tillage; one sample per replicate was taken to 15 cm depth with a soil auger. For amendment treatments, a hand shovel of the upper 15 cm was collected from each replicate and composited. Samples were stored in plastic ziploc bags, and frozen until sent to a commercial laboratory for analyses.

Inorganic and organic carbon were determined by carbon dioxide loss (Loeppert and Suarez 1996) and total carbon by combustion (Nelson and Sommers 1996). Cation exchange capacity was determined by ammonium acetate extraction (Chapman 1965). Chloride in saturated paste was determined colorimetrically by auto-analyzer (Hendershot 2008). Mercury was determined spectrochemically (EPA 200.2/245.1). Metals were determined by acid digestion and inductively coupled plasma mass spectrometry (EPA 200.2). Total nitrogen was determined by combustion (Bremner 1996), available ammonium nitrogen by potassium chloride extraction and available nitrate nitrogen colorimetrically in calcium chloride solution (Maynard et al. 2008). Plant available phosphorus and potassium were determined by modified Kelowna process (Ashworth and Mrazek 1995). Particle size (sand, silt, clay) was determined by pipette with removal of organic matter and carbonate (Burt 2014). Sodium adsorption ratio was calculated and calcium, magnesium, sodium, potassium and sulfate were determined in saturated paste by inductively coupled plasma (Miller et al. 2007, EPA6010B). Electrical conductivity and pH were determined in saturated paste by meters (Miller et al. 2007).

3.8. Statistical Analyses

Statistical analyses were conducted using R version 3.1.2 (R Core Team 2014). In most cases data from the last monitoring date in 2015 were statistically analyzed to evaluate overall performance of species at the end of the experiment.

Chi-square analysis was used to identify effects of soil treatment on seedling survival. Due to small numbers per species, statistical analysis was conducted species grouped by family. Chi-square criteria were applied to groups, and analyses conducted only if assumptions were met (< 20 % of expected frequencies < 5).

Soil preparation and amendment factors were analyzed per species. Interaction was tested but due to the small data set and mortality, significance was not found for any species. Normality was tested with Shapiro's test and homoscedasticity with Levene's test. Soil preparation and amendment effects were analyzed per species with one way analysis of variance. Significant effects were further assessed with HSD Tukeys tests.

4. RESULTS

4.1. Forb Species and Family Survival

Forb species with highest survival were *Penstemon procerus* Dougl. Ex Graham (slender penstemon), *Fragaria virginiana* Dcne. (wild strawberry), *Heuchera cylindrica* Douglas ex Hook.

(round leaved alum root), *Agastache foeniculum* (Pursh) ktze. (giant hyssop), *Antennaria microphyla* Rydb. (little leaf pussy toes) and *Geum aleppicum* Jacq. (three flowered avens) (Figure 3.2). These had less than 10 dead plants throughout the experiment.

Mortality was high for some forb species, with over half the plants dead by end of the experiment (Figure 3.2). These species were *Cornus canadensis* L. (bunchberry), *Pulsatilla patens* L. (prairie crocus), *Liatris ligulistylis* A. Nels. K. Schum. (dotted blazing star), *Allium textile* A. Nels. & J. F. Macbr. (prairie onion), *Eriogonum flavum* Nutt. (yellow buckwheat), *Viola adunca* Sm. (early blue violet), *Potentilla arguta* Pursh (prairie cinquefoil), *Heterotheca villosa* Pursh Shinners (hairy false golden aster), *Anemone cylindrica* Gray long fruited anemone), *Rudbeckia hirta* L. (black eyed susan), *Thalictrum venulosum* Trel. (veiny meadow) and *Anemone canadensis* L. (Canada anemone).

Mortality was generally low at the first monitoring in August 2014 then increased with time (Table 3.5). *Penstemon procerus*, *Galium boreale* L. (northern bedstraw) and *Thalictrum venulosum* showed high mortality as early as October 2014. Small stature plants had higher mortality; *Cornus canadensis* was the only species to not survive by the end of 2015.

Species in this experiment belong to 12 plant families. Significant effects of soil treatments on survival were only found for *Asteraceae* and *Ranunculaceae* families (Table 3.6). Mortality for *Asteraceae* was significantly highest in the control. Mortality for *Ranunculaceae* was significantly highest with herbicide. Amendments had significant effects for *Asteraceae*, *Ranunculaceae* and *Roseaceae* families (Table 3.7). Mortality was significantly highest in unamended soils for all three families. *Ranunculaceae* mortality was significantly lowest in compost 20. Soil preparation treatments did not significantly affect family survival.

4.2. Forb Species Spread

The only species responding significantly to soil preparation treatments was *Thalictrum venulosum* (Tables 3.8, 3.9). Spread for *Thalictrum venulosum* was significantly higher with herbicide than herbicide tillage and tillage, but statistically similar to untreated.

Soil amendment had a significant effect on spread for 9 of the 24 evaluated forb species (Tables 3.8, 3.10). *Fragaria virginiana*, *Penstemon procerus*, *Delphinium elatum* L. (tall larkspur), *Symphyotrichum falcatum* Lindl. G.L. Nesom (white prairie aster) and *Heuchera cylindrica* spreads were significantly lowest in unamended treatments. *Antennaria microphylla*, *Rudbeckia hirta*, *Geum aleppicum* and *Mentha arvensis* L. (wild mint) spread had more complex responses to amendments, with significantly higher spreads in compost 100 than unamended treatments and more variable significant responses with the other compost treatments.

4.3. Phenology Of Plant Species

Phenological stage of development for each forb species varied with assessment date (Figure 3.3). Most species were flowering by June 2015 and seeding by August 2015. Started seeding was the least common category among seedlings, as it corresponds to the transitional stage between flowering and seed maturity. Only *Penstemon procerus* was in this stage by June 2015. At both assessment dates, vegetative growth was always present. Neither soil preparation (Figures 3.4, 3.5) nor amendment mix (Figures 3.6, 3.7) treatments significantly affected phenological development of any species.

4.4. Plant Community Development

To assess plant community development, species were categorized as native (9 species), non native (13 species), noxious (3 species) and prohibited noxious (23 species) (Table 3.11). Cover by plant categories followed similar trends for most soil preparation and amendment treatments. Exceptions were the untreated, herbicide tillage and tillage treatments which had greater cover of native species and the herbicide tillage treatment which had greater bare ground than other treatments (Figure 3.8).

Plant community composition responded most significantly to amendment treatments relative to the unamended (Figure 3.9). Planted forb species cover was significantly higher in compost treatments than in the untreated.

4.5. Soils Response To Treatment

Many soil properties did not differ between 2014 and 2015 (Table 3.12), including cation exchange capacity, electrical conductivity, pH, total nitrogen, nitrate, chloride and magnesium. Slight increases from 2014 to 2015 were noted for sodium adsorption ratio, sulfur, calcium, potassium, sodium and sulphate. Decreases from 2014 to 2015 were seen for total carbon, total organic carbon, ammonium, phosphorus, copper and zinc.

Even with amendments, soil properties did not generally change dramatically (Tables 3.13, 3.14, 3.15). Order of magnitude decreases from 2014 to 2015 were only noted consistently for nitrate. Other small changes were unremarkable, with most nutrients decreasing with time.

5. DISCUSSION

Native forbs planted in naturalized areas and exposed to urban disturbance and naturalization treatments behaved quite differently on a species level. General conclusions to be drawn focus on recommending some species for use and not others and use of some specific soil treatments and management. So few native forbs have been used in naturalization that there is no literature to compare it to, except for a study conducted by Bretzel et al. (2009) where they evaluated the performance of twenty-six species of wild flowers planted in poor condition soils in an urban setting of Tuscany in Italy. No water, fertilizer or pesticides were applied. Species developed and flowered in the first and second year of the experiment, co-existing and creating an ornamental meadow rich in species.

Field observations suggest that the combination of plant structure and seedling size at the time of transplanting contributed to species survival in both the first and second years of naturalization. Tufted structure plants that grew quickly and/or were planted as larger size seedlings were more successful. Seedlings of species that were very small or tended to grow in clusters of low size and single stem plants were more difficult to establish. Thus hardy and larger stock than used in our study would be beneficial to elevated success levels.

Amendment with compost was clearly a useful treatment for forb survival and spread. Other researchers also found a relationship to naturalization and forb survival including Marrs and Gough (1989) who found floristic composition of wild flower meadows was controlled by soil fertility. A site established wild flower diversity index was related to cation exchange capacity and carbon nitrogen ratio (Bretzel et al. 2009). Native forbs used in this experiment were small, with a shallow root system, and when planted into the upper 15 cm of soil that had been structurally altered and amended with compost, had a new growing medium. Even the small changes in nutrients in amended substrates may have impacted tiny seedlings at a vulnerable time when they needed nutrition. Plant phenology was likely more influenced by other environmental conditions like daylight length, accumulation of degree days or time than by naturalization treatments. Soil preparation and amendment application combinations are expected to influence soil water dynamics, indirectly determining stress and winterizing conditions. Site preparation techniques can alter soil water availability in the soil profile, and with strategic plant treatments, can increase revegetation success (Ruthrof et al. 2013).

Amendments resulted on a higher proportion of desired planted species cover; in contrast it exposed the site to invasion by noxious and prohibited noxious weed species. The loss of ecological memory in urban settings is thought to facilitate establishment of foreign invasive or weed species. Without management intervention such as native seeding, common seed bank species, especially exotic and noxious plants, may exclude or inhibit desirable later successional species until resources are made available by their damage or death (Connell and Slatyer 1977, Pickett et al. 1987). Skrindo and Pedersen (2004), using topsoil as an amendment to restore a roadside in Norway found that vegetation cover increased significantly from year one for other species such as *Cirsium arvense*. Weed management undertaken during this experiment played a key role in assemblage of the plant communities. Targeted hand weeding clearly benefitted planted seedlings, especially in amended plots where seedlings clearly grew larger. Weed management needs to be viewed as a tool to build plant communities rather than simply for containment and eradication of undesired species. Plant community weed management opens the possibility of using competitive native species to shift the plant community to a more desirable state, and reduce weed management in the long term.

Weed control can be complex for native forbs as they tend to be more sensitive to chemical control than other species. There are few selective herbicides targeted to weeds that will not also kill the native forbs. Manually weeding the sites is an efficient practice but it is time consuming and requires specific plant identification skills to separate the undesired forbs from the desired ones. This type of manual weeding would need to be implemented early in the naturalization program and continue at least beyond two years.

Due to the elevated level of exposure of the research site, it appeared that using native forbs was a great way to raise ecological awareness and involvement of the local community in citizen science. People are often interested in wild flowers and the location of the research site to the high traffic using the recreation centre sparked a lot of attention. This opens up the possibility to integrate common citizens in maintenance and weed management strategies associated with naturalization, potentially reducing costs and creating a common goal among the community members.

Human disturbance due to pedestrian traffic resulted in physical damage to seedlings and soil disruption. Wildlife predation showed certain preference for some species over others and depending on location it can impact species establishment. Tiny forbs are very susceptible to these disturbances which may preclude their use in areas that are targets for wildlife or easily used for foot traffic by humans. Thus controlling factors such as human disturbance and wildlife predation are advisable for naturalization with forbs. During urban ecological restoration, anthropogenic modifications of soil factors (such as impacts on soils by temperature from urban heat islands, altered plant communities or depositional chemistry) may impact naturalization success by shifting soil quality, competitive regimes, seedling establishment and disturbance patterns (Pavao-Zuckerman 2008).

Native forbs constitute part of our natural heritage and deserve to be protected and preserved. This experiment confirmed that native forb species will stretch their resources to the limit to remain resilient in their endemic environment. Human landscape modifications may be just another phase on their evolutionary journey and as long as humans provide spaces where their journey can continue, they can grow, mature and adapt to the new conditions. In this way our role as ecological architects evolves from constructors to shapers of plant communities.

6. CONCLUSIONS

Of the 24 forb species evaluated in this experiment, 9 showed good potential for naturalization under the management approach used during this study. *Penstemon procerus*, *Fragaria virginiana*, *Heuchera cylindrica*, *Agastache foeniculum*, *Antennaria microphyla* and *Geum aleppicum* are recommended for future use in naturalization for the city of Edmonton and similar urban centres. *Cornus canadensis*, *Pulsatilla patens*, *Liatris ligulistylis* cannot be recommended for use due to their poor performance. *Allium textile*, *Eriogonum flavum*, *Viola adunca*, *Potentilla arguta*, *Heterotheca villosa*, *Anemone cylindrica*, *Rudbeckia hirta*, *Thalictrum venulosum* and *Anemone canadensis* cannot be recommended for naturalization without further study.

Amendment of soil with compost is recommended as it had a direct positive impact on plant survival, growth and cover of planted seedlings. Although compost amendment also increased non native species and noxious weeds, these could be appropriately managed with hand weeding of small naturalized sites.

Table 3.1. Short grass native seed mix.

Common Name	Percentage
Mountainview june grass	25
Glacier alpine blue grass	20
Spike trisetum	30
Plateau rocky mountain fescue	25

Seeded at 150 kg/ha; City of Edmonton.

Table 3.2. Tall grass native seed mix.

Common Name	Percentage
Canada wild rye	10
Northern wheat grass	15
Western wheat grass	15
Awned wheat grass	10
Rough fescue	30
Hookers oat grass	10
Green needle grass	10

Seeded at 35 kg/ha; City of Edmonton.

Table 3.3. Research treatment details.

Treatment	Tillage	Herbicide	Amendment
Control	None	None	None
Compost 100	None	None	Compost
Compost 20	None	None	Compost Soil
Compost 50	None	None	Compost Soil
Herbicide	None	Glyphosate	None
Herbicide Compost 100	None	Glyphosate	Compost Soil
Herbicide Compost 20	None	Glyphosate	Compost Soil
Herbicide Compost 50	None	Glyphosate	Compost Soil
Tillage	Rototill	None	None
Tillage Compost 100	Rototill	None	Compost
Tillage Compost 20	Rototill	None	Compost Soil
Tillage Compost 50	Rototill	None	Compost Soil
Tillage, Herbicide	Rototill	Glyphosate	None
Tillage, Herbicide Compost 100	Rototill	Glyphosate	Compost
Tillage, Herbicide Compost 20	Rototill	Glyphosate	Compost Soil
Tillage, Herbicide Compost 50	Rototill	Glyphosate	Compost Soil

Table 3.4. Forb species planted at the research site.

Common Name	Scientific Name	Family
Black eyed susan	*Rudbeckia hirta* L.	Asteraceae
Dotted blazing star	*Liatris ligulistylis* A. Nels. K. Schum.	Asteraceae
Hairy false golden aster	*Heterotheca villosa* Pursh Shinners	Asteraceae
Little leaf pussy toes	*Antennaria microphylla* Rydb.	Asteraceae
Prairie sagewort	*Artemisia frigida* Willd	Asteraceae
White prairie aster	*Symphyotrichum falcatum* Lindl. G.L. Nesom	Asteraceae
Harebell	*Campanula rotundifolia* L.	Campanulaceae
Bunchberry	*Cornus canadensis* L.	Cornaceae
Giant hyssop	*Agastache foeniculum* Pursh ktze.	Lamiaceae
Wild mint	*Mentha arvensis* L.	Lamiaceae
Prairie onion	*Allium textile* A. Nels. & J. F. Macbr.	Liliaceae
Yellow buckwheat	*Eriogonum flavum* Nutt.	Polygonaceae
Canada anemone	*Anemone canadensis* L.	Ranunculaceae
Long fruited anemone	*Anemone cylindrica* Gray	Ranunculaceae
Prairie crocus	*Pulsatilla patens* L.	Ranunculaceae
Tall larkspur	*Delphinium elatum* L.	Ranunculaceae
Veiny meadow	*Thalictrum venulosum* Trel.	Ranunculaceae
Prairie cinquefoil	*Potentilla arguta* Pursh	Rosaceae
Three flowered avens	*Geum aleppicum* Jacq.	Rosaceae
Wild strawberry	*Fragaria virginiana* Dcne.	Rosaceae
Northern bedstraw	*Galium boreale* L.	Rubiaceae
Round leaved alumroot	*Heuchera cylindrica* Douglas ex Hook.	Saxifragaceae
Slender penstemon	*Penstemon procerus* Dougl. Ex Graham	Scrophulariaceae
Early blue violet	*Viola adunca* Sm.	Violaceae

Table 3.5. Dead plants, non cumulative mortality and cumulative mortality for planted species.

Forb Species		August 2014	October 2014	June 2015	August 2015
Wild strawberry	Number of plants		1	3	3
Fragaria virginiana	% non-cumulative		1.6	4.7	4.7
	% cumulative			4.8	4.9
Slender penstemon	Number of plants	2	3	1	2
Penstemon procerus	% non-cumulative	3.1	4.7	1.6	3.1
	% cumulative	3.1	4.8	1.6	3.2
Giant hyssop	Number of plants	1		5	5
Agastache foeniculum	% non-cumulative	1.6		7.8	7.8
	% cumulative	1.6			8.5
Round leaved alumroot	Number of plants	1	1	3	7
Heuchera cylindrical	% non-cumulative	1.6	1.6	4.7	10.9
	% cumulative	1.6	1.6	4.8	11.5
Three flowered avens	Number of plants		3	6	7
Geum aleppicum	% non-cumulative		4.7	9.4	10.9
	% cumulative			9.8	12.1
Little leaf pussytoes	Number of plants	1	4	6	5
Antennaria microphylla	% non-cumulative	1.6	6.3	9.4	7.8
	% cumulative	1.6	6.3	10.0	8.6
White prairie aster	Number of plants	3	2	14	3
Symphyotrichum falcatum	% non-cumulative	4.7	3.1	21.9	4.7
	% cumulative	4.7	3.3	22.6	6.0
Wild mint	Number of plants		5	12	7
Mentha arvensis	% non-cumulative		7.8	18.8	10.9
	% cumulative			20.3	13.5

Table 3.5. Dead plants, non cumulative mortality and cumulative mortality for planted species (continued).

Forb Species		August 2014	October 2014	June 2015	August 2015
Prairie sagewort	Number of plants	1	3	11	12
Artemisia frigida	% non-cumulative	1.6	4.7	17.2	18.8
	% cumulative	1.6	4.8	18.0	22.6
Tall larkspur	Number of plants		6	6	21
Delphinium elatum	% non-cumulative		9.4	9.4	32.8
	% cumulative			10.3	36.2
Northern bedstraw	Number of plants	2	10	9	19
Galium boreale	% non-cumulative	3.1	15.6	14.1	29.7
	% cumulative	3.1	16.1	16.7	34.5
Harebell	Number of plants	2	7	14	21
Campanula rotundifolia	% non-cumulative	3.1	10.9	21.9	32.8
	% cumulative	3.1	11.3	24.6	42.0
Canada anemone	Number of plants	1	6	10	37
Anemone canadensis	% non-cumulative	1.6	9.4	15.6	57.8
	% cumulative	1.6	9.5	17.2	68.5
Veiny meadow	Number of plants	4	18	16	30
Thalictrum venulosum	% non-cumulative	6.3	28.1	25.0	46.9
	% cumulative	6.3	30.0	34.8	62.5
Black eyed susan	Number of plants	1	2	29	36
Rudbeckia hirta	% non-cumulative	1.6	3.1	45.3	56.3
	% cumulative	1.6	3.2	46.8	102.9
Long fruited anemone	Number of plants	1	4	13	51
Anemone cylindrical	% non-cumulative	1.6	6.3	20.3	79.7
	% cumulative	1.6	6.3	21.7	100
Prairie cinquefoil	Number of plants		16	28	26
Potenitilla arguta	% non-cumulative		25.0	43.8	40.6
	% cumulative			58.3	72.2
Hairy false golden aster	Number of plants	2	26	30	33
Heterotheca villosa	% non-cumulative	3.1	40.6	46.9	51.6
	% cumulative	3.1	41.9	78.9	97.1
Early blue violet	Number of plants	1	16	35	42
Viola adunca	% non-cumulative	1.6	25.0	54.7	65.6
	% cumulative	1.6	25.4	72.9	144.8
Yellow buckwheat	Number of plants	1	7	45	49
Eriogonum flavum	% non-cumulative	1.6	10.9	70.3	76.6
	% cumulative	1.6	11.1	78.9	257.9
Prairie onion	Number of plants	6	27	31	45
Allium textile	% non-cumulative	9.4	42.2	48.4	70.3
	% cumulative	9.4	46.6	83.8	136.4
Dotted blazing star	Number of plants	7	29	43	41
Liatris ligulistylis	% non-cumulative	10.9	45.3	67.2	64.1
	% cumulative	10.9	50.9	122.9	195.2
Prairie crocus	Number of plants	9	28	40	50
Pulsatilla patens	% non-cumulative	14.1	43.8	62.5	78.1
	% cumulative	14.1	50.9	111.1	208.3
Bunchberry	Number of plants	7	30	63	64
Cornus canadensis	% non-cumulative	10.9	46.9	98.4	100
	% cumulative	10.9	52.6	185.3	6400

Table 3.6. Mortality (%) grouped by family by soil treatment.

Treatment	Asteraceae (%) Mortality	Ranunculaceae (%) Mortality
Compost 100	29	55
Compost 20	42	50
Compost 50	33	85
Control	67 *	75
Herbicide	42	95 *
Herbicide Compost 100	29	50
Herbicide Compost 20	29	40
Herbicide Compost 50	29	60
Herbicide Tillage	33	65
Herbicide Tillage Compost 100	25	35
Herbicide Tillage Compost 20	33	40
Herbicide Tillage Compost 50	25	70
Tillage	54	80
Tillage Compost 100	13	40
Tillage Compost 20	29	35
Tillage Compost 50	29	70

* Significant differences within columns from chi square analysis, no significant interactions.

Table 3.7. Mortality (%) grouped by family by soil amendment.

Amendment	Asteraceae	Ranunculaceae	Rosaceae
Compost 100	24.0 b	45.0 b	8.3 b
Compost 20	33.3 b	41.3 c	16.7 b
Compost 50	29.2 b	71.3 b	10.4 b
Unamended	49.0 a	78.8 a	39.6 a

Different letters within columns denote significant differences.

Table 3.8. Spread measurements by soil treatment analysis of variance.

Forb Species	Soil Treatment	Sum of Squares	Degrees of Freedom	F Value	P (>F)
Thalictrum venulosum	Soil preparation	754.07	3	4.6773	0.008506 **
	Residuals	1612.17	30		
Antennaria microphylla	Amendment	978.00	3	5.2504	0.002942 **
	Residuals	3415.10	55		
Delphinium elatum	Amendment	785.35	3	6.5508	0.001077 **
	Residuals	1558.51	39		
Fragaria virginiana	Amendment	768.57	3	10.4070	1.467e-05 ***
	Residuals	1403.17	57		
Geum aleppicum	Amendment	914.04	3	7.9161	0.0001867 ***
	Residuals	2039.89	53		
Heuchera cylindrica	Amendment	1937.00	3	21.6160	2.819e-09 ***
	Residuals	1583.10	53		
Mentha arvensis	Amendment	23815.00	3	9.1138	5.796e-05 ***
	Residuals	46165.00	53		
Penstemon procerus	Amendment	8974.50	3	26.5150	6.311e-11 ***
	Residuals	6543.90	58		
Rudbeckia hirta	Amendment	2040.90	3	3.7079	0.02531 *
	Residuals	4403.20	24		
Symphyotrichum falcatum	Amendment	15610.00	3	16.4290	8.217e-08 ***
	Residuals	18053.00	57		

Table 3.9. Mean spread by species in response to soil preparation treatments in 2015.

Species	Calculation	Herbicide	Herbicide Tillage	Tillage	Untreated
Agastache foeniculum	Mean	57.1	49.3	48.6	54.4
	Standard deviation	32.1	28.9	28.5	30.8
Allium textile	Mean	14.0	6.0	9.3	5.5
	Standard deviation	13.3	3.2	2.5	3.4
Anemone canadensis	Mean	19.9	14.4	18.7	13.0
	Standard deviation	5.6	6.3	6.9	10.5
Anemone cylindrica	Mean	14.4	9.3	16.3	23.0
	Standard deviation	11.2	5.7	5.5	NA
Antennaria microphylla	Mean	23.1	29.9	23.5	24.4
	Standard deviation	6.9	8.3	8.5	10.1
Artemisia frigida	Mean	93.5	106.0	100.6	113.2
	Standard deviation	51.6	46.9	30.3	45.8
Campanula rotundifolia	Mean	18.3	23.7	21.9	16.8
	Standard deviation	9.3	16.1	15.1	9.1
Delphinium elatum	Mean	18.4	15.0	19.7	13.7
	Standard deviation	6.2	7.0	7.8	7.8
Eriogonum flavum	Mean	11.3	11.3	11.3	11.7
	Standard deviation	2.5	1.2	5.2	3.5
Fragaria virginiana	Mean	18.5	16.6	14.0	15.2
	Standard deviation	5.2	6.1	5.0	7.3
Galium boreale	Mean	14.8	19.5	19.9	23.8
	Standard deviation	9.1	8.8	10.3	9.8
Geum aleppicum	Mean	20.7	18.7	16.5	17.2
	Standard deviation	8.5	7.7	6.4	6.2
Heterotheca villosa	Mean	29.0	34.1	36.1	20.6
	Standard deviation	16.7	19.3	23.1	14.3
Heuchera cylindrica	Mean	20.4	18.6	20.1	16.9
	Standard deviation	9.5	8.1	6.8	7.3
Liatris ligulistylis	Mean	12.7	13.0	12.3	10.6
	Standard deviation	5.3	3.9	2.4	6.1
Mentha arvensis	Mean	51.9	39.4	36.0	49.2
	Standard deviation	43.1	37.3	20.2	38.3
Penstemon procerus	Mean	39.9	39.3	35.6	36.5
	Standard deviation	15.9	14.2	15.7	18.9
Potentilla arguta	Mean	30.2	22.2	26.5	24.7
	Standard deviation	6.7	10.5	7.4	6.5
Pulsatilla patens	Mean	8.0	8.8	9.0	4.3
	Standard deviation	2.8	3.7	0.0	3.2
Rudbeckia hirta	Mean	39.4	39.3	34.9	29.0
	Standard deviation	19.8	13.1	17.1	5.3
Symphyotrichum falcatum	Mean	45.3	54.0	52.2	50.9
	Standard deviation	18.9	26.0	25.6	24.9
Thalictrum venulosum	Mean	25.0 a	14.8 ab	12.9 b	19.4 b
	Standard deviation	5.6	6.1	9.3	7.3
Viola adunca	Mean	14.1	13.0	6.8	8.0
	Standard deviation	7.7	4.2	3.5	5.2

Different letters within rows for species denote significant differences.

Table 3.10. Mean spread by species in response to soil amendment treatments in 2015.

Species	Calculation	Compost 100	Compost 20	Compost 50	Untreated
Agastache foeniculum	Mean	68.8	72.0	46.5	11.4
	Standard deviation	28.6	17.2	13.4	4.6
Allium textile	Mean	8.2	9.6	7.5	6.5
	Standard deviation	9.2	7.6	2.1	3.7
Anemone canadensis	Mean	24.3	16.2	17.0	8.7
	Standard deviation	5.4	4.4	NA	4.1
Anemone cylindrica	Mean	18.7	11.7	9.7	5.0
	Standard deviation	7.1	10.0	7.5	NA
Antennaria microphylla	Mean	30.7 a	27.3 ab	21.6 b	20.7 b
	Standard deviation	9.4	9.2	4.4	7.3
Artemisia frigida	Mean	99.2	128.0	118.7	16.2
	Standard deviation	43.1	15.7	26.8	7.4
Campanula rotundifolia	Mean	26.4	25.4	15.8	7.4
	Standard deviation	11.4	14.7	6.9	2.9
Delphinium elatum	Mean	21.0 a	16.4 a	16.4 a	5.3 b
	Standard deviation	7.3	7.2	4.3	1.0
Eriogonum flavum	Mean	12.4	14.0	9.0	8.5
	Standard deviation	2.3	4.7	0.8	3.5
Fragaria virginiana	Mean	19.0 a	18.0 a	16.6 a	9.5 b
	Standard deviation	4.6	6.8	4.1	3.3
Galium boreale	Mean	21.3	24.2	19.9	8.8
	Standard deviation	10.4	10.4	3.8	4.2
Geum aleppicum	Mean	21.0 a	22.5 a	18.1 ab	12.1 b
	Standard deviation	8.3	6.9	4.6	4.1
Heterotheca villosa	Mean	38.6	37.6	21.6	16.3
	Standard deviation	19.6	21.8	13.0	8.4
Heuchera cylindrica	Mean	23.6 a	24.0 a	19.8 a	9.4 b
	Standard deviation	6.4	4.7	7.1	2.4
Liatris ligulistylis	Mean	14.3	13.5	10.0	9.6
	Standard deviation	3.7	2.1	6.2	3.8
Mentha arvensis	Mean	52.2 a	67.5 a	39.1 ab	9.7 b
	Standard deviation	31.1	41.2	23.9	8.8
Penstemon procerus	Mean	49.8 a	47.1 a	33.3 b	18.9 c
	Standard deviation	9.9	10.6	13.4	7.2
Potentilla arguta	Mean	30.2	25.7	22.6	5.0
	Standard deviation	8.7	6.8	5.5	NA
Pulsatilla patens	Mean	10.0	8.1	6.0	2.5
	Standard deviation	3.6	2.7	4.2	0.7
Rudbeckia hirta	Mean	46.8 a	39.1 ab	38.4 ab	21.7 b
	Standard deviation	16.5	15.6	11.4	10.6
Symphyotrichum falcatum	Mean	62.7 a	55.3 a	60.1 a	21.8 b
	Standard deviation	22.5	18.4	17.4	10.1
Thalictrum venulosum	Mean	19.7	19.8	13.8	7.3
	Standard deviation	5.1	8.8	11.4	5.0
Viola adunca	Mean	12.6	11.2	10.6	7.5
	Standard deviation	5.7	5.3	9.7	0.7

Different letters within rows for species denote significant differences.

Table 3.11. Species by category.

Plant category	Scientific name
Non Native	*Avena sativa*
	Bromus inermis Leyss.
	Chenopodium album L.
	Elymus repens (L.) Gould
	Festuca rubra L.
	Plantago major L.
	Poa pratensis L.
	Polygonum convolvulus L.
	Sonchus asper (L.) Hill
	Stellaria media (L.) Vill.
	Taraxacum officinale F.H. Wigg.
	Trifolium hybridum L.
	Trifolium repens L.
Native	*Astragalus* L.
	Festuca hallii (Vasey) Piper
	Festuca saximontana Rydb.
	Hordeum jubatum L.
	Pascopyrum smithii (Rydb.) Á. Löve
	Poa alpina L.
	Poa nemoralis L. subsp. interior (Rydb.) W.A. Weber
	Pseudoroegneria spicata (Pursh) Á. Löve
	Thermopsis rhombifolia (Nutt. ex Pursh) Nutt. Ex Richardson
Noxious	*Cirsium arvense* (L.) Scop.
	Sonchus arvensis L.
	Tripleurospermum perforatum (Mérat) M. Lainz
Prohibited Noxious	*Potentilla recta* L.
Planted	*Agastache foeniculum* Pursh ktze.
	Allium textile A. Nels. & J. F. Macbr.
	Anemone canadensis L.
	Anemone cylindrica Gray
	Antennaria microphylla Rydb.
	Artemisia frigida Willd
	Campanula rotundifolia L.
	Delphinium elatum L.
	Eriogonum flavum Nutt.
	Fragaria virginiana Dcne.
	Galium boreale L.
	Geum aleppicum Jacq.
	Heterotheca villosa Pursh Shinners
	Heuchera cylindrica Douglas ex Hook.
	Liatris ligulistylis A. Nels. K. Schum.
	Mentha arvensis L.
	Penstemon procerus Dougl. Ex Graham
	Potentilla arguta Pursh
	Rudbeckia hirta L.
	Symphyotrichum falcatum Lindl. G.L. Nesom
	Thalictrum venulosum Trel.
	Viola adunca Sm.

Table 3.12. Soil property changes by year in non amended treatments.

	Cation Exchange Capacity meq/100g	Electrical Conductivity dS/m	PH	Sodium Adsorption Ratio	Total Carbon %	Total Nitrogen %	Total Organic Carbon %
2014	33.8	1.05	6.5	0.7	4.3	0.3	4.3
2015	35.7	1.19	6.9	1.0	3.4	0.3	3.2
	Ammonium (mg/kg)	Nitrate (mg/kg)	Phosphorus (mg/kg)	Potassium (mg/kg)	Sulfur (mg/kg)	Copper (mg/kg)	Zinc (mg/kg)
2014	4.4	4.5	29.9	176.5	44.1	16.6	67.8
2015	2.3	4.3	8.3	121.8	82.0	0.9	2.8
	Calcium (mg/L)	Chlorine (mg/L)	Potassium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Sulphate (mg/L)	
2014	135.2	36.6	6.9	32.8	31.8	223.8	
2015	170.0	36.5	8.2	39.5	56.4	323.3	

Table 3.13. Mean available nutrients (mg/kg) of amendment treatments in 2014 and 2015.

Amendment	Year	Ammonium	Nitrate	Phosphorus	Potassium	Sulfur	Copper	Zinc
Compost 100	2014	70.4	104.0	2580	1100	372	308.0	526
	2015	23.7	91.6	1550	1050	274	40.6	119
Compost 50	2014	17.4	139.0	470	330	213	55.5	130
	2015	14.9	55.1	412	290	178	5.1	22
Compost 20	2014	8.8	117.0	251	231	154	44.0	110
	2015	2.6	56.4	212	186	129	2.9	14

Table 3.14. Mean amendment properties in 2014 and 2015.

Amendment	Year	Cation Exchange Capacity meq/100g	Electrical Conductivity dS/m	PH	Sodium Adsorption Ratio	Total Carbon %	Total Nitrogen %	Total Organic Carbon %
Compost 100	2014	61.6	1.6	5.8	0.26	18.4	1.4	18.3
	2015	71.8	2.1	5.7	0.28	20.8	1.5	20.7
Compost 50	2014	43.1	3.2	6.0	0.42	81.3	6.4	81.3
	2015	42.6	2.0	6.2	0.45	6.1	0.6	6.1
Compost 20	2014	39.8	2.8	6.2	0.43	5.6	0.5	5.6
	2015	41.5	2.2	6.3	0.50	5.1	0.5	5.1

Table 3.15. Mean cation concentration (mg/L) by amendment in 2014 and 2015.

Amendment	Year	Calcium	Chlorine	Potassium	Magnesium	Sodium	Sulphate
Compost 100	2014	178	1	41.6	73.7	16.6	512
	2015	299	5	73.1	114.0	22.5	811
Compost 50	2014	467	4	23.2	128.0	40.0	928
	2015	328	5	18.9	91.5	35.6	807
Compost 20	2014	408	3	14.3	93.0	37.0	678
	2015	379	2	13.4	89.7	41.7	866

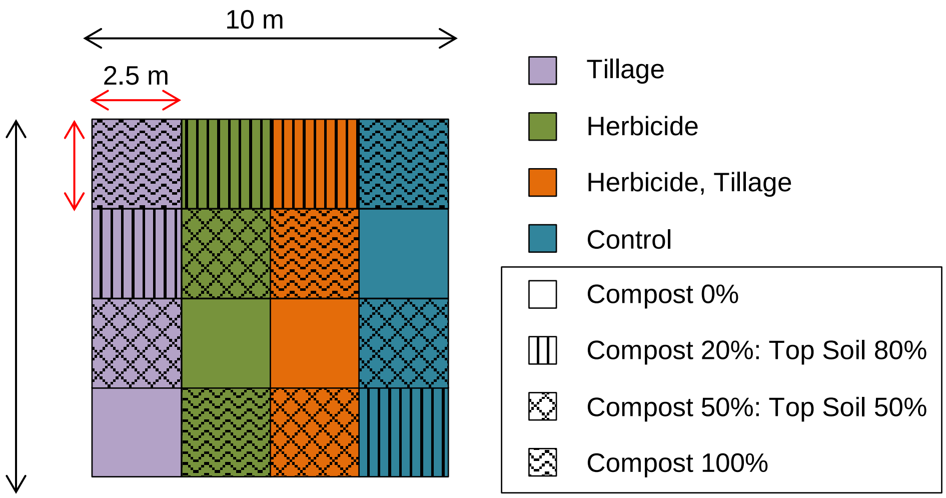

Figure 3.1. Replicate plot, soil preparation treatments (coloured boxes) randomly applied in columns. Amendment treatments (patterns) randomly distributed within columns.

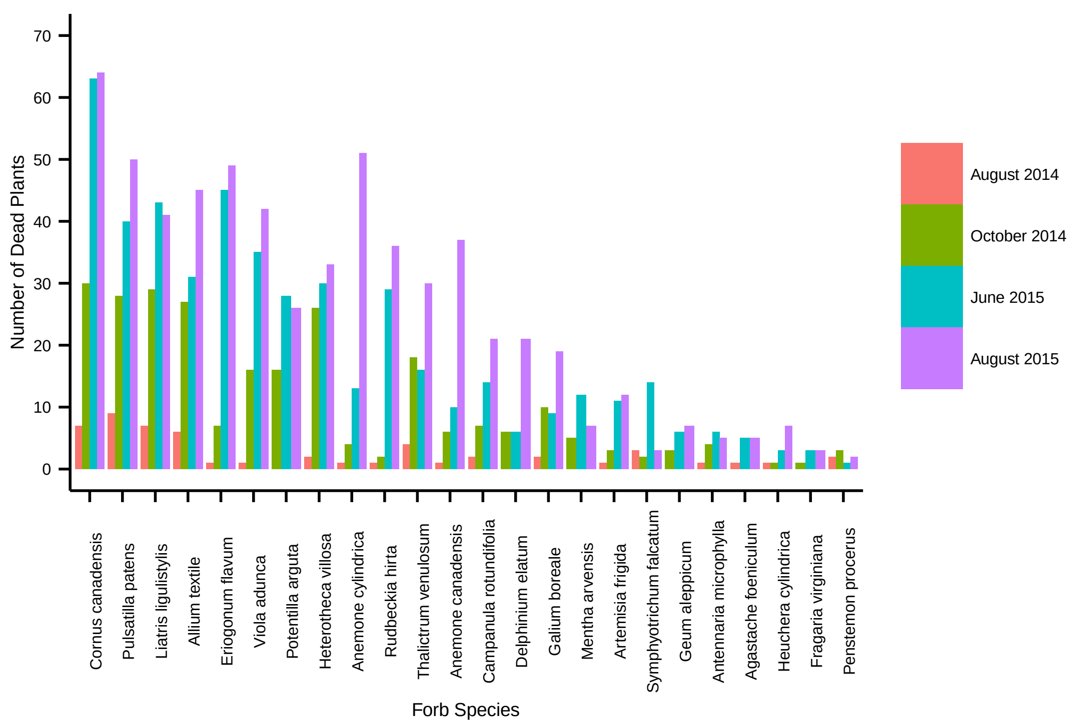

Figure 3.2. Number of dead plants per species at each of four monitoring dates. A total of 64 plants per species were planted.

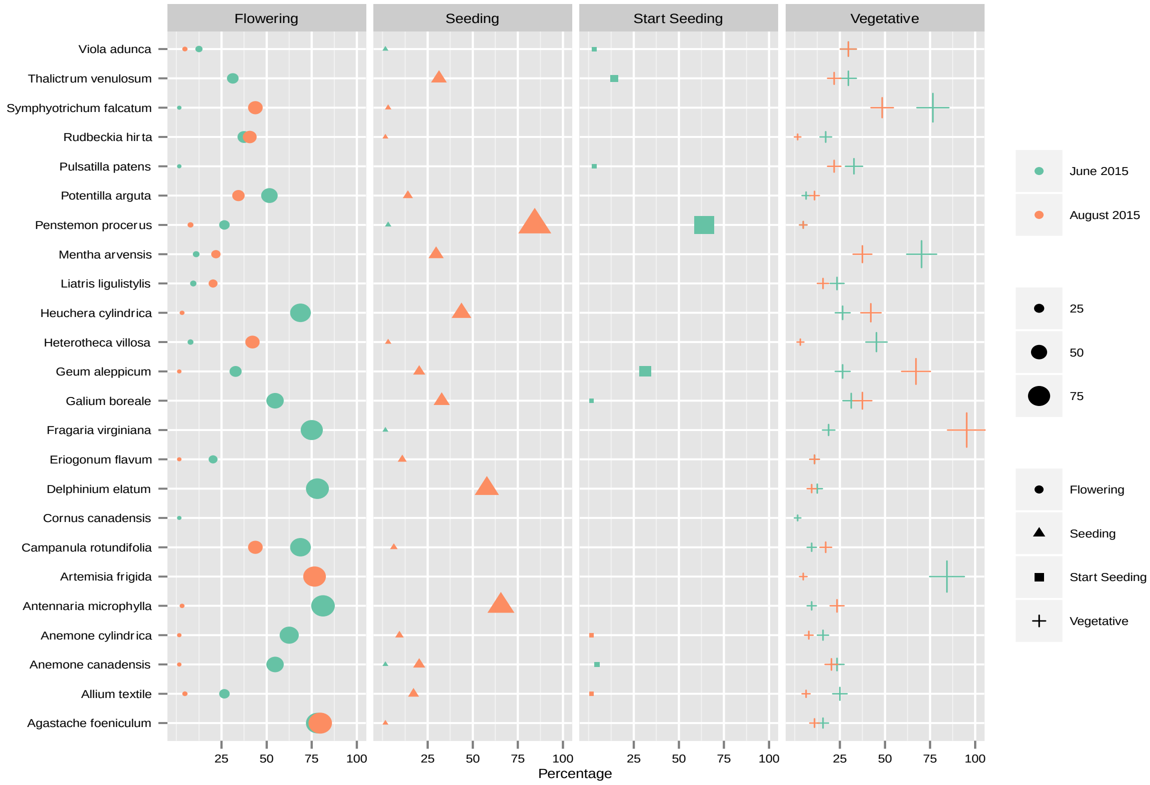

Figure 3.3. Percent species in phenological stages in June and August 2015.

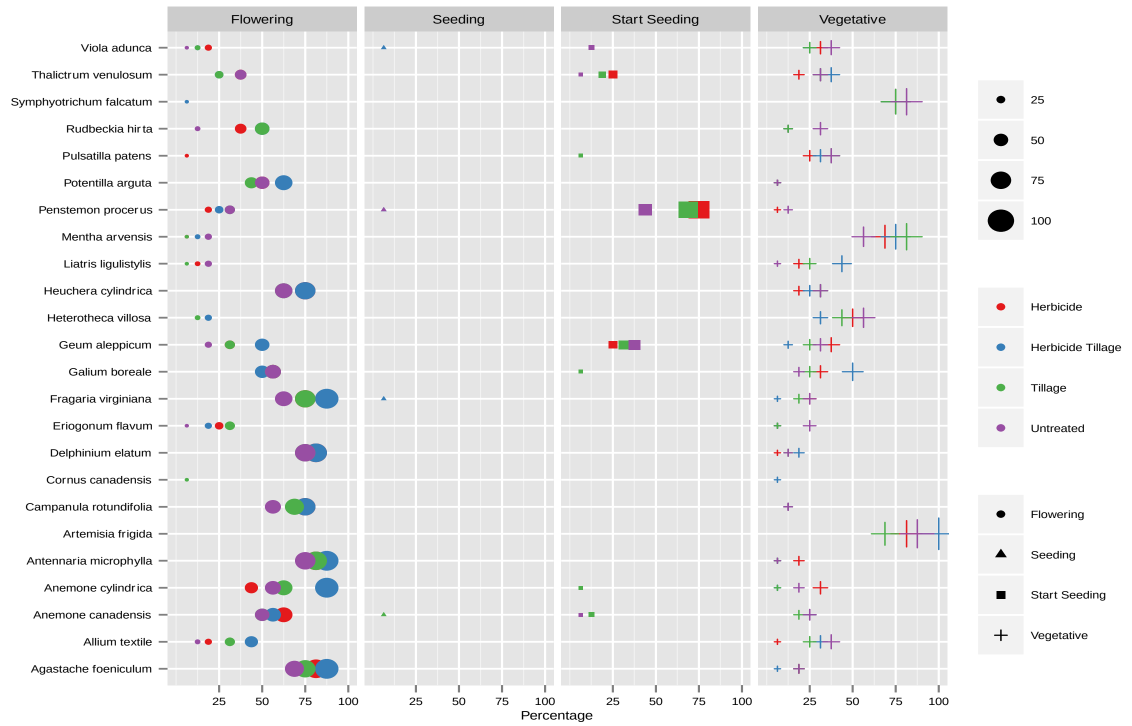

Figure 3.4. Soil preparation effects on percent species in phenological stages in June 2015.

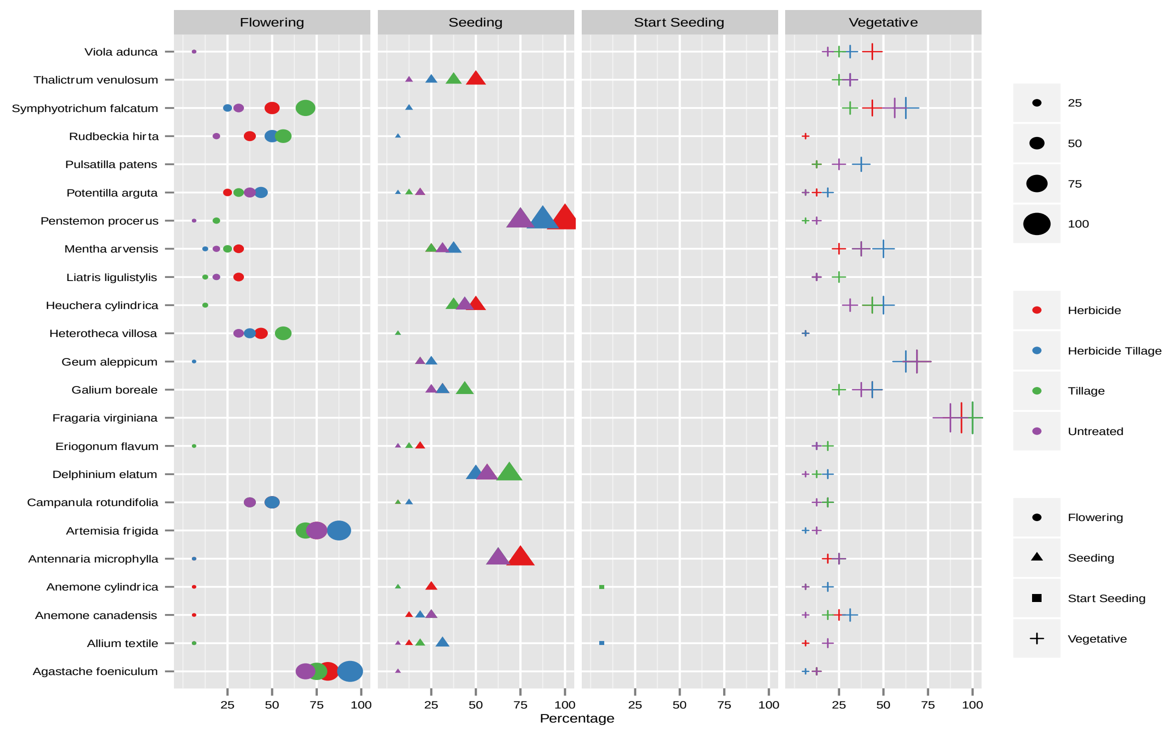

Figure 3.5. Soil preparation effects on percent species in phenological stages in August 2015.

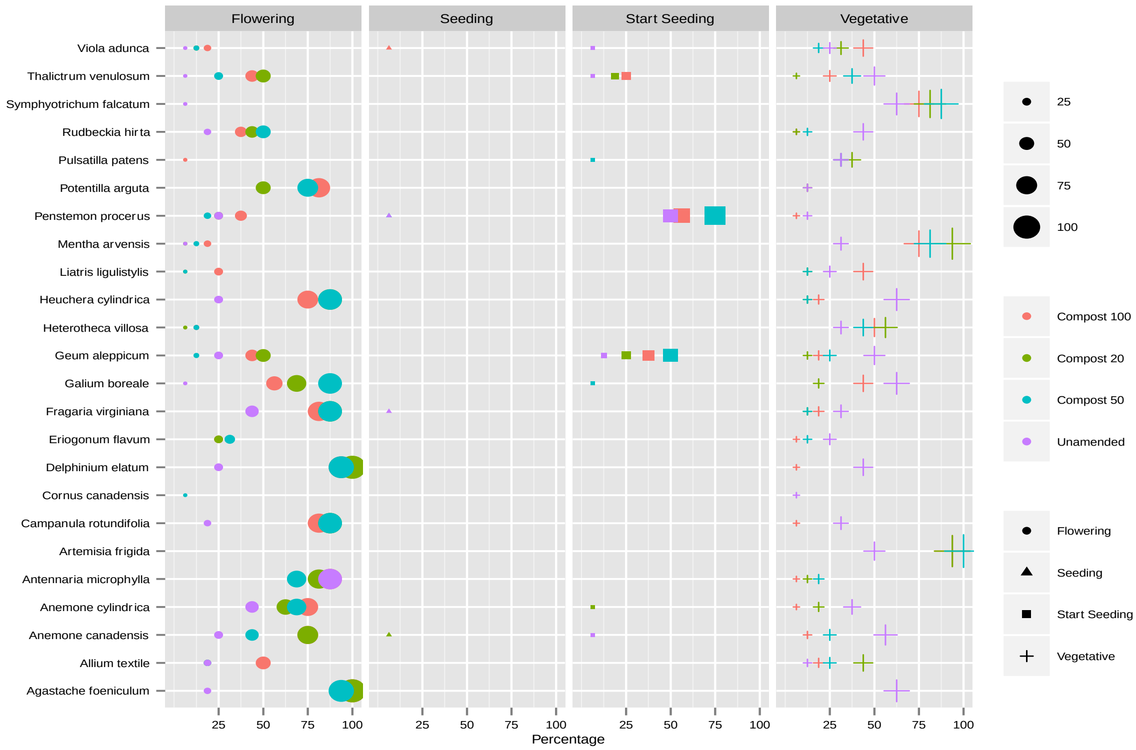

Figure 3.6. Amendment effects on percent species in phenological stages in June 2015.

Figure 3.7. Amendment effects on percent species in phenological stages in August 2015.

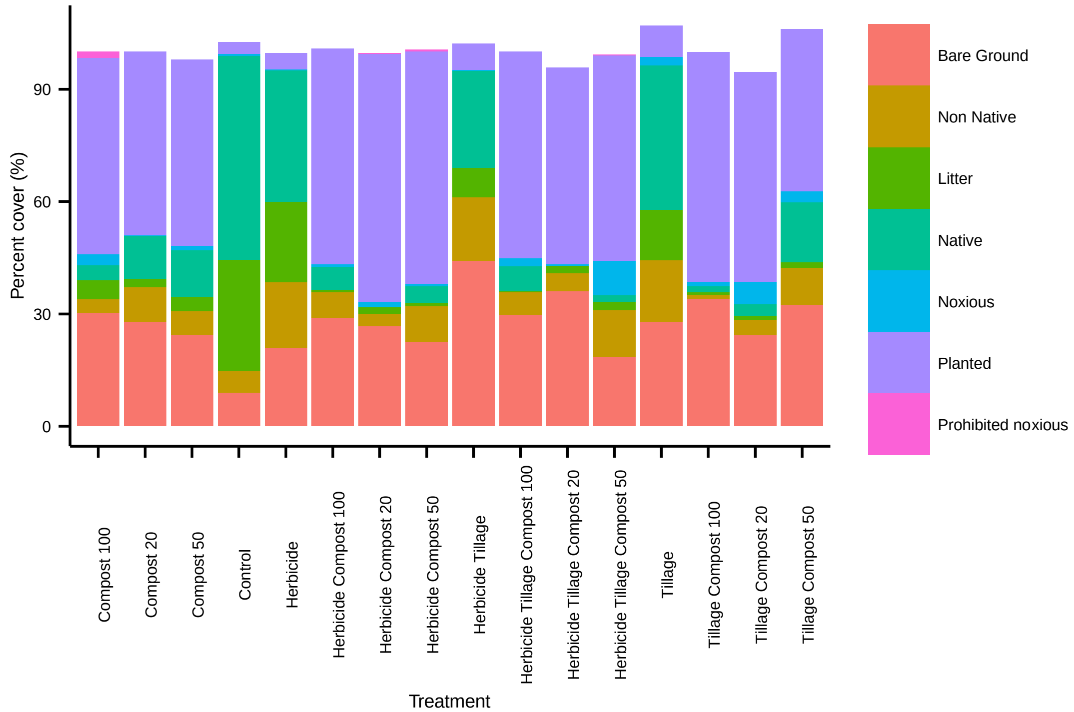

Figure 3.8. Plant community composition by category for soil preparation treatments.

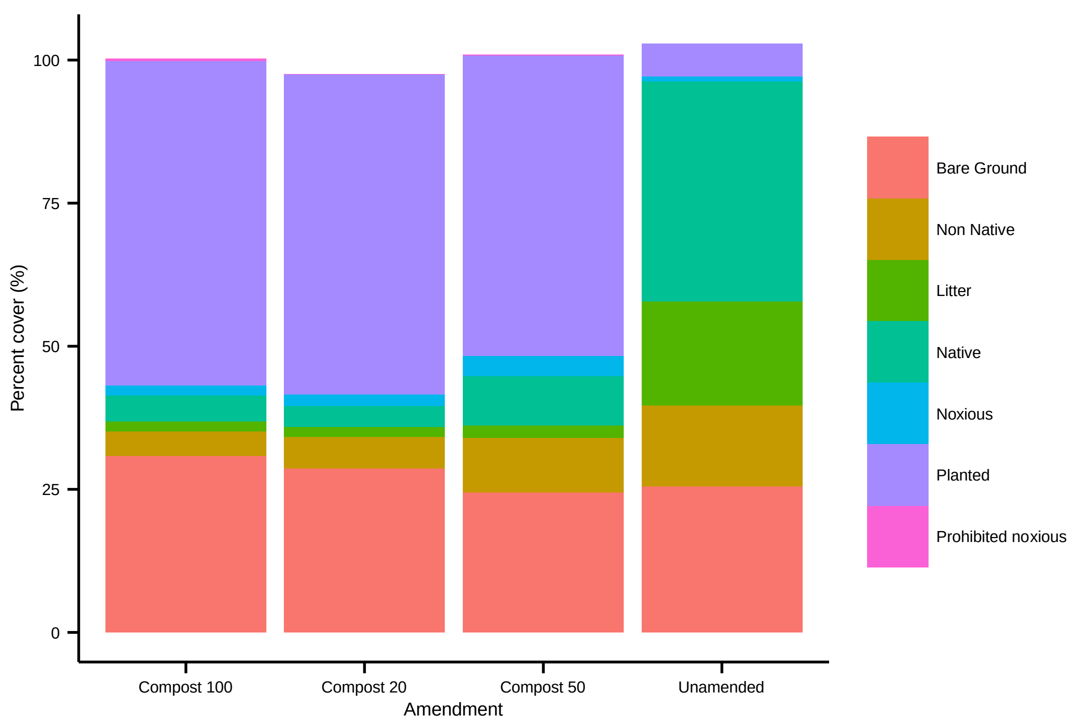

Figure 3.9. Plant community composition by category for soil amendment.

IV. PLANT COMMUNITY RESPONSE TO SOIL TREATMENTS AND CESSATION OF MOWING DURING URBAN NATURALIZATION

1. INTRODUCTION

Urban naturalization is an alternative landscape management technique where natural processes of plant colonization and growth are generally unrestricted, allowing the landscape to return to a natural state. Environmental benefits include increased biodiversity and wildlife use, soil stabilization, improved ground water recharge, provision of windbreaks for snow capture and dust reduction, reduction of atmospheric greenhouse gases and cleaner air (Savard et al. 2000, Chiesura 2004, Millard 2004). Economic benefits include a significant reduction in maintenance costs such as mowing, irrigation and herbicide use. Quality of life benefits include landscape beautification, increased green and shady areas for recreation, increased community awareness of environmental issues and noise reduction by mature plantings (Chiesura 2004).

Urban naturalization historically focused on planting trees to restore urban forests. However, naturalization can occur in urban grassland and wetland areas. It requires careful selection of plant species for development of an appropriate plant community (Saebo et al. 2003, Pavao-Zuckerman 2008). Usually native plant species are used, although in many urban centres, local cultivars and non native species have been included. In many naturalization processes trees are planted and other species are allowed to establish naturally.

Naturalization can address inherent soil limitations (Pollak 2006, Pavao-Zuckerman 2008, Schafer and Alien 2009). Compacted soils can prevent or restrict root growth and therefore successful plant establishment and long term development (Millwood et al. 2011). Naturalization can reduce soil compaction, through root expansion, increased biological activity and frost heave (Alukukku 1996, Niwa et al. 2001), subsequently increasing infiltration rates (Beven et al. 1982, Savard et al. 2000). Naturalized sites retain leaf litter and woody debris, which decomposes, adding organic material, which is positively correlated with increased plant available soil water (Craul 1985, Gomez et al. 2002). Alternatively, these soil limitations can be reduced as part of the naturalization process through use of soil amendments.

Naturalization can result in unrestricted growth of herbaceous understory plants and increased root density in upper soil horizons (Millwood et al. 2011). Open spaces in an urban environment present an opportunity for plants to grow and disperse. Naturalization is founded on the principle that native species adapted to local conditions will compete and establish with little human intervention. However, some of these species may be aggressive weeds or undesired competitive grasses. Thus management must be used, including pre-planting use of herbicides to reduce competitive species and follow up noxious weed removal.

Little scientific research has been conducted on methods to achieve naturalization of urban parklands. Research is especially lacking in assessment of the plant community that develops along with the planted species. Many of these sites require reclamation to address soil issues and all require revegetation to facilitate development into a naturalized ecological community. Results of naturalization efforts to date have been inconsistent.

2. RESEARCH OBJECTIVES

The research objectives for this naturalization project were as follows.

- To evaluate effects of mowing cessation on species richness and cover of naturalized sites.
- To evaluate soil treatment impacts on plant community composition and cover.

3. MATERIALS AND METHODS

3.1. Research Sites

The study area is on the south side of the City of Edmonton in Alberta, Canada, located at 53°34'19.000" N latitude and 113°31'10.000" W longitude (Environment Canada 2015). Elevation is 671.4 m above sea level. Average temperature is 4.2 °C; growing season temperature from May to October averages 13.0 °C and winter temperature from November to April averages -4.6 °C. Total average rainfall is 348 mm with greatest amounts from June to October (284.4 mm). Snowfall averages 122 to 124 cm from October to May.

In May 2014 seven research sites representing the variety of locations for naturalization in the City of Edmonton were established (Figure 4.1). The four flat and three sloped sites reflected variability in topography, management and exposure to urban disturbance (Table 4.1).

Lendrum site is flat and located between the back entrance of an old neighbourhood and the rail tracks of the Light Rail Transit system. A dense canopy of *Caragana arborescens* L. (caragana) surrounds the site. The area is dominated by grasses, with high populations of noxious weeds such as *Cirsium arvense* L. (Canada thistle) and *Tripleurospermum perforatum* L. Sch. Bip. (scentless chamomile). Most of the area was mowed annually until the beginning of this research. Mowing is not possible on a small area with *Caragana arborescens* trunks from a previous removal, presenting a management challenge, as unmowed areas are seed banks for weeds which can disperse across the city, increasing weed management costs. Lendrum has low pedestrian and vehicle traffic. Evidence suggests the site may have been used as a dump. Grass was seeded, with no information on species, seeding method or seeding density.

Wagner site is located in an industrial area, inside Wagner Park at the back of the WP Wagner School and close to the train tracks. The area was managed as a flat grass area, and mowed until the beginning of this research. Traffic flow is low, with pedestrian traffic the main impact and some maintenance vehicle use. The site is a well established and maintained green space. *Taraxacum officinale* L. (common dandelion) is present due to the adjacent train tracks area.

The 91 Street site is located off a main street running north to south. It is a small hill, sloped to reduce noise to nearby buildings and enhance the landscape. The west slope faces a street; the east slope faces a lawn and a small urban forest of *Populus tremuloides* Michx. (trembling aspen). This area had not been mowed for over two years. Old dying trees and shrubs suggest past revegetation attempts. The site is exposed to wind and has a significant Canada thistle presence on the west facing slope bordered by urban forest. Vehicle traffic is very heavy on the street, but not on the green area; pedestrian traffic is limited. Wild coyotes and birds are present

The 18 Avenue Blackmud (Blackmud) site is a flat area in a residential neighbourhood. The lawn was heavily mowed until the beginning of this research and is frequently exposed to pedestrian traffic and pets. A small forested area with a high diversity of native trees, shrubs and forbs borders the site. Herbivores such as deer and rabbits have a limited presence.

Smith Crossing site is a complex of slopes at 23 Avenue running east to west and crossed by White Mud Creek. An old forest borders the north and south and a high bridge crosses east to west. Vehicle traffic is heavy, with low traffic on green areas; pedestrian traffic mainly links to hiking paths. One portion of the south west edge is mowed where a green picnic area is located; the rest of the site has begun naturalization. Herbivores such as deer and rabbits are present.

Terwillegar Whitemud (Terwillegar) site is located at the intersection of two main streets, Terwillegar Drive and White Mud Drive. This site has highest vehicle traffic and lowest pedestrian traffic. Slopes face north and were planted with native vegetation in 1993. Mowing had not occurred for more than two years. There are no visible signs of herbivores.

Terwillegar Recreation Centre site (TRC) is located at 2051 Leger Road, at the roundabout entrance of a community sports facility and Lillian Osborne High School. The area is flat with a gentle slope to the southwest. Asphalt surrounds the roundabout, then buildings, small canopy trees and open lawn areas. Traffic conditions are very high for vehicles near the roundabout; pedestrian traffic is concentrated on walking paths, although occasional pedestrians cross on the green section. Site landscaping is intended to incorporate native species and was initially seeded with native grasses. Mowing was conducted until summer 2014; in 2012 Milestone™ herbicide was applied to control an outbreak of *Cirsium arvense*. Presence of wild fauna such as rabbits has been an issue for plant establishment. Landscaping design in this site dictates that only short stature species can be used for planting and/or seeding.

3.2. Experimental Design

The experiment followed a complete randomized design with replication. Experimental plots (replications) were 10 m x 10 m, each divided into 16 small 2.5 m x 2.5 m subplots, covering an area of 6.25 m^2 (Figure 4.2). Soil preparation treatments were randomly assigned vertically to the plots in strips, with amendment treatments applied randomly within each strip. Site preparation consisted of soil tilling, foliar herbicide application, a combination of tilling and herbicide and no site preparation (Table 4.2). Soil amendments were compost 100, compost 50, compost 20 and no amendment. Thus there were 4 soil preparation treatments x 4 amendment treatments x 3 replicates for a total of 48 plots per site.

3.3. Experimental Treatments

3.3.1. Herbicide

Roundup Transorb™ was applied as a 1 % solution (540 g/L glyphosate) by City of Edmonton personnel with backpack sprayers on June 12 2014, two weeks prior to soil preparation treatment implementation. Volumes applied depended on vegetation height and density (Table 4.3). Herbicide treatments were oriented in sections inside replicates for operational efficiency. Roundup is a broad spectrum systemic herbicide, providing control for broad leaf and grasses species, with low persistence in the environment of 1 to 10 days. It controlled most weeds, although some species showed considerable resistance. For example, dandelion was stressed but did not completely die like the rest of the sprayed vegetation.

3.3.2. Soil tillage

Rototilling was performed June 24 and 25 2014 to a depth of approximately 10 to 15 cm with a rear tined, 9 HP hydraulic drive, Power Dog 209 rototiller. The gear was placed in forward and rotary blades in the opposite direction, for maximum soil penetration and control over the equipment. Flat sites were tilled in one direction, then crossed perpendicularly; sloped sites were tilled in one direction and due to safety concerns complimented by a second pass in the same direction. Tillage was oriented in sections inside each replicate for operational efficiency.

3.3.3. Amendments

Amendments were topsoil and compost, mixed in proportions based on availability and cost effectiveness of material for the City of Edmonton and standard naturalization materials available for operational work. Compost was from the City of Edmonton Waste Management Centre. Topsoil was from developments on previously agricultural land. Amendments were applied June 24 to 29 2014 using a mini steer loader and/or wheel barrow. Amendments were added to the surface of each subplot and spread by hand with shovels in a 15 cm deep layer.

Compost 100 was 80 % compost and 20 % wood chips by volume. It is a standard mix used by the City of Edmonton and was delivered ready to apply at each site. Compost 20, 80 % topsoil and 20 % compost, was delivered to each site mixed and ready to use. Compost 50, 50 % compost and 50 % topsoil, was prepared on subplots. To achieve a homogeneous mixture, compost mix was laid and distributed on treatment areas, capped with topsoil, then homogenized with a mini cultivator Honda model FG110K1CT.

3.4. Planting And Plot Management

Native woody species of standard stock for City of Edmonton naturalization were planted the first two weeks of July 2014 (Chapters 2 and 3). Plants were watered with an irrigation truck, 24 to 48 hours post planting; then every 2 to 3 days for the next two weeks, twice per week for the next four weeks, then once per week until end of the growing season. 2015 plant watering was based on availability of water trucks as per standard City of Edmonton procedures for second year naturalization plantings; this approximated once per month from May to September. Lendrum was not watered in July 2015; 18 Avenue Blackmud was not watered in August 2015.

All sites were managed for weed species as needed to meet City of Edmonton standards. Lendrum, 91 Street, Wagner, Terwillegar and Smith Crossing plots were partially weeded by hand on August 11 2014. Lendrum was selectively sprayed with Trillion (2,4-D, mecoprop, dicamba) on September 4 2014 in response to complaints from neighbours regarding increasing weed abundance. Spraying occurred as per manufacturer directions. Blackmud was the only site that was not weeded in 2014.

Noxious weeds were hand pulled in 2015 by City of Edmonton personnel. It took 9 crew members 8 hours to clear all of the sites (72 hours weeding). Sites with highest noxious and non noxious weed densities were Lendrum and Blackmud, where pulled weeds filled 15 and 30 bags (89 x 127 cm), respectively. At Blackmud, weed pullers targeted *Chenopodium album* L. (lambs quarters) seedlings. On other sites 1 to 2 bags of noxious weeds per site were removed.

Inside research plots at TRC, all noxious weeds were hand pulled; non-noxious weeds were hand pulled when located within 10 cm of the seedlings. Manual weeding was conducted on areas within 2 m from the edge of the research plots to provide a weed control buffer zone. Outside the 2 m buffer zone, the herbicide 2,4 Dichlorophenoxyacetic acid (2-4-D) was used according to manufacturer's recommendation.

3.5. Vegetation Assessments

Vegetation assessments were conducted during the second week of August 2014 and 2015. Outside plot assessments were to assess how the plant community was affected by mowing cessation. Inside plot assessments were to provide tracking of plant community development in response to soil preparation treatment and site characteristics. All plants were identified inside and outside treatment plots, followed by an ocular estimate of cover. Species richness was determined from vegetation cover by counting the number of species found in each treatment.

Inside plot assessments were on three randomly located 0.1 m^2 quadrats inside each treatment (2.5 x 2.5 m subplot). Each 0.1 m^2 quadrat was assessed for % live vegetation, bare ground, litter and other (rocks, trash, feces, etc.) cover. Live vegetation was assessed on an individual species basis to determine development of non planted species.

At each site, outside plot vegetation assessments were conducted on three permanent 10 m long transects. Transects were 3 m apart from the research plots in parallel to one of the border lines of the plot. Transects were located to avoid established woody vegetation. Five 0.1 m^2 alternated permanent quadrats were assessed on each transect for % cover using the same procedures for inside plot vegetation assessment (Figure 4.3).

3.6. Statistical Analyses

All statistical analyses were conducted using R version 3.1.2 (R Core Team 2014). In most cases data from the last monitoring date in 2015 were statistically analyzed to evaluate overall performance of species at the end of the experiment. An accidental operation by City of

Edmonton workers occurred at Smith Crossing in September 2014, destroying one replicate; hence for analyses this replicate was removed.

Permanent quadrat cover by plant category from 2014 and 2015 was analyzed on a per site basis. Normality was checked using Shapiro-Wilk test, and homogeneity of variance using Levene’s test. A paired t-test was used to compare means when parametrical assumptions were met; where homogeneity of variance assumption was violated, a Mann-Whitney Wilcoxon non-parametric test was used.

To analyze the effect of soil preparation treatment on cover by plant category, only six sites were used as the Terwillegar Recreation Centre weed management did not provide the necessary requirements to study plant community succession. Vegetation assessment data were converted to total percent cover by plant category by site by obtaining a mean percent cover for each species for each site and then summing those means. A Shapiro-Wilk test was used to assess normality followed by Levene’s test for homogeneity of variance. For each plant category (non native, native, noxious) a simple two way analysis of variance (ANOVA) was performed to identify significant effects from soil preparation, amendments and interaction between soil preparation and amendments. Once significant factors were identified an HSD Tukey’s test was applied to perform pairwise comparisons and identify differences in means.

4. RESULTS

4.1. Species Richness And Cover In Permanent Quadrats

Total species richness (number of species) differed with site (Figure 4.4; Table 4.4). Highest species richness was at Lendrum and lowest was at Blackmud in 2014 and 2015. With cessation of mowing, species richness increased at three sites, decreased at two and remained the same at two. Between 2014 and 2015 non native species richness declined at three sites and increased at two; native species richness increased at two and decreased at two; noxious species increased at four sites. Greatest increases in undesirable species occurred at Lendrum, with a 2 species increase.

Non native species were the most common plant type, with all categories varying by site (Table 4.5). *Elymus repens* (L.) Gould (quack grass) was the only species found in all sites. *Poa pratensis* L. (Kentucky blue grass) was found in six sites; *Taraxacum officinale* F.H. Wigg (common dandelion) and *Cirsium arvense* (L.) Scop (Canada thistle) were found in five sites.

Live vegetation cover generally decreased from 2014 to 2015 after the naturalization process was initiated (Figure 4.5; Table 4.6). Significant differences in cover between 2014 and 2015 were only found for non native species at Smith Crossing (Table 4.7). The small changes in native and noxious species cover from 2014 and 2015 were not statistically significant. Vegetation cover changes, increasing or decreasing from 2014 to 2015, did not follow any specific pattern of response.

4.2. Species Richness Inside Plots

A total of 37 plant species were identified inside the random quadrats located in the plots (Table 4.8). There were 26 non native species identified, 6 native species and 5 noxious species. *Chenopodium album*, *Elymus repens* and *Poa pratensis* were found at all of the research sites. *Bromus inermis* Leyss. (smooth brome grass), *Polygonum convolvulus* L. (wild buckwheat), *Thlaspi arvense* L. (stink weed), *Sonchus arvensis* L. (sow thistle) and *Tripleurospermum perforatum* (M rat) M. Lainz (scentless chamomile) were found at 5 of the 6 research sites. Species richness was similar among sites, ranging from 16 to 22, and being highest at Lendrum and lowest at 91 Street.

Non native species richness was influenced by site more than by soil treatment (Figure 4.6; Table 4.9). In general, highest non native species richness occurred with herbicide tillage. Soil treatments containing compost 100, except for herbicide tillage compost treatments, limited non native species richness. Native species were completely absent with compost 100 and were low in all other treatments (Table 4.10). Noxious species richness was higher on soil treatments with herbicide and herbicide tillage than other treatments (Table 4.11). Species richness had small but insignificant changes with soil amendments (Table 4.12). Herbicide tillage treatments tended to have numerically highest species richness (Table 4.13).

4.3. Vegetation Cover Inside Plots

Significant effects of soil preparation treatments occurred with cover of non native and noxious species (Table 4.14). Significant amendment effects on cover only occurred for noxious species. Non native species composed the majority of live vegetation cover across all of the soil treatments and sites (Figure 4.7). The only exception occurred with herbicide and herbicide tillage treatments where noxious species cover were comparable to non native species cover, and at Terwillegar and 91 Street which had very high noxious weed cover relative to non native and native species cover (Figure 4.7)

Vegetation cover per plant category generally varied with site and with soil treatment (Tables 4.15, 4.16, 4.17). Non native species cover tended to be higher with treatments that included compost than treatments without compost; non native species cover was lowest in treatments that included herbicide than those without herbicide (Table 4.15). Native species cover was greatest with compost 20 (Table 4.16). Noxious species were generally higher in treatments with herbicide than with any other treatment (Table 4.17).

When soil preparation and amendment treatments were analyzed individually, significant effects became evident (Tables 4.18, 4.19). Non native species cover was significantly higher with herbicide tillage and tillage than without tillage (Table 4.18). The opposite trend occurred for noxious species cover which was significantly higher with herbicide. Amendment application only had a significant effect on noxious species cover, with cover significantly higher in unamended treatments than in compost 100 (Table 4.19). Other treatments had no significant differences in their effects.

5. DISCUSSION

5.1. Outside Plots Permanent Quadrats Plant Community

After a community or ecosystem is destroyed or lost through urbanization, it may leave behind an ecological memory (Schaefer 2009). Ecological memory is lower in areas with habitat loss such as cities, in areas dominated by invasive species and in other disturbed sites. Urbanization changes naturalization dynamics, as urban soils possess many traits that promote continued invasion of sites by undesirable and invasive species (Pavao-Zuckerman 2008). The small amount of time over which the study was conducted may not be sufficient to register significant plant community changes. This was not unexpected and suggests the sites are at a relatively stable state from years of mowing. The reduced cover in 2015 was most likely related to a dry and warm year more than to cessation of mowing. Low precipitation, especially early in the 2015 growing season was likely a factor (See Appendix). Smith Crossing was the only site where introduced species cover decreased from 2014 to 2015. Its proximity to a river bend, with prevailing soil conditions resembling those of riparian areas, with higher sand content may have failed to retain water, resulting in lower live plant cover. Areas undergoing naturalization for longer or exposed to less disturbance have a higher water infiltration rate (Millward et al. 2011).

Interestingly for naturalization, native species rarely colonized naturalized areas in a two year time period. Naturalizing an urban area without a planned reintroduction of native species will most likely lead to a naturalized area mainly dominated by non native and noxious species as the capacity of native species to migrate inside the city is highly limited. Conservation and passive management of degraded ecosystems is widely recognized as an insufficient strategy to ensure autogenic, spontaneous recolonization and recovery of native assemblages and ecosystem function (Hobbs 2007, Jackson and Hobbs 2009).

Clearly within the same urban center, there are differences in plant community species richness and cover. There is some overlap in the species identified across the sites, although all species are not occurring at all of the sites and in the same proportions.

5.2. Inside Plots Soil Treatment Effects On Plant Community Composition

The small number of native species and their sporadic ocurrencess at different sites and in different treatments, suggests almost no native species were introduced with amendments. In contrast two noxious weeds occurred in research plots at all locations. *Cirsium arvense* and *Linaria vulgaris* may have been brought in with materials used in the experiment and/or viable seeds were present and treatment application provided conditions for them to germinate. This is consistent with Skrindo and Pedersen (2004) who found using topsoil as an amendment to restore a roadside in Norway increased vegetation cover from one year to the other for species like *Cirsium arvense*. Noxious weeds possess adaptations that make it easy for them to naturally colonize urban spaces, making them highly effective at establishing in recently disturbed urban environments due to very high seed output, phenotypic and germination plasticity, adaptations for short and long distance dispersal, small seed size and high seed longevity (Baker 1974, Louda 1989, Radosevich et al. 2007). It is clear that the effect of soil treatment on species richness cannot be ignored in naturalization, although site influences may be more critical. Urbanization changes naturalization dynamics, as urban soils possess many traits that promote continued invasion by undesirable species (Pavao-Zuckerman 2008).

Exposing a naturalized site to soil treatment either by conducting soil preparation or amendment application will most likely lead to development of a different plant community on a treated area. When cover by species is oriented into plant categories, it becomes evident how desirable or undesirable the output of applied treatments can be. Naturalization must address aesthetic and ecological functions; therefore native species constitute the most desirable plant category. Although non native species may not need to be labeled as undesirable, management strategies should address limiting their spread while reducing or eliminating noxious weeds which truly are undesirable species. This should better facilitate favouring native species.

Soil preparation was the most significant factor influencing percent cover of non native and noxious species. In both categories soil preparation differences are clearly divided by presence or absence of herbicide. Spraying herbicide either alone or combining it with tillage resulted in a high cover of noxious weeds and low cover of non native species while not applying herbicide resulted in high cover of non native species and low cover of noxious weeds. This contradicts the results of work by Buonopane et al. (2013) who found that no significant differences in vegetation cover, germinant density or species richness between herbicide and non-herbicide plots, including noxious weeds.

The success of herbicides in this naturalization study adds to the challenge of adapting agricultural approaches to solve ecological challenges. There is concern that prolonged exposure to herbicide application results in increased resistance to it. The glyphosate herbicide used in this experiment is the most broadly used herbicide for agricultural and for home and garden purposes. Noxious weeds colonizing urban settings are continuously exposed to these chemicals, as extensive home use and repetitive use contrasts with agricultural applications where regulation and technical guidance is more accessible. Even though noxious species are continuously exposed to these chemicals they are extremely proficient at producing and dispersing seeds, facilitating proliferation of genes resistant to herbicide. Non native species are not as heavily exposed to herbicide applications as in many cases they are species used for landscaping, and therefore are more sensitive to herbicide application. Weed management strategies implemented in this experiment were intended to reflect the range of situations where naturalization is adopted as management. Weed management is one of the strongest drivers of plant communities and plays a critical role when naturalizing spaces in urban environments.

Tillage treatments resulted in exposing seeds from species that were not located in the area prior to soil disturbance. Tillage acted to refresh the existing soil seed bank. Although compost 100 accounted for the lowest cover of noxious weeds, it also suppressed naturally occurring native species. Hence its use in naturalization may be limited when native species encroachment is desired at this rate.

6. CONCLUSIONS

Within two growing seasons since mowing cessation, species richness remained relatively stable in areas outside the plots where species had been planted as part of the naturalization process. Percent cover per species category varied, although except for one site it remained within a range that did not denote a significant change to the overall plant community. Thus mowing cessation had no negative or positive impacts on the developing plant community in areas outside the planted plots.

Soil treatment effect on plant community cover varied among sites. Herbicide application increased cover of noxious weeds and decreased cover of non native species relative to soil treatments where no herbicide was applied. Only compost 100 amendment significantly affected native species cover relative to unamended treatments.

Table 4.1. Site location, last mowing event and traffic exposure.

Topography	City Address	Last Mow	Pedestrian Traffic
Flat			
Lendrum	11240 59 Avenue	1 year	Light
Wagner	6359 Wagner Road	1 year	Light
Blackmud	11407 18 Avenue	1 year	Heavy
Terwillegar Recreation Centre	2051 Leger Road	1 year	Heavy
Sloped			
91 Street	4321 91 Street	> 2 years	Light
Smith Crossing	11903-13063 23 Avenue	> 2 years	Light
Terwillegar	4004-4460 Terwillegar Drive	> 2 years	None

Table 4.2. Research treatment details.

Treatment	Tillage	Herbicide	Amendment
Control	None	None	None
Compost 100	None	None	Compost
Compost 20	None	None	Compost Soil
Compost 50	None	None	Compost Soil
Herbicide	None	Glyphosate	None
Herbicide Compost 100	None	Glyphosate	Compost Soil
Herbicide Compost 20	None	Glyphosate	Compost Soil
Herbicide Compost 50	None	Glyphosate	Compost Soil
Tillage	Rototill	None	None
Tillage Compost 100	Rototill	None	Compost
Tillage Compost 20	Rototill	None	Compost Soil
Tillage Compost 50	Rototill	None	Compost Soil
Tillage, Herbicide	Rototill	Glyphosate	None
Tillage, Herbicide Compost 100	Rototill	Glyphosate	Compost
Tillage, Herbicide Compost 20	Rototill	Glyphosate	Compost Soil
Tillage, Herbicide Compost 50	Rototill	Glyphosate	Compost Soil

Table 4.3. Herbicide application rates by site.

Site Name	1 % Solution Rate L/ha	Glyphosate Rate L/ha
Lendrum	1,514.0	15.140
Wagner	1,009.3	10.090
91 Street	1,009.3	10.090
Terwillegar Recreation Centre	757.1	7.570
Blackmud	882.6	8.826
Smith Crossing	882.6	8.826
Terwillegar	768.0	7.680

Table 4.4. Species richness (number of species) in plant categories per site by year.

Site	Year	Non Native	Native	Noxious	Total
91 Street	2014	4	0	1	5
	2015	2	0	1	3
Blackmud	2014	4	2	0	6
	2015	5	3	0	8
Lendrum	2014	8	0	2	10
	2015	9	1	3	13
Smith Crossing	2014	4	1	3	8
	2015	4	2	4	10
Terwillegar Recreation Centre	2014	4	4	1	9
	2015	4	4	1	9
Terwillegar	2014	5	0	0	5
	2015	4	0	1	5
Wagner	2014	5	2	0	7
	2015	3	1	1	5

Table 4.5. Species by category outside experimental plots at each site.

Scientific Name	Site						
Non Native	A	B	C	D	E	F	G
Agropyron cristatum L.	X			X		X	
Bromus inermis Leyss.			X	X		X	
Caragana Fabr.			X				
Chenopodium album L.			X				
Elymus repens (L.) Gould	X	X	X	X	X	X	X
Festuca rubra L.					X		
Lotus corniculatus L.					X		
Lychnis L.			X				
Medicago lupulina L.			X				
Melilotus officinalis (L.) Lam.					X		
Poa pratensis L.	X	X	X	X		X	X
Polygonum arenastrum Jord. ex Boreau			X				
Polygonum convolvulus L.			X				
Stellaria media (L.) Vill.							X
Taraxacum officinale F.H. Wigg.		X	X	X	X		X
Thlaspi arvense L.	X		X			X	
Tragopogon dubius Scop.		X					
Trifolium hybridum L.					X		
Trifolium repens L.		X			X		X
Urtica dioica L.			X				
Native	A	B	C	D	E	F	G
Astragalus L.		X		X			X
Astragalus americanus (Hook.) M.E. Jones		X		X			
Astragalus bisulcatus (Hook.) A. Gray				X			
Festuca hallii (Vasey) Piper					X		
Fragaria virginiana Duchesne		X					
Hordeum jubatum L.			X		X		
Pascopyrum smithii (Rydb.) L.					X		
Poa alpina L.					X		
Poa nemoralis L. subsp. interior (Rydb.) W.A. Weber					X		
Symphyotrichum laeve L.		X					X
Thermopsis rhombifolia (Nutt. ex Pursh) Nutt. ex Richardson					X		
Noxious	A	B	C	D	E	F	G
Cirsium arvense (L.) Scop.	X		X	X	X	X	
Euphorbia esula L.				X			
Linaria vulgaris Mill.			X	X			X
Sonchus arvensis L.				X			
Tripleurospermum perforatum (M rat) M. Lainz			X				

Sites: A = 91 Street, B = Blackmud, C = Lendrum, D = Smith Crossing, E = Terwillegar Recreation Centre, F = Terwillegar, G = Wagner

Table 4.6. Percent cover of plant categories by site per year.

Site	Year	Non Native	Native	Noxious
91 Street	2014	68.6	0	7.7
	2015	46.5	0	1.5
Blackmud	2014	96.3	1.0	0
	2015	71.2	0.9	0
Lendrum	2014	53.8	0	6.3
	2015	32.2	0.9	2.8
Smith Crossing	2014	43.5 a	2.0	6.7
	2015	22.5 b	1.1	4.6
Terwillegar Recreation Centre	2014	13.4	50.8	1.7
	2015	8.8	46.0	1.3
Terwillegar	2014	53.7	0	0
	2015	27.9	0	3.0
Wagner	2014	107.2	0.4	0
	2015	65.4	5.0	1.7

Table 4.7. Significance for mean percent cover change from 2014 to 2015.

Site	Non Native	Native	Noxious
91 Street	0.06993	NA	0.09349
Blackmud	0.1322	0.8687	NA
Lendrum	0.1438	NA	0.1411
Smith Crossing	0.01347*	NA	0.6726
Terwillegar Recreation Centre	0.5061	0.1653	0.9181
Terwillegar	0.05541	NA	NA
Wagner	0.7355	NA	NA

* Significant difference, ***Highly significant

Table 4.8. Species list by category inside experimental plots at each site.

Scientific Name	Site					
Non Native	A	B	C	D	F	G
Agropyron cristatum L.	X		X	X	X	
Amaranthus retroflexus L.		X	X			X
Bromus inermis Leyss.		X	X	X	X	X
Chenopodium album L.	X	X	X	X	X	X
Crepis tectorum L.					X	
Echinochloa crus-galli (L.) P. Beauv.		X	X			X
Elymus repens (L.) Gould	X	X	X	X	X	X
Erodium cicutarium (L.) L'H r. ex Aiton		X			X	
Festuca rubra L.			X			
Lactuca serriola L.			X	X	X	
Lychnis L.	X			X	X	
Medicago lupulina L.						X
Melilotus officinalis (L.) Lam.	X			X		X
Plantago major L.		X		X	X	
Poa compressa L.						X
Poa pratensis L.	X	X	X	X	X	X
Polygonum convolvulus L.		X	X	X	X	X
Polygonum lapathifolium L.					X	
Setaria viridis (L.) P. Beauv.		X	X		X	X
Sonchus asper (L.) Hill	X	X	X			
Spergula arvensis L.		X				
Thlaspi arvense L.	X		X	X	X	X
Tragopogon dubius Scop.	X					X
Trifolium hybridum L.			X	X		
Trifolium repens L.	X	X	X		X	X
Taraxacum officinale F.H. Wigg.	X	X	X	X	X	X
Native	A	B	C	D	F	G
Astragalus L.	X		X			X
Astragalus bisulcatus (Hook.) A. Gray				X		
Hordeum jubatum L.			X			
Polygonum amphibium L. var. emersum Michx.			X			X
Salix exigua Nutt.				X		
Symphyotrichum leave L.				X		
Noxious	A	B	C	D	F	G
Cirsium arvense (L.) Scop.	X	X	X	X	X	X
Euphorbia esula L.				X		
Linaria vulgaris Mill.	X	X	X	X	X	X
Sonchus arvensis L.	X	X		X	X	X
Tripleurospermum perforatum (M rat) M. Lainz	X	X	X	X	X	

Sites: A = 91 Street, B = Blackmud, C = Lendrum, D = Smith Crossing, F = Terwillegar, G = Wagner

Table 4.9. Non native species richness by soil treatment.

Treatment	91 Street	Blackmud	Lendrum	Smith Crossing	Terwillegar	Wagner	Mean
Compost 100	1	5	4	4	3	3	3
Compost 20	2	5	8	2	2	5	4
Compost 50	2	5	4	4	3	3	4
Control	3	4	4	4	4	4	4
Herbicide	3	4	4	6	5	5	5
Herbicide Compost 100	2	5	3	2	4	4	3
Herbicide Compost 20	3	3	5	3	7	4	4
Herbicide Compost 50	3	6	6	3	5	5	5
Herbicide Tillage	2	6	8	8	8	6	6
Herbicide Tillage Compost 100	3	5	5	3	5	8	5
Herbicide Tillage Compost 20	3	6	6	2	9	6	5
Herbicide Tillage Compost 50	3	4	6	4	6	5	5
Tillage	1	4	6	5	3	4	4
Tillage Compost 100	2	4	3	2	2	3	3
Tillage Compost 20	1	4	7	2	2	7	4
Tillage Compost 50	2	4	3	3	3	4	3

Table 4.10. Native species richness by soil treatment.

Treatment	91 Street	Blackmud	Lendrum	Smith Crossing	Terwillegar	Wagner	Mean
Compost 100	0	0	0	0	0	0	0.0
Compost 20	NA	NA	2	1	NA	NA	0.5
Compost 50	NA	NA	NA	NA	NA	1	0.2
Control	NA	NA	1	NA	NA	NA	0.2
Herbicide	NA	NA	NA	3	NA	NA	0.5
Herbicide Compost 100	0	0	0	0	0	0	0.0
Herbicide Compost 20	1	NA	2	1	NA	1	0.8
Herbicide Compost 50	NA	NA	NA	1	NA	1	0.3
Herbicide Tillage	NA	NA	1	NA	NA	NA	0.2
Herbicide Tillage Compost 100	0	0	0	0	0	0	0.0
Herbicide Tillage Compost 20	NA	NA	NA	NA	NA	1	0.2
Herbicide Tillage Compost 50	NA	NA	1	1	NA	1	0.5
Tillage	NA	NA	1	NA	NA	NA	0.2
Tillage Compost 100	0	0	0	0	0	0	0.0
Tillage Compost 20	NA	NA	1	1	NA	1	0.5
Tillage Compost 50	0	0	0	0	0	0	0.0

Table 4.11. Noxious species richness by soil treatment.

Treatment	91 Street	Blackmud	Lendrum	Smith Crossing	Terwillegar	Wagner	Mean
Compost 100	1	NA	1	2	1	1	1.0
Compost 20	1	NA	1	2	1	1	1.0
Compost 50	1	NA	NA	1	2	NA	0.7
Control	1	NA	2	2	1	1	1.2
Herbicide	2	4	2	3	1	2	2.3
Herbicide Compost 100	1	1	1	NA	1	NA	0.7
Herbicide Compost 20	1	NA	1	1	1	NA	0.7
Herbicide Compost 50	2	NA	1	2	1	NA	1.0
Herbicide Tillage	2	3	2	3	2	3	2.5
Herbicide Tillage Compost 100	2	NA	NA	1	1	1	0.8
Herbicide Tillage Compost 20	2	NA	1	1	1	NA	0.8
Herbicide Tillage Compost 50	1	NA	1	2	2	1	1.2
Tillage	1	NA	1	3	NA	1	1.0
Tillage Compost 100	1	1	NA	1	1	1	0.8
Tillage Compost 20	1	NA	1	1	1	2	1.0
Tillage Compost 50	NA	1	1	2	1	1	1.0

Table 4.12. Species richness by amendment.

Amendment	91 Street	Blackmud	Lendrum	Smith Crossing	Terwillegar	Wagner	Mean
Non Native							
Compost 100	4	8	7	6	7	9	7
Compost 20	5	8	12	5	11	11	9
Compost 50	4	8	10	8	8	8	8
Unamended	5	6	10	11	10	6	8
Native							
Compost 100	0	0	0	0	0	0	0.0
Compost 20	1	NA	2	2	NA	2	1.2
Compost 50	NA	NA	1	2	NA	1	0.7
Unamended	NA	NA	2	3	NA	NA	0.8
Noxious							
Compost 100	3	2	1	2	1	2	2
Compost 20	2	NA	1	2	2	2	1.5
Compost 50	2	1	1	4	3	2	2
Unamended	3	4	3	4	2	3	3

Table 4.13. Species richness by soil preparation.

Soil Preparation	91 Street	Blackmud	Lendrum	Smith Crossing	Terwillegar	Wagner	Mean
Non Native							
Herbicide	7	10	10	10	9	9	9
Herbicide Tillage	6	10	11	11	15	11	11
Tillage	3	6	9	6	4	9	6
Untreated	5	8	11	4	5	6	7
Native							
Herbicide	1	NA	2	3	NA	1	1.2
Herbicide Tillage	NA	NA	2	1	NA	2	0.8
Tillage	NA	NA	2	1	NA	1	0.7
Untreated	NA	NA	2	1	NA	1	0.7
Noxious							
Herbicide	2	4	2	3	1	2	2
Herbicide Tillage	4	3	2	3	3	3	3
Tillage	2	1	2	4	1	2	2
Untreated	1	NA	2	2	2	1	1.3

Table 4.14. Plant categories percent cover analysis of variance.

Plant Category	Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	P (>F)
Non native	Amendment	3	1204.5	401.48	1.2956	0.2817
	Soil Preparation	3	7847.4	2615.78	8.4409	6.118e-05 ***
	Amendment Soil Preparation	9	1603.7	178.19	0.5750	0.8138
	Residuals	80	24791.5	309.89		
Native	Amendment	2	18.91	9.4569	1.6318	0.2049
	Soil Preparation	3	18.94	6.3125	1.0892	0.3614
	Amendment Soil Preparation	5	43.32	8.6637	1.4949	0.2065
	Residuals	9	318.75	5.7955		
Noxious[1]	Amendment	3	499.36	166.454	4.6526	0.0047584**
	Soil Preparation	3	738.18	246.060	6.8777	0.0003521***
	Amendment Soil Preparation	9	584.05	64.894	1.8139	0.0783571
	Residuals	80	2862.13	35.777		

[1] Did not meet homogeneity of variance (0.0123)

Table 4.15. Non native mean percent cover by soil treatment for each site.

Treatment	91 Street	Blackmud	Lendrum	Smith Crossing	Terwillegar	Wagner	Mean
Compost 100	71.9	76.6	30.7	38.9	52.9	78.3	58.2
Compost 20	53.8	67.6	18.8	29.4	36.4	63.4	44.9
Compost 50	67.2	68.6	37.2	35.4	46.7	56.2	51.9
Control	50.9	80.3	30.3	28.2	28.3	68.1	47.7
Herbicide	34.4	74.9	33.0	24.9	30.4	74.3	45.3
Herbicide Compost 100	32.2	30.6	6.6	23.9	25.4	53.6	28.7
Herbicide Compost 20	37.2	15.8	22.4	19.0	26.7	47.4	28.1
Herbicide Compost 50	41.6	29.6	18.3	21.7	29.7	43.0	30.6
Herbicide Tillage	37.2	58.9	36.2	19.2	17.0	70.1	39.8
Herbicide Tillage Compost 100	55.8	30.3	20.8	19.1	20.4	43.6	31.7
Herbicide Tillage Compost 20	14.8	18.2	25.7	24.9	30.9	31.2	24.3
Herbicide Tillage Compost 50	31.3	25.0	8.6	22.1	30.1	37.4	25.8
Tillage	39.4	82.4	39.2	28.3	25.3	74.8	48.3
Tillage Compost 100	64.4	68.8	26.7	26.2	52.4	67.0	50.9
Tillage Compost 20	62.2	60.1	30.2	23.4	39.9	56.2	45.4
Tillage Compost 50	73.4	69.8	29.6	30.4	43.9	55.0	50.4

Table 4.16. Native mean percent cover by soil treatment for each site.

Treatment	91 Street	Blackmud	Lendrum	Smith Crossing	Terwillegar	Wagner	Mean
Compost 100	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Compost 20	NA	NA	2.4	0.3	NA	NA	0.5
Compost 50	NA	NA	NA	NA	NA	0.9	0.2
Control	NA	NA	5.0	NA	NA	NA	0.8
Herbicide	NA	NA	NA	3.2	NA	NA	0.5
Herbicide Compost 100	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Herbicide Compost 20	14.6	NA	0.3	1.3	NA	6.9	3.9
Herbicide Compost 50	NA	NA	NA	2.8	NA	2.8	0.9
Herbicide Tillage	NA	NA	0.6	NA	NA	NA	0.1
Herbicide Tillage Compost 100	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Herbicide Tillage Compost 20	NA	NA	NA	NA	NA	0.6	0.1
Herbicide Tillage Compost 50	NA	NA	6.4	0.2	NA	2.8	1.6
Tillage	NA	NA	1.1	NA	NA	NA	0.2
Tillage Compost 100	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tillage Compost 20	NA	NA	8.8	0.3	NA	4.2	2.2
Tillage Compost 50	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 4.17. Noxious mean percent cover by soil treatment for each site.

Treatment	91 Street	Blackmud	Lendrum	Smith Crossing	Terwillegar	Wagner	Mean
Compost 100	1.3	NA	4.4	1.6	0.3	1.1	1.5
Compost 20	2.2	NA	2.8	2.9	1.0	2.2	1.9
Compost 50	2.2	NA	NA	2.8	16.0	NA	3.5
Control	1.1	NA	2.4	8.8	12.8	0.8	4.3
Herbicide	26.1	4.8	13.3	3.8	26.7	1.3	12.7
Herbicide Compost 100	6.4	11.9	11.7	NA	5.0	NA	5.8
Herbicide Compost 20	7.8	NA	16.1	7.7	15.6	NA	7.9
Herbicide Compost 50	10.6	NA	3.1	8.9	17.8	NA	6.7
Herbicide Tillage	28.1	6.4	22.2	22.9	26.8	2.6	18.2
Herbicide Tillage Compost 100	5.3	NA	NA	4.4	10.9	0.1	3.5
Herbicide Tillage Compost 20	22.6	NA	3.9	6.0	2.8	NA	5.9
Herbicide Tillage Compost 50	3.3	NA	0.1	4.0	12.2	3.3	3.8
Tillage	2.2	NA	0.1	3.8	NA	3.8	1.7
Tillage Compost 100	2.2	0.4	NA	5.7	4.8	6.7	3.3
Tillage Compost 20	0.3	NA	2.0	4.2	2.8	3.3	2.1
Tillage Compost 50	NA	2.2	0.6	3.3	2.4	3.6	2.0

Table 4.18. Mean percent cover by soil preparation for each site.

Soil Preparation	91 Street	Blackmud	Lendrum	Smith Crossing	Terwillegar	Wagner	Mean
Non Native							
Herbicide	36.4	37.7	20.1	22.4	28.1	54.6	33.2 b
Herbicide Tillage	34.8	33.1	22.8	21.3	24.6	45.6	30.4 b
Tillage	59.9	70.3	31.4	27.1	40.4	63.3	48.7 a
Untreated	60.9	73.3	29.3	33.0	41.1	66.5	50.7 a
Native							
Herbicide	3.6	NA	0.1	1.8	NA	2.4	1.3
Herbicide Tillage	NA	NA	1.8	0.1	NA	0.8	0.5
Tillage	NA	NA	2.5	0.1	NA	1.1	0.6
Untreated	NA	NA	1.9	0.1	NA	0.2	0.4
Noxious							
Herbicide	12.7	4.2	11.1	5.1	16.3	0.3	8.3 a
Herbicide Tillage	14.8	1.6	6.6	9.3	13.2	1.5	7.8 a
Tillage	1.2	0.7	0.7	4.3	2.5	4.3	2.3 b
Untreated	1.7	NA	2.4	4.0	7.5	1.0	2.8 b

Table 4.19. Mean percent cover by amendment for each site.

Amendment	91 Street	Blackmud	Lendrum	Smith Crossing	Terwillegar	Wagner	Mean
Non Native							
Compost 100	56.1	51.6	21.2	27.0	37.8	60.6	42.4
Compost 20	42.0	40.4	24.3	24.2	33.5	49.6	35.7
Compost 50	53.4	48.2	23.4	27.4	37.6	47.9	39.7
Unamended	40.5	74.1	34.7	25.2	25.3	71.8	45.3
Native							
Compost 100	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Compost 20	3.6	NA	2.9	0.5	NA	2.9	1.7
Compost 50	NA	NA	1.6	0.8	NA	1.6	0.7
Unamended	NA	NA	1.7	0.8	NA	NA	0.4
Noxious							
Compost 100	3.8	3.1	4.0	2.9	5.3	2.0	3.5 b
Compost 20	8.2	NA	6.2	5.2	5.5	1.4	4.4 b
Compost 50	4.0	0.6	0.9	4.8	12.1	1.7	4.0 b
Unamended	14.4	2.8	9.5	9.8	16.6	2.1	9.2 a

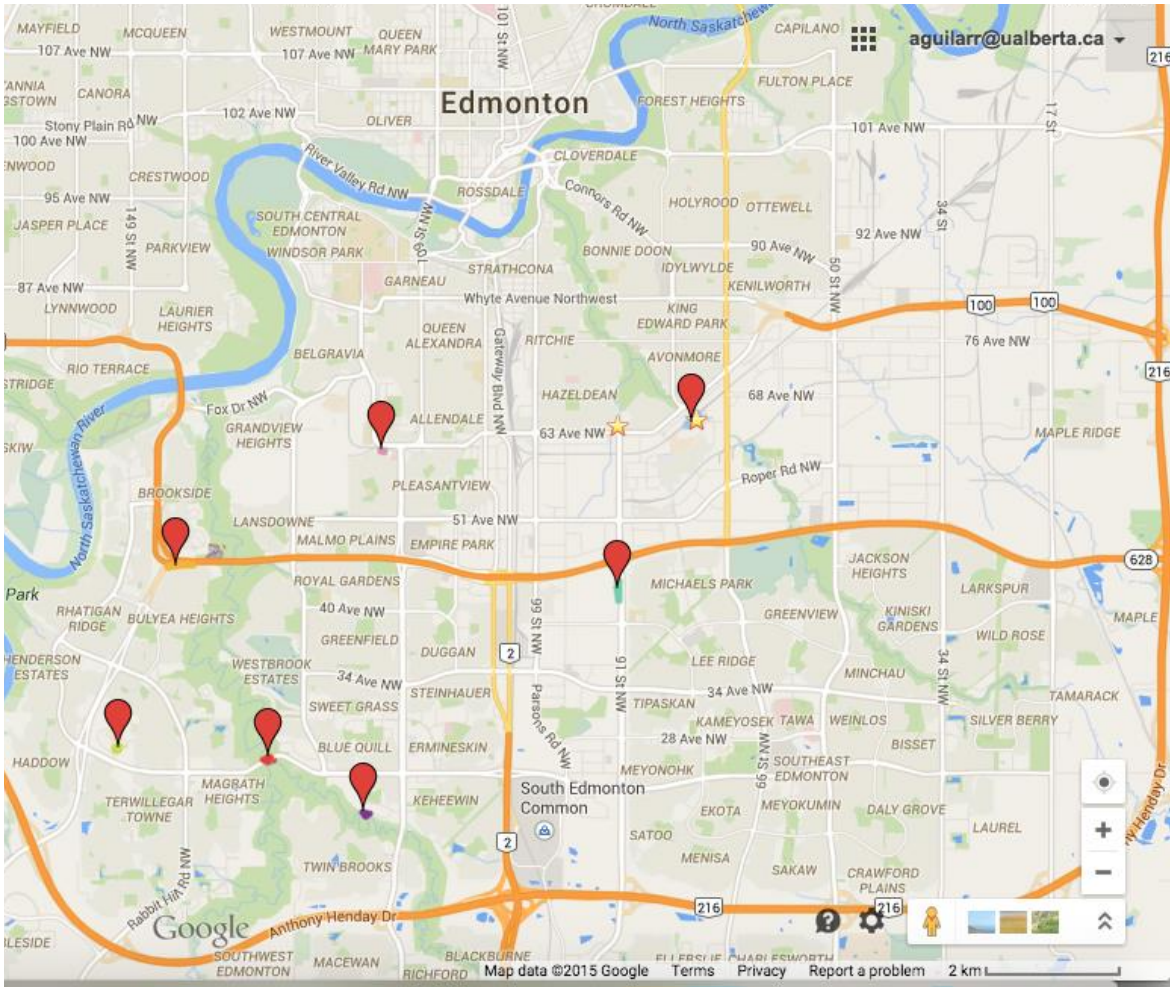

Figure 4.1. Site location map in the city of Edmonton.

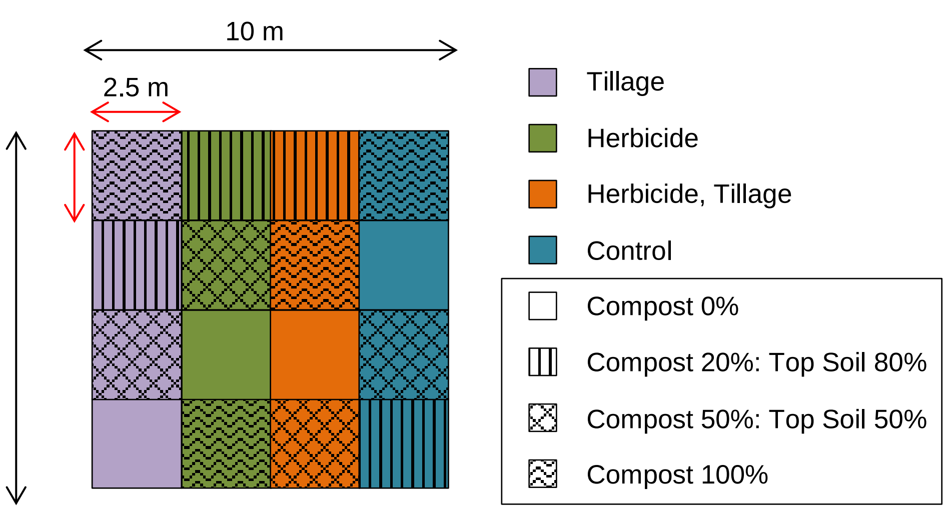

Figure 4.2. Replicate plot soil preparation treatments (coloured boxes) randomly applied in columns. Amendment treatments (patterns) randomly distributed within columns.

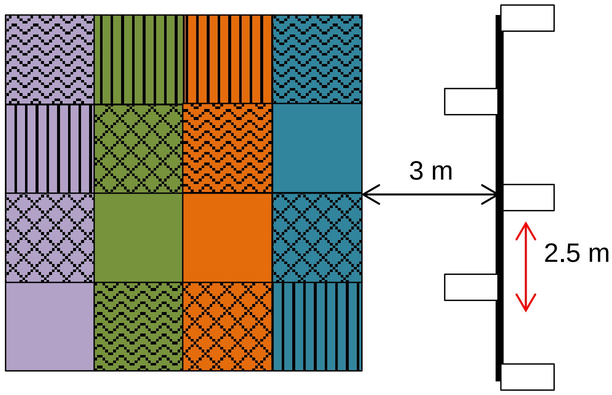

Figure 4.3. Location of permanent quadrats outside research plot replicates.

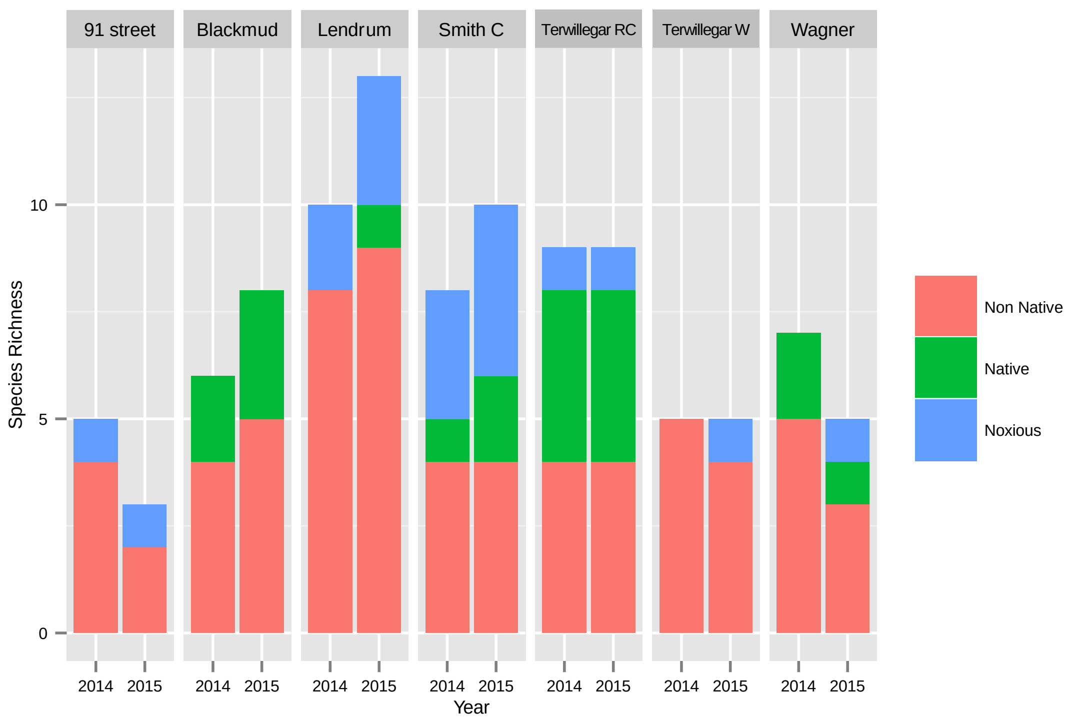

Figure 4.4. Species richness outside plots per site by year.

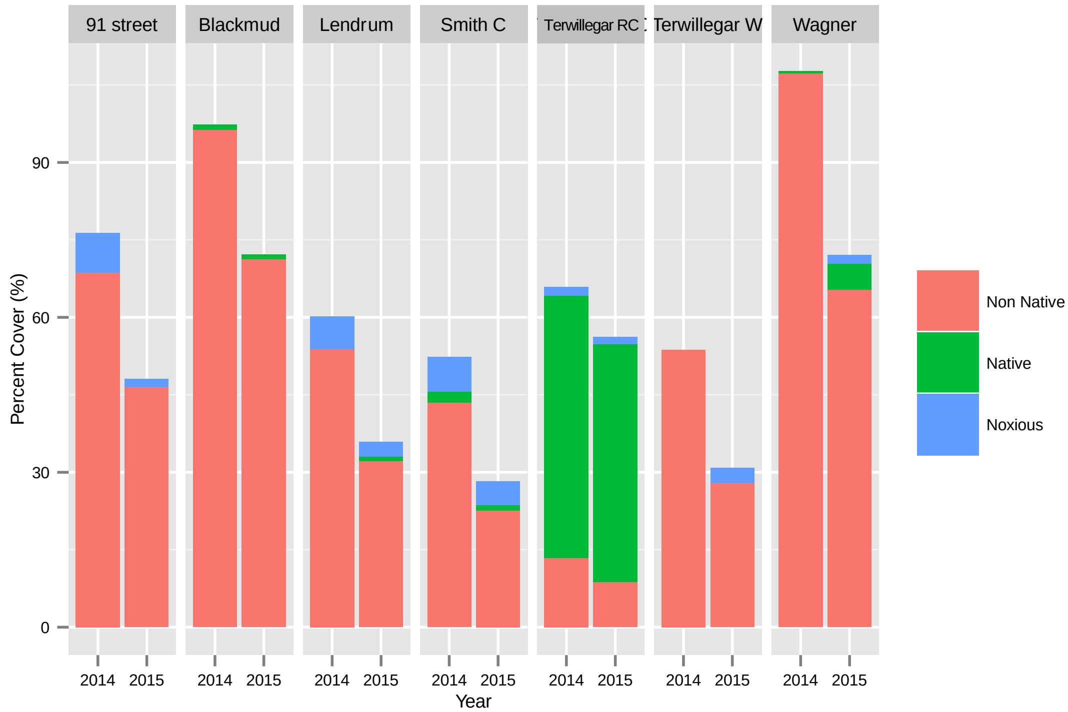

Figure 4.5. Percent cover outside plots per site by year.

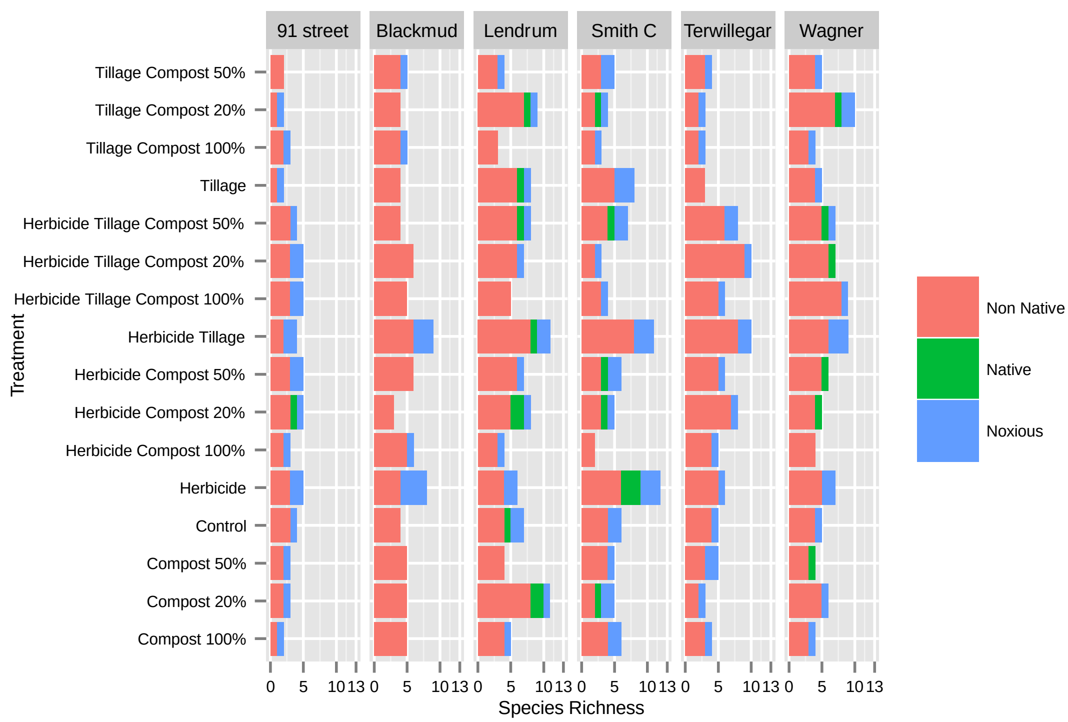

Figure 4.6. Species richness inside plots per treatment, by site and plant category.

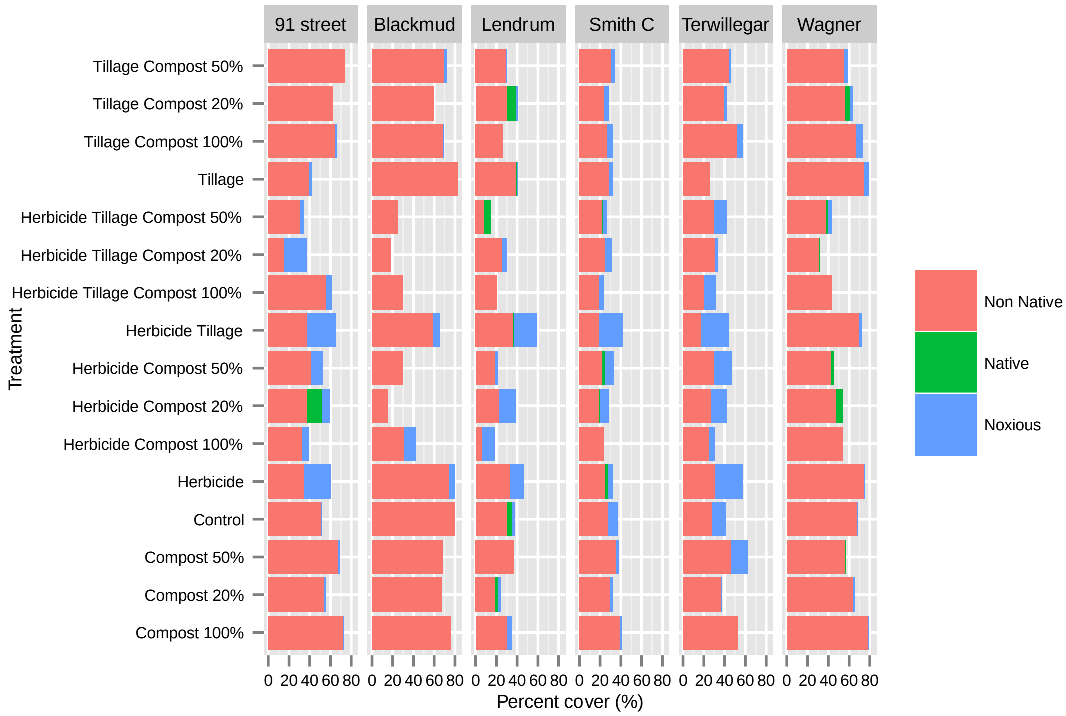

Figure 4.7. Percent cover inside plots per treatment, by site and plant category.

V. RESEARCH SUMMARY, RESEARCH LIMITATIONS, RECLAMATION APPLICATIONS AND FUTURE RESEARCH

1. RESEARCH SUMMARY

Several of the eight native tree and shrub species responded positively to naturalization practices in the City of Edmonton. The top surviving and performing tree and shrub species were *Picea glauca* (Moensch) Voss (white spruce) and *Symphoricarpos albus* L. (snowberry), respectively. *Symphoricarpos albus* was one of the hardiest and most resilient species for planting in a naturalized area. The poorest performing tree and shrub species were *Populus tremuloides* Michx. (trembling aspen) and *Viburnum trilobum* L. (highbush cranberry), respectively. Plant species evaluated in this study responded differently to soil treatments. Survival and plant growth were positively influenced by soil preparation treatments relative to no soil preparation treatment. In general, soil preparation treatments involving either herbicide with tillage or herbicide alone were most effective. Amendments were not as important to survival and plant growth as soil preparation, but were significant for some species. Compost 100 mix resulted in larger plants.

Of the twenty-four forb species evaluated in this experiment, nine showed good potential for naturalization under the management approach used during this study. *Penstemon procerus* Dougl. Ex Graham (slender penstemon), *Fragaria virginiana* Dcne. (wild strawberry), *Heuchera cylindrica* Douglas ex Hook. (round leaved alum root), *Agastache foeniculum* (Pursh) ktze. (giant hyssop), *Antennaria microphyla* Rydb. (little leaf pussy toes) and *Geum aleppicum* Jacq. (three flowered avens) are recommended for future use in naturalization for the City of Edmonton and similar urban centres. *Cornus canadensis* L. (bunchberry), *Pulsatilla patens* L. (prairie crocus), *Liatris ligulistylis* A. Nels. K. Schum. (dotted blazing star), *Allium textile* A. Nels. & J. F. Macbr. (prairie onion), *Eriogonum flavum* Nutt. (yellow buckwheat), *Viola adunca* Sm. (early blue violet), *Potentilla arguta* Pursh (prairie cinquefoil), *Heterotheca villosa* Pursh Shinners (hairy false golden aster), *Anemone cylindrica* Gray long fruited anemone), *Rudbeckia hirta* L. (black eyed susan), *Thalictrum venulosum* Trel. (veiny meadow) and *Anemone canadensis* L. (Canada anemone) cannot be recommended for naturalization in the City of Edmonton or similar urban centres without further study. Soil amendment with compost is recommended for use with forb naturalization as it had a direct and positive impact on survival, growth and cover of planted seedlings. Although compost amendment to the soil also increased non native species and noxious weeds, these could be appropriately managed with hand weeding of small naturalized sites.

After a year of mowing cessation, species richness across the sites remained stable. The total mean cover by species within plant category (native, non native, noxious) varied with location from one year to the other. With the exception of Smith Crossing, it remained within a range that did not denote a significant change.

Within two growing seasons after mowing cessation, species richness remained relatively stable in areas outside the plots where species had been planted as part of the naturalization process. Percent cover per species category varied, although except for one site it remained within a range that did not denote a significant change to the overall plant community. Thus mowing cessation had no negative or positive impacts on the developing plant community in areas outside the planted plots.

Soil treatment effect on plant community cover varied among the research sites. In general herbicide application increased cover of noxious weeds and decreased cover of non native species relative to soil treatments where no herbicide was applied. Only compost 100 amendment significantly affected native species cover relative to unamended treatments. Herbicide was the most effective treatment although results were not always positive from a naturalization perspective.

2. APPLICATIONS FOR RECLAMATION

As human population grows and migrates to urban centers, it becomes imperative to integrate natural zones to the landscape as a direct measurement to promote mental health and well-being. Cities and other urban centres have to evolve into areas with a practical and functional role as urban ecosystems, acting as native species sanctuaries and providing ecological services to the region where they are located.

As urban centers become more valuable to society, and residents develop an environmental conscience, attempts to reintegrate native species to resemble the pre development landscape will likely become more common. Reclaiming urban areas into naturalized sites will likely become more attractive to boost economic value, ecological services and none tangible benefits to local residents. By understanding how the naturalization process evolves in urban environments, reclamation practitioners, naturalization experts and urban managers can achieve a deeper understanding of the role the human population plays as ecosystem architects, the tangible (economic) and none tangible challenges and opportunities this reclamation strategy implies and the potential of native species to adapt and thrive in dynamic and ever variable growing conditions.

This research helped to identify best suited species, factors constraining their establishment and growth and provide a benchmark of alternatives to boost naturalization success. The plant community study, provided an appreciation of the variability of plant communities within the same urban center in composition, abundance and the effect of management. With the information generated in this study, naturalization strategy can be engaged from the perspective of functionality. It can be complemented with site specific conditions, and management strategies (previous, during and post naturalization). All species used for naturalization should be checked for toxicity to humans and pets.

3. STUDY LIMITATIONS

The time period for assessment is one of the major limitations of this research. When studying plant and plant community development, two growing seasons is simply not enough to collect all the data necessary to state how those parameters will change in the longer term. Although there is no indication of the trajectory these plant communities will take in the future the study provided a good indication of limiting factors in the first two years of naturalization, which are generally the most challenging.

With site variability, research replications are limited and hence there is often a lack of statistical significance. However, strong trends that were shown in spite of these site differences clearly indicate the importance of some factors and treatment responses.

Plant quality of the seedlings used was a limitation of this research. With the exception of *Picea glauca*, species often varied in size (container and seedling), propagation method, age and origin. Within the same species, seedling general health, vigour and pre-planting management varied considerably. Although this is often the case for naturalization materials in an urban centre, it does not facilitate optimum research. In spite of these differences, some strong trends for species success or failure emerged, indicating the robustness of results and their interpretation for this first research for the city of Edmonton.

The technical framework for successful naturalization was limited from the social dimension perspective of naturalization. During the research time period, the human dimensions aspect of working in an urban environment was either very gratifying or very frustrating. It was gratifying to have communities supporting the work and frustrating when there were constant complaints about weeds or vandalism of planted woody seedlings. For this study, social dimensions of the different research sites were not included although they would play a major role in naturalization in short and long terms.

4. RECOMMENDATIONS FOR FUTURE RESEARCH

Social aspects of naturalization, particularly as linked to weed or noxious plant species control, need to be addressed. This could mean putting more focus on getting neighbourhood residents involved in the research and the perspective behind it.

A valuable tool that needs to be developed to improve naturalization performance is related to weed management. As maintenance budgets shrink and chemical options become more restricted, effective and cost efficient weed management strategies become crucial to naturalization success. The need and desire to reduce herbicide use in naturalization needs to be addressed as herbicide use is currently the most successful treatment. Research could focus on other weed control mechanisms, which may include more hand weeding by neighbourhood volunteers. This would not only help with weed control, but provide a valuable way to get input and buy in for naturalization from the community members.

Early establishment of native species after planting in naturalized areas would be highly valuable to increase the success rate. Further research is needed on how to facilitate or smooth the transition between a relatively fragile seedling to a mature specimen on site. Research could be focused on different sizes and ages of plants species. Research is needed to address the use of native species and their cultivars or even non native species. There is always concern that cultivars or non native species can become aggressive and invade true native areas in an urban centre.

To provide a more accurate response of specific species to soil treatments in naturalized sites, research should use standardized or controlled external factors that interfere with plant response like human disturbance, wild life predation, seedling homogeneity and watering measurement. Although it could be argued that these are the factors always present in a naturalization scenario, it is not conducive to truly evaluate transplanting success of individual species since they are not all predated the same.

REFERENCES

Alakukku, L. 1996. Persistence of soil compaction due to high axle load traffic. II. Long-term effects on the properties of fine-textured and organic soils. Soil and Tillage Research 37:223-238.

Alberti, M. 2005. The effects of urban patterns on ecosystem function. International Regional Science Review 28:168-192.

Ashworth, J. and K. Mrazek. 1995. Modified Kelowna test for available phosphorus and potassium in soil. Communications in Soil Science and Plant Analysis 26:731-739.

Baker, H.G. 1974. The evolution of weeds. Annual Review of Ecology and Systematics 5:1-24.

Beckett, K.P., P.H. Freer-Smith and G. Taylor. 1998. Urban woodlands: their role in reducing the effects of particulate pollution. Environmental Pollution 99:347-360.

Beven, K. and P. Germann. 1982. Macropores and water flows in soils. Water Resource Restoration 18:1311-1325.

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

Brazel, A., N. Selover and R. Voes. 2000. The tale of two cities - Baltimore and Phoenix urban LTER sites. Climate Research 15:123-135.

Bremner, J.M. 1996. Nitrogen - total. In D.L. Sparks, A.L. Page, P.A. Helmke and R.H. Loeppert (eds.). Methods of soil analysis. Part 3 - chemical methods. Soil Science Society of America, American Society of Agronomy. Madison, Wisconsin. Pp. 1085-1121

Bretzel, F., F. Malorgio, C. Carrai and B. Pezzarossa, 2009. Wildflower plantings to reduce the management costs of urban gardens and roadsides. Acta Horticulturae 813:263-269.

Buonopane, M., G. Snider, B.K. Kerns and P.S. Doescher. 2013. Complex restoration challenges: weeds, seeds, and roads in a forested wildland urban interface. Forest Ecology and Management 29587-96. doi:10.1016/j.foreco.2013.01.013.

Burch, W.R. Jr. and J.M. Grove. 1993. People, trees, and participation on the urban frontier. Unasylva 44:19-27.

Burt R. and soil survey staff. 2014. Soil survey field and laboratory methods manual. Soil survey investigations report No. 51 Version 2.0. US department of natural resources. Available at http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1244466.pdf. Accessed on 23 February 2016.

Chapman, H.D. 1965. Cation-exchange capacity. In Black C.A. (ed.). Methods of soil analysis. Soil Science Society of America, American Society of Agronomy. Madison, Wisconsin. Pp. 891-901

Chiesura, A. 2004. The role of urban parks for the sustainable city. Landscape and Urban Planning 68, 129-138.

Christian-Smith, J. and A.M. Merenlender. 2010. The disconnect between restoration goals and practices: a case study of watershed restoration in the Russian River Basin, California. Restoration Ecology 18:95-102.

City of Edmonton. 2015. Environmental stewardship Naturalization. On line at http://www.edmonton.ca/city_government/environmental_stewardship/naturalization.aspx. Accessed 15 May 2015.

Civeira, G. 2010. Influence of municipal solid waste compost on soil properties and plant reestablishment in peri-urban environments. Chilean Journal Of Agricultural Research 70:446-453.

Civeira, G. and R.S. Lavado. 2008. Nitrate losses, nutrients and heavy metal accumulation from substrates assembled for urban soils reconstruction. Journal of Environment Management 88:1619-1623.

Cogger, C.G. 2005. Potential compost benefits for restoration of soils disturbed by urban

development. Compost Science and Utilization 13:243-251.
Connell, J.H. and R.O. Slatyer. 1977. Mechanisms of succession in natural communities and their role in community stability and organization. American Naturalist 111:1119-1144.
Craul, P.J. 1985. A description of urban soils and their desired characteristics. Journal of Arboriculture 11:330-339.
Craul, P.J. 1999. Urban soils: applications and principles. Wiley. New York, New York.
Crecchio, C., M. Curci, M. Pizzigallo, P. Ricciuti and P. Ruggiero. 2004. Effects of municipal solid waste compost amendments on soil enzyme activities and bacterial genetic diversity. Soil Biology and Biochemistry 36:1595-1605.
Drozd, J. 2003. The risk and benefits associated with utilizing composts from municipal solid waste (MSW) in Agriculture. In J.M. Lynch, J.S. Schepers and I. Unver (eds.). Innovative soil plant systems for sustainable agricultural practices. Organisation for Economic Co-operation and Development. Paris, France. Pp. 211-226.
Ellis, E.C. and N. Ramankutty. 2008. Putting people in the map: anthropogenic biomes of the world. Frontiers in Ecology and Environment 6:439-447.
Environment Canada. 2015. Historic weather data. On line at http://climate.weather.gc/climate Data/dailydata_e.html?StationID=27214&Month=5&Day=13&Year=2015&timeframe=2 Accessed 25 November 2014.
Environmental Protection Agency (EPA). 1994. Method 200.2. Sample preparation procedure for spectrochemical determination of total recoverable elements. Online at http://www.epa.gov/sites/production/files/2015-08/documents/method_200-2_rev_2-8_1994.pdf. Accessed 20 February 2016.
Environmental Protection Agency (EPA). 1994. Method 245.1, Determination of mercury in water by cold vapor atomic absorption spectrometry (CVAA). Online at https://www.epa.gov/sites/production /files/2015-06/documents/epa-245.1.pdf. Accessed 20 February 2016.
Environmental Protection Agency (EPA). 1996. Method 6010B: Inductively coupled plasma-atomic emission spectrometry. Online at http://www.epa.gov/sites/production/files/ documents/6010b.pdf. Accessed 20 February 2016.
Evergreen. 2001. Urban naturalization in Canada: a policy and program guidebook. Online at http://www.evergreen.ca/downloads/pdfs/Urban-Naturalization-in-Canada-1.pdf. Accessed 4 February 2016.
Gilbert, O.L. 1989. The ecology of urban habitats. Chapman and Hall. New York, New York.
Giusquiani, P.L., M. Pagliai, G. Gigliotii, D. Businelli and A. Benetti. 1995. Urban waste compost: effects on physical, chemical and biochemical soil properties. Journal of Environmental Quality 24:175-182.
Gobster, P.H. 2001. Visions of nature: conflict and compatibility in urban park restoration. Landscape and Urban Planning 56:35 -51.
Gomez, A., R.F. Powers, M.J. Singer and W.R. Horwath. 2002. Soil compaction effects on growth of young ponderosa pine following litter removal in California's Sierra Nevada. Soil Science Society America Journal 66:1334-1343.
Groffman, P.M., D.J. Bain, L.E. Band, K.T. Belt, G.S. Brush, J.M. Grove, R.V. Pouyat, I.C. Yesilonis and W.C. Zipperer. 2003. Down by the riverside: urban riparian ecology. Frontiers in Ecology and Environment 1:315-321.
Groffman, P.M., R.V. Pouyat, M.J. McDonnell, S.T.A. Pickett and W.C. Zipperer. 1995. Carbon pools and trace gas fluxes in urban forest soils. In R. Lal, J. Kimble, E. Levine and B.A. Stewart (eds.). Soil management and the greenhouse effect. CRC Inc. London, United Kingdom. Pp. 147-158.
Gross, M. and H. Hoffmann-Riem. 2005. Ecological restoration as a real-world experiment: designing robust implementation strategies in an urban environment. Public Understanding of Science 14:269-284.

Heena, P.B., I. Breitwieser D.S. Glenny, P.J DeLange and P.J. Brownsey. 1998. Checklist of dicotyledons and pteridophytes naturalzed or casual in New Zealand: additional records 1994–96. New Zealand Journal of Botany 36:155-162.

Hendershot, W.H., H. Lalande and M. Duquette. 2008. Ion exchange and exchangeable cations. In M.R. Carter and E.G. Gregorich (eds.). Soil sampling and methods of analysis. Canadian Society of Soil Science. Boca Raton, Florida. Pp. 199-201.

Heneghan, L., S.P. Miller, S. Baer, M.A. Callaham Jr., J. Montgomery, M.A. Pavao-Zuckerman, C.C. Rhoades and S. Richardson. 2008. Integrating soil ecological knowledge into restoration management. Restoration Ecology 16:608–617.

Higgs, E. 2003. Nature by design: people, natural processes and ecological restoration. MIT Press. Cambridge, Massachusetts.

Hill, K. 2001. Design and planning as healing arts: the broader context of health and environment. In K. Hill and B.R. Johnson (eds.). Ecology and design: frameworks for learning. Island Press. Washington, District of Columbia. Pp. 203-214.

Hobbs, R.J. 2007. Setting effective and realistic restoration goals: key directions for research. Restoration Ecology 15:354-357.

Iglesias-Jimenez, E. and C. Alvarez. 1993. Apparent availability of nitrogen in composted municipal refuse. Biology and Fertility of Soils 16:313-3168.

Jackson, S.T. and R.J. Hobbs. 2009. Ecological restoration in the light of ecological history. Science 325:567-569.

Kareiva, P., S. Watts, R. McDonald and T. Boucher. 2007. Domesticated nature: shaping landscapes and ecosystems for human welfare. Science 316:1866-1869.

Kuo, F.E. and W.C. Sullivan. 2001. Aggression and violence in the inner city: effects of environment via mental fatigue. Environment and Behavior 33:543-571.

Loeppert, R.H. and D.L. Suarez. 1996. Carbonate and gypsum. In D.L. Sparks, A.L. Page, P.A. Helmke and R.H. Loeppert (eds.). Methods of soil analysis. Part 3 - chemical methods. Soil Science Society of America, American Society of Agronomy. Madison, Wisconsin Pp. 437-474.

Louda, S.M., 1989. Chapter seed bank processes. In: M.A. Leck, V.T. Parker and R.L. Simpson (eds.). Ecology of soil seed banks. Academic Press. New York, New York.

Lovett, G.M., M.M. Traynor, R.V. Pouyat, M.M. Carreiro, W.X. Zhu and J.W. Baxter. 2000. Atmospheric deposition to oak forests along an urban-rural gradient. Environmental Science and Technology 34:4294-4300.

Markkola, A.M., R. Ohtonen, O. Tarvainen and U. Ahonen-Jonnarth. 1995. Estimates of fungal biomass in Scots pine stands on an urban pollution gradient. New Phytologist 131:139-147.

Marrs, R.H. and M.W. Gough. 1989. Soil fertility – a potential problem for habitat restoration. In G.P. Buckley (ed.). Biological habitat reconstruction. Belhaven Press. London, United Kingdom. Pp. 29-44.

Maynard, D.G., Y.P. Kalra and J.A. Crumbaugh. 2008. Nitrate and exchangeable ammonium nitrogen. in M.R. Carter and E.G. Gregorich (eds.). Soil sampling and methods of analysis. 2nd ed. CRC Press, Boca Raton, Florida. Pp. 71-80.

McPherson, E.G., D. Nowak, G. Heisler, S. Grimmond, C. Souch, R. Grant and R. Rowntree. 1997. Quantifying urban forest structure, function, and value: the Chicago urban forest climate project. Urban Ecosystems 1:49-61.

Millard, A. 2004. Indigenous and spontaneous vegetation: their relationship to urban development in the city of Leeds, UK. Urban Forestry and Urban Greening 3: 39-47.

Miller, J.J. and D. Curtin. 2007. Chapter 15: Electronical conductivity and soluble ions. In M.R. Carter and E.G. Gregorich (eds). Soil sampling and methods of analysis second edition. Canadian soil science society. CRC Press and Taylor and Francis Group. Boca Raton, Florida

Millward, A.A., S.E. Briggs and K. Paudel. 2011. Naturalization as a strategy for improving soil

physical characteristics in a forested urban park. Urban Ecosystems 14:261-278.
Millwood, A.A., K. Paudel and S.E. Briggs. 2011. Naturalization as a strategy for improving soil physical characteristics in a forested urban park. Urban Ecosystems 14, 261-278.
Myers, J.H. and D.R. Bazely. 2003. Ecology and control of introduced plants. Cambridge University Press. New York, New York.
Mylavarapu, R.S. and G.M. Zinati. 2009. Improvement of soil properties using compost for optimum parsley production in sandy soils. Scientia Horticulturae 120:426-430.
Naeem, S., J.M.H. Knops, D. Tilman, K.M. Howe, T. Kennedy and S. Gale. 2000. Plant diversity increases resistance to invasion in the absence of covarying extrinsic factors. Oikos 91:97-108.
Nelson, D.W. and L.E. Sommers. 1996. Total carbon, organic carbon, and organic matter. In D.L. Sparks, A.L. Page, P.A. Helmke and R.H. Loeppert. Methods of soil analysis. Part 3 - chemical methods. Soil Science Society of America, American Society of Agronomy. Madison, Wisconsin. Pp. 961-1010.
Niwa G., R.W. Peck and T.R. Torgersen. 2001. Soil, litter, and coarse woody debris habitats for arthropods in eastern Oregon and Washington. Northwest Science 75:141-148.
Northridge, M.E., E.D. Sclar and P. Biswas. 2003. Sorting out the connections between the built environment and health: a conceptual framework for navigating pathways and planning healthy cities. Journal of Urban Health 80:556-568.
Nowak, D.J., D.E. Crane and J.F. Dwyer. 2002. Compensatory value of urban trees in the United States. Journal of Arboriculture 28:194-199.
Oke, T.R. 1995. The heat island of the urban boundary layer: characteristics, causes, and effects. In J.E. Cermak (ed.). Wind climate in cities. Kluwer Academic. Amsterdam, Netherlands. Pp. 81-107.
Pavao-Zuckerman, M.A. 2008. The nature of urban soils and their role in ecological restoration in cities. Restoration Ecology 16:642-649.
Pavao-Zuckerman, M.A. and D.C. Coleman. 2005. Decomposition of chestnut oak (*Quercus prinus*) leaves and nitrogen mineralization in an urban environment. Biology and Fertility of Soils 41:343-349.
Pickett, S.A., S.L. Collins and J.J. Armesto. 1987. Models, mechanisms and pathways of succession. Botanical Review 3:335.
Pickett, S.T.A. and M.L. Cadenasso. 2008. Linking ecological and built components of urban mosaics: an open cycle of ecological design. Journal of Ecology 96:8-12.
Pizl, V. and G. Josens. 1995. Earthworm communities along a gradient of urbanization. Environmental Pollution 90:7-14.
Pollak, L. 2006. The landscape for urban reclamation-infrastructures for the everyday space that includes nature. Lotus International 128:32-45.
Pouyat, R.V. and M.J. McDonnell. 1991. Heavy metal accumulations in forest soils along an urban-rural gradient in southeastern New York, USA. Water, Air and Soil Pollution 57-58:797-807.
Pouyat, R.V., J. Russell-Anelli, I. Yesilonis and P.M. Groffman. 2003. The potential of U.S. soils to sequester carbon and mitigate the greenhouse effect. In J.M. Kimble, L.S. Heath, R.A. Birdsey and R. Lal, (eds.). Soil carbon in urban forest ecosystems. CRC Press. Boca Raton, Florida. Pp. 347-362.
Pouyat, R.V., R.W. Parmelee and M.M. Carreiro. 1994. Environmental effects of forest soil-invertebrate and fungal densities in oak stands along and urban-rural land use gradient. Pedobiologia 38:385-399.
Radosevich, S.R., J.S. Holt and C.M. Ghersa. 2007. Ecology of weeds and invasive plants: relationship to agriculture and natural resource management. John Wiley and Sons. Hoboken, New Jersey.
R Core team. 2014. R: A Language and Environment for Statistical Computing. R Foundation

for Statistical Computing. Vienna, Austria. On line at http://www.R-project.org/. Accessed 2 February 2016.
Richardson, D.M., P. Pysek, M. Rejmanek, M.G. Barbour, F.D. Panetta and C.J. West. 2000. Naturalization and invasion of alien plants: concepts and definitions. Diversity and Distributions 6:93-107.
Risse, L.M. and B. Faucette. 2001. Compost utilization for erosion control. University of Georgia Cooperative Extension Service University of Georgia, College of Agricultural and Environmental Sciences, Bulletin 1200. Athens, Georgia.
Rosenzweig, M.L. 2003. Win-win ecology: how the earth's species can survive in the midst of human enterprise. Oxford University Press. New York, New York.
Ruthrof, K.X., M.P. McHenry, G.E.St.J. Hardy, G. Matusick, J.B. Fontaine and M. Buizer. 2013. Linking restoration outcomes with mechanism: the role of site preparation, fertilisation and revegetation timing relative to soil density and water content. Plant Ecology 214:987-998.
Saebo, A.., T. Benedikz and T.B. Randrup. 2003. Selection of trees for urban forestry in the Nordic countries. Urban Forestry and Urban Greening 2, 101–114
Savard, J-P.L., P. Clergeau and G. Mennechez. 2000. Biodiversity concepts and urban ecosystems. Landscape and Urban Planning 48, 131-142.
Schaefer, V. 2009. Alien Invasions, ecological restoration in cities and the loss of ecological memory. Restoration Ecology 17:171-176.
Schaefer, V.H. 1999. The green links project: a holistic approach to habitat restoration in cities. Ecological Restoration 17:250-251.
Schaefer, V.H., H. Rudd and J. Vala. 2004. Urban biodiversity: exploring natural habitat and its value in cities. Captus Press. Concord, Ontario.
Scharenbroch, B.C., J.E. Lloyd and J.L. Johnson-Maynard. 2005. Distinguishing urban soils with physical, chemical and biological properties. Pedobiologia 49:283-296.
Short, J.R., D.S. Fanning, M.S. McIntosh, J.E. Foss and J.C. Paterson. 1986. Soils of the mall in Washington, D.C. Soil Science Society of America Journal 50:699-705.
Sinnett, D., J. Poole and T.R. Hutchings. 2008. A comparison of cultivation techniques for successful tree establishment on compacted soil. Forestry 81:663-679.
Skrindo, A.B. and P.A. Pedersen. 2004. Natural revegetation of indigenous roadside vegetation by propagules from topsoil. Urban Forestry and Urban Greening 3:29-37.
Snep, R.P.H., P.F.M. Opdam, J.M. Baveco, M.F. Wallis DeVries, W. Timmermans, R.G.M. Kwak and V. Kuypers. 2006. How periurban areas can strengthen animal populations within cities: a modeling approach. Biological Conservation 127:345-355.
Standish, R.J., J.B. Fontaine, R.J. Harris, W.D. Stock and R.J. Hobbs. 2012. Interactive effects of altered rainfall and simulated nitrogen deposition on seedling establishment in a global biodiversity hotspot. Oikos 121:2014 -2025.
Steinberg, D.A., R.V. Pouyat, R.W. Parmelee and P.M. Groffman. 1997. Earthworm abundance and nitrogen mineralization rates along an urban-rural land use gradient. Soil Biology and Biochemistry 29:427-430.
Tognetti, C., M.J. Mazzarino and F. Laos. 2007. Improving the quality of municipal organic waste compost, Bioresource Technology 98:1067-1076.
United Nations. 2015. The future we want, cities. On line at http://www.un.org/en/sustainablefuture/pdf/Rio+20_FS_Cities.pdf. Accessed 20 May 2015.
Unsal, T. and S.S. Ok. 2001. Description of characteristics of humic substances from different waste materials. Bioresource Technology 78:239-242.
Vetterlein, J. and D. Hüttl. 1999. Can applied organic matter fulfill similar functions as soil organic matter? Risk benefit analysis for organic matter application as a potential strategy for rehabilitation of disturbed ecosystems. Plant and Soil 213:1-10.
Walter, I., F. Martínez F. and G. Cuevas. 2006. Plant and soil responses to the application of composted MSW in a degraded, semiarid shrubland in central Spain. Compost Science and

Utilization 14(2):147-154.
Yates, C.J., R.J. Hobbs, I. Atkins 2000. Establishment of perennial shrub and tree species in degraded eucalyptus salmonophloia (salmon gum) remnant woodlands: effects of restoration treatments. Restoration Ecology 8:135-143.

APPENDIX

Table A1. Mean minimum and maximum temperatures during the study years and historically.

	Minimum (^oC)			Maximum (^oC)		
Month	Historical	2014	2015	Historical	2014	2015
January	-15.9	-11.8	-11.7	-5.7	-2.1	-2.7
February	-14.0	-19.9	-13.4	-2.8	-10.6	-3.6
March	-8.9	-11.2	-4.2	1.9	-3.0	6.8
April	-1.5	-1.8	0.2	10.9	8.8	12.7
May	4.3	3.9	4.7	17.5	15.2	18.0
June	8.9	8.9	10.9	20.9	20.1	23.1
July	11.1	13.1	13.2	23.2	24.6	25.1
August	9.8	11.9	11.2	22.4	23.1	24.3
September	4.6	5.7	5.3	17.5	17.9	16.6
October	-1.3	2.2	1.8	10.2	13.1	14.1
November	-9.2	-10.5	-5.4	0.0	-2.6	2.5
December	-15.2	-10.5	-12.1	-5.3	-2.0	-3.7

Data from AgroClimatic Information Service (ACIS), township T052R24W4 (Edmonton), online at http://agriculture.alberta.ca/acis/township-data-viewer.jsp. Accessed 27 February 2016.
Historical = 30 years before 2014

Table A2. Mean precipitation (mm) during the study years and historically.

Month	Historical	2014	2015
January	18.6	8.0	21.0
February	10.6	6.5	24.4
March	15.0	12.0	22.9
April	27.0	36.9	6.5
May	47.8	51.5	18.1
June	76.8	59.9	25.9
July	93.2	112.8	67.3
August	61.7	23.2	25.0
September	40.0	23.3	62.1
October	19.6	9.2	12.9
November	17.4	29.8	13.2
December	13.8	3.8	8.5

Data from AgroClimatic Information Service (ACIS), township T052R24W4 (Edmonton), online at http://agriculture.alberta.ca/acis/township-data-viewer.jsp. Accessed 27 February 2016.
Historical = 30 years before 2014